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Techniques for Signaling and Service Discovery in DVB-H Networks

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Abstract

Mobile TV was a service concept first adopted by the Japanese ISDB-T standard and soon afterwards it was adopted by the European DVB standard. In the context of DVB, specific standard branch, Digital Video Broadcasting – Handheld (DVB-H) was developed. The DVB-H was tailored for the delivery of IP based services to the handheld devices over DVB network. Furthermore, it was developed as backwards compatible with the DVB-T and hence enabled re-use of the existing network infrastructure used for the DVB-T. Time Slicing, MPE-FEC and enhanced signaling are the main elements which make DVB-H different when compared to DVB-T.

This thesis was done in two parts. In the first part the signaling and service discovery of DVB-H in mobile environment is investigated by using traditional scientific engineering methods. The focus in the first part is in the basic principles of the service discovery and soft handover in DVB-H. The second part of the thesis deals with the robustness of link layer signaling transmission in DVB-H. The robustness is investigated by means of theoretical analysis, simulations and laboratory measurements.

The main results of this thesis can be summarized as follows:

1. Definition of new PSI/SI and TPS signaling elements in DVB-H and IPDC over DVB-H standards [34], [39], [47]
2. PSI/SI Transmission optimization and configuration recommendations provided as input to the DVB-H Implementation Guidelines [38].

Preface

This work has been carried out at Nokia during 2003-2008. The initiative for starting this work came through with my work relating to DVB-H development. The scope of this thesis spans from the early stages of DVB-H through the standard development and verification. I had just recently finalized my Masters thesis which was also dealing with the service discovery in DVB and therefore this thesis was a natural 'next step'. The Thesis has been partially funded by KAUTE and Ulla Tuomisen säätiö.

I would like to thank all those people who have been involved in the process of creating this thesis throughout the years. First, I would like to thank my thesis instructor Professor Pekka Loula who pushed me to complete this work. Many thanks to Dr.Tech. Janne Aaltonen, who initially inspired me to start this work and also gave important guidance in the early phase of the thesis as an instructor on the behalf of Nokia. I also want to thank Mr. Jari Koskinen, who has also been in important role as my former manager by providing the possibility to start this project.

Next, I would like to thank M.Sc. Jyrki Alamaunu, Lic. Tech. Pekka Talmola, M.Sc.Tommi Auranen, M.Sc. Harri Pekonen, Mr. Matti Puputti, Mr. Jarno Kallio, Dr.Tech. Tero Jokela, M.Sc. Arto Hamara, Dr. Jukka Henriksson, Dr. Juhani Huttunen, Dr. Jussi Vesma and M.Sc. Miika Tupala who have teamed up with me in the creation of publications and/or patents related to this thesis or otherwise have been involved in a way or another. I'd also like to thank the pre-examiners Professor Petri Vuorimaa and Dr.Tech. Gunther May of their constructive comments and criticism which has been invaluable for the completion of the thesis.

Finally, I'd like to express my gratitude for the troops at home; my children Katariina and Eemeli, Katariina Korhonen and her children Essi and Milla .

Contents

List of Publications

This thesis consists of the following publications:

[P1] J. Väre and M. Puputti, “Soft Handover in Terrestrial Broadcast Networks”, in Proceedings of the 5th IEEE International Conference on Mobile Data Management (MDM), Berkeley, CA, USA, Jan 2004, pp. 236 – 242.

[P2] J. Väre, A. Hamara and J. Kallio, "Approach for Improving Receiver Performance in Loss-free Handovers in DVB-H Networks", in Proceedings of the Globecom 2004, USA December 2004, pp. 3326 – 3331.

[P3] X. Yang, J. Väre and T.J. Owens "A Survey of Handover Algorithms in DVB-H", IEEE Communications Society, Survey & Tutorials, Volume 8, issue 4, 2006, pp. 16 – 29.

[P4] J. Väre, "A Prioritization Method for Handover Algorithm in IPDC over DVB-H System", in Proceedings of the IEEE International Symposium on Broadband Multimedia Systems and Broadcasting (BMSB), Las Vegas, USA, March 2008, pp.1 – 5.

[P5] J. Väre and T. Auranen, ”Transmission Aspects and Service Discovery Strategy for Seamless Handover in DVB-H” Chapter 14 in Handbook of Mobile Broadcasting, edited by Borko Furht and Syed Ahson, CRC Press, Taylor Francis Group, April 2008.

[P6] J. Väre, J. Alamaunu, H. Pekonen and T. Auranen, “Optimization of PSI/SI Transmission in IPDC over DVB-H Networks”, in Proceedings of the 56th Annual IEEE Broadcast Symposium, Washington, DC, USA, Sep 2006. CD-ROM.

[P7] T. Jokela and J. Väre, “Simulations of PSI/SI Transmission in DVB-H Systems”, in Proceedings of the 2007 IEEE International Symposium on Broadband Multimedia Systems and Broadcasting (BMSB), Orlando, FL, USA, Mar 2007. CD-ROM.

[P8] J. Väre, J. Alamaunu and H. Pekonen, "Laboratory Measurements and Verification of PSI/SI Transmission in DVB-H Systems", in Proceedings of the 27th IEEE International Performance and Communications Conference (IPCC), Austin, TX, USA, December 2008, pp. 225 – 232.

List of Symbols

PSI_SI_{SP}	The success probability in the reception of sub-tables
TS_{PERR}	The averaged error rate of transport stream packets
TS_{pok}	The probability of unbroken TS packets
SEC_{pok}	The probability of N consecutive unbroken TS packets
TS_{count}	The number of TS packets per one PSI/SI sub-table.
SEC_{PERR}	The probability for N consecutive TS packets
Bs	The available service bitrate
S	The number of services
B_{TS}	The total bitrate of TS
B_{FPSISI}	The fixed bitrate reserved for PSI/SI
MPE_FEC_{CE}	The coefficient for the bitrate reserved for MPE-FEC support
${}_{C}\_PSI\_SI_{tot}$	The total network capacity consumed by the PSI/SI sub-tables
${}_{C}NIT$	The network capacity consumed by NIT
${}_{C}PAT$	The network capacity consumed by PAT
${}_{C}PMT$	The network capacity consumed by PMT
${}_{C}INT$	The network capacity consumed by INT
${}_{C}TDT$	The network capacity consumed by TDT
${}_{C}SUB$	The network capacity consumed by NIT, PAT, PMT, INT and TDT
${}_{S}TS^{SEC}$	The size of one PSI/SI section in the TS level
${}_{SS}SUB$	The maximum section size of one sub-table
${}_{SC}SUB$	The number of sections per each sub-table
$riSUB$	The repetition interval of the sub-table
$oriSUB$	The optimized repetition interval of sub-table
mnt	Maximum number of transmission of a sub-table
$stsSUB$	The total size of sub-tables including TS overhead

1 Introduction

The television broadcasting [1], [2], [3], [4] was first introduced publicly in 1927 when one the first television broadcasts was provided from Washington, D.C. Since then the broadcast television transmission has become mainstream in every household. The broadcast television systems have evolved during the years, still the main principle has remained the same. The core principle in broadcast is the unidirectional mass distribution of content, where the receiving devices do not have any communication with the network end and all receivers of the network are able to receive the same data at the same time. On the other hand, the network end in the broadcast system either has no information about the receivers receiving the content. The broadcast systems are further split into terrestrial, cable and satellite systems.

The digitalization in the telecommunication systems [5], [6], [7], [8], [9], [10] had also impact on the television broadcasting and gradually the analogue television broadcasting systems have been upgraded into digital television broadcasting systems in which the transmission is provided via terrestrial, cable or satellite system. The digitalization of broadcast systems and the different transmission mediums resulted in the emergence of several different and parallel digital television standards in the different continents of the world. Currently, there are five different digital television broadcasting standards which are being used in the different parts of the globe. Majority of these standards form a standards family, which may include own branches for terrestrial, cable and satellite systems.

The Advanced Television Systems Committee (ATSC) [11], is the digital television standard used in the North America, where the main standard is a terrestrial and cable system [12], [13], [14], [15], [16], [17], [18] and the ATSC-M/H (Mobile/Handheld) [19] [20] [21] [22][23][24][25][26] is purposed for the mobile broadcasting. The ATSC defines also a satellite system [27], but that is not as widely used as terrestrial, cable and mobile/handheld systems are. Digital Video Broadcasting (DVB) [28] is the European digital television standard which has also been adopted in the many other continents of the world, such as in Australia and Singapore. The DVB standard has variations for satellite (DVB-S) [29], cable (DVB-C) [30] and terrestrial

(DVB-T) [31] systems, including handheld for terrestrial (DVB-H) [32], [34], [37], [38], [39], [40], [41] and for satellite/handheld (DVB-SH) [42], [43], [44]. The DVB-H and DVB-SH have further end-to-end specifications specified by OMA [45] and DVB-IPDC (IP Datacast) standards [46], [47], [48], [49], [50], [51], [52], [53], [54], [55], [56], [57], [58]. The OMA-BCAST over DVB-H [59], [60] is the end-to-end DVB-H system which is adopted globally, while the IPDC over DVB-H specifications in turn were widely adopted by the OMA-BCAST but whereas the commercial deployment has been relatively small. Furthermore, the DVB has also a few second generation revisions, such as the DVB-T2 [61], [62], [63] and DVB-C2 [64], [65]. The Integrated Services Digital Broadcasting (ISDB) is a Japanese standard family created by Association of Radio Industries and Businesses (ARIB) [66],[67] and it has branches for the terrestrial (ISDB-T) [68], [69], [70], [71], [72], [73], [74], [75], [76], [77], [78], [79], [80], [81], satellite (ISDB-S) [82] and cable (ISDB-C) [83] and it is used mainly in Japan and also in some South American countries. The Korean standard for digital television is Digital Multimedia Broadcasting (DMB) [91, which has branches for satellite (S-DMB) [84] and terrestrial (T-DMB) [85], [86]. China has two known digital television standards where the Digital Terrestrial Multimedia Broadcast (DTMB) [87], which is purposed for the fixed reception and Chinese Multimedia Broadcasting standard (CMMB) [88], [89], [90], which is purposed for the mobile/handheld reception. Finally, the Media FLO [92] is a digital television standard dedicated only to Mobile TV services.

The size and performance of computers and consumer electronics is evolving fast. Also, the presence of different media among end users lives has become imminent. Hence, the Mobile broadcasting could be seen as inevitable and natural evolution of Digital television, which has become more common in the different continents of the world. Similarly as in the traditional digital television broadcasting, the mobile broadcasting standards come in different forms, typically as a separate branch within the core standard. Today, in 2010 the most well known application in the Mobile broadcasting is Mobile TV [93]. ISDB-T was the first Digital Television standard which had mobile broadcast functionality as in-built feature. After that several different standard branches have emerged to support digital television also in mobile and handheld devices. Today ATSC-M/H, ISDB-T, CMMB, Media FLO, DMB-T and perhaps the most widely adopted Digital Video Broadcasting-Handheld (DVB-H) are the Mobile Broadcasting standards spread in the different continents of the world.

All the aforementioned digital television standards share lot of common features and the core principle, i.e., one-to-many broadcasting. For example the OSI layer 2 signaling within ATSC, ISDB-T and DVB-H is mutually very similar and even some parts are the same.

1.1 Scope and goals

The DVB-H standard was built as backwards compatible with DVB-T in which a subset of DVB-T was taken as a basis and new technologies such as Time slicing and MPE-FEC were defined to address the needs for the mobile receivers. The Time slicing was developed to address power consumption requirements and the MPE-FEC was developed to address the robustness of data transmission. Time Slicing and MPE-FEC further generated need to enhance the TPS signaling and PSI/SI signaling. In addition to the new signaling enhancements due Time Slicing and MPE-FEC, the receiver functionality in service discovery and especially in making handovers was different to that of previously defined and considered for the DVB-T systems. As the DVB-H was developed as backwards compatible with the DVB-T, the design of all new elements needed to be designed in a way that the core DVB-T standard was not affected. The mobility in DVB-H generated also challenges for the robustness of PSI/SI signaling. The MPE-FEC was defined to be used only for the protection of data transmission and while the PSI/SI transmission was provided by using same principles as within the DVB-T. The decision of not to protect PSI/SI signaling was made due to backwards compatibility reasons. However, the robustness of PSI/SI transmission has consequential influence on the service discovery e.g. in the receiver latency point of view.

This thesis has two goals. The first goal is to investigate and define the proper signaling methods for the service discovery in DVB-H. The second goal is to investigate the robustness level of PSI/SI signaling and define possible necessary improvements.

1.2 Research questions

The thesis focuses on solving two different problem areas. First it focuses on developing signaling enhancements and de-facto methods for enabling service discovery in the DVB-H system. The second part of the thesis focuses on the inspection of the robustness of PSI/SI signaling in DVB-H and addresses on the claim that the robustness of PSI/SI signaling is not sufficient as some configurations but it can be improved by using backwards compatible methods and without causing excessive increase in the network capacity of signaling.

The first part of the thesis aims to provide answers to the following questions;

Q1: What are the signaling elements needed to enable full service discovery in DVB-H?

Q2: How are different parameters used in the service discovery of DVB-H?

Q3: What are the main principles and procedures to enable seamless handover in DVB-H?

The second part of the thesis aims to find answers to the following questions:

Q4: What is the robustness of PSI/SI in different configurations?

Q5: What is the impact of poor robustness of PSI/SI into the receiver latency?

Q6: What can be done to improve the robustness of PSI/SI without changing the standard?

1.3 Related work

Service discovery mechanism, handover and different system specific aspects of DVB-H have been previously investigated in [94]-[114]. In [94] the utilization of Time Slicing off-periods for the seamless handover was introduced for the first time. The publications [95]-[97] focus on analyzing the performance of Time Slicing and seamless handover functionality. In [98] and [99] the focus is in the utilization of Phase-shifting for performing handovers. The publications [100] and [101] provide a survey of the different research work related to DVB-H service discovery and mobility aspects. The publication [102] investigates the service discovery and soft handover in DVB-H by focusing in the receiver implementation and interpretation of the signaling definitions in the DVB standards. In [103]-[111] the seamless handover in DVB-H is investigated in the case where also interaction network is utilized. In [112] – [114] the focus is in general system specific aspects of DVB-H while the service discovery and handover are have been dealt with lower detail.

Regarding the investigation of the robustness of PSI/SI, no related work has been published.

1.4 Research approach and methodologies

The research approach used in the first part of the thesis is based on traditional scientific engineering methods [115], [116], where the best practice implementations have been proposed in the publications [P1]-[P5]. The validation has been done by the qualitative analysis provided by the experts in the DVB standardization forum, proof of concept implementations and field trials. The research questions Q1-Q3 are covered by the publications [P1]-[P5]. The work carried out in the publications [P6]-[P8] is done by using the following steps; 1) The definition of hypothesis and problem identification, 2) theoretical analysis, 3) simulations and laboratory measurement, 4) Analysis of the results and solution validation. Hence the research questions Q4-Q6 are covered with the publications [P6]-[P8], in which hypothesis is given on the PSI/SI robustness and it’s impact on the service discovery and signaling in DVB-H as stated in the research questions.

1.5 Structure

This thesis is structured in two main areas. First, the service discovery and signaling procedures of DVB-H system are thoroughly explained in chapter 2. The chapter focuses on describing the main parts of the signaling and service discovery in DVB-H and also pointing out the author's contribution in different parts. The signaling and service discovery aspects have been covered in [P1]-[P5]. The chapter 3 tackles with the robustness of Program Specific Information (PSI) [119], [120], [47] and Service Information (SI) [47], [121], [39], [122]. The chapter 3 outlines the process conducted on the study of PSI/SI robustness and points out the relevant findings and summarizes the results and findings which have been covered in [P6]-[P8]. The chapter 4 summarizes the main results of the thesis. Finally, the chapter 5 explains the author's contribution in the publications

2 Signaling and Service Discovery in DVB-H Systems

Digital Video Broadcasting-Handheld (DVB-H) is the most widely adopted mobile broadcasting standard [28]. Currently it has been commercially deployed within several different countries, such as in Finland, Italy, South-Africa, Switzerland, Netherlands, Nigeria and Gambia. Moreover, the commercial or technical trials have been carried out already over 40 countries [28]. The DVB-H standard specifies the lower layers, i.e., OSI layers 1 and 2 of the entire end-to-end system. The IPDC over DVB-H standard was developed to complete the definition of the remaining upper layers. A bit later OMA-BCAST adopted great part of the IPDC over DVB-H standard and today OMA BCAST over DVB-H is the commercially adopted system providing Mobile TV services over DVB-H.

The signaling within DVB-H systems is provided in three different layers (Figure 2-1), which are Upper Layer signaling, Layer 2 signaling and Layer 1 signaling. The Upper Layer signaling with DVB-H systems consists mainly of that of defined within the OMA-BCAST standard. The core part of the Upper Layer signaling consists of Electronic Service Guide [51] specific signaling protocols. The main purpose of the Upper Layer signaling is to provide description of the services and associate IP addresses with the service description information and with the information needed for rendering the services in the terminal applications. The Upper Layer signaling is transparent to that of Layer 2 and Layer 1 signaling. The mapping element between the Upper Layer and Layer 2 signaling is IP address, which maps services with the L2 parameters in L2 signaling. The Layer 2 signaling, i.e., Program Specific Information/Service Information (PSI/SI) [47], provides the signaling parameters for the service mapping within the actual multiplex as well as information of the network topology. The purpose of L1 signaling, i.e., Transmission Parameter Signaling (TPS) [34], is to aid receiver in the synchronization and for example within the initialization procedures in the signal detection.

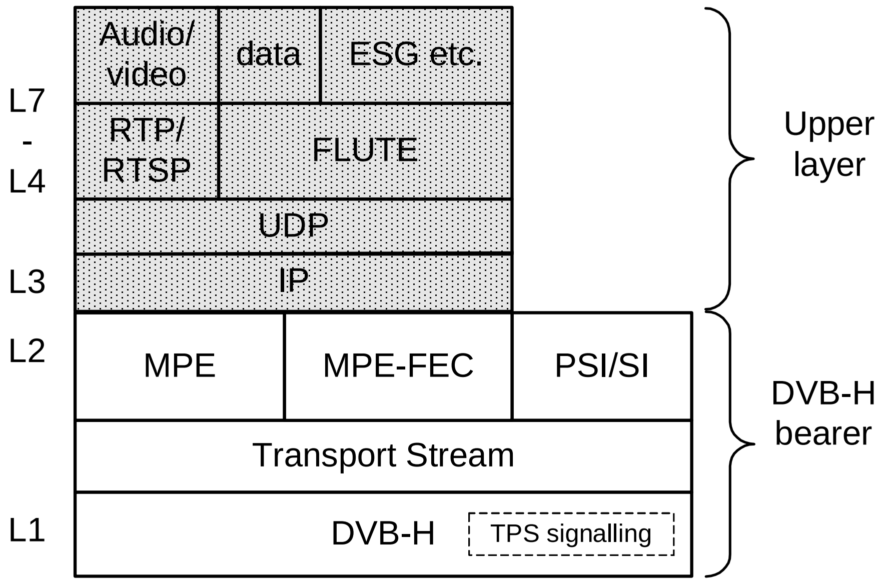

Figure 2-1. Overview of the protocol stack of end-to-end DVB-H system.

2.1 L1 signaling

The L1 signaling in DVB-H consists of Transmission Parameter Signaling (TPS) which is transmitted in the beginning of each orthogonal frequency division multiplexing (OFDM) frame. The purpose of TPS signaling is to aid receiver synchronization and signal detection and hence the TPS information is typically obtained by the receiver with ‘TPS lock’ slightly prior the actual synchronization into the signal. The TPS signaling is defined over 68 consecutive OFDM symbols per one OFDM frame. (See Figure 2-2). Four sequential OFDM frames, in turn, compose one OFDM superframe where one TPS bit is carried within each OFDM symbol. The TPS bits have 37 information bits while the remaining bits are categorized as follows: 1 initialization bit, 16 synchronization bits and 14 redundancy bits for error protection.

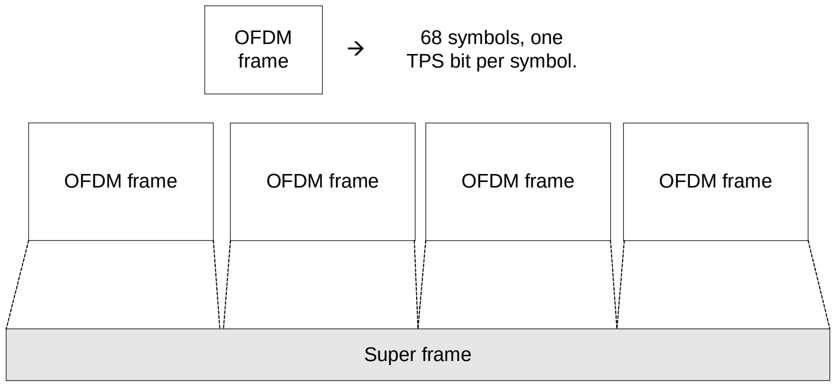

Figure 2-2. The relation between OFDM frames, superframes, symbols and TPS bits.

The 37 information bits are allocated mainly for the signaling of modulation parameters, but the 10 bits have importance in the DVB-H specific signaling and are defined as follows:

- Time-slicing indicator (one bit): Indicates whether the current signal carries DVB-H services. The purpose of the Time Slicing indicator is obvious in the elimination of DVB-T signals, which do not carry any DVB-H services.
- MPE-FEC indicator (one bit): Indicates whether the current signal carries at least one service with MPE-FEC support. Typically this would mean that there is at least one elementary stream protected with MPE-FEC.
- Cell_identification (eight bits): This signaling provides 16 bit cell identification by splitting the signaling of the cell identifier for the duration of one OFDM super frame. One half, i.e., 8 bits of the cell identification, is signaled in the first and third OFDM frame, while the remaining 8 bits is signaled within the second and fourth OFDM frame. The cell identification is important for the mutual distinguishion of signals which have same frequency but are from different networks.

The Time Slicing and MPE-FEC indicators where defined for the DVB-H in order to be able to distinguish DVB-T and DVB-H signals from each other. This reduces the receiver latency significantly especially when the receiver discovers several DVB-T and DVB-H signals available in parallel. The solution for the Time Slicing and MPE-FEC indicators [36] was developed by Nokia during the pre-standardization process and it was initiated by the author.

2.2 The L2 signaling

The L2 signaling within the DVB-H systems consists of Program Specific Information (PSI) and Service Information (SI). PSI/SI forms the core part of the signaling within DVB-H. The main purpose of PSI/SI signaling is to provide signaling information for the mapping of services within the multiplex as well as for the network topology information. The PSI/SI used within DVB-H systems is composed of five PSI/SI tables, which are defined within [47]. These PSI/SI Tables are Program Association Table (PAT), Program Map Table, (PMT), Network Information Table (NIT), IP/MAC Notification Table (INT) and Time and Date Table (TDT). Next, the PSI/SI basics are described within section 2.1.1. The section 2.1.2 explains the PSI/SI signaling structure and finally the section 2.1.3 provides a walkthrough example of the service discovery covering L1 and L2 signaling.

2.2.1 The basics of PSI/SI

Each of these PSI/SI tables, except TDT which has unique section structure, obey the principles of the generic section header (Figure 2-3). The length of the generic section header is always 64 bits, where the table_id_extension field is always allocated to different parameter based on the value of the table_id.

Syntax	No. of bits
table_id	8
section_syntax_indicator	1
reserved_future_use	1
reserved	2
section_length	12
table_id_extension	16
reserved	2
version_number	5
current_next_indicator	1
section_number	8
last_section_number	8
[table specific]	
CRC_32	32

Figure 2-3. The generic header structure of PSI/SI section

In addition to the concept of table and section, the term sub-table is often used in conjunction of PSI/SI. The sub-table means individual collection of sections of single PSI/SI table, i.e., sub-table. The set of one or more sub-tables with the same table_id_extension compose one table. Figure 2-4 illustrates an example of the relation between table, sub-table and section where one NIT sub-table has two sections and one NIT sub-table has single section and both compose one NIT table.

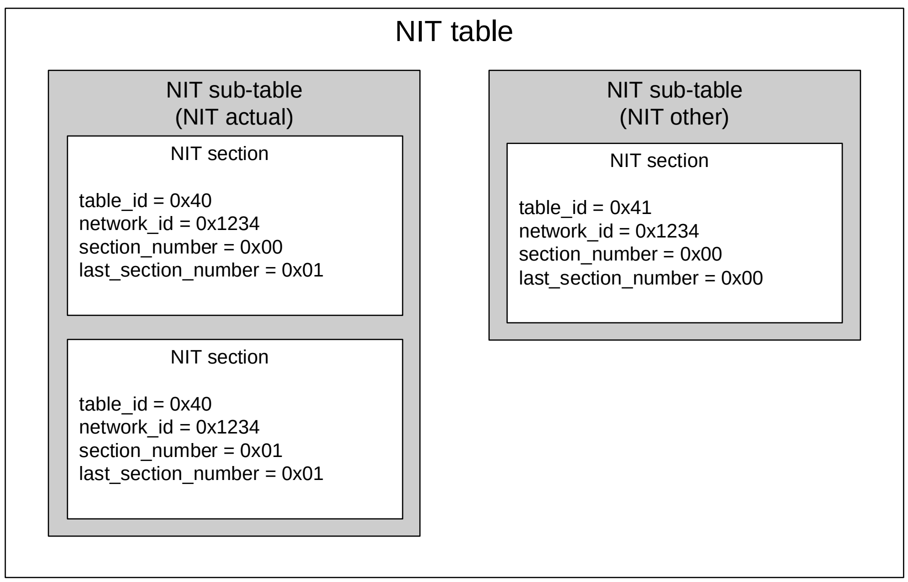

Figure 2-4. An example of the relation between table, sub-table and section where one NIT sub-table has two sections and one NIT sub-table has single section and both compose one NIT table.

The most of the signaling parameters carried within the PSI/SI tables are located within the descriptors, which are essential part of the PSI/SI tables. The descriptors enable flexible extensions to all PSI/SI tables and the actual content within the descriptor may vary depending on the table and purpose.

In addition to the data being carried within the descriptors, the signaling parameters are carried within the section headers or in the fixed parts of the sections. The descriptors have mutually common header structure, nevertheless it consists of only two fields, which are *descriptor_tag* and *descriptor_length*. The *descriptor_tag* field is a unique identifier for each descriptor, while the *descriptor_length* field indicates the length of the descriptor.

The PSI/SI tables are transmitted within the transport streams. Hence, the sections are first allocated into elementary streams which are further split into the transport stream packets. Each table type is carried on individual elementary streams and thus the discovery of PSI/SI tables is done via table_id and PID. Incase of most PSI/SI tables the PID values are static, though for example INT and PMT have dynamically allocated PID values. The scheduling of PSI/SI transmission is configured based on the minimum and maximum repetition intervals which are defined for each table. The minimum and maximum repetition interval is defined for each table and these are listed in Table 2-1.

Table 2-1. The minimum and maximum repetition intervals of DVB-H specific PSI/SI tables.

Table	**Minimum**	**Maximum**
NIT	25 ms	10 s
PAT	25 ms	100/500 ms
PMT	25 ms	100/500 ms
INT	25 ms	30 s
TDT	25 ms	30 s

2.2.2 PSI/SI signaling structure

The information carried within the PSI/SI has been split into different tables based on the purpose where it is used. The NIT has two main purposes within the DVB-H service discovery procedure. First, it provides information on the network topology, i.e., the identification and location information of cells and association of cells with the signal transmission parameters. Another purpose of NIT is to provide the discovery information of INT table. There can be two kinds of NIT tables. The NIT actual provides information of the network of the signal carrying it and it is always present in all DVB-H signals. NIT other is optional table and has identical structure with NIT actual, though it provides information of other network not present within the current signal. Since NIT actual and NIT other share the same PID value, the mutual separation of these can be done based on the table_id. If more than one NIT other tables are transmitted within the same signal, then the mutual separation of two NIT other tables can be done based on the network_id. The PAT and PMT have a chain structure, where PAT is used as a 'table of contents', where list of program_numbers, i.e., service_ids are associated with each PMT subtable. The PMT subtables, in turn, associate each service_id with the PID values of elementary streams. The elementary streams announced within PMT may carry service data or INT subtables. Figure 2-5 illustrates the mapping principle of INT subtable by using NIT, PAT and PMT.

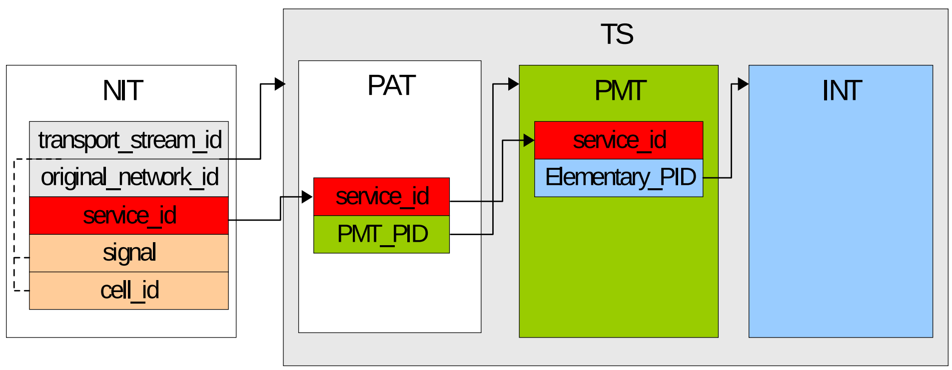

Figure 2-5. The mapping principle of INT by using NIT, PAT and PMT.

The purpose of INT is to associate IP addresses with the location within the transport stream. Ultimately the elementary streams are associated with IP addresses by using INT, PAT and PMT. Figure 2-6 illustrates the association of IP addresses with the elementary streams by using INT, PAT and PMT. The service_id points to the service_id, i.e., program_number announced within PAT and in parallel it is also associated with one or more IP addresses and transport stream specific identifiers, i.e., network_id, original_network_id and transport_stream_id announced within INT. The component_tag, also announced within INT, is needed to distinguish the Elementary_PID for the associated service_id, since one service_id may be associated with multiple IP addresses and Elementary_PIDs.

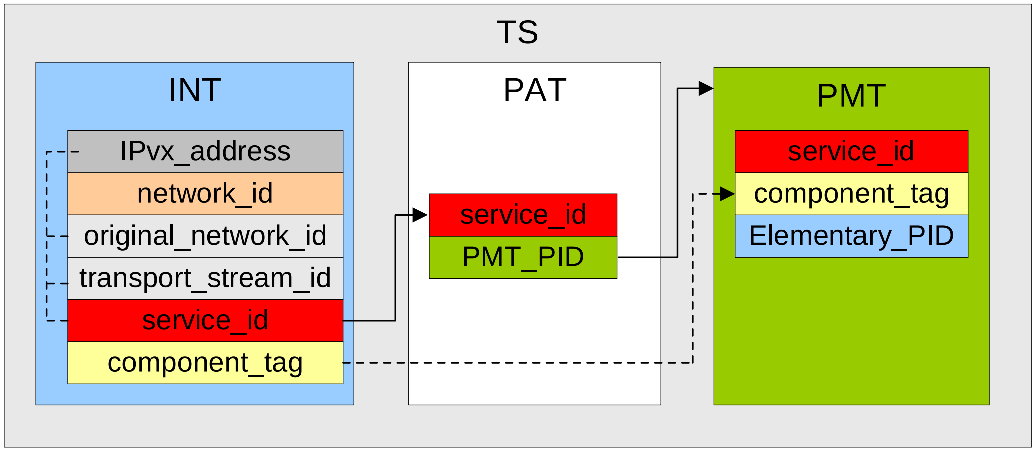

Figure 2-6. The association of IP addresses with the elementary streams by using INT, PAT and PMT.

The Figure 2-5 and Figure 2-6 depicted the DVB-H service discovery signaling chain as the 'table-by-table' illustration in general level. Next, the Table 2-2 lists the DVB-H specific descriptors and association for table which these are carried, followed with the description of the purpose and function of each descriptor.

Table 2-2. The DVB-H specific descriptors and the purpose of each descriptor.

Descriptor name	Table	Purpose
linkage_descriptor	NIT	Linkage into the INT table which provides the association between IP addresses and location with the transport streams.
network_name_descriptor	NIT	Network name
cell_list_descriptor	NIT	Cell identification and location information
time_slice_fec_identifier_descriptor	NIT and INT	Associates Time Slicing and MPE_FEC parameters with Elementary streams.
terrestrial_delivery_system_descriptor	NIT	Associates tuning information with transport streams and frequencies
cell_frequency_link_descriptor	NIT	Associates transport streams and frequencies with the cell identification
stream_identifier_descriptor	PMT	Associates Elementary streams with the information announced within the INT.
data_broadcast_id_descriptor	PMT	Associates the Elementary stream with the platform information and gives access information to the INT.

target_IPv4_descriptor	INT	Provides IP address information of the associated IP streams
target_IPv6_descriptor	INT	Provides IP address information of the associated IP streams
target_IPv4_slash_descriptor	INT	Provides IP address information of the associated IP streams
target_IPv6_slash_descriptor	INT	Provides IP address information of the associated IP streams
target_IPv4_source_slash_descriptor	INT	Provides IP address information of the associated IP streams
target_IPv6_source_slash_descriptor	INT	Provides IP address information of the associated IP streams
IP/MAC_stream_location_descriptor	INT	Provides IP address information of the associated IP streams

linkage_descriptor: This descriptor provides parameters which enable the INT subtable discovery through the PAT and PMT. One linkage descriptor may provide the INT discovery information to multiple INT subtables.

network_name_descriptor: This descriptor announces the network name. The name may be up to 256 characters long. The information announced within this field does not have importance from the service discovery point of view and it is only purposed as end user information.

cell_list_descriptor: This descriptor provides the identifications of cells and subcells located within the cells. It also associates the cell coverage area information with the cells and subcells. The spherical rectangle of the cell and cubcell is defined by using the following parameters; cell_longitude, cell_latitude, cell_extent_of_latitude, and cell extent_of_longitude and subcell_longitude, subcell_latitude, subcell_extent_of_latitude, and subcell extent_of_longitude, respectively. According to the definition in [47], the cell coverage area roughly encloses the cell coverage area inside the rectangle. Figure 2-7 illustrates the cell coverage areas of the cell and subcell, in which the coverage areas of the two cells are overlapping and a subcell is located inside the coverage area of cell.

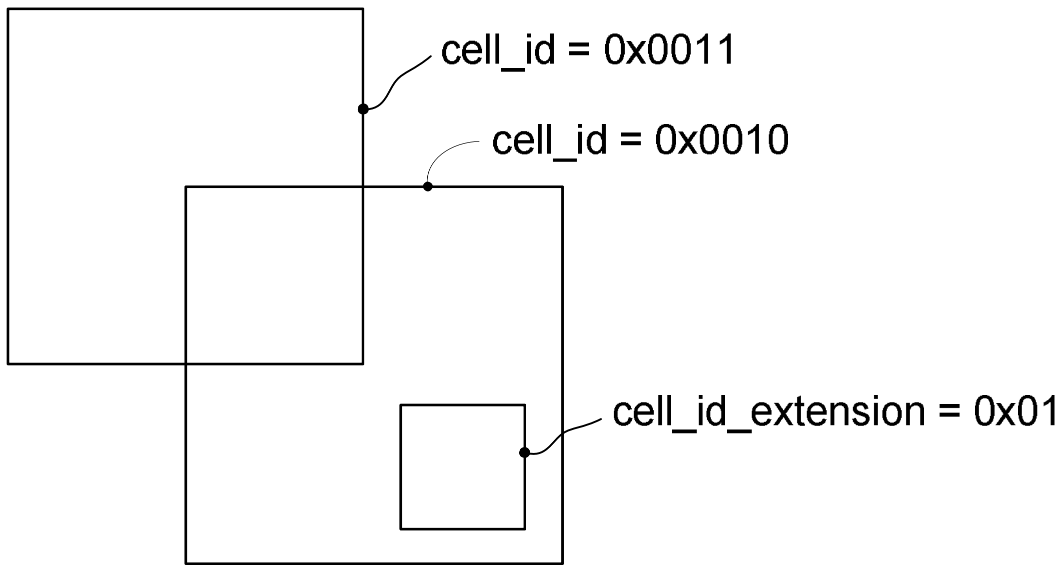

Figure 2-7. The definition of cell and subcell coverage areas and the signaling parameters.

time_slice_fec_identifier_descriptor: This descriptor is used for associating Elementary streams or transport streams with time-slicing and MPE-FEC parameters. In general the DVB-H specific descriptors are always located within one table type. However, this descriptor is an exception since it may be located only within NIT or INT or in both. In all this descriptor may be located within four different locations and may associate time-slicing and MPE-FEC parameters with transport streams, platforms or elementary streams. Figure 2-8 illustrates the four locations for the allocation of time_slice_fec_identifier_descriptor within NIT and INT, and the different allocations are explained below the figure.

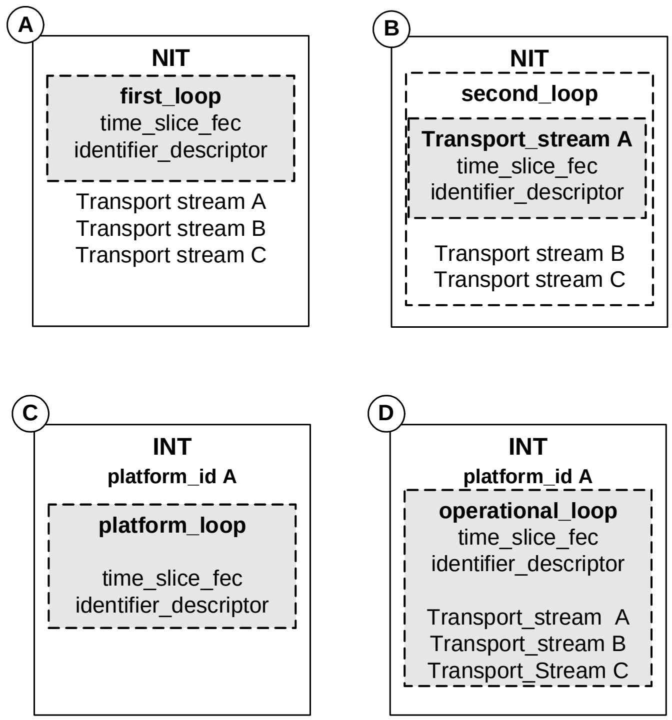

Figure 2-8. The allocation of time_slice_fec_identifier_descriptor within NIT and INT.

A. The time_slice_fec_identifier_descriptor is located within the first loop of NIT. All transport streams announced within the NIT are associated with the time-slice and MPE-FEC parameters announced within the descriptor. Hence, all elementary streams provided by the network are now associated with the same time-slice and MPE-FEC information.

B. The time_slice_fec_identifier_descriptor is located within the second loop of NIT. This allows labeling of individual transport streams with the information carried within the time_slice_fec_identifier_descriptor. Also, time_slice_fec_identifier_descriptor was allocated also according to A., then that information is overwritten with the information provided within this location.

C. The time_slice_fec_identifier_descriptor is located within the platform loop of INT. Now, all elementary streams announced within the INT subtable are overwritten with the information provided within this location.

D. This is the fourth and the last possible location for the time_slice_fec_identifier_descriptor. When announced within this location, the time-slicing and MPE-FEC information may be provided on elementary stream basis. That is, all information associated prior on the elementary stream is overwritten with the information provide by the time_slice_fec_identifier_descriptor within this location.

This descriptor was defined by Nokia and it was co-invented by the author in [33]. The need for this descriptor was critical, since there were no other means to provide signaling for these additional Time Slicing and MPE-FEC parameters defined in [34].

terrestrial_delivery_system_descriptor: This descriptor associates L1 parameters such as frequency, hierarchical priority, and modulation parameters with the transport streams. In addition to the L1 parameters, it provides also indication whether particular transport streams carry time-slicing and/or MPE-FEC supporting elementary streams.

This descriptor was enhanced by the Nokia proposal when the lack in the signaling of hierarchical transport stream information was detected. The solution was patented as [35] where the author was co-inventor.

cell_frequency_link_descriptor: This descriptor provides association between transport stream, frequency and cell identification. One such descriptor is allocated for the each transport stream announced within NIT.

stream_identifier_descriptor: This descriptor is used for associating components with the elementary streams. It carries the component_tag parameter which is also announced within INT.

data_broadcast_id_descriptor: This descriptor is used for the association of INT subtable with the elementary stream. The link is created between platform_id, program_number and transport stream.

target_IPv4_descriptor: This descriptor is used to list the IPv4 addresses of the IP streams listed within the INT. Only the destination IPv4 addresses are announced within this descriptor. This descriptor may be carried in parallel with other target descriptors.

target_IPv6_descriptor: This descriptor is similar to the previous descriptor, except that this is used to announce IPv6 addresses of the IP streams. This descriptor may be carried in parallel with other target descriptors.

target_IPv4_slash_descriptor: This descriptor is used to list the IPv4 addresses of the IP streams listed within the INT. In addition, it announces slash masks for each IP stream. Only the destination IPv4 addresses are announced within this descriptor. This descriptor may be carried in parallel with other target descriptors.

target_IPv6_slash_descriptor: This descriptor is similar to the previous descriptor, except that this is used to announce IPv6 addresses of the IP streams. This descriptor may be carried in parallel with other target descriptors.

target_IPv4_source_slash_descriptor: This descriptor is used to list the IPv4 addresses of the IP streams listed within the INT. In addition, it announces slash masks for each IP stream. In addition to the IPv4 destination addresses also the IPv4 source addresses are announced within this descriptor. This descriptor may be carried in parallel with other target descriptors.

target_IPv6_source_slash_descriptor: This descriptor is similar to the previous descriptor, except that this is used to announce IPv6 addresses of the IP streams. This descriptor may be carried in parallel with other target descriptors.

IP/MAC_stream_location_descriptor: This descriptor is used to associate the network, transport stream, service_id and component with the IP addresses announced within any of the ‘target’ descriptors. This descriptor can be said to be the main interface between INT table and other PSI/SI tables.

2.3 Service Discovery Principles

Service discovery within DVB-H means the resolving procedure of the association of IP addresses with the platform, transport stream, elementary stream, frequency, cell identification and network. The service discovery in DVB-H is needed for the initial service acquisition, i.e., when the service is sought for the first time. Service discovery is also needed to maintain the service reception and consumption during handovers. The Service discovery in DVB-H system can be split into two separate phases. These are signal scan, also referred as Initialization and PSI/SI parameter discovery. The signal scan consists of procedure where information on all potentially available DVB-H signals and networks are sought. The PSI/SI parameter discovery, in turn, refers to the different stages of service discovery where the mapping between services and their location within different DVB-H multiplexes is being sought. The Signal scan is described in section 2.3.1, while the section 2.3.2 explains the PSI/SI parameter discovery.

2.3.1 Signal scan

The signal scan is the procedure which needs to be done by the receiver at least once prior it can start the actual service discovery procedure. In addition it may be necessary to renew the initialization process once in a while in order to ensure that all possibly available services can be utilized by the end user. The initialization procedure in the context of DVB-H was first introduced in [P1]. However, the procedure presented in the latter was later improved by the extension to the DVB-H signaling, which was first introduced in [36]. The generic example of the signal scan procedure published in [P5] is depicted in Figure 2-9 and it has been used as a basis for the de-facto implementation in [57]. The steps of the signal scan are described in the following:

Step1: The receiver attempts tuning to the given frequency. The frequency range depends on the particular receiver implementation. The full frequency range covers frequencies from 474 to 858 MHz, where the offset is determined by the used bandwidth. The bandwidth can be 5, 6, 7, or 8 MHz.

Step2: Prior the actual synchronization is done, the receiver attempts to have TPS lock. Through the TPS information receiver is able to discover the cell identification and also whether the found signal carries DVB-H services. In case the TPS signaling indicates that the current signal does not carry DVB-H services, it is dropped.

Step3: In case the TPS signaling indicates that the signal carries DVB-H services, the receiver proceeds by synchronizing into the signal. Next, it starts to receive the NIT actual and NIT other subtables and hence is able to collect information on the other signals available within the current location and elsewhere within the network. In minimum, receiver should collect INT access information for the INT subtables carried within the current signal and on the signals carried within the adjacent signals. Based on the information obtained from the NIT subtables, receiver can narrow the frequencies that it attempts to tune when entering the Step1 next time.

Step4: Once the frequency range has been exhausted, the signal scan procedure is completed. If there are still frequencies left, the procedure continues from Step1.

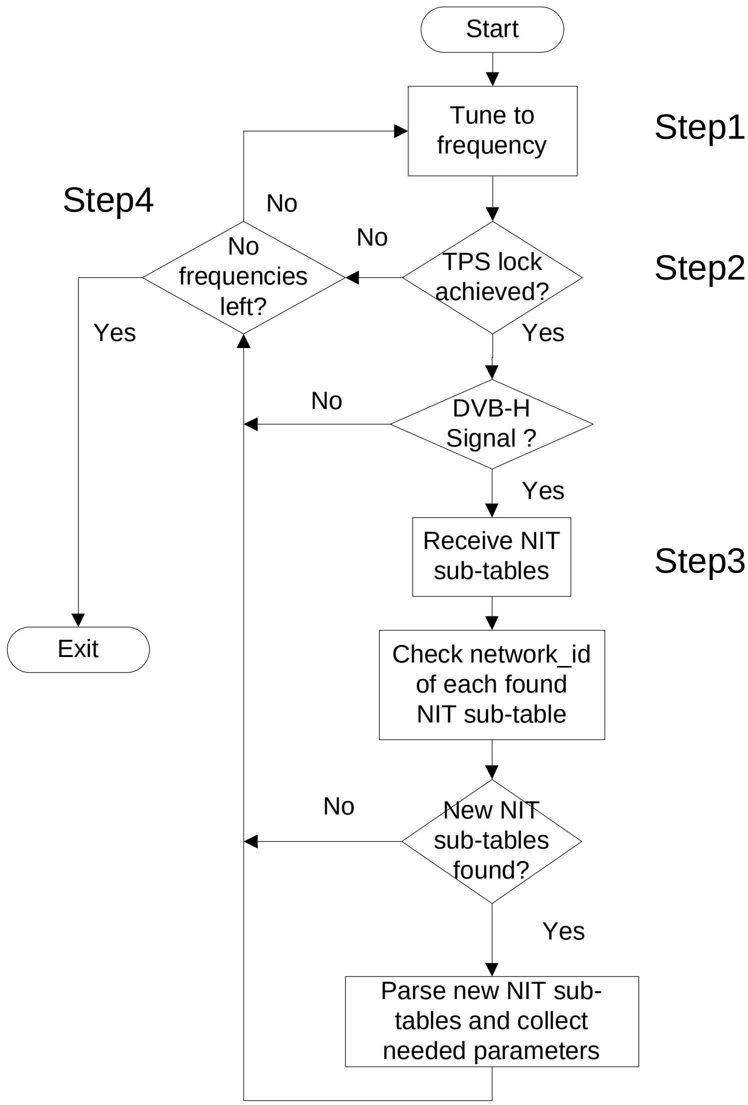

Figure 2-9. The generic example of the signal scan procedure.

2.3.2 PSI/SI parameter discovery for service access

The service discovery information carried within the PSI/SI is a combination of several PSI/SI parameters. The PSI/SI parameter discovery can be further split into the three procedures which form the core part of the DVB-H service discovery. These three procedures are named as INT Access Discovery, Network Discovery and INT Discovery. Typically the signal scan has been executed prior starting the PSI/SI parameter discovery for the services. The Figure 2-10 illustrates an example of the INT Access Discovery procedure with three steps.

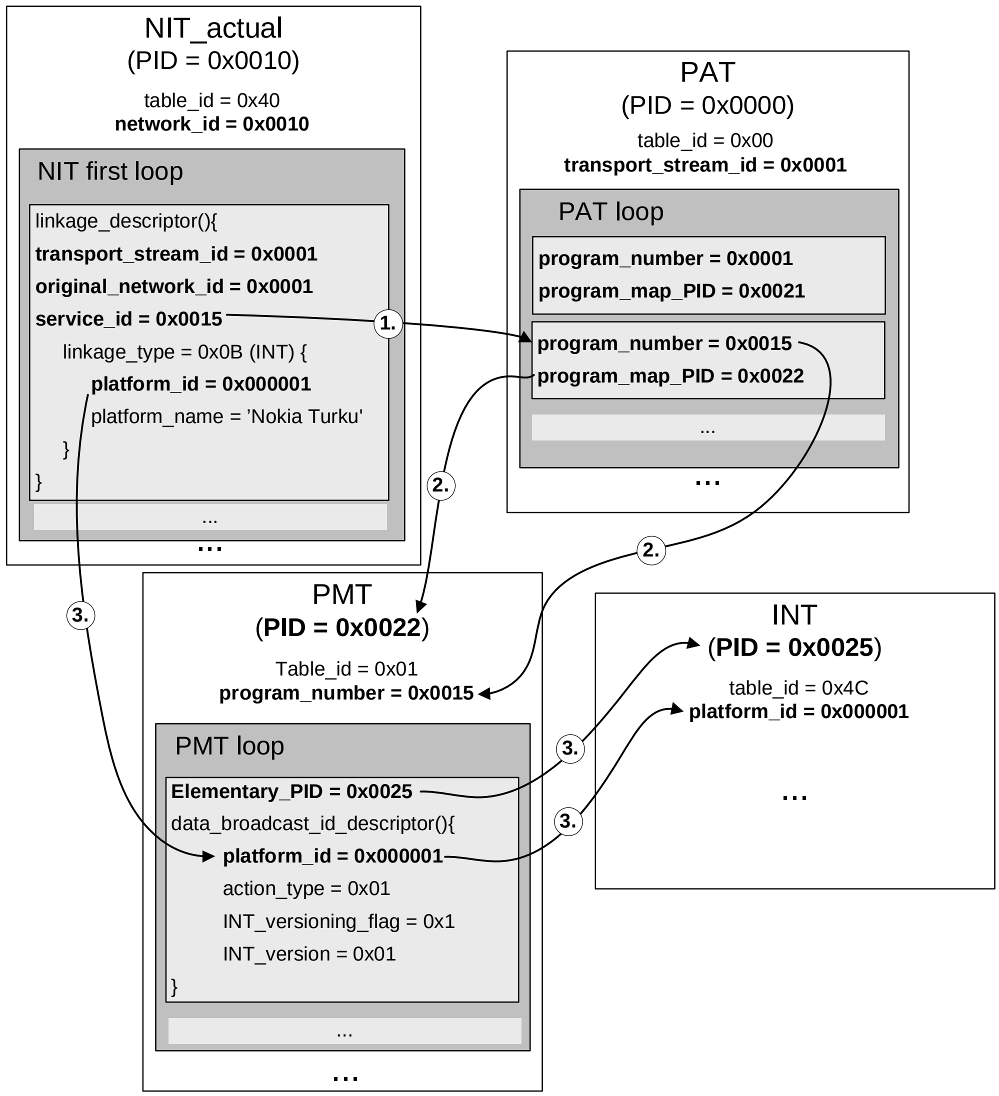

Figure 2-10. A three-step example of the 'INT Access discovery' procedure.

Step1: The program_number with the same value as that of the service_id announced within the linkage_descriptor and associated with the platform_id 0x000001, i.e., service_id = 0x0015, is sought from the PAT.

Step2: The PAT associates program_number = 0x0015 and program_map_PID = 0x0022. Hence, the PMT sub-table identified with program_number = 0x0015 is sought from the elementary stream with the PID value of 0x0022.

Step3: The PMT associates elementary_PID = 0x0025 with platform_id = 0x000001. Hence, the INT sub-table identified with platform_id = 0x000001 is sought from the elementary stream with the PID value = 0x0025.

Next, the network discovery procedure is described in Figure 2-11.

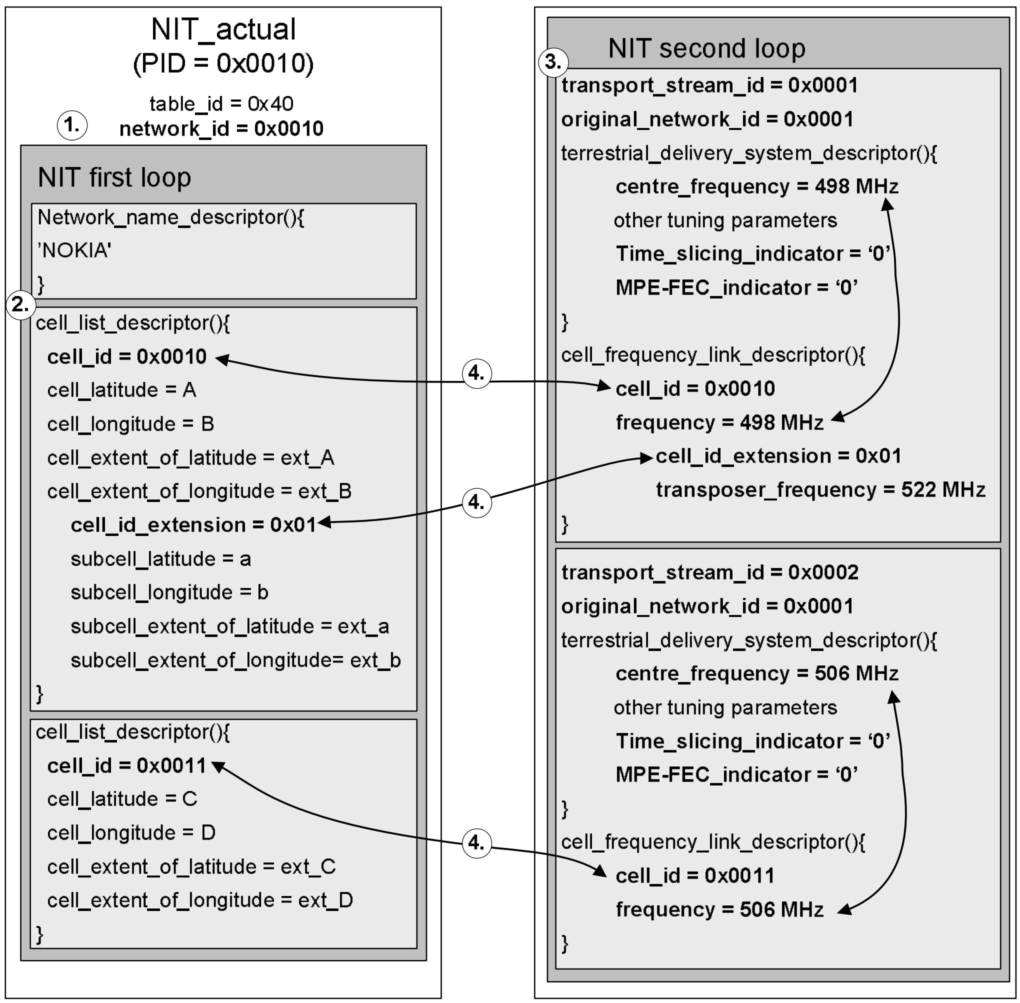

Figure 2-11. The Network Discovery procedure.

Step1: All information announced within this sub-table is associated with network_id = 0x0010, which is associated with the network name 'NOKIA'. The network name descriptor is always transmitted in the beginning of the first descriptor loop.

Step2: The cell_list_descriptors announce cells with cell_id = 0x0010 and 0x0011. Furthermore, the cell with cell_id 0x0010 is associated with the subcell identified by cell_id_extension = 0x01.

Step3: The second loop of the NIT associates transport streams with cells, subcells, frequencies and other tuning parameters. First, the transport stream identified with transport_stream_id = 0x0001 and original_network_id = 0x0001 is associated with the frequency of 498 MHz and other tuning parameters carried within terrestrial_delivery_system_descriptor. Next, the same transport stream is further associated with cell_id = 0x0010 by the cell_frequency_link_descriptor. Also, the subcell with cell_id_extension = 0x01 and transposer_frequency = 522 MHz is associated with the given transport stream and cell.
Another transport stream identified with transport_stream_id = 0x0002 and original_network_id = 0x0001 is associated, by following a principle similar to the first-mentioned transport stream, with the frequency of 506 MHz, other tuning parameters, and cell_id = 0x0011. Also, for both transport streams, the Time_slicing_indicator and MPE-FEC_indicator are set to '0', which indicate that the associated transport streams carry at least one DVB-H service which has MPE-FEC support.

Step4: As the cell_list_descriptor defines the coverage areas, the receiver is able to deduce that the cell with cell_id = 0x0011, the cell with cell_id = 0x0010 and the subcell with cell_id_extension = 0x01 are all neighboring and hence also potential handover candidate, regardless of the current location of the receiver. Based on the mapping with the information acquired from the NIT second loop, the receiver has complete tuning information for these potential candidates.
Finally, the INT discovery procedure is depicted in Figure 2-12.

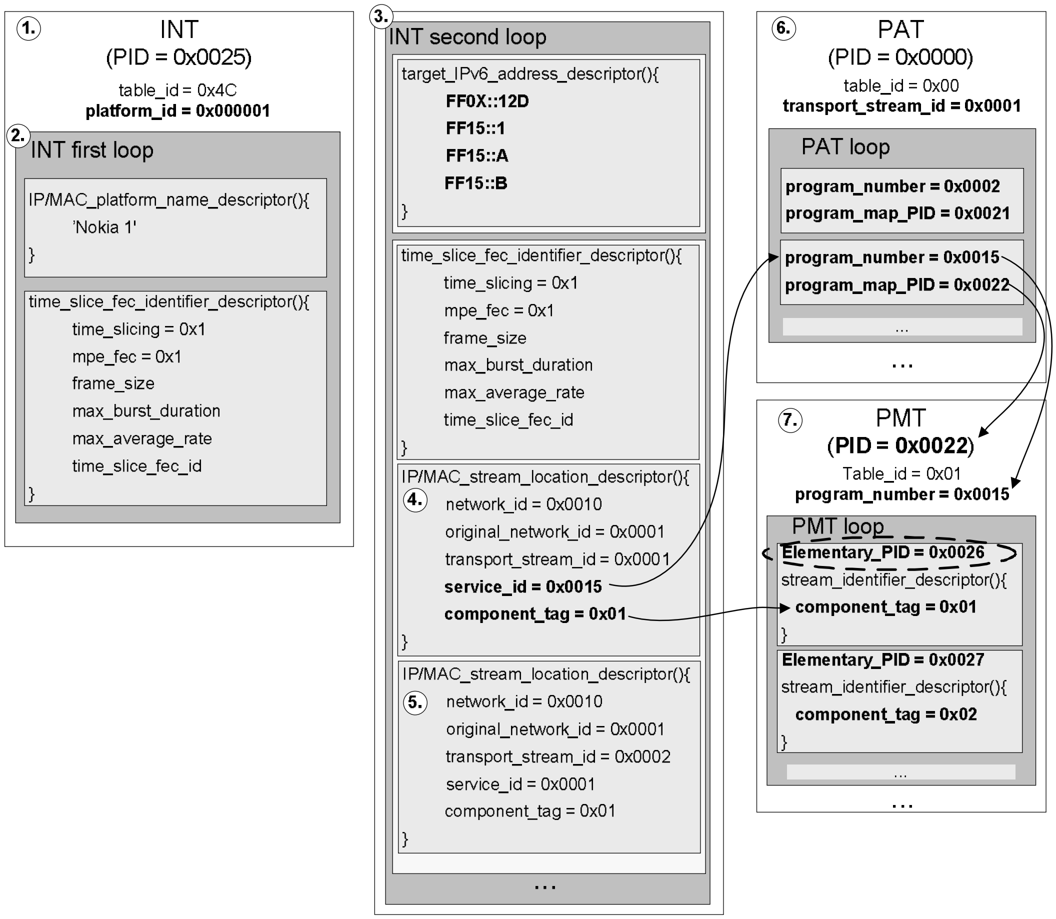

Figure 2-12. The INT Discovery procedure.

1. The table_id and platform_id within the INT sub-table header identify the INT sub-table. Platform can be unique within the network or globally, depending on the allocated value.

2. The first loop of the INT carries the platform_name descriptor, which indicates the name of the platform associated with platform_id = 0x000001. In addition, the first loop also carries the time_slice_fec_identifier_descriptor, which associates all IP streams announced within this table with the time-slicing and MPE-FEC-specific parameters. First, time_slicing and MPE-FEC indicators are set to the value 0x1, which indicates that all IP streams announced within this table are DVB-H services which also support MPE-FEC. The other parameters associated with the descriptor are frame_size, max_burst_duration, max_average_rate and time_slice_fec_id. The latter four parameters provide information on time-slicing and MPE_FEC and may be used by the receiver.

3. The second loop of the INT associates the addresses of the target IP streams with the PSI/SI parameters which further associate the IP streams with the Elementary streams carried within one or more transport steams. It is mandatory for each INT sub-table to associate IP streams with the current transport stream and with the transport streams available in the neighboring cells. Moreover, the time_slice_fec_identifier_descriptor is also located within the beginning of the loop, overriding the information associated with the same descriptor previously. The parameters are valid until the next occurrence of the same descriptor.

4. The first IP/MAC_stream_location_descriptor announces the parameters of the transport stream identified with original_network_id = 0x0001 and transport_stream_id = 0x0001. The Network Discovery procedure in Figure 2-11 shows that the associated transport stream is the transport stream carried with the signal that the receiver has currently tuned. As well, the same transport stream is available within a sub-cell of the current cell, i.e., on the frequency 522 MHz.

5. The second IP/MAC_stream_location_descriptor announces parameters of the transport stream identified with original_network_id = 0x0001 and transport_stream_id = 0x0002. According to the parameter mapping in the Network Discovery procedure, the transport stream associated within this descriptor is available within a neighboring cell. With the service_id and component_tag, the receiver may discover a corresponding elementary stream through the PAT and PMT available within the neighboring cell, similarly as was done in the current transport stream in step 4.

6. The program_number corresponding with the service_id = 0x0015 is sought from the PAT, which associates it with program_map_PID = 0x0022.

7. The PMT sub-table identified with program_number = 0x0015 is sought from the elementary stream with a PID value of 0x0022. Finally, the elementary stream carrying the associated four IP streams are found based on the component_tag associated with the service_id in step 4. The receiver can now access the four IP streams announced within the INT by filtering the elementary stream with PID value 0x0026.

2.4 Soft handover principle in DVB-H

The Time Slicing was initially defined to improve power saving but it also enabled a possibility to interrupt-free reception of services when the receiver switches from one signal to another. In [P1], the aforementioned interrupt-free switch from a signal to another was called soft handover. The solution proposed in [P1] (See Figure 2-13) was based on [117] where an algorithm for soft handover was introduced for the first time. While the [117] focused on the physical layer aspects, the solution in [P1] was more comprehensive by taking account also the PSI/SI signaling and cell_id inspection from the TPS signaling. Furthermore, in [P1] an analysis was provided on the capability for seamless handover in case of multiple candidate signals.

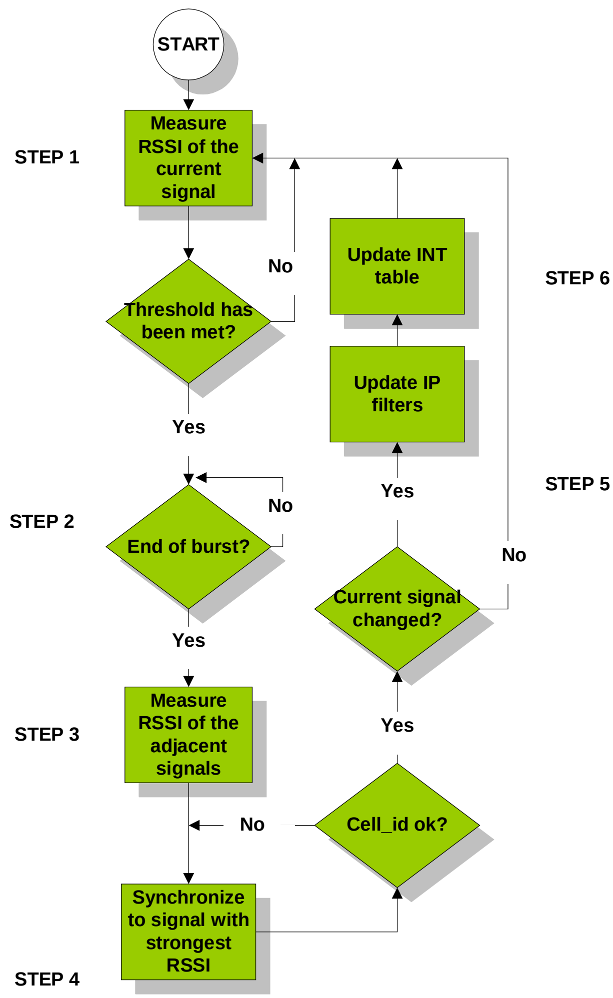

Figure 2-13. Handover algorithm proposed in [P1].

Later, the handover algorithm of [P1] was further enhanced with the DVB-H signal detection signaling in [36] and with the prioritization method of candidate cells in [118], [P4] and [P5]. Also, an alternative signaling of cell coverage areas was investigated to be used in handover algorithm in [P2].

2.5 Summary

The [P1] introduced the generic procedures for the service discovery in DVB-H, which consisted of Signal scan and principle for performing soft handover during the Time Slicing off-periods. The Signal scan described in [P1] is very similar to that of in DVB-T and it was later enhanced by the TPS signaling solution [36]. Also the handover algorithm introduced in [P1] was further enhanced by [36] and [P4]. The comprehensive handover algorithm including elements of [P1], [36] and [P4] was published in [P5], which also covered the entire DVB-H signaling chain with complete examples and detail presentations on the parameter mappings. The [P2] consists of a proposal as an alternative method to signal cell coverage areas and hence improve the handover performance, but it was concluded as too expensive solution from the operator point of view and hence was not adopted into DVB standards.

The [P3] consisted of a survey of the development of DVB-H and IPDC over DVB-H standards at the time it was published and elaborates the findings in [P1],[P2] as well as in many other publications representing the related work.

3 PSI/SI Robustness

MPE-FEC was developed for the DVB-H to provide error correction mechanism for burst errors which are typical in the mobile environment. The MPE-FEC was defined only for the protection of the service data carried within MPE sections and not for the transmission of PSI/SI [119], [120], [47], [121], [39], [122]. The PSI/SI has only cyclic redundancy check (CRC), which can be used for the detection of errors, but which has no use for the correction of the errors. The decision of not to provide error protection for PSI/SI in DVB-H was merely based on assumption without any concrete evidence of whether error correction mechanism would have been needed also for the transmission of PSI/SI. The fundamental difference on the importance of robustness within the transmission of service data and PSI/SI signaling is that the former can resist more errors than the latter. The small errors within the service data are barely noticeable whereas even one bit difference in the signaling data carried in PSI/SI may result in erroneous service selection and rendering or completely disable the service discovery and consumption. Since there is no means to correct erroneous PSI/SI signaling, receiver needs to re-receive it until it has received correctly all needed signaling. The lack of robustness in PSI/SI may be problematic especially in the dense Multi-Frequency Networks (MFN)s , where receiver needs to receive the updated signaling information each time when it has performed handover in order to be able to make handover to the next cell. The signaling information carried within the PSI/SI is split into several different sub-tables, which are typically further been split into multiple sections. If one or more sections of particular sub-table is corrupted, the receiver needs to wait until the next transmission of the sub-table prior it is able to collect the complete set of sections of that particular sub-table. The following sections give a summary of the PSI/SI robustness study which was carried out in [P6], [P7] and in [P8].

3.1 Theoretical analysis and optimization methods

The robustness of PSI/SI was first investigated in [P6] where theoretical analysis was provided based on probability of the error occurrence in the PSI/SI transmission. The impact of the receiver implementation for the reception of PSI/SI transmission was also taken into account when considering the reception probability calculations.

In [P6] the analysis was done based on three different modulation schemes (Table 3-1), which were based on practical and empirical experience of the used and planned network configurations at the time.

Table 3-1. The parameters of the modulation schemes used as a basis of the analysis.

	Modulation scheme		
Parameter	Low cost	Typical	Max mobile
Transmission mode	8k	8k	8k
Constellation	QPSK	16QAM	16QAM
Code rate	1/2	1/2	2/3
Guard Interval	1/8	1/8	1/8
Bandwidth	8	8	8
Bitrate (Mbps)	**5.53**	**11.06**	**14.75**

The default service that was used in all modulation schemes is composed of four components; IRD A video, Audio, Subtitles and Filecast (See Table 3-2)

Table 3-2. The resulting bitrate per IP stream within one service.

IP stream type	**Bitrate (kbps)**
IRD A video	106
Audio	68
Subtitles	5
Filecast	0
$\sum$	179

The PSI/SI signaling scheme which was used within all three modulations is the same and it is based on the network elements listed in Table 3-3. The network elements listed in Table 3-3 have all impact on the size of different PSI/SI tables depending on how many times each parameter is needed within the signaling structure.

Table 3-3. The network elements used as the basis for the PSI/SI signaling scheme.

Network component	**Amount**
Platform	1
Cell	11
IP streams per service	4
Transport stream (TS)	11
Announced neighboring cells per TS	6

Since there was no error criteria for the PSI/SI transmission, the error criteria that of used in data transmission was used as a basis. The robustness is analyzed based on the success probability in the reception of sub-tables PSI_SI_{SP} in simulation where TS packets of the transmission are corrupted with an error pattern. The used error pattern is based on the averaged error rate of transport stream packets TS_{PERR}, which is assumed as 0.15. In theory, MPE-FEC is able to correct up to 25% of erroneous TS packets, if a typical MPE-FEC coderate of ¾ is used [40]. On average 15% TS_{PERR} leads to a 5% MPE-FEC Frame Error Rate (MFER) reception, with typical high quality receiver implementation, when the channel model Typical Urban with six paths (TU6) [123] is used. The MFER of 5% is the failure criteria set in [124] leading to acceptable picture quality. Therefore an average TS_{PERR} target of 15% was selected.

It is assumed that the receiver implementation is ‘intelligent’, i.e., it is able to parse PSI/SI tables immediately after all sections of each sub-table have been received, even if these are received in reverse or random order. Since 100% PSI_SI_{SP} is not reasonable, the minimum PSI_SI_{SP} was set at 0.95. As well, other confidence levels could be used for the comparisons, with minor effect on the results. The PSI_SI_{SP} is calculated as follows:

First we get the probability of unbroken TS packets *TSpok* by

$$TS_{pok} = 1 - TS_{PERR} \tag{3-1}$$

The probability of N consecutive unbroken TS packets *SECpok* is calculated as follows:

$$SEC_{pok} = (TSpok)^{TS_{count}} \tag{3-2}$$

where *TScount* is the number of TS packets per one PSI/SI sub-table. Respectively, the probability for *N* consecutive TS packets SEC_{PERR} is calculated with the following

$$SEC_{PERR} = 1 - SEC_{pok} \tag{3-3}$$

Finally, the PSI_SI_{SP} can be derived from the following

$$\frac{\left(\left(n \text{ over } k\right) \times a^{k} \times b^{(n-k)}\right)}{\left(a+b\right)^{n}} \tag{3-4}$$

where $k = PSI\_SI_{SP}$, n is the number of trials, $a = SECpok$ and $b = SEC_{PERR}$. Next, the PSI_SI_{SP} and receiver latency is calculated separately for each sub-table when the maximum section sizes and repetition intervals are used.

Furthermore, it was assumed that receiver should be able to receive all signaling information within the time consumed for the error-free transmission when maximum repetition intervals are used. Also, a maximum value for the total network capacity allowed for the signaling was defined as 1%, which was considered as reasonable based on the known DVB-H network implementations and configurations at the time.

Since the IP configuration scenario and the PSI/SI signaling is the same in all three modulation schemes, the network capacity consumption of PSI/SI signaling is determined by the number of signaled IP streams. The latter, in turn, is calculated based on the available service bitrate B_S, within each scheme.

The B_S is constrained by the bitrate consumed by the PSI/SI signaling and the bitrate reserved for MPE-FEC signaling. Since the network capacity for PSI/SI signaling cannot be accurately calculated before the number of signaled services is known, and vice versa, 1% of total capacity is reserved as a fixed bitrate for PSI/SI signaling. Since the latter is significant as regards the number of signaled services, it cannot be exceeded. The coefficient of 0.75 is used for reserving extra network capacity for the MPE-FEC code rate. Hence, the number of services *S* within the three modulation schemes is calculated as follows:

$$S = \left(\frac{B_{TS} - B_{FPSISI}}{B_S} \right) \times MPE\_FEC_{CE} \qquad (3\text{-}5)$$

where B_{TS} is the total bitrate of TS, B_{FPSISI} is the fixed bitrate reserved for the PSI/SI and B_S stands for the bitrate of one service. Finally, MPE_FEC_{CE} is the coefficient for the bitrate reserved for MPE-FEC support.

Ultimately, the actual bitrate of PSI/SI is determined by the size and repetition interval of each sub-table. Hence, the total network capacity consumed by the PSI/SI sub-tables *cPSI_SItot* is calculated as follows:

$$_{C}PSI\_SI_{tot} = {_C}NIT + {_C}PAT + {_C}PMT + {_C}INT + {_C}TDT \qquad (3\text{-}6)$$

where $_{C}NIT$, $_{C}PAT$, $_{C}PMT$, $_{C}INT$ and $_{C}TDT$ equal network capacity consumed by NIT, PAT, PMT, INT and TDT sub-tables, and are calculated as follows:

$$_{c}SUB = \frac{_{sTS}SEC \times _{sc}SUB}{_{ri}SUB} \qquad (3\text{-}7)$$

where sTS^{SEC} equals the size of one PSI/SI section in the TS level and is calculated by

$$sTS\,SEC = Round\left(\frac{_{SS}SUB}{184}\right) \times 188 \qquad (3\text{-}8)$$

where $_{SS}SUB$ indicates the maximum section size of the sub-table and Round (x) rounds upwards to the next integer. Respectively, $_{SC}SUB$ indicates the number of sections per each sub-table. Finally, *riSUB* is the repetition interval of the sub-table.

Table 3-4 lists S (3-5) and *cPSI_SItot* (3-6) in all three given modulation schemes, when the maximum repetition intervals listed in Table 2-1 and maximum section sizes are used. The B_{FPSISI} is also given for each scheme as a reference.

Table 3-4. S, CPSI_SITOT and BFPSISI of the given modulation schemes, when maximum repetition intervals and section sizes are used.

	Low cost	**Typical**	**Max mobile**
S	22	45	61
CPSI_SITOT (kbps)	47.23	62.95	63.69
BFPSISI (kbps)	55.3	110.6	147.5

Hence, the time consumed to receive the signaling information, i.e., receiver latency and the network capacity consumption were taken as measuring factors in the study.

In [P6], all five PSI/SI tables used within the DVB-H signaling were analyzed. It was discovered that the PSI/SI tables with large sections, i.e., NIT and INT, and long repetition intervals resulted in unacceptable receiver latency. Especially in the case of the transmission of INT table the latency could be as high as 5100 seconds. In the cases of PAT and PMT, there was no significant extra receiver latency, since in both cases the sub-tables can be received in less than 500 ms with the PSI_SI_{SP} of 95%, hence it was discovered that no optimization is needed to PAT and PMT.

After detecting the robustness problems, the goal was to discover the most optimal method to transmit PSI/SI signaling by adjusting the existing variables, i.e., repetition intervals and section sizes. The solution was sought after with two different ‘optimization methods’. The first optimization method was called “Simple optimization”, in which only repetition intervals are changed to meet the receiver latency and network capacity constraints. The “Advanced Optimization” was the second method, in which repetition intervals and section sizes are changed.

3.1.1 Simple optimization

The simple optimization determines the optimized repetition interval of each sub-table *oriSUB* that is needed in order to achieve PSI_SI_{SP} of 95%. The *oriSUB* can be calculated by means of maximum number of transmission of a sub-table (*mnt)* as follows:

$$_{ori}SUB = \frac{_{ri}SUB}{mnt} \tag{3-9}$$

where the *riSUB* stands for the repetition interval of the sub-table. Furthermore, the required network capacity for each sub-table *cSUB* is calculated as follows:

$$_{c}SUB = \frac{\left(\frac{_{sts}SUB}{_{ori}SUB}\right) \times 8}{1024} \tag{3-10}$$

where *stsSUB* equals the total size of sub-tables including TS overhead

3.1.2 Advanced optimization

As the simple optimization solved the robustness problem by decreasing the repetition intervals, the resulting increase of the network capacity needed for the PSI/SI signaling may not be acceptable.

Advanced optimization aims to find an optimized setting which improves robustness and maintains the network capacity consumed by the PSI/SI signaling on a reasonable level. The goal is to find a combination of section sizes and repetition intervals which result in robust transmission whilst the network capacity consumed by the PSI/SI signaling is maintained at a reasonable level.

3.1.3 Summary of results

The simple optimization showed that all other PSI/SI sub-tables except INT could be optimized simply by re-configuring the repetition interval. In the case of INT, the *cSUB* exceeded the set 1% limit for the network capacity consumption of PSI/SI signaling. Table 3-5 summarizes the results of the simple optimization in the case of the three modulation schemes.

Table 3-5. The summary of *oriSUB*, *cSUB* and input parameters of NIT, INT and TDT.

	Sub-table	${}_{sts}SUB$ *(Bytes)*	*mnt*	${}_{ri}SUB$ *(s)*	${}_{ori}SUB$ *(s)*	${}_{c}SUB$ *(kbps)*
Low cost	NIT	940	5	10	2	3.67
	INT	3948	111	30	0.27	198.41
	TDT	188	2	30	15	1.47
Typical	NIT	940	5	10	2	3.67
	INT	7896	153	30	0.19	569.20
	TDT	188	2	30	15	1.47
Max mobile	NIT	940	5	10	2	3.67
	INT	10904	170	30	0.17	871.46
	TDT	188	2	30	15	1.47

The advanced optimization focused on the inspection of INT and NIT only, since the TDT has fixed section size and structure and it cannot be changed. The *oriSUB* and the optimal section size of sub-table were sought for each sub-table.

It was assumed that each NIT section carries information of at least one transport stream, and hence the minimum section size for the NIT sub-table with the given configuration is 96 Bytes. The minimum network capacity per section is calculated based on the payload of the TS packet, i.e. 184 Bytes.

Figure 3-1 illustrates the PSI_SI_{SP} of the NIT in the case of different section sizes. The graph shows that the mnt for NIT varies from three to five and hence all section sizes illustrated within Figure 3-1 meet the receiver latency constraint when the repetition interval is decreased.

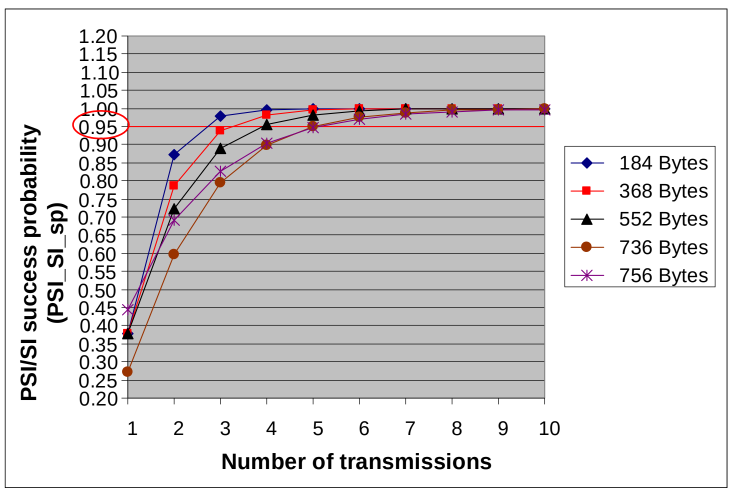

Figure 3-1. PSI_SI_{SP} of NIT sub-table in the case of different section sizes.

The cNIT for each section size (See Figure 3-2) indicates that 184 Bytes is the most optimal section size for the transmission of NIT.

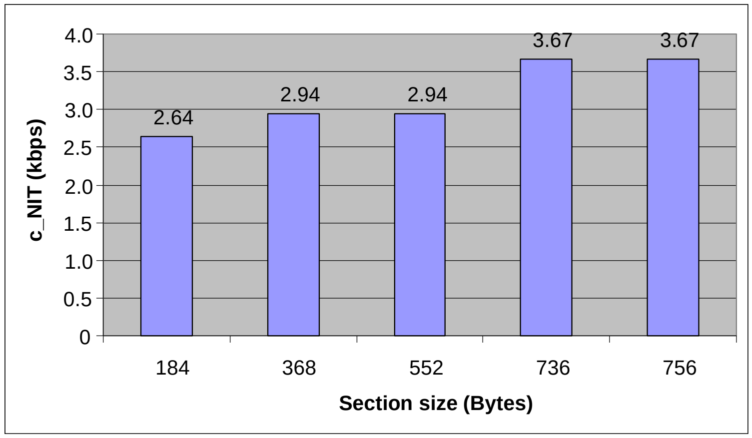

Figure 3-2. cNIT in the case of different section sizes.

The minimum size for one INT section is 203 Bytes, in the case where only one IP service is carried within each INT section. The maximum section size used in the calculations is the standard maximum 4096 Bytes. Figure 3-3 illustrates the relation of needed transmissions and PSI_SI_{SP} as a function of section sizes. Each set of curves presents the number of transmissions and PSI_SI_{SP} for Low cost, Typical and Max mobile configurations, when read from the left.

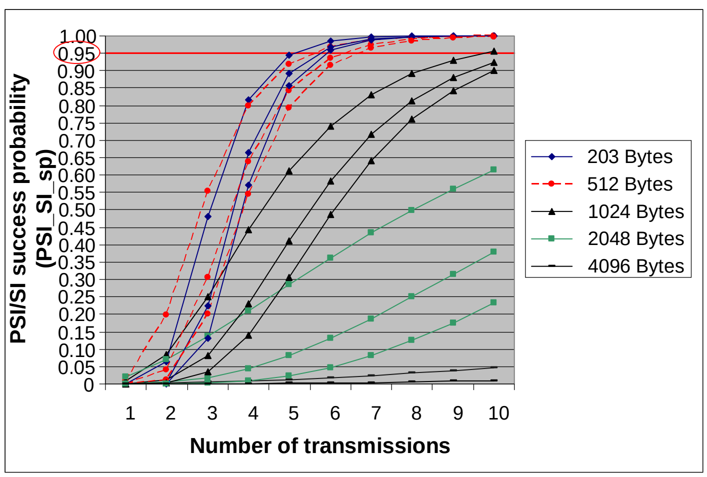

Figure 3-3. PSI_SI_{SP} of INT sub-table in the case of different section sizes.

The results in Figure 3-3 show that with the section sizes of 203 and 512 the number of transmissions is under 10, until the PSI_SI_{SP} of 95% is met. For the larger section sizes the number of needed transmissions is beyond 10 and hence results in excessive share of network capacity.

The results showed that the latency in the default transmission was unacceptably high for some of the sub-tables, such as INT. As well, even though the simple optimization succeeded in decreasing the latency to the minimum, the network capacity required for PSI/SI signaling was too high, exceeding many times the 1% BFPSISI. The advanced optimization provided the best trade-off between receiver latency and PSI/SI network capacity consumption. Finally, the PAT and PMT did not need any optimization due to the initially low repetition intervals which allow multiple re-receptions until the maximum repetition intervals are exceeded. Hence, the concluded 'Optimized transmission method' is a combination of 'Default transmission', 'Simple optimization' and 'Advanced optimization'. Table 3-6 lists the composition of the 'Optimized transmission method'.

Table 3-6. The composition of the 'optimized transmission' method.

	NIT	**PAT**	**PMT**	**INT**	**TDT**
Default transmission		X	X		
Simple optimization					X
Advanced optimization	X			X	

Next, the comparison of total network capacity consumed by the PSI/SI signaling $_{C}PSI/SI_{TOT}$ and total receiver latency according to the 'Default transmission' and 'Optimized transmission' is illustrated separately in Figure 3-4 and Figure 3-5. The total receiver latency is the total time consumed when each PSI/SI sub-table is received at least once. Also the fixed bitrate reserved for the PSI/SI signaling is also included in the comparison. As can be seen from the results, the total receiver latency can be decreased significantly with the optimized transmission. Moreover, the total increase in network capacity of PSI/SI in the optimized transmission is negligible. Finally, the 1% limit in the reserved PSI/SI network capacity is not exceeded in any configuration.

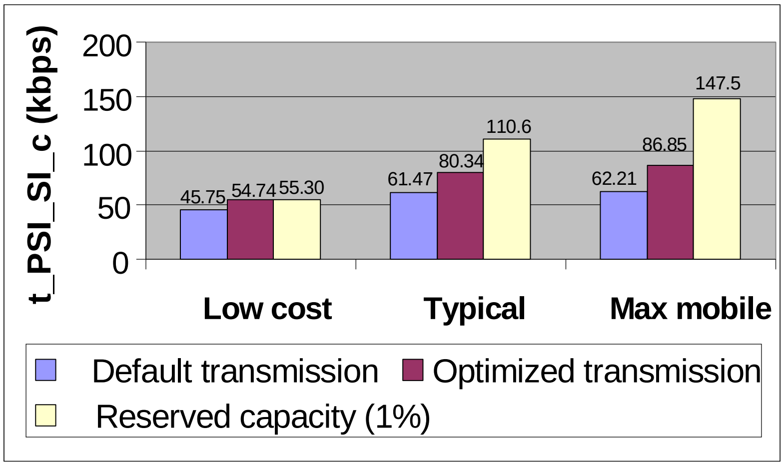

Figure 3-4. The $_{C}PSI/SI_{TOT}$ in default and optimized transmission.

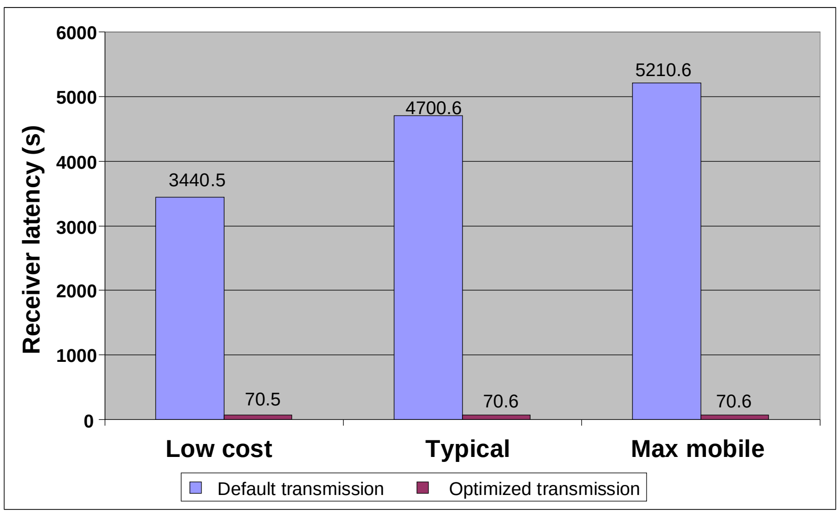

Figure 3-5. The total receiver latency in default and optimized transmission.

3.2 Simulations

The Studies on the PSI/SI robustness was continued with TU6 simulations in [P7], where recorded TS packet error traces measured with real receiver implementation were used as a basis. Separate error traces were used for the following Doppler frequencies; fD = 2 Hz, 10 Hz, 30 Hz and 80 Hz. The C/N (Carrier to Noise ratio) value is corresponding to TS PER ranging from 40 % to nearly error free transmission with 1 dB resolution. The configurations used within [P6], i.e., Low Cost (LC), Typical (T) and Maximum Mobile (MM) were taken as a basis by deviating only with different Guard Interval value which was 1/4 instead that of 1/8 used within [P6]. In addition the scope of the robustness analysis was extended also by taking into account the receiver implementation in the decoding of the PSI/SI tables.

3.2.1 Decoding methods

The decoding methods used within [P7] are called; *intelligent, correct order* and *all ok at once.* The characteristics of the decoding methods have been further clarified by means of the following description and Figure 3-6, which illustrates an example of transmission where one PSI/SI table is partially corrupted in three consecutive transmissions, while the fourth transmission is error-free.

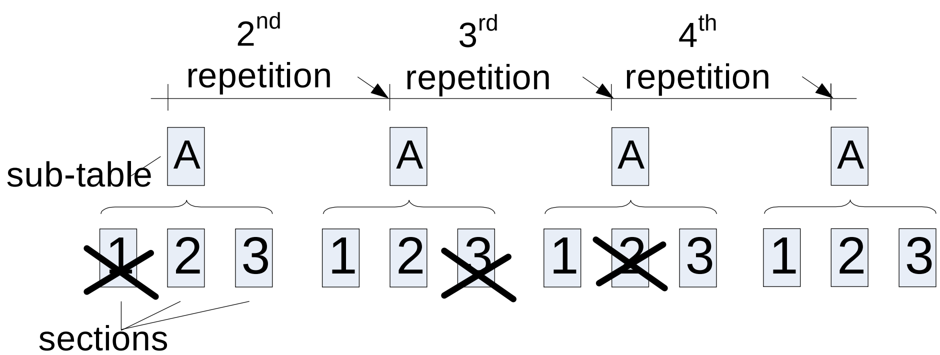

Figure 3-6. An example of the PSI/SI sub-table transmission where the sub-table is partially corrupted in three consecutive transmissions and the fourth transmission is error-free.

The intelligent decoding method is able to receive the sub-table A after the second repetition, since the transmission order of the sections doesn't have any influence. The *correct order* decoding method is able to collect all sections only after the third repetition, since only after then all sections can be received in correct order. Finally, the *all ok at once* decoding method needs to wait until all sections are transmitted within the same transmission, in correct order and are all error-free.

Next, Figure 3-7 illustrates the performance of the different decoding methods, where the curve for the 'intelligent' decoding method deviates from the other two. The curve for the 'all ok at once' decoding method, in turn, shows that such decoding method is not practical.

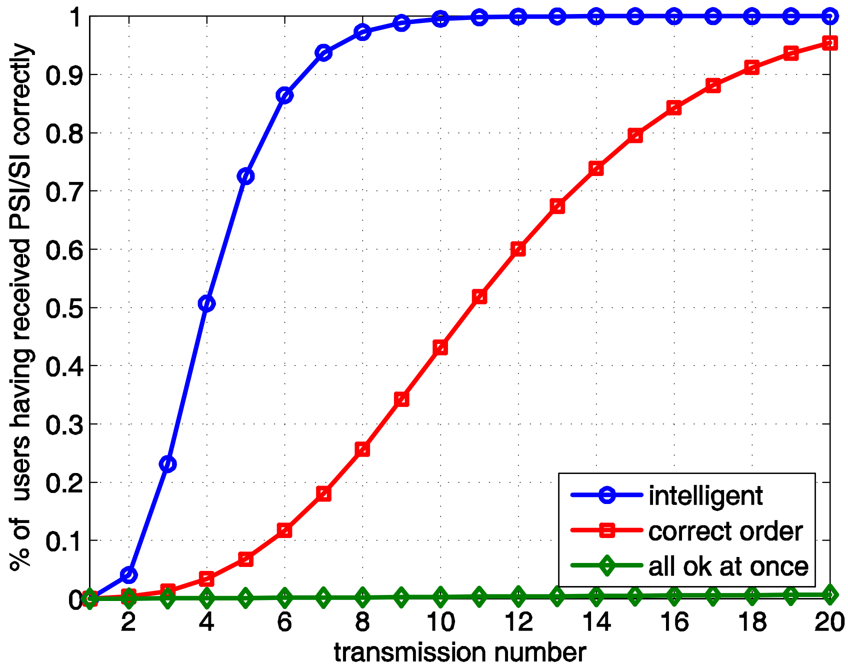

Figure 3-7. Performance of the different decoding methods.

Based on the performance of the intelligent decoding method, it was also taken as the decoding method which was further used in the simulations of the different PSI/SI transmission schemes. The Table 3-7 lists the different table sizes, section lengths and repetition intervals which were used within the simulations.

Table 3-7. The different PSI/SI transmission combinations used within the simulations.

Table B	Section lengths (B)	Rep. Intervals (s)
16384	64, 128, 256, 512, 1024, 2048, 4096	1, 5, 10, 15, 30
8192	64, 128, 256, 512, 1024, 2048, 4096	1, 5, 10, 15, 30
4096	64, 128, 256, 512, 1024, 2048, 4096	1, 5, 10, 15, 30
1024	64, 128, 256, 512, 1024	1, 5, 10, 15, 30
768	64, 128, 256, 512	1, 5, 10, 15, 30
512	64, 128, 256, 512	1, 5, 10, 15, 30
256	64, 128, 256	1, 5, 10, 15, 30
16	8, 16	.025, .05, .075, .1
8	8	.025, .05, .075, .1

3.2.2 Summary of results

The simulations were carried out for the all three network configurations by using the error traces for the Doppler frequencies of fd = 2Hz, 10 Hz, 30 Hz and 80 Hz. The C/N values were corresponding to TS PER ranging from transmission with the error percentage of 40% to the almost error free transmission by using 1 dB resolution.

The simulations showed that by only changing the repetition interval as within the 'Simple optimization' in [P6], there is practically no gain in C/N. Hence the change of repetition interval is only applicable to those PSI/SI tables which have already rather small section size, which was the case with TDT in [P6]. The effect of the section size for the robustness was clear when the simulation results were observed. Figure 3-8 illustrates the comparison of the simulation results with the different section sizes by using Doppler frequencies fd = 10 Hz and 80 Hz with Typical network configuration.

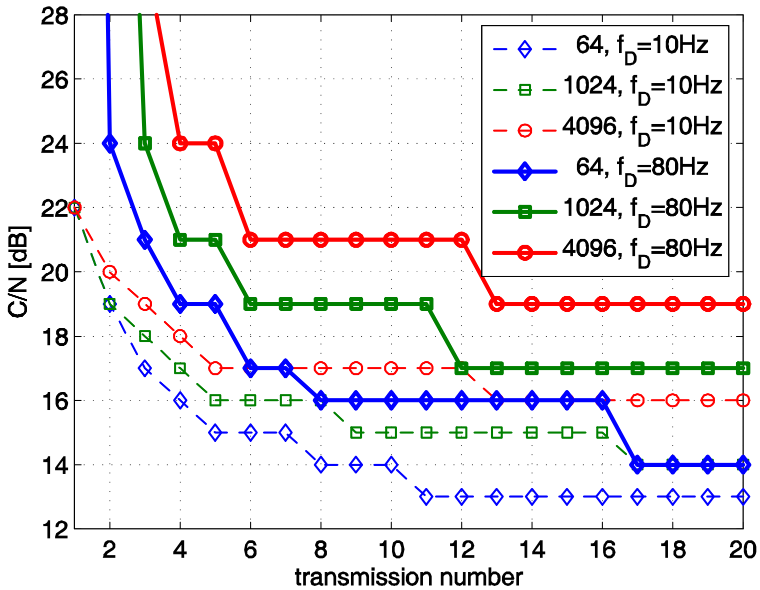

Figure 3-8. The comparison of the simulation results with different section sizes by using Doppler frequencies fd = 10 Hz and 80 Hz with Typical network configuration.

As seen from Figure 3-8, there is even 4 dB difference in C/N as a favor of the section size of 64 Bytes, when the section sizes of 64 Bytes and 4096 Bytes are compared in a TU channel with fd

= 80 Hz. Also, the difference in the same comparison with the fd = 10 Hz, the difference is 2-3 dB.

In [P7] the simulation results were compared also with the robustness of the MPE-FEC protected service transmission. Figure 3-9 illustrates the comparison of the simulation results when LC configuration is used and the transmission of INT table is observed with 5 second repetition interval. The used section size is 1024 Bytes and it is received with all three decoding methods. The service transmission is protected by MPE-FEC with 512 row frame and coderate of 3/4. Hence, in order to meet the requirement for receiving the entire INT table within the maximum repetition interval, i.e., 30 seconds, receiver is allowed to re-receive the entire INT table for six times.

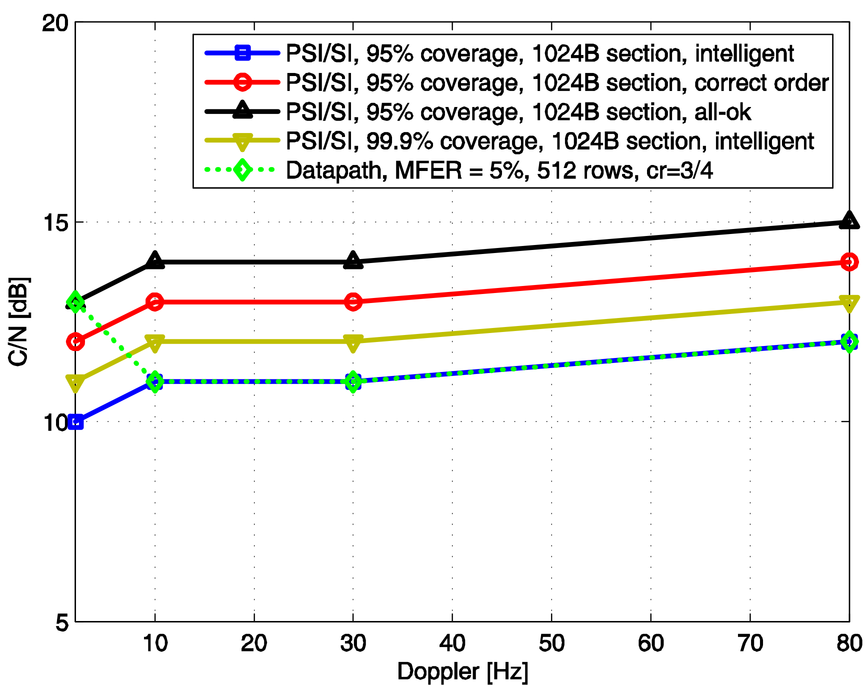

Figure 3-9. The comparison between the INT reception with different decoding methods and the service reception when 1024 Byte section sizes are used in the INT transmission and MPE-FEC protection of 512 rows and coderate of ¾ for the transmission of service data.

It was also noted that all simulated Doppler frequenecies didn't give as optimistic results as the ones got with the Doppler frequencies Fd = 10 Hz and 80 Hz. However, it was clear that the trend was the smaller the section size, the more robust the transmission was. Also the Intelligent decoding method had significant influence on the total receiver latency.

The goal of the study of PSI/SI robustness was to make the PSI/SI transmission as robust as possible and at the same time to maintain the network capacity of the PSI/SI signaling as low level as possible, i.e., below 1%. Hence, the effect of the section sizes on the total network capacity consumed by the PSI/SI signaling needs also to be taken into account. The optimal section size for the INT was discovered as 512 Bytes and for the INT 756 Bytes.

3.3 Laboratory measurements

In [P8] the target was to verify the earlier work carried out in [P6] and [P7] by means of laboratory measurements. The same error criterion was used that is used in the transmission of the service data in DVB-H, i.e., MFER5%. The laboratory measurement set-up is depicted in the Figure 3-10, followed with the description of each part.

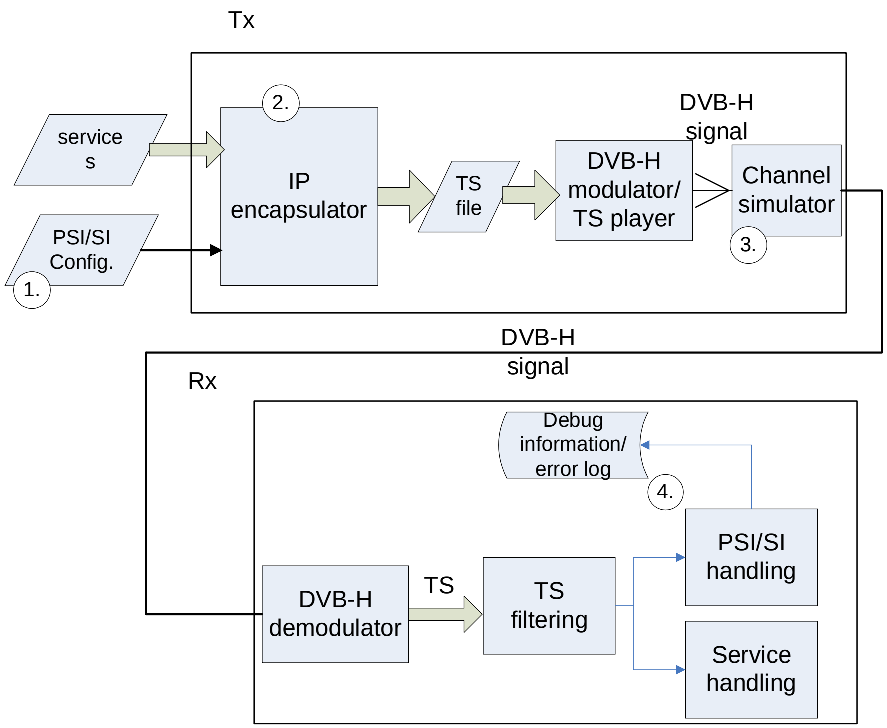

Figure 3-10. The laboratory measurement set-up.

1.) The PSI/SI configurations which were used within the test set-up, were based on the [9] and [10]. More detailed description of the used PSI/SI configuration is explained in section 3.2.

2.) The IP encapsulator was used to generate the transport stream (TS) which combines the services and PSI/SI data.

3.) The channel simulator was used to generate impairments into the radio channel, which in turn resulted as errors within the received transport stream. The used channel model was Typical Urban (TU6) with six paths. The used degradation criteria was 5% errors in the MPE-FEC frames (MFER5%). Figure 3-11 illustrates the DVB-H receiver behavior in the mobile reception conditions with Doppler. The measurements were done in the measurement points TP1 and TP3. The TP1 presents the minimum C/N requirement for the receiver in low Doppler conditions and TP3 presents the Doppler performance with C/N increased by 3 dB from the minimum value of TP1. Typically the TP3 is the practical maximum operating point of the receiver. The minimum receiver performance in terms of C/N and Doppler is specified in [124] and in [125]. The receiver calibration is further explained in section 3.3.2

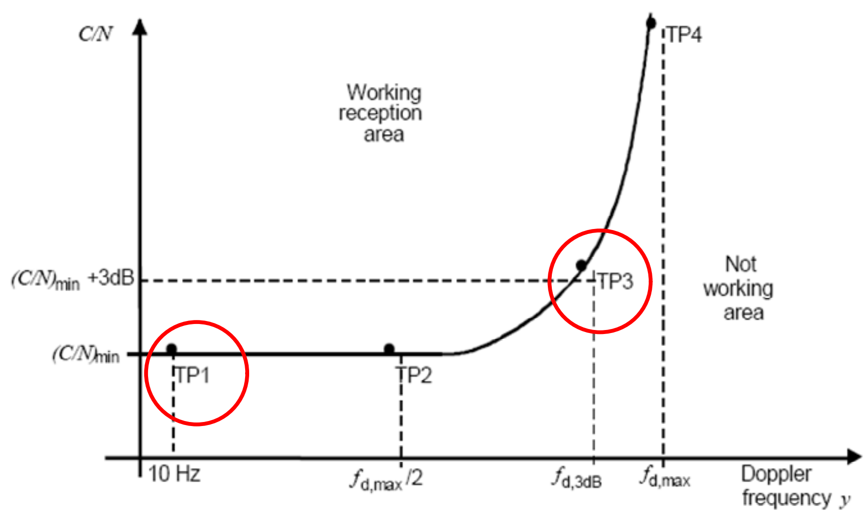

Figure 3-11. The mobile DVB-H receiver behavior and the the measurement points used within the tests.

4.) Receiver, which generated a log of the PSI/SI reception, each time when it was able to receive PSI/SI section. The time which was consumed to receive the complete sub-tables was stored.

3.3.1 The network configurations

The network configuration used within the measurements was based on the findings in [P6] and [P7]. Furthermore, only the transmission of INT table was inspected as it was considered to be the 'worst-case' in the earlier work. Two different setting were used, Max Mobile Maximum Repetition (MMMR) and Max Mobile Optimized Transmission (MMOT). The MMMR had the maximum repetition interval and maximum section size, while the MMOT has the optimized setting for the repetition interval and section size, as discovered in [P6] and [P7]. Table x lists the section sizes and repetition intervals used for MMMR and MMOT. The section sizes vary slightly from the values discovered in [P6] and [P7], since the values in Table 3-8 are absolute values derived from the actual stream generated for the laboratory measurements.

Table 3-8. The section sizes and repetition intervals of the MMMR and MMOT configurations.

Parameter	**Value**	
	MMMR	MMOT
Repetition interval (s)	30	6
Maximum section size (Bytes)	4068	501
Number of sections	4	28

The section size of the all sections within the configurations was approximately equal with the respective maximum section size, except for the last section. The size of the last section within MMMR was 117 Bytes while within the MMOT it was 453 Bytes.

Next, the modulation parameters used in the configurations are described in Table 3-9 and the description of the network configuration is summarized in Table 3-10.

Table 3-9. The modulation parameters of the configurations.

Parameter	Value
Code Rate	2/3
Constellation	16QAM
Transmission mode (FFT)	8k
Guard Interval	1/4
Bandwidth	8 MHz

Table 3-10. The description of the network configuration.

Parameter	Value
Number of transport streams and cells	11
Number of neighbouring cells	6
Number of services	45

3.3.2 Receiver calibration and configuration

Since there are variations in all actual receiver implementations, the receivers needed to be calibrated in order to be able to have comparative results. Receivers from two different receiver manufacturers, i.e., receiver A and B, were used within the laboratory measurements. For the both receivers C/N and Doppler performance was measured in the TP3 to meet the MFER5% criteria. In addition also the TP3 performance values, which were taken directly from the [124], were used. Table 3-11 lists the C/N and Doppler frequencies for the receivers A and B at TP3. The used RF input level was -50 dBm.

Table 3-11. The C/N and Doppler frequencies for the receivers A and B @ 50 dBm.

Receiver	**TP3 Values**	
	C/N	Doppler frequency (f_d)
A	21.50	147 Hz
B	17.80	110 Hz

The calibration point for the receiver B according to [16] were as follows; C/N =18.5 + 3 = 21.5 dB, fd=95 Hz. Three different receiver algorithms were tested in the measurements, based on the ability to parse complete PSI/SI sub-table from the set of partially corrupted subtables. The algorithms were named as intelligent, semi-dummy and dummy. In [P7] the aforementioned algorithms were known as intelligent, correct order and all ok at once.

3.3.3 Summary of results

The laboratory measurements were done by using measurement points defined in [124]. The measurement points were obtained by varying the C/N and keeping the Doppler constant. The used Doppler frequency was receiver specific and varied case by case depending on the receiver implementation. However, after the measurements it was discovered that the measurement results from the both receivers were almost identical and hence only the measurement results of receiver B were published and analyzed.

The results showed that with MMMR configuration the MFER5% limit could not be reached at any of the measurement points. Figure 3-12 depicts the results of the MMRR, where the average reception duration is below the 30 second limit in the measurement point TP3+5dB, but closer inspection of the measurement data revealed that only 73,7% of the received sub-tables were received within or under 30 seconds.

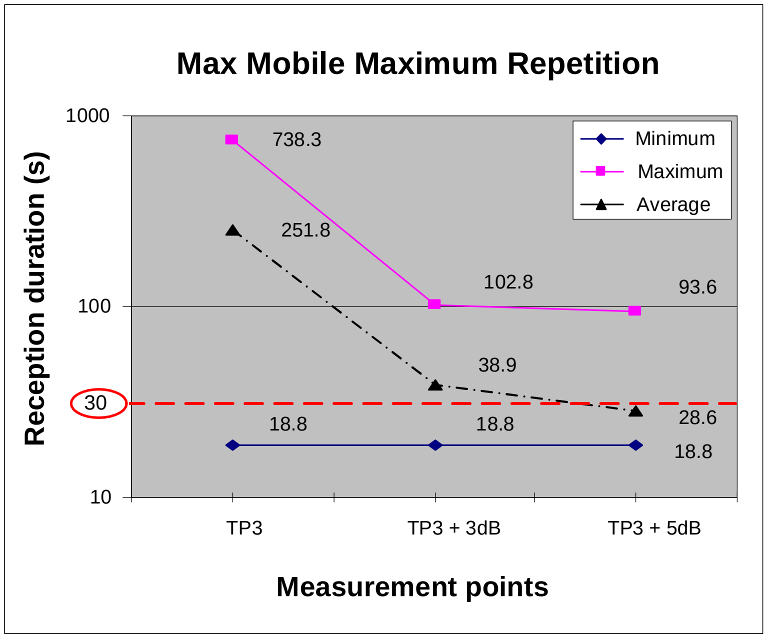

Figure 3-12. The minimum, maximum and average reception duration of the complete subtables in case of the transmission based on the MMMR configuration.

The MMOT configuration was test against the MBRAI and MBRAI2 measurement points. The results in MMOT were radically different to that of in MMMR when the results derived from the MBRAI measurement points are observed. The 95 % of the subtables were received within 30 second limit in almost all measurement points. Figure 3-13 illustrates the minimum, maximum and average curves of the reception duration in MMOT. Only measurement point where the 30 second limit was completely failed with all subtables was measurement point TP3-3 dB. Instead, within the measurement points TP3, TP3 + 3 dB and in TP3 + 5 dB, the average reception duration of the subtables was remarkable lower than the targeted 30 second limit. The percentage of subtables received within or under 30 seconds in the TP3 measurement point was 98.6 %. In the measurement points TP3 + 3 dB and TP3 + 5dB the 30 second limit was achieved with 100% of the subtables. Even the maximum reception duration within the TP3 + 5dB point was two times lower when compared to that of 30 second limit.

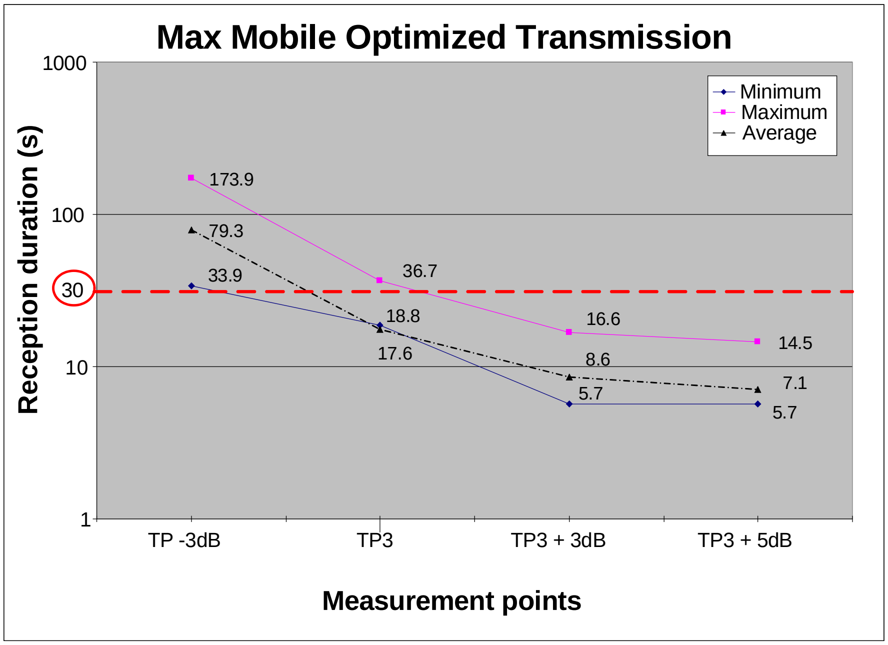

Figure 3-13. The minimum, maximum and average reception duration of the complete subtables in case of the transmission based on the MMOT configuration.

In the two MBRAI2 measurement points the results were mutually contrast. While the 30 second reception limit was by passed by 100% of the tables in the MBRAI2 -3 dB measurement point, in the MBRAI2-6 dB measurement point the amount of satisfactorily received subtables was only 16.5 %. The minimum, maximum and average reception durations of the MMOT in MBRAI2 measurement points can be seen in Figure 3-14.

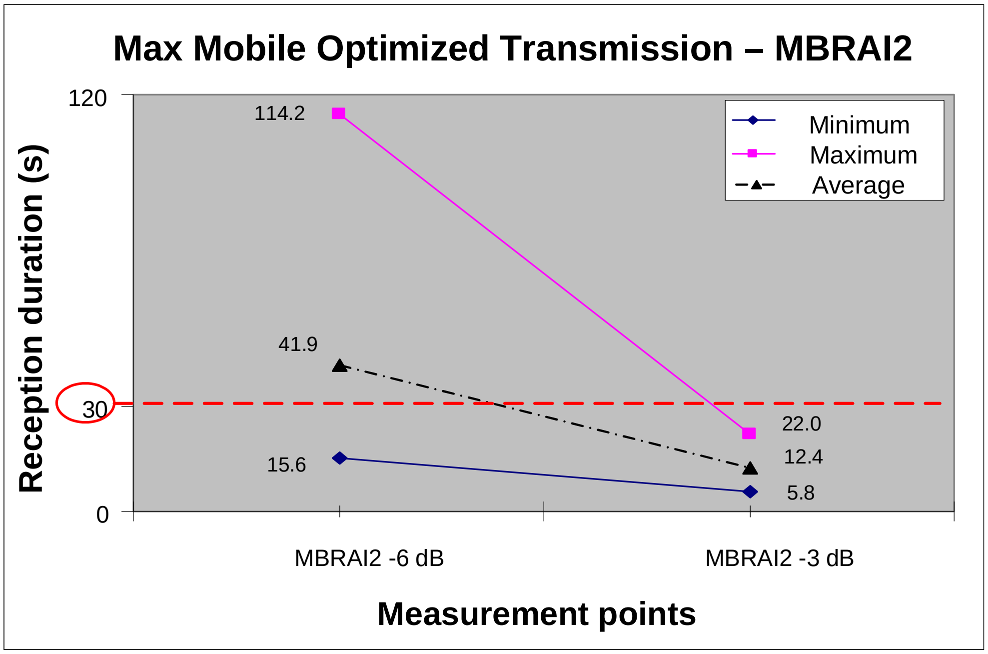

Figure 3-14. The minimum, maximum and average reception duration of the complete subtables in case of the transmission based on the MMOT configuration in MBRAI2 measurement points.

As the influence of the decoding method, i.e., receiver algorithm was discovered significant in [P7], the three receiver algorithms were tested with the most challenging measurement point, i.e., MBRAI2-3dB. Figure 3-15 depicts the reception durations with the three receiver algorithms, where it can be seen that the Intelligent algorithm is clearly superior when compared with the other two.

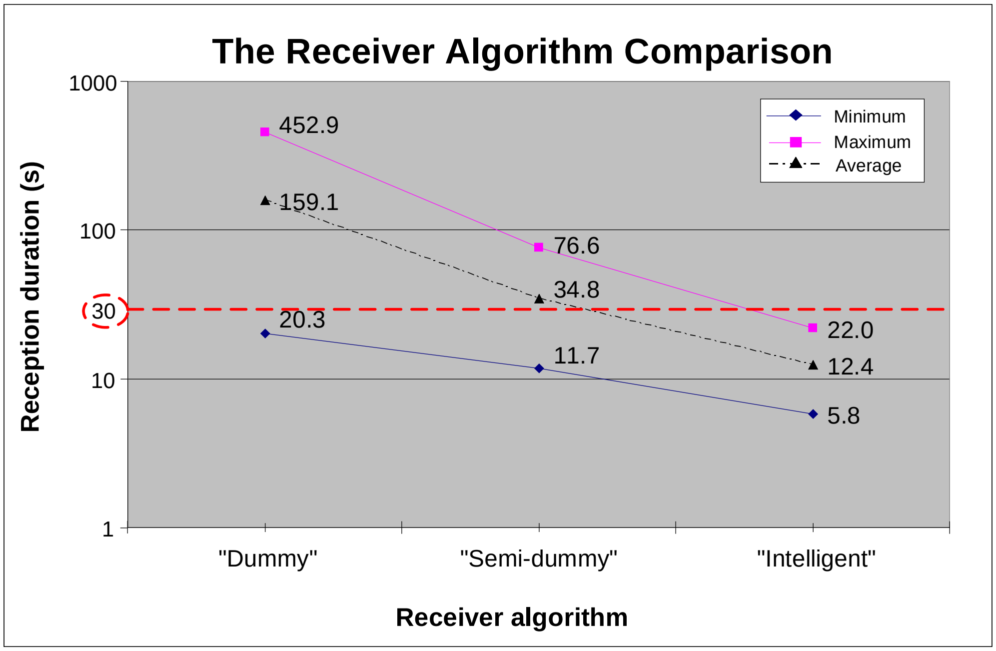

Figure 3-15. The minimum, maximum and average reception duration of the complete subtables with the three different receiver algorithms in case of the transmission based on the MMOT configuration and MBRAI2 – 3 dB measurement point.

3.4 Summary

The findings in [P6], [P7] and in [P8] showed that robustness of PSI/SI could generate problems and that the problems could be avoided with proper configuration and receiver implementation. It was also shown that optimal configuration for the PSI/SI transmission can be found and it has influence on the robustness and hence on the receiver latency. The correct combination of section sizes and repetition intervals are the main elements in the optimal configuration. In addition, the receiver implementation influences also on the total receiver latency in the erroneous transmission. The optimal section size is dependent on the amount of signaling and thus on the resulting subtable size. Not all section sizes are optimal for all configurations, but the optimization should be done for each configuration case sensitively. Another discovery in [P6], [P7] and in [P8] was that the maximum repetition intervals are not reasonable to all network configurations. The most optimal size for PSI/SI section is 512 Bytes, whereas the most optimal maximum repetition interval is between 4.29 and 6 seconds. The network capacity consumed by the PSI/SI remained under one percent in all inspected network configurations, even when the total network capacity of PSI/SI was increased due to larger amount of sections.

Three different receiver algorithms were considered in [P7] and in [P8]. The algorithms were named as *dummy/all ok at once*, *semi-dummy/correct order* and *intelligent*. The simulations and the actual laboratory measurements showed that the selection of the receiver algorithm has significant influence on the total receiver latency. The results of the work of [P6], [P7] and [P8] were incorporated also into the DVB-H Implementation Guidelines [38].

4 The Main Results of the Thesis

This thesis provided significant improvements for the two areas. First, several techniques were defined and incorporated into the service discovery procedures of DVB-H and IPDC over DVB-H standards [P1]-[P5]. Secondly, it provided optimization principles for the PSI/SI transmission and reception [P6]-[P8], which have also been adopted into [38]. The techniques and improvements are based on the granted patents and/or pending patens where the author is inventor or co-inventor. The signaling techniques resulted by this thesis are essential and mandatory features in the DVB-H standard, and hence part of the core functionality in the signaling and service discovery of DVB-H. The optimization of the PSI/SI transmission has also been adopted by the DVB-H standard in the DVB-H implementation guidelines.

The main results of this thesis can be summarized as follows:

3. Definition of new PSI/SI and TPS signaling elements in DVB-H and IPDC over DVB-H standards [34], [39], [47]
4. PSI/SI Transmission optimization and configuration recommendations provided as input to the DVB-H Implementation Guidelines [38].

4.1 Answers to the research questions

The research questions were provided in 1.2 and are herewith answered as they are fulfilled by the work carried out in this thesis.

Q1: What are the signaling elements needed to enable full service discovery in DVB-H?

The handover algorithm published in [P1] showed that SI signaling is needed in addition to the signaling provided in the MPE header. Such signaling was co-invented by the author and it was adopted as part of the core DVB-H signaling in [39]. The other signaling elements adopted for the DVB-H standard and later published in [P5] and co-invented by the author were [36] and [35]. The solution invented in [36] was the TPS signaling enhancement which enables the mutual separation of DVB-T and DVB-H signals. In [35], the solution consists of signaling which enables the detection of HP and LP streams in the hierarchical transmission. It should be noted, that the solution in [35] is applicable also to DVB-T.

Q2: How are different parameters used in the service discovery of DVB-H?

The [P5] provided a comprehensive description of the relation of different parameter mappings in DVB-H and how these are used by the receiver in the service discovery.

Q3: What are the main principles and procedures to enable seamless handover in DVB-H?

The seamless handover was introduced in the author in [P1]. The solution was based on the earlier work carried out in [117] where e.g. SI signaling aspect was also considered. The principles and procedures on seamless handover were further enhanced in [P4] and in [P5]. [P2] investigated a possibility to use alternative signaling to determine the cell coverage areas, but it was not considered applicable.

Q4: What is the robustness of PSI/SI in different configurations?

It was shown in [P6] that the robustness of PSI/SI could be problematic in some configurations and especially with long section sizes. The theoretical analysis carried out in [P6] was verified by simulations in [P7] and finally by the field trials. The outcome was the recommendation for the PSI/SI configuration constraints in [38].

Q5: What is the impact of poor robustness of PSI/SI into the receiver latency?

The poor robustness has direct impact on the receiver latency as the receiver is unable to receive full signaling information in case the robustness is poor. This was verified with the publication series of [P6]-[P8].

Q6: What can be done to improve the robustness of PSI/SI without changing the standard?

It was discovered in [P6]-[P8] that by using the optimal values for the section sizes and repetition intervals, the robustness of PSI/SI can be improved without creating excessive increase on network capacity consumption due to the signaling.

In addition, this thesis introduced de facto implementations for the DVB-H service discovery. The step-by-step explanations given in the service discovery procedures are beyond compare with anything published before. The thesis also provided first ever soft handover algorithm and analysis published within the field, which has also been referenced by the IPDC over DVB-H standard specification [57].

5 The Author's Contribution to the Publications

The research work for this thesis was done at the Nokia Ventures Organization and within the Nokia Technology Platforms during the years 2003-2008. The author has been actively involved throughout the entire development processes of DVB-H and IPDC over DVB-H standards since the early development phase of DVB-H technology until to the verification and validation phase. In addition to the publications, the work consists of several standard essential patents and pending patents as well as of the contributions to the different DVB standard specifications and guidelines.

This thesis includes eight publications [P1]-[P8]. The publications can be further categorized under two main topics: Signaling and service discovery [P1]-[P5], and The robustness of PSI/SI [P6]-[P8]. The author has been fully responsible of editing and writing the context for all publications except for the [P3], [P5] and [P7], where the other authors have participated also on the editing and writing process. The author's main contribution to the publications is as follows. In [P1] the author introduced the basic principles for the signal scan/initialization and handover within the DVB-H. In addition the soft handover mechanism was analyzed for the first time. The publication was later used as reference for the IPDC over DVB-H technical specification [57] and it also triggered several DVB-H standard essential patents, such as [33] and [36] co-invented by the author. In [P2], the use of cell coverage areas was analyzed in the DVB-H handover. Author co-invented a new signaling method for the cell coverage area, which was developed and analyzed for the possible use in DVB-H. The author also co-invented the new signaling mechanism which was patented in [126]. In [P3] the author provided technical background as well as helped the Dr. X.D.Yang in the writing work, resulting as total of 40% contribution. In [P4], the author described a technique for DVB-H handover algorithm, which was based on the patent [118] invented by the author. In [P5], an exhaustive explanation of the de-facto implementation of the service discovery procedure in DVB-H was provided, covering service discovery, signaling and handover. The author was responsible for providing all input to the service discovery and signaling part and also in some parts in the handover description resulting roughly into 50-60% contribution. Especially the first part of the [P5] includes several patents and pending patents where the author has had major input. In [36], the author initiated the original idea and made the invention report. Next, the invention report was refined and reviewed by the other inventors and the resulted refined invention report was used as a basis of the actual patent application. The author was also responsible on the final review and edit of the final patent application. The [33] was a group effort and the author contributed evenly in the invention idea together with the other inventors. The author was also responsible in review and edit process of the final patent application, resulting roughly into 30% contribution. The [35] was result of the brainstorming session and hand-on analysis of the early development phase DVB-H service discovery procedure and was concluded together by the author and the two other inventors. The author was again responsible on the final review of the patent application and edit as well as on the contribution to the DVB standardization. The total contribution by the author to the [35] was roughly 40%. The [118] and [127] were solely based on author's ideas and contribution. Apart from the writing the actual patent application, the author's contribution to [118] and [127] is 100%. In [P6], the scene setting and initial analysis on the robustness of PSI/SI was provided. The author was responsible on defining the configurations used within the analysis as well as providing the capacity calculations. Finally, the author analyzed the results of the calculations and provided conclusions. The author's contribution as percentage into [P6] was roughly 85%, while the rest was contributed mainly by Jyrki Alamaunu. In [P7], the author provided the initial set-up for the simulations and consulted the main author Tero Jokela in the process of completing the paper and hence the contribution into [P7] was roughly 10%. In [P8], the author was responsible on defining the measurement set-up, as well as analyzing the measurements results and providing comparison with the earlier work conducted in [P6] and [P7]. The author was responsible on concluding the constraints defined and recommendations given for the PSI/SI transmission and also providing the actual text included in [38]. The author's contribution as percentage into [P8] was roughly 75%, while the rest of the work was mainly carried out by Jyrki Alamaunu.

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PUBLICATIONS I-VIII

(ORIGINAL) PUBLICATION P1

“Soft Handover in Terrestrial Broadcast Networks”

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Soft Handover in Terrestrial Broadcast Networks

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Abstract

The 3rd generation mobile cellular communication systems will provide high-capacity bandwidth, enabling rich media and even TV services to be accessible via mobile handheld devices. For the reception of such services, seamless mobility is a must rather than an option. Alternatively, Digital Television standards, particularly data broadcasting in Terrestrial Digital Video Broadcasting (DVB-T), can be used for the delivery and reception of similar services. However, the current DVB-T standard lacks adequate methods that enable seamless mobility. In cellular delivery systems, this can be achieved by so-called soft handovers. Time Slicing is a recent enhancement proposed for the new – still being developed – Digital Video Broadcasting for Handheld (DVB-H) standard, which together with DVB-T enables a feasible solution for soft handover to be implemented. This paper considers how Time Slicing can be utilized in implementing soft handover in a DVB-H receiver. An algorithm for soft handover is proposed and evaluated.

1. Introduction

The current 3G standards enable rich media and TV services to be available to mobile handheld devices. Alternatively Terrestrial Digital Video Broadcasting (DVB-T) [1], together with Digital Video Broadcasting for Handheld (DVB-H), formerly known as DVB-X [2], can be used for the delivery and reception of similar services. DVB-T is one of the three main physical transmission media defined in the DVB standards. The other two are Satellite Digital Video Broadcasting (DVB-S) [3] and Cable Digital Video Broadcasting (DVB-C) [4]. DVB-H is a new standard, currently being developed, which defines mobile enhancements for the DVB-T standard

Originally, the service infrastructure specified by the DVB standards was intended for stationary reception of digital television services, i.e. audio and video services. However, soon after the completion of the specifications for the DVB standards, several studies were carried out on the mobility aspects of DVB. It was discovered [5] that DVB-T is also suitable for the mobile environment. Moreover, data broadcasting, i.e. the transmission of IP over DVB, has been defined by DVB [6]. Finally, DVB-H, once finalized, will become the latest addition to the DVB standards family. DVB-H will bring mobility enhancements to the current DVB-T standard, creating a new concept, hereafter called DVB-T/H.

Mobility in DVB-T/H is rather different to that of mobility in cellular systems. This is mainly due to the unidirectional nature of the DVB-T/H networks and the difference in the physical medium. The soft handover discussed in this paper means that a receiver, which is synchronized to a single frequency and is using one or more IP service, switches to another signal seamlessly without any service breaks. Currently, this is not possible without 'two front-end solutions' in which the receiver can receive two signals simultaneously. This enables the receiver to use one front-end for synchronizing to the signal of the consumed services and the other for handover.

Time Slicing [7] is one of the main enhancements in DVB-H. It is an extension of the DVB data broadcasting profile, Multiprotocol Encapsulation (MPE) [6], enabling a receiver to switch power off when no data are being received. This reduces the power consumption by

90% or more [7]. Also, due to the smaller power consumption, the thermal load is decreased. Finally, Time Slicing brings new possibilities when considering handover in a unidirectional DVB-T/H network. During the “Off-times”, i.e. when no data are being received, the receiver is able to measure signals in the adjacent cells and perform soft handovers.

This paper focuses on considering how Time Slicing can be used for assisting handovers in mobile DVB-T/H networks, where all signaling is carried through a unidirectional broadcast link. A soft handover algorithm is presented and analyzed. Also, signaling issues in mobile DVB-T/H are discussed. Finally, the proposed algorithm is evaluated by means of an example.

2. Signaling in DVB-T

2.1. General

Program Specific Information (PSI) and Service Information (SI) are an important part of the DVB transmission system. PSI/SI [8,9] forms a set of tables that is carried within the DVB transmission. PSI/SI tables provide the mechanism to signal information concerning the services conveyed within the DVB-T transmission. In short, PSI/SI can be perceived as being similar to a table of contents, which enables terminals to select the desired services from the content. Each table is transmitted at a certain interval, which is specified in the DVB standards.

In addition to PSI/SI signaling, Transmission Parameter Signaling (TPS) has been specified in the DVB-T standard [1]. The TPS carriers are used for signaling the parameters related to the physical signal. Figure 1 illustrates the location of the PSI/SI and TPS signaling in the DVB-T protocol layer. PSI/SI is located in the Data Link Layer similarly as the two other parallel protocols, Packetized Elementary Streams (PES) and MPE. TPS, in turn, is carried in the physical layer within the Orthogonal Frequency Division Multiplexing (OFDM) frames [1].

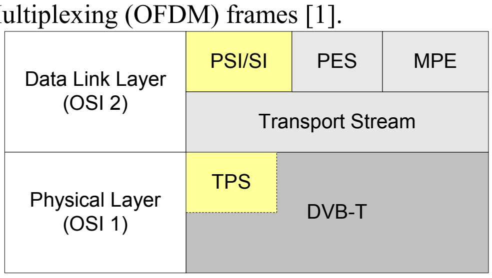

Figure 1. Location of PSI/SI and TPS signaling in DVB-T protocol layers.

2.2. PSI/SI Signaling in mobile IP Datacasting (IPDC)

DVB-T Guidelines on the Implementation and Usage of Service Information (SI) [8] describe a few methods for implementing handover in DVB-T networks. However, excluding the “two front-end solutions”, none of the described methods guarantee a handover performance without interruptions or service breaks, i.e. a soft handover. Also, the aforementioned guidelines are focused only on solving issues regarding the mobile reception of audio and video services, excluding the mobile reception of IP datacasting (IPDC). This is obvious, since the set of PSI/SI tables required for the service discovery of IPDC services is different to that required for audio and video services.

The PSI/SI needed for the service discovery of the IPDC services is: a Network Information Table (NIT), a Program Association Table (PAT), a Program Map Table (PMT) and an IP/MAC Notification Table (INT) [6].

The NIT identifies the network and provides information on the multiplexes included in the network. It maps each multiplex, i.e. the Transport Stream (TS) for the physical frequencies. Moreover, in the NIT, the frequencies are mapped to the cells. Also, the NIT provides a linkage for the TS locating IP/MAC Notification Table (INT). The mapping for the INT within the TS is done by means of PAT and PMT. Table 1 lists the essential parameters announced in the NIT.

Table 1. The essential parameters announced in the NIT.

parameter	Purpose
Network_id	Identifies the network
Modulation parameters	Signal synchronization parameters
Frequency	Identifies the frequency of each signal
Transport_stream_id	Identifies uniquely the Transport Stream (TS) within an original network.
Original_network_id	Unique identifier of a network.
Cell_id	Cell identifier .
Linkage_type	Indicates the linkage for INT.

Each transport stream contains one IP/MAC Notification Table (INT) for each Platform. Moreover, each INT provides the mapping for the location of the IP streams of the corresponding platform, for the TSs in the current and adjacent cells. Similarly, as in the case of INT mapping, PAT and PMT are used for mapping within one TS.

2.3. TPS Signaling

The DVB-T standard defines the TPS carriers that can be used for the signaling transmission scheme related parameters, i.e. channel coding and modulation. The TPS is conveyed in OFDM frames, where each symbol conveys one bit. The total number of OFDM symbols in one frame is 68. The receiver can obtain TPS information simultaneously when it synchronizes to the signal. Cell identification, i.e. cell_id, is provided by means of eight TPS bits.

From the handover point of view, only the TPS bits that indicate the cell identification, i.e. cell_id, are relevant. Cell_ids can be used to discard "Fake signals", should they occur. A "Fake signal" is a signal that has the same frequency as any of the signals found in the NIT, but belongs to another network. Validation can be done by comparing the cell_id originating from the TPS bits with that of the cell_id originating from the NIT.

3. Time Slicing and mobility

Multiprotocol Encapsulation (MPE) is one of the data broadcasting profiles that DVB has defined for data transmission over DVB. Time Slicing is a modification for the MPE, introducing a Time Division Multiplexing (TDM) type of data transmission to DVB-T/H.

In Time Slicing, the data are sent in bursts with a significantly higher bit rate compared to that of data transmission where the data is transmitted using a constant bandwidth. One burst may contain one or more MPE sections. The time to the start of the next burst, delta-t, is signaled in each MPE header (see Figure 2).

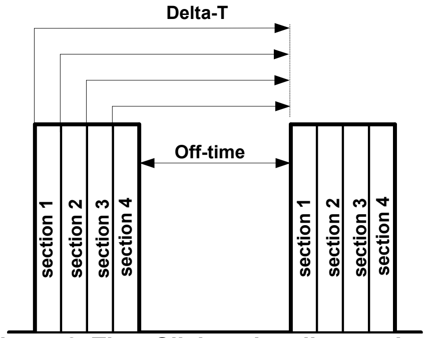

Figure 2. Time Slicing signaling method.

In addition to delta-t, the last section of each burst is signaled in the corresponding MPE header. Moreover, the maximum burst duration is signaled in the SI. Therefore, the receiver is able to constantly calculate and trace the off-times between the bursts and keep it up to date.

Figure 3 illustrates the Off-period principle for the soft handover, where the receiver first measures the RSSI of the signals in the adjacent cells and ultimately executes handover to the cell containing the signal with the strongest RSSI.

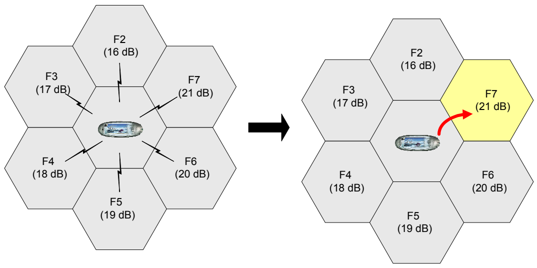

Figure 3. Off-period principle for soft handover.

4. Proposed soft handover algorithm

The proposed soft handover algorithm is described in two phases. These are initialization and handover measurement & decision.

Initialization is a fundamental process that is needed for initializing the receiver with the network parameters. During the handover measurement & decision, available signals in the adjacent cells are measured and a new signal for the handover execution is selected. Execution refers to the actual handover, where the client switches from one signal to another. Switching is needed when the client moves to the edge of a signal's coverage area and the RSSI of the current signal becomes too weak for reception.

4.1. Initialization

Initialization is a process that needs to be repeated only occasionally. During initialization, the receiver scans the signals within the frequency range of the current region/country (e.g. 474-858 MHz). Information regarding each network of interest is stored to memory. The Initialization Steps as illustrated in Figure 4 are described below.

Step1: The receiver attempts to synchronize to the signal within the given frequency range.

Step2: If synchronization is successful, the process moves to Step3, otherwise to Step6.

Step3: NIT is sought from the synchronized frequency.

Step4: If no NIT is found, the process moves to Step6. If NIT is found, the support of the IPDC services is checked (i.e. a linkage to IP/MAC Notification exists in the NIT). If IPDC services are available, the process moves to Step5. Otherwise, the NIT is discarded and Step6 is next.

Step5: The parameters listed in Chapter 2 are collected and stored as a list of 'possible signals'.

Step6: The current signal is checked to ascertain whether it is the last frequency in the selected frequency range. If any frequencies are left, the process moves to Step7. Otherwise Initialization is completed.

Step7: The next frequency is selected and the process is continued from Step1.

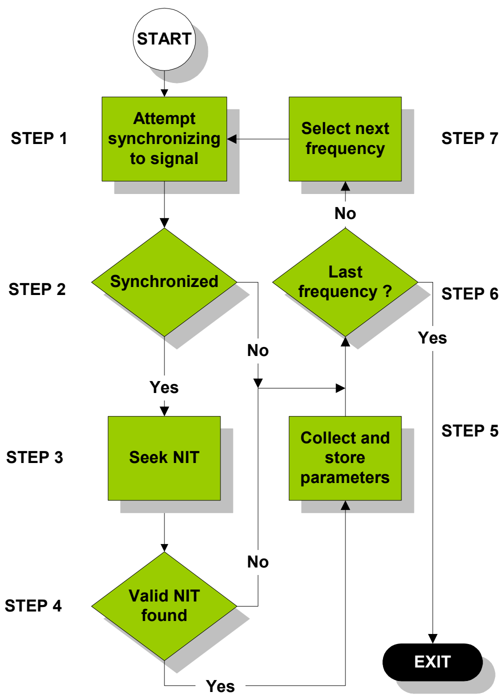

Figure 4. Initialization.

4.2. Handover measurement & decision

During this process, the RSSI values of the 'possible signals', derived from the initialization phase, are measured. A "possible signal" implies a signal that has been found in the NIT of the current network and which carries the IPDC services. The signal with the strongest RSSI is selected as the "new current signal candidate", meaning that it can still be discarded during the handover execution. This is due to the possibility that so-called "fake signals " may exist.

A 'fake signal' is a signal that has a similar frequency to any one of the frequencies found in NIT, but is actually from another network. Figure 5 illustrates an example of a 'fake signal' occurrence, where the receiver is executing handover to the frequency of network 2, instead of the intended frequency of network 1.

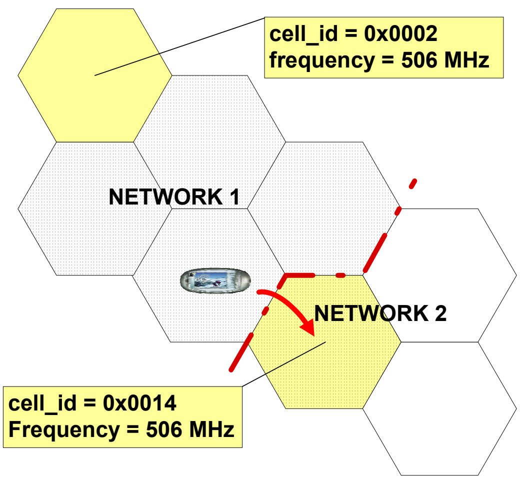

Figure 5. Fake signal occurrence during the handover.

The situation illustrated in Figure 5 would cause an erroneous handover and lead to a fatal service break in the receiver. Fortunately, it can be avoided by validating the cell_id of the candidate signal. This can be done by comparing the cell_id derived from the NIT to the cell_id derived from the TPS bits. Theoretically, there is still a possibility of erroneous handover if both parameters, frequencies and cell_ids are identical in two different networks. However, such a situation should be taken into consideration when the networks are planned – two mutually adjacent or overlapping networks must not have identical frequency and cell_id pairs.

The Handover measurement & decision steps as illustrated in Figure 6 are described below.

Step1: The Requested Signal Strength Indication (RSSI) of the current signal is measured. If the threshold has been met the process moves to Step 2. Otherwise Step1 is repeated. While this step is being repeated, the receiver goes to 'sleep' for each Off-period.

Step2: The receiver can calculate the duration and the end of each burst on the basis of signaling in MPE and SI (see Figure 1). Once the burst ends, the process moves to Step3.

Step3: The RSSI of the 'possible signals' is measured and a list of 'available signals' is created of those signals that meet the set threshold.

Step4: The signal with the strongest RSSI is selected from the list of 'available signals' and synchronized. Simultaneously, during the synchronization, the cell_id is checked from the TPS bits and it is compared with the frequency + cell_id combinations of the 'possible signals'. If the cell_ids do not match, the signal is discarded and Step4 is repeated from the beginning.

Step5: If the current signal has been changed, the IP filters are updated. Otherwise, the procedure continues from Step1

Step6: The INT table carried within the new signal is updated.

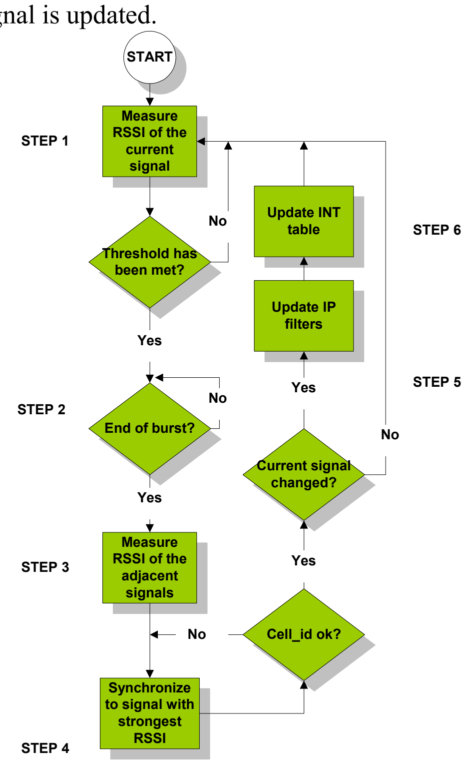

Figure 6. Handover measurement & decision.

5. Evaluation

5.1. Power saving and Off-time principle

Time Slicing enables power saving for the receiver, because the receiver is turned off when no data is being received (Off-times). In a previous publication [7], which discussed Time Slicing and Power saving, it was estimated that Power Saving (Ps) enabled by Time Slicing can be up to 92%. The Ps percentage depends on various parameters, particularly Burst duration (Bd) and Off-time (Ot). The relation between these two, in turn, is dependent on the Burst Size (Bs) used, the Burst bandwidth (Bb) and the Constant bandwidth (Cb). The formula for calculating Ps uses Bd, Synchronization time (St), Cb and Bs. Ps is measured from the beginning of one burst to the beginning of the next burst. Equations describing the above parameters are listed as follows:

$$\mathbf{Bd} = \frac{\mathbf{Bs}}{\mathbf{Bb * 0.96}} \quad \mathbf{(1)}$$

$$\mathbf{Ot} = \frac{\mathbf{Bs}}{\mathbf{Cb * 0.96}} - \mathbf{Bd} \quad \mathbf{(2)}$$

$$\mathbf{Ps} = \left(1 - \frac{\mathbf{(Bd + St) * Cb * 0.96}}{\mathbf{Bs}}\right) * 100\% \quad \mathbf{(3)}$$

where

Bd (Burst duration) is the time in seconds from the beginning to the end of a burst.

Bs (Burst size) refers to the number of Network Layer bits within a burst. Network Layer bits consist of bits on section payloads.

Bb (Burst bandwidth) is an approximate momentary bandwidth (bits per second) used by a time-sliced elementary stream while transmitting a burst.

Ot (Off-time) is the time in seconds between bursts. During Off-time, no transport packets are delivered in the current elementary stream.

Cb (Constant bandwidth) is the average bandwidth (bits per second) that would be required by the elementary stream to be transmitted without Time Slicing .

St (Synchronization time) is the time in seconds taken by the receiver front-end to synchronize to the signal. Synchronization time is implementation specific and it may vary between different receivers.

Ps **(**Power saving) is the total amount of Power saving percentage gained per cycle.

Moreover, **0.96** is the compensation factor used to diminish the overhead caused by the Transport packet and the section headers. Figure 7 illustrates the relation between Bd, Ot, Bs, Bb and Cb.

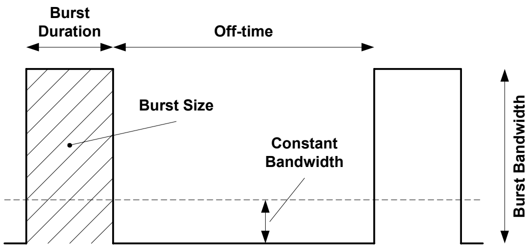

Figure 7. The relation between Bd, Ot, Bs, Bb and Cb.

Next, the relation between Ot and Ps is evaluated by means of an example, where the Ps requirement is set to 90%:

St = 250 ms
Bs = 2 Mb
Cb = 500 kbps

In the mobile reception of DVB-T, the burst bandwidth can vary from 1 Mbps to ~15 Mbps [5].

The relation between Ps and Bb is illustrated in Figure 8. Ps is ≥90%, when the burst bandwidth is 12.5 Mbps or higher.

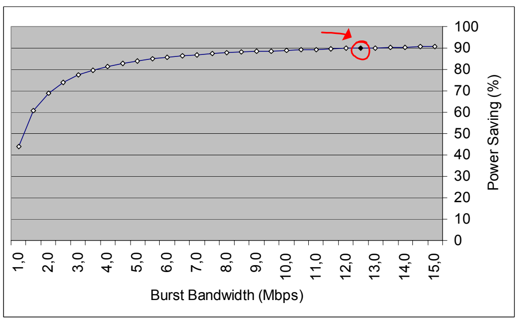

Figure 8. The relation between Ps and Bb.

The Off-time for a Ps of 90% and a Bb of 12.5 Mbps is 4.006 s. Figure 9 illustrates the relation between Burst Bandwidth and Off-times.

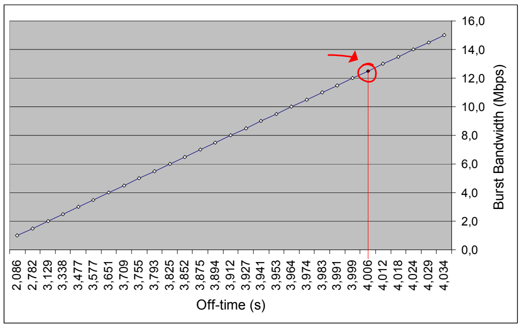

Figure 9. The relation between Bb and Ot.

Hence, using the selected parameters, there is at least 4.006 seconds for the receiver to carry out handover measurements each time a burst ends.

5.2. Handover and Off-time

The number of RSSI measurements (RSSIm) and signal synchronizations (Ss) prior to handover execution are limited by the Ot. The total time used for the handover measurements (Hms) should not exceed the time consumed by the Ot. Equation 4 can be used to calculate the Hms.

$$\mathbf{Hms = ((RSSIm * t_{RSSIm}) + (Ss * t_{Ss}))} \qquad \mathbf{(4)}$$

where

Hms Total time used for the handover measurements

RSSIm The number of RSSI measurements per Off-time.

t_{RSSIm} Time consumed for the one RSSI measurement. Similar to St, t_{RSSIm} is implementation specific and may vary between different receivers.

Ss The number of Signal synchronizations per Off-time. (Includes also the 'final synchronization' when handover is executed.)

t_{Ss} Time taken to synchronize one signal.

It is estimated that t_{RSSIm} is 20 ms and t_{Ss} is 250 ms. Moreover, Hms = Ot. Hence, the RSSIm and Ss are derived as follows (see Figure 10):

$$4{,}006\text{s} = ((\text{RSS Im} * 20\text{ms}) + (\text{Ss} * 250\text{ms}))$$

$$\Rightarrow \text{RSS Im} = \frac{4{,}006\text{s} - (\text{Ss} * 250\text{ms})}{20\text{ms}}$$

and

$$\Rightarrow \text{Ss} = \frac{4{,}006\text{s} - (\text{RSSIm} * 20\text{ms})}{250\text{ms}}$$

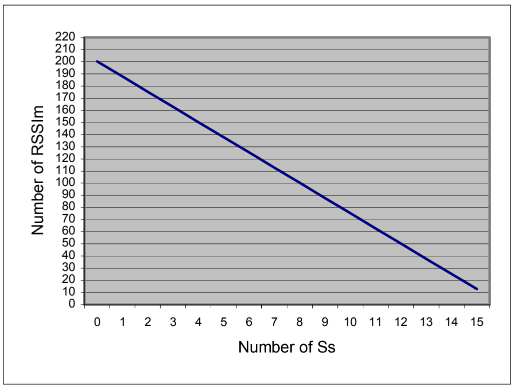

Figure 10. Distribution of RSSIm and Ss.

Figure 9 illustrates that in an optimal situation, where no 'fake signals' exist, the receiver is able to measure RSSI from over 180 signals during the Off-time. Even if 14 'fake signals' should occur, the receiver is still able to perform RSSI measurement for over 10 signals.

The frequency range used in Europe allows for up to 48 different frequencies to be used within one network if 8 MHz bandwidth is used. With the given example, this would allow 11 'fake signals' to occur prior to handover execution. Due to regulatory reasons, one network cannot administer all 48 signals. However, given the above parameters, the proposed handover algorithm would be able to get over such a situation.

6. Conclusions

Seamless mobility is challenging for any communication system. It is even more challenging for unidirectional systems, such as DVB-T/H. However, Time Slicing enables soft handovers to be implemented in any unidirectional communication system, where sufficient signaling is provided for the services and Time Slicing parameters. This paper presented a soft handover algorithm for DVB-T/H networks. The proposed algorithm was evaluated by means of an example. It was shown that the proposed algorithm is capable of full performance even in the most improbable situation, i.e. where the number of signals per network and 'fake signals' per handover are beyond the realistic limit.

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(ORIGINAL)
PUBLICATION P2

"Approach for Improving Receiver Performance in Loss-free Handovers in DVB-H Networks"

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Approach for Improving Receiver Performance in Loss-free Handovers in DVB-H Networks

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***Abstract* — DVB-H (Digital Video Broadcasting for Handheld) is one of the key technologies that enables new services such as Mobile Phone TV to be used in handhelds. DVB-H enhances mobile features found in the DVB-T standard, enabling new techniques, e.g., loss-free handover. For services such as mobile TV, loss-free handovers must be supported. Different positioning technologies, such as GPS, also play an important role in enhancing today's mobile technologies. This paper proposes a new feature for DVB-H, a new method for signalling cell coverage area, thus improving performance for loss-free handovers. The proposed method is targeted at DVB-H handhelds that have GPS receivers. The benefits of the proposed method for handover and power consumption are evaluated. In addition, its effect on the consumption of bandwidth and receiver memory is estimated.**

I. Introduction

DVB-H (Digital Video Broadcasting for Handheld) [1] is a new standard that enhances mobile features for Terrestrial Digital Video Broadcasting (DVB-T) [2]. DVB-H enables new services, such as Mobile Phone TV [3], to be used in handhelds.

In the mobile reception of services such as Mobile Phone TV, a seamless mobility is mandatory for enabling an uninterrupted service experience. In DVB-H networks, seamless mobility can be achieved by loss-free handover, in which a DVB-H receiver may switch between different frequencies without losing any data. Loss-free handover has been previously discussed as soft handover [4].

The signalling of cell coverage area information [5] can be used to improve handover performance for DVB-H receivers equipped with a GPS receiver. The existing method, however, only provides approximate information on the cell coverage area; this could be elaborated further.

This paper proposes a new method for signalling cell coverage areas by means of bitmap data. As with the DVB standard method, the proposed solution aims at improving handover performance in DVB-H receivers equipped with a GPS receiver. A new addition — Cell Description Table (CDT) — is proposed for the set of PSI/SI tables in DVB-H in [4]. The principle for the proposed solution and the semantics of the CDT table are given. Moreover, the advantages and disadvantages of the proposed method are considered from the perspective of handover bandwidth and power consumption. The power consumed by a DVB-H receiver has been previously discussed in [6]. Finally, conclusions were drawn.

II. DVB-T-specific Signalling for Cell Identification and Cell Coverage Areas

A DVB-T cell is a *"geographical area that is covered with DVB-T signals delivering one or more particular transport streams throughout the area by means of one or more transmitters"* [5]. Cell information is signalled by means of cell identification and a cell coverage area.

A. Cell Identification

Cell identification [5] is provided in the DVB Service Information (SI) by means of cell_id. In addition, the signalling of cell identification within Transmission Parameter Signalling (TPS) bits has been defined in [2].

B. Cell coverage area

In the current DVB specifications, a cell is defined as a geographical area covered by the signals delivering one or more transport streams by means of one or more transmitters. Cell coverage area, in turn, is defined as a rectangle that encloses approximately all of the signal coverage of the signals that are part of that particular cell. Thus, cell coverage area is dependent on the shape of the cell. The shape of the cell, in turn, depends on the transmitters transmitting the signals and on the landscape and environmental effect for the propagation of signals. Fig. 1 illustrates an example of the cell coverage area definition according to the DVB specifications where the omnidirectional signal is transmitted by one transmitter and is not affected by the landscape or by any other environmental factors. Furthermore, Table I describes the parameters presented in Fig. 1.

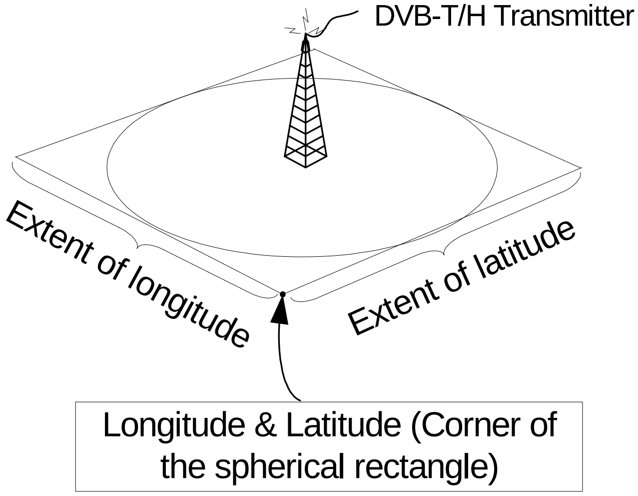

Figure 1. Cell coverage area in case of an omnidirectional signal, according to DVB standards.

TABLE I
PARAMETERS RELATED TO CELL COVERAGE AREA

Parameter	Description
Extent of longitude	The extent of longitude of a spherical rectangle describing the approximate coverage area of the cell.
Extent of latitude	The extent of latitude of a spherical rectangle describing the approximate coverage area of the cell.
Longitude	Longitude of the corner of a spherical rectangle describing the approximate coverage area of the cell.
Latitude	Latitude of the corner of a spherical rectangle describing the approximate coverage area of the cell.

As Fig. 1 illustrates, current DVB signalling only roughly defines the cell coverage area. In fact, it even provides erroneous information as it indicates that the areas beyond the actual cell coverage area are part of the cell. Furthermore, in the current method, there are no means for indicating signal strength levels within the different areas of the cell coverage area.

III. THE PROPOSED METHOD – CELL DESCRIPTION TABLE

Instead of having a bulky rectangular representation of a DVB-T cell coverage area, a new model for defining the cell coverage area is proposed. Cell Description Table (CDT) is the name of the proposed method; in this method, the signal levels are presented as bitmap information and signalled to the receivers.

A. Principle

Bitmap information can be based on the measurements or estimates of the signal levels within the coverage area of the transmitted signal. Fig. 2 illustrates the principle for mapping different quantized signal levels into pixels within the actual cell coverage area. The highest signal level within the area represented by the pixel is selected as the signal level of the pixel.

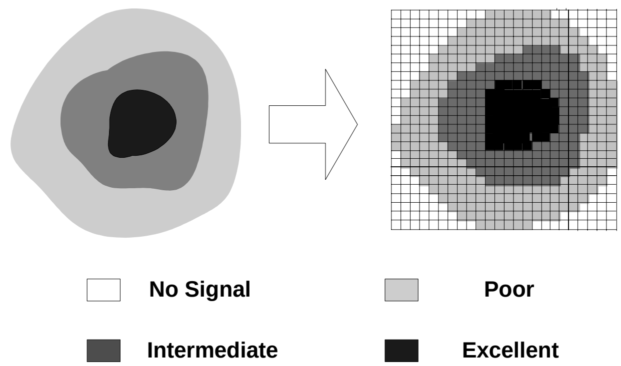

Figure 2. The principle for mapping different signal levels within the actual cell coverage area. This example uses two-bit values to represent the signal level, resulting in four discrete levels.

B. Cell Description Table (CDT)

Cell Description Table (CDT) is in full conformance with the structures and semantics of the existing DVB Service Information tables. Up to 256 different signal levels within the cell coverage area can be signalled to a receiver with CDT. Moreover, a compression method that can be used for decreasing the size of the table can be optionally used with CDT. Table II illustrates the structure of the CDT, followed by the semantics for each field.

TABLE II

CELL DESCRIPTION TABLE (CDT)

Syntax	Bits	Type
cell_description_section() {		
table_id	8	uimsbf
section_syntax_indicator	1	bslbf
reserved_future_use	1	bslbf
reserved	2	bslbf
section_length	12	uimsbf
cell_id	16	uimsbf
reserved	2	bslbf
version_number	5	uimsbf
current_next_indicator	1	bslbf
section_number	8	uimsbf
last_section_number	8	uimsbf
network_id	16	uimsbf
width	12	uimsbf
height	12	uimsbf
scale	8	uimsbf
lo_bound	8	uimsbf
hi_bound	8	uimsbf
depth	3	uimsbf
compression	2	bslbf
reserved_future_use	2	bslbf
latitude	25	uimsbf
longitude	26	uimsbf
reserved_future_use	2	bslbf
total_data_length	20	uimsbf
reserved_future_use	4	bslbf
data_offset	12	uimsbf
reserved_future_use	4	bslbf
data_length	12	uimsbf
for(i=0;i<N;i++){		
byte	8	uimsbf
}		
CRC_32	32	rpchof
}		

table_id: This is an 8-bit field that identifies table type.

section_syntax_indicator: This is a 1-bit field that will be set to "1".

section_length: This is a 12-bit field. It specifies the number of bytes for the section, starting immediately after the section_length field and including the CRC. The section_length may not exceed 4093, which means that the entire section will have a maximum length of 4096 bytes.

cell_id: This is a 16-bit field that uniquely identifies each cell.

version_number: This 5-bit field is the version number of the sub_table. The version_number will be incremented by 1 when the information conveyed by the sub_table changes. When it reaches 31, the number wraps around to 0. When the current_next_indicator is set to '1', then the version_number will be that of the currently applicable sub_table defined by the table_id. When the current_next_indicator is set to '0', then the version_number will be that of the next applicable sub_table as defined by the table_id.

current_next_indicator: This 1-bit indicator, when set to '1', indicates that the sub_table is the currently applicable sub_table. When the bit is set to '0', it indicates that the sub_table sent is not yet applicable and will be the next sub_table to become valid.

section_number: This 8-bit field gives the number of the section. The section_number of the first section in the sub_table will be "0x00". The section_number will be incremented by 1 for each additional section with the same table_id.

last_section_number: This 8-bit field indicates the number of the last section (that is, the section with the highest section_number) of the sub_table that this section is part of.

network_id: This is a 16-bit field that identifies the network that the described cell is part of.

width: This 12-bit field specifies the width of the bitmap in pixels.

height: This 12-bit field specifies the height of the bitmap in pixels.

scale: This 8-bit field tells the geographical size of one bitmap pixel. The size is scale*10m, which means that 42 would specify that each pixel represents a geographical area of 420m*420m.

lo_bound: This 8-bit field is the lowest boundary for field strength. It is the absolute value of the dBm value represented by the pixel value 1. If the bit depth is 1, this will be the same as hi_bound.

hi_bound: This 8-bit field is the highest boundary for field strength. It is the absolute value of the dBm value represented by the highest possible pixel value. If the bit depth is 1, this will be the same as lo_bound.

depth: This 3-bit field is the bit depth of the bitmap. The bit depth tells how many bits are used to specify each pixel, i.e., a bit depth of 4 would indicate that the bitmap has 2^4=16 levels. This field cannot be 0.

compression: This 2-bit field indicates the compression method used to compress the bitmap data. Its values are described in Table III.

TABLE III

CDT COMPRESSION METHOD

Compression	Compression method
00	Uncompressed
01	reserved for future use
10	reserved for future use
11	reserved for future use

latitude: This 25-bit field tells the geographical position of the lower-left (southwest) corner of the bitmap. This field shall be set to the two’s complement value of the latitude, referenced to the WGS-84 reference ellipsoid, in units of $180/2^{25}$ degrees, from -90 degrees to $+90\times(1-2^{-24})$ degrees, counting positive angles north of the equator and negative angles south of the equator.

longitude: This 26-bit field tells the geographical position of the lower-left (southwest) corner of the bitmap. This field shall be set to the two's complement value of the longitude, referenced to the WGS-84 reference ellipsoid, in units of $360/2^{26}$ degrees, from -180 degrees to $+180\times(1-2^{-25})$ degrees, counting positive angles east of the Greenwich meridian and negative angles west of the Greenwich meridian.

total_data_length: This 20-bit field specifies the length in bytes of the complete map bitstream.

data_offset: This 12-bit field specifies the offset in bytes of the following data block; for example, the following data is located, starting at this position, in the complete map bitstream.

data_length: This 12-bit field specifies the length in bytes of the following data block.

byte: This is an 8-bit field. An array of byte fields that specifies a block of the complete map bitstream. If necessary, the bitstream is padded with zeroes so that it is 8-bits long.

CRC_32: This is a 32-bit field that contains the CRC value that provides the registers in the decoder [5] with zero output after the entire section is processed.

IV. EVALUATION

The method proposed by this paper has been evaluated from three different perspectives. The first part of the evaluation focuses on considering the benefits of the proposed method in handover cases. In the second part, the signalling of a cell coverage area in accordance with CDT is compared to the signalling according to the current DVB standard by means of simulated DVB-H cell. The third part evaluates the bandwidth consumption of the proposed method by means of calculation, based on the simulation presented in the second part.

A. Loss-free Handover

Handover decision and measurement, as defined in [4], is a situation where the receiver has to determine and select a new signal, to which then it then executes handover. Fig. 3 illustrates an example of the handover decision and measurement when the receiver is located at the conjunction of three cells. The dashed line designates the cell coverage area of each cell according to the current DVB specifications. The solid lines stand for the actual cell coverage areas.

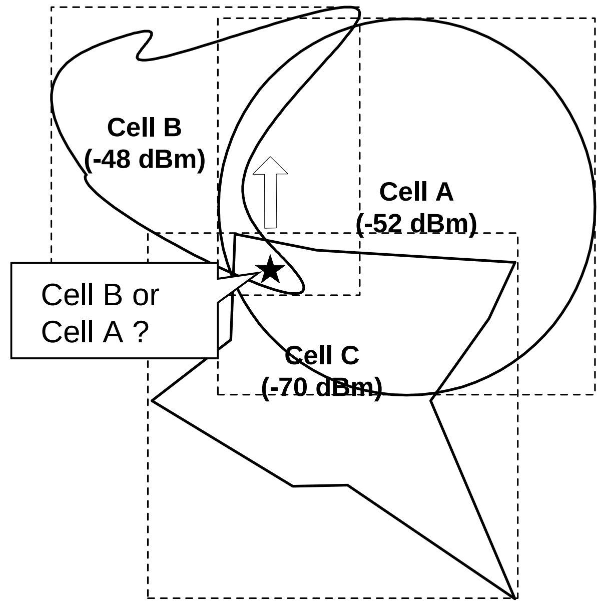

Figure 3. Handover decision at a conjunction of three cells.

The receiver is moving away from the signal covering area of cell C that it is currently synchronized into so it needs to switch into the signal covering area of cell B or into that of cell A. If the decision was made only on the basis of signal strength, it would be obvious that the receiver would choose cell B, since it has the best signal strength. In addition, if the receiver algorithm for handover was adjusted with the cell coverage area information according to the current DVB specifications, it would favor the selection of cell B.

If the handover decision and measurement in the described situation was performed according to the actual cell coverage areas, the resulting cell would be cell A. Even though the signal covering area of cell B has the best signal strength, it would not be a wise selection as the signal would not be available for long if the receiver continued along the same path. Soon after selecting cell B, the receiver would need to make another handover decision and measurement again, which would result in unnecessary power consumption.

B. Comparison between the Cell Description Table and the current DVB standard method by means of simulation

Fig. 4 illustrates simulation data for one DVB-H cell coverage area from the Helsinki area. It is based on estimates of the signal propagation affected by the different terrain shapes and obstacles. No reference is provided for the simulation data as its only purpose is to provide a way of emphasizing the differences between signalling in the cell coverage area as defined in [5] and as proposed in this paper.

The rectangle enclosing the cell coverage area is in accordance with the DVB specifications and has dimensions of

25 km x 15 km. The simulated signal levels vary from 'no signal' to 'excellent'. Different shades of grey are used to indicate four different signal levels. The scale, which is in accordance with that of CDT, is 10.

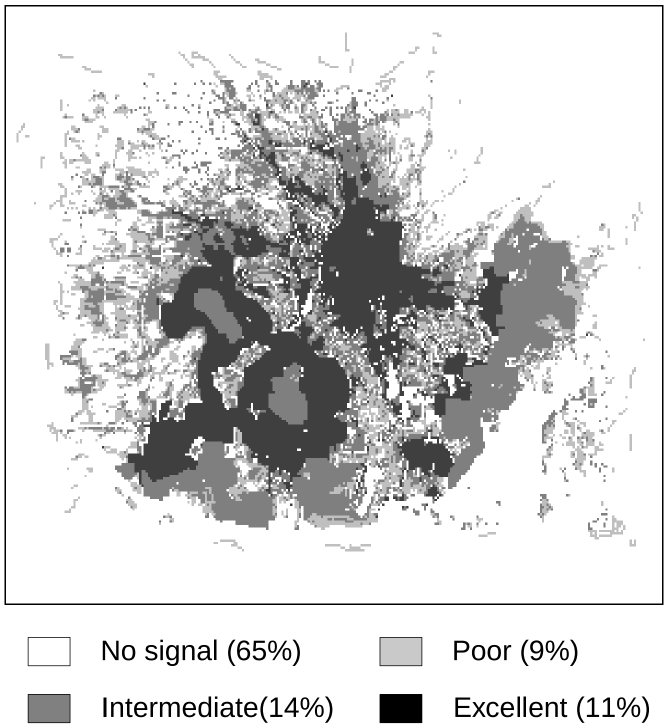

Figure 4. Simulation of four signal levels within a DVB-T/H cell coverage area.

Signalling of four different signal levels, as illustrated in Fig. 4, is not provided for in the DVB standard. Currently, the only method for the receiver to detect different signal levels within the cell coverage area is by signal strength measurement. As Fig. 4 illustrates, the majority (65%) of the cell coverage area has no signal, resulting in gratuitous signal strength measurement, which increases power consumption.

CDT enables signalling for up to 256 signal levels; thus, the signal level can be detected with a CDT receiver without measuring the signal strength. This is a particularly good idea when the receiver is on the move in areas where there is no signal, eliminating the needless consumption of power to measure signal strength.

C. Bandwidth consumption of the CDT

The bandwidth consumed by the CDT is directly related to the size of the bitmap per CDT. The size of the bitmap depends on the following parameters: the number of the signal levels used, the length of the side of one pixel, the scale and the square area in the presented bitmap information. In addition, the basic structure of one CDT uses 264 bits. Moreover, different compression methods can be used for reducing the size of bitmap, although such methods are not utilized in the calculations below.

Fig. 5 illustrates the uncompressed size of a bitmap when 2, 4, 8 and 256 signal levels are checked. The scale used for the bitmap is 10, so the length of the side of a pixel is 100 m.

The DVB-T/H cell presented in section B is 25,000 m x 15,000 m, which equals 375,000 m^2. When this is then converted to a square bitmap area, we have for the four signal levels:

The length of one square side = $\sqrt{375{,}000\ m^2} \cong 19{,}365$ m. Thus, one square side is approximately 20,000 m and the resulted bitmap size for the simulation is approximately 10,000 bytes.

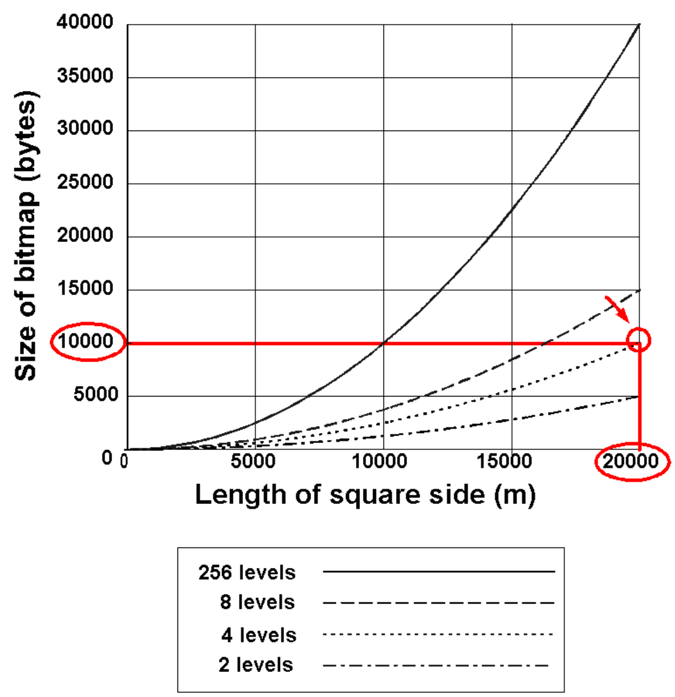

Figure 5. The relation of the uncompressed size of bitmap and square side length for different signal levels.

Furthermore, Fig. 6 illustrates the sizes of bitmaps for three different cell sizes with four signal levels with the scale of the function of the square bitmap area varies from 0 to 12. If the size of the bitmap is 10,000 bytes (cf. Fig. 5), the length of the side of one pixel is approximately 100 m.

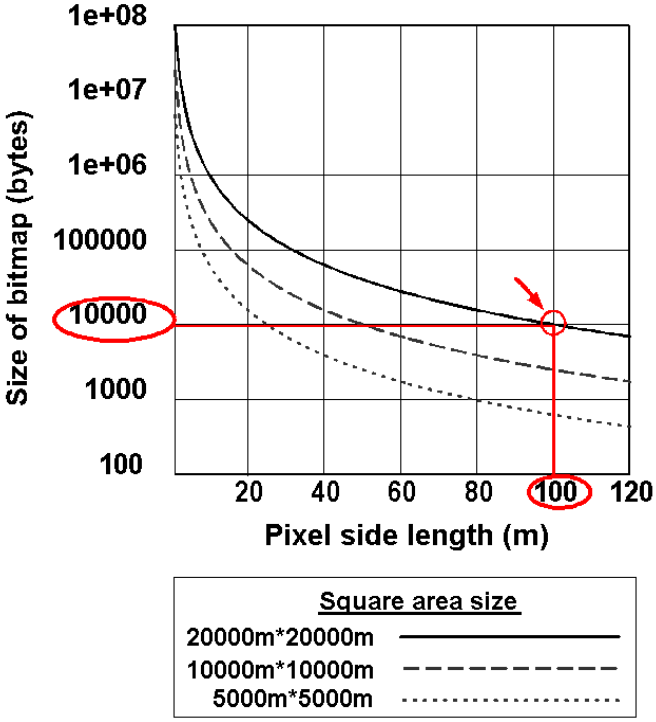

Figure 6. The relation of the uncompressed size of a bitmap and pixel side length for the varying size of square bitmap area.

V. Conclusions

This paper addressed deficiencies in the definition and signalling of the cell coverage areas according to the current DVB standard. A new method, that targeted receivers with GPS support — a CDT table — was proposed with the objective of improving mobility in DVB-T/H networks. The proposed method was evaluated from several different perspectives. It was shown that the proposed method could reduce the power consumption of loss-free handovers in DVB-T/H receivers. On the other hand, it was noted that the consumption of bandwidth increased; this could, thus, be considered a disadvantage of the proposed method. Furthermore, the increased bandwidth consumption can also increase memory consumption, depending on the implementation. For this reason, decreased power consumption can be considered to be a trade-off with bandwidth and memory consumption. Finally, the proposed method has other advantages that were not discussed in this paper: enhancement of position determination based on cell coverage areas, etc.

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A SURVEY OF HANDOVER ALGORITHMS IN DVB-H

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ABSTRACT

Digital Video Broadcasting for Handhelds (DVB-H) is a standard for broadcasting IP Datacast (IPDC) services to mobile handheld terminals. Based on the DVB-T standard, DVB-H adds new features such as time slicing, MPE-FEC, in-depth interleavers, mandatory cell id identifier, optional 4K-modulation mode and the use of 5 MHz bandwidth in addition to the usually used 6, 7, or 8 MHz raster. IPDC over DVB-H is proposed for ETSI to complement the DVB-H standard by combining IPDC and DVB-H in an end-to-end system. Handover in such unidirectional broadcasting networks is a novel issue. In the last few years since the birth of DVB-H technology, great attention has been given to the performance analysis of DVB-H mobile terminals. Handover is one of the main research topics for DVB-H in mobile scenarios. Better reception quality and greater power efficiency are considered to be the main targets of handover research for DVB-H. New algorithms for different handover stages in DVB-H have been the subject of recent research and are currently being studied. Further novel algorithms need to be designed to improve the mobile reception quality. This article provides a comprehensive survey of the handover algorithms in DVB-H. A systematic evaluation and categorization approach is proposed based on the problems the algorithms solve and the handover stages being focused on. Criteria are proposed and analyzed to facilitate designing better handover algorithms for DVB-H that have been identified from the research conducted by the authors.

Digital Video Broadcasting — Terrestrial (DVB-T) was not only designed for transmitting TV-like video contents but also for transmitting data services [1–3]. Digital Video Broadcasting — Handheld (DVB-H) [4–6], formerly known as "DVB-X" [7], is a unidirectional communication technology based on DVB-T. DVB-H and DVB-T were developed by the organization called DVB Project [8]. Recently, the DVB ad-hoc group Convergence of Broadcast and Mobile Services (CBMS) developed IPDC (IP Datacast) [9] over the DVB-H standard [10], which is currently being processed by the European Telecommunications Standards Institute (ETSI). The IPDC over DVB-H standard complements the DVB-H standard by defining OSI layers 3–7 and refining some of the OSI layer 2 specific protocols, especially Program Specific Information (PSI) and Service Information (SI). DVB-H poses novel challenges for handover research. Before talking about the origin of the handover issues in DVB-H it is necessary to take a look at the services that are transmitted in DVB-H networks. The service contents in DVB-H networks are delivered in the form of IP datagrams using IP-based mechanisms or in the form of other network layer datagrams encapsulated into Multi-Protocol Encapsulation (MPE) sections [11]. This kind of service is called IPDC. Although IPDC services can be offered via existing GPRS or UMTS cellular networks by Multimedia Broadcast/Multicast Service (MBMS) [12–14], MBMS is only suitable for light traffic services such as short video clips. For heavy-duty streaming services, DVB-H is a better solution because of its higher bit rate compared with that of MBMS. [15]. IPDC brings new characteristics for DVB-H networks. The benefits are as follows [16]:

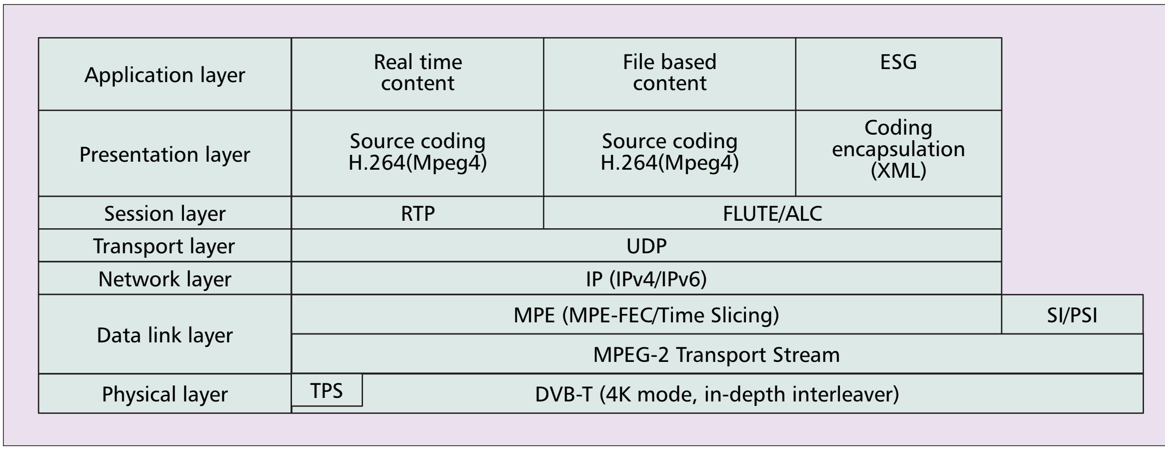


Figure 1. *DVB-H protocol stack.*

- IPDC provides a platform for true convergence of services between DVB-H and cellular telecommunication networks (GPRS/UMTS).
- IPDC allows the coding to be decoupled from the transport layer, thus opening the door to a number of features benefiting handheld mobile terminals, including a variety of encoding methods which only require low power from a decoder (decoding high-bandwidth MPEG-2 encoded streaming video/audio is relatively power consuming).
- IPDC is relatively insensitive to any buffering or delays within the transmission (unlike MPEG-2).
- IPDC is well-suited for time-sliced transmission.

In a word, an IPDC service is suitable for handover in DVB-H.

But what are the advantages of mobile reception of DVB-H compared to that of DVB-T?

VALIDATE [17] and MOTIVATE [18] were two European projects that addressed the issues of mobile reception of DVB-T signals [19]. Laboratory tests and field trials have shown that mobile applications of DVB-T are feasible using the code rate equals 1/2 modes of the specification [20]. However, the tests of receivers also showed the limits of performance achievable for mobile television using DVB-T without enhancements to the receivers [21]. In addition, the power consumption of mobile reception of DVB-T is a big issue for battery powered terminals [22, 23].

DVB-H is the technique that was rolled out for the mobile portable reception of IPDC contents [24, 25]. Similar standards are used in Japan and Korea for mobile data broadcasting [26, 27]. The scenario of single-frequency DVB-H networks consists of high-power DVB-H transmitters like those of DVB-T. However, multifrequency networks comprised of low power DVB-H transmitters are also expected to be a typical network scenario for DVB-H. With decreasing cell size, handover in DVB-H becomes a critical issue.

Handover in traditional cellular telecommunications networks (like GSM) refers to the mechanism that transfers an ongoing call from one cell to another as a user moves through the coverage area of the cellular system [28] and has long been a research topic. However, handover in DVB-H refers to the switching of the reception of IP-based services from one transport stream to another when the terminal moves through the coverage area of a DVB-H network [29]. In this survey the two different terms "channel" and "transport stream" are used for the same meaning. They both mean the path along which a communications signal is transmitted.

Soft handover is usually used to mean that radio links are added and removed in such a way that the device always keeps at least one radio link to the base station [30]. In DVB-H, this means that the received frequency and/or transport stream is changed without interruption of the ongoing reception.

It is considered important for researchers in the DVB-H area to understand the importance of handover, especially in multifrequency DVB-H networks. Therefore, this article provides a comprehensive survey of various aspects of the handover algorithms in DVB-H networks.

The article is structured as follows. We describe the technical features of DVB-H. Then a detailed introduction to handover in DVB-H is given and the differences between handover in DVB-H, DVB-T and cellular telecommunications networks are presented. Next, the authors' approaches to handover research in DVB-H are described with the handover challenges and handover stages followed. The different handover algorithms currently available are investigated. The authors' view of how to design a handover algorithm for DVB-H is presented. Finally, the article closes with the conclusions and a discussion of the projects related to and the research trends in handover algorithms in DVB-H networks.

Technical Features Of DVB-H

Time slicing, MPE-FEC, 4K mode, in-depth interleavers, DVB-H signaling (including the mandatory cell id identifier), and the use of 5 MHz bandwidth are the essential elements that are introduced in DVB-H [29]. These features are located in the data link layer and the physical layer of the DVB-H protocol stack. Time slicing (in the data link layer) and DVB-H signaling (in the data link layer and the physical layer) are the two features that are directly related to DVB-H handover.

Protocol Stack

The DVB-H protocol stack is shown in Fig. 1. The newly introduced DVB-H technical features are in the data link layer and the physical layer. The application services may be sent via Real Time Protocol (RTP) [31] for real time content (for example a TV program). Non-real-time data may be sent via a File Delivery Over Unidirectional Transport/Asynchronous Layered Coding (FLUTE/ALC) [32] data carousel (for example for file downloads). The Electronic Service Guide (ESG) is also broadcast using FLUTE/ALC. The handover issue in DVB-H is mainly an issue for the data link layer and the physical layer. An analysis and simulation of DVB-H link layer is done using finite-state Markov models in [33].

Time Slicing

Time slicing is used in DVB-H to transmit data in periodic

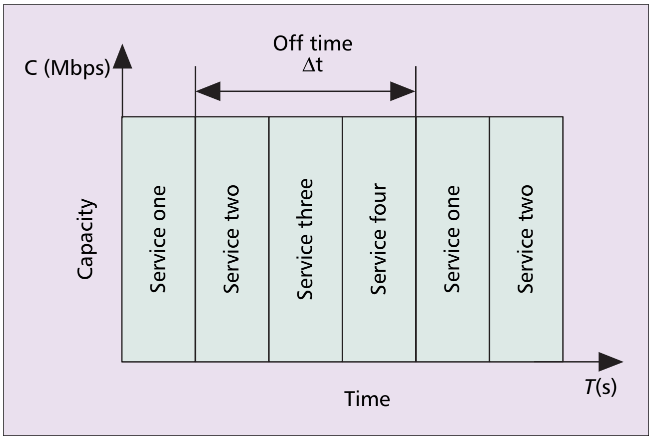


Figure 2. *Time slicing illustration.*

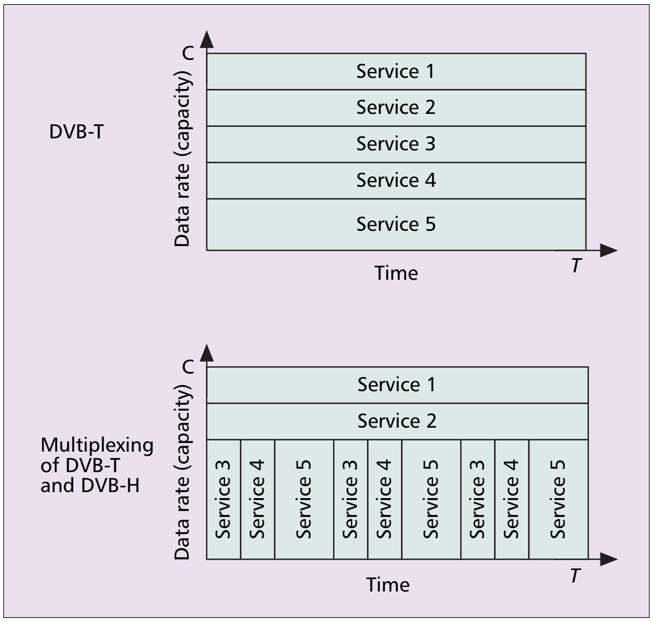


Figure 3. *DVB-T and multiplexing of DVB-T and DVB-H.*

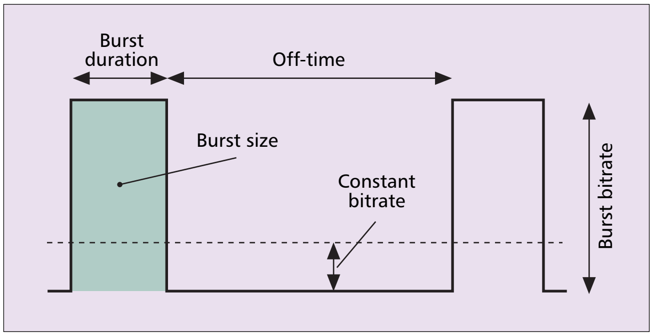


Figure 4. *Time slicing burst parameters [16].*

bursts. For a single service, the burst bit rates are significantly higher compared with that of DVB-T. Time slicing enables the tuner in a receiver to stay active only a fraction of the time while receiving bursts of a requested service; this saves battery power. It is claimed that up to 95 percent power saving can be achieved as compared with conventional and continuously operating DVB-T tuners [11]. The high-bit-rate signals will be buffered in the receiver memory. A brief performance analysis of the time slicing scheme in DVB-H is done by simulation in [34]. Time slicing offers, as an extra benefit, the possibility to use the same front-end to monitor neighboring cells between bursts, thus making seamless soft handover possible. May [35] showed how the off times between the transmissions bursts can be used to perform handovers, how they have to be synchronized, and what boundary conditions exist. A technology called "phase shifting" is proposed as a solution. Time slicing is illustrated in Fig. 2.

It is possible to use a combination of DVB-H (time sliced) and DVB-T (not time sliced) services in a single multiplex, as shown in Fig. 3 [36]. However, the power saving is decreased in this case due to a smaller data rate being available for time sliced services [36].

Another benefit of time slicing in DVB-H is that it is unique in terms of the power saving achieved. This means that the amount of power savings achieved by time slicing in DVB-H could not be obtained when time slicing is used in DAB or DMB [37].

Depending on the transmission bit rate, burst size and burst duration, the off time Δt in the transmission stream can vary [38]. According to [16], the burst parameters are shown in Fig. 4 and the formulas used to calculate the length of a burst, the off time and the achieved saving in power consumption are shown in Fig. 5. The DVB-H receiver can use this off time to synchronize and initialize soft handover to another cell that would be impossible without the use of time slicing.

MPE-FEC

Multi-Protocol Encapsulation (MPE) is a method to transmit IP data over DVB networks [39]. It specifies the carriage of IP packets within MPEG Private Data sections. The mobile reception of DVB-H is characterized by non-line-of-sight, multipath, Doppler impairments, strong propagation loss (especially for indoor reception), poor receiving antenna gain [40], and mobile channel interferences from adjacent TV and GSM channels and environmental factors such as weather and traffic. As a result, accessing a downstream high-bit-rate service with a handheld terminal is very demanding. The objective of the MPE Forward Error Correction (MPE-FEC) is to improve the Carrier/Noise (C/N) ratio and Doppler tolerance in mobile channels and to improve the tolerance to impulse interference [29]. However, MPE-FEC only works within individual time slices [41] and the size of one burst exactly corresponds to the content of one MPE-FEC frame [4]. Consequently, if a single transmission error cannot be corrected, the service drops out not only for the duration of the burst but also during the time up until the next burst is received.

4K Mode and In-depth Interleavers

The 4K mode and the in-depth interleavers affect the physical layer of DVB-H, but do not affect the soft handover directly. However, their objectives are to improve Single Frequency Network (SFN) planning flexibility and to protect against short noise impulses caused by, for example, ignition interference and interference from various electrical appliances [29, 42]. In this case, they affect the mobile reception of DVB-H signals. The 4K mode offers a trade off between mobility and SFN size in the network planning [29]. Since DVB-T does not include this mode, it is an option only in dedicated DVB-H networks [4]. For the 2K and 4K modes, the in-depth interleaver increases the flexibility of the symbol interleaving by decoupling the choice of the inner interleaver from the transmission mode [16, 29].

DVB-H Signaling

The objective of DVB-H signaling is to provide robust and

Bd Burst duration (seconds)
Bs Burst size (bits)
Bb Burst bitrate (bits per second)
Cb Constant bitrate (bits per second)
Ot Off-time (seconds)
St Synchronization time (seconds)
Ps Power saving (per cent)
Dj Delta-jitter (seconds)

$$Bd = \frac{Bs}{Bb*0.96}$$

$$Ot = \frac{Bs}{Cb*0.96} * Bd$$

$$Ps = (1* \frac{(Bd+St+(3/4*Dj))*Cb*0.96}{Bs})*100\%$$

Figure 5. *Formulas to calculate the length of a burst, off time and the achieved saving on power consumption [16].*

easy-to-access signaling to DVB-H receivers, thus enhancing and speeding up service discovery [29]. It should be noted that DVB-H is based on DVB-T and most of the DVB-H specifications in the physical layers are the same as those of DVB-T which can be found in [43]. Besides the specifications in common with DVB-T, DVB-H has unique physical specifications. Only the DVB-H signaling used for handover is considered in this section. (The signaling bits specified for DVB-H but not used directly for handover will not be discussed.) There are two kinds of signaling information the DVB-H receiver can use. One is Transmission Parameter Signaling (TPS) signaling bits in the physical layer. The other is DVB-H specific signaling within Program Specific Information (PSI)/Service Information (SI) [39, 44, 45]. PSI/SI is the core signaling for enabling service discovery within DVB-T and also within other DVB systems. Since the PSI/SI used within DVB-H is different to that of other DVB systems, a subset of PSI/SI for IPDC over DVB-H is defined in [46]. The PSI/SI data enables a DVB-H receiver to discover IPDC over DVB-H specific services in the transport stream and also provides essential information for enabling handover.

The TPS is defined over 68 consecutive OFDM symbols, referred to as one OFDM frame. Each OFDM symbol conveys one TPS bit, so each TPS block contains 68 bits [43]. The TPS bits are located within the physical layer [42] so the signal for synchronization in the handover process is first obtained by utilizing the information contained in the TPS bits [47].

The Synchronization Word bits aid the receiver in synchronizing with the target frequency. The Cell Identifier conveys unique cell identification information to the receiver. The PSI/SI provides information on the DVB-H services carried by the different transport streams. Handover-related information in the PSI/SI is mainly contained in the Network Information Table (NIT), Program Association Table (PAT), Program Map Table (PMT) [44], and IP/MAC Notification Table (INT) [39].

5 MHz bandwidth

DVB-T standards use the 6, 7, or 8 MHz raster in the frequency spectrum (namely, UHF and VHF). The introduction of 5 MHz bandwidth into DVB-H provides new possibilities for using frequency spectrum other than that allocated to traditional broadcast use, for example, in the L band, which creates new challenges in terms of receiver design and also provides benefits in terms of system performance such as tolerance to Doppler shift in a mobile environment [16].

Handover in DVB-H

This section gives an overview of DVB-H handover and points out the key enablers that are needed for accomplishing DVB-H handover by means of currently available standard methods. The aim is to give an overview of the handover principle that applies to all network configurations and hence the less efficient methods have been left out. A more extensive description of DVB-H handover, including the less efficient methods, is presented in [48].

Even though DVB-H was designed to be backwards compatible with DVB-T, there are differences between handover in DVB-T and handover in DVB-H. In addition to the use of time slicing and the resulting off-periods in DVB-H, another fundamental difference is in the signaling. Regardless of the fact that DVB-T and DVB-H share some PSI/SI tables, such as the NIT, PAT, PMT, INT and Time and Date Table (TDT), the DVB-H receiver does not need to support the Service Description Table (SDT) and Event Information Table (EIT). In [46], the SDT and EIT tables are considered mandatory for an IPDC over DVB-H network but optional for the receiver. Also, the linkage modes to enable support for handover to associated services, as defined in [45], are not supported in [46] and hence are not discussed within this section.

In DVB-T, a service is identified by a service_id within the SDT and EIT. The EIT provides schedule information for the services advertised within the SDT. The PAT and PMT are used for associating services with elementary streams.

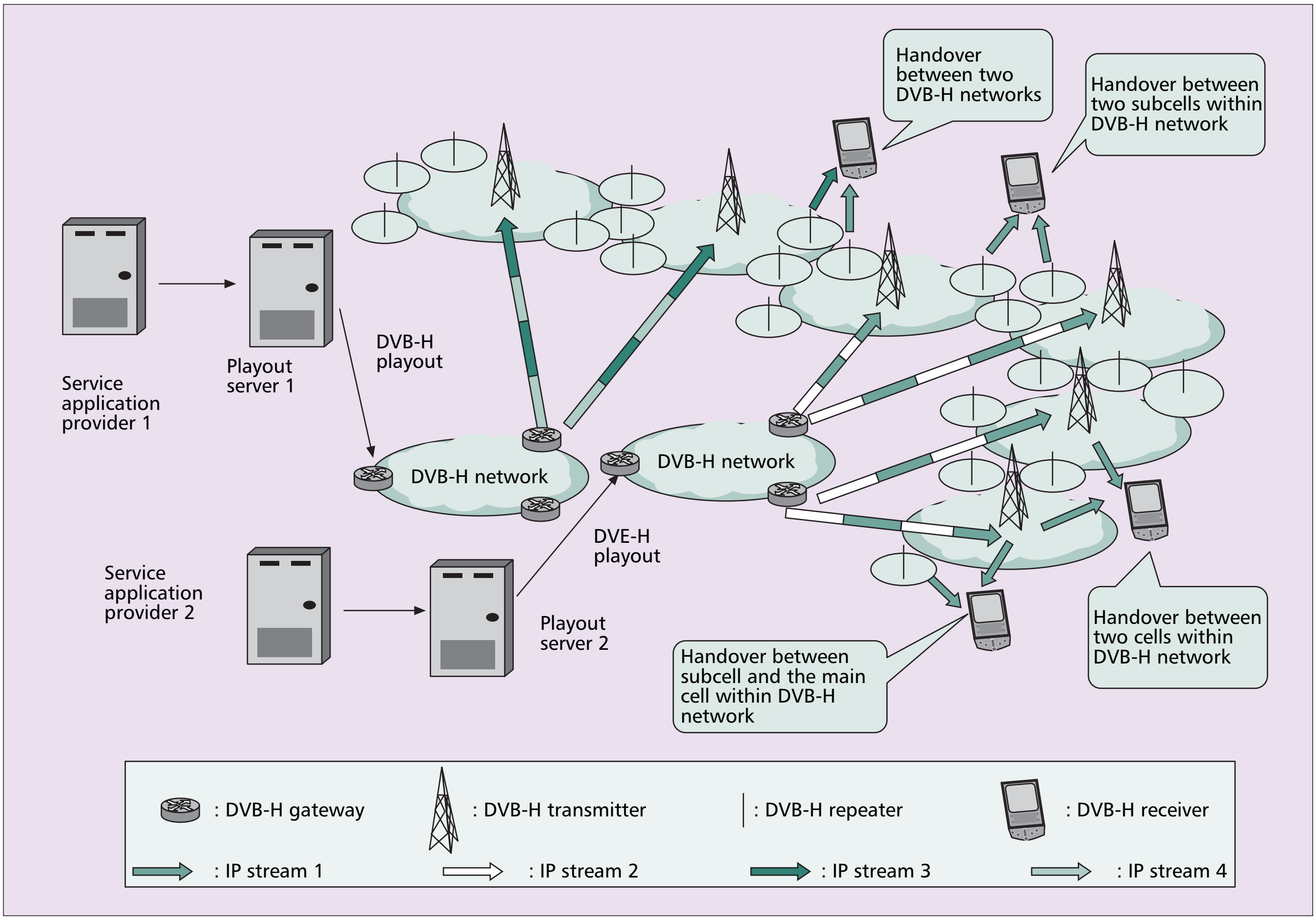
The identification of a service and the use of a service_id in DVB-H are rather different to that of DVB-T. In DVB-H, the services are first mapped to IP addresses within the Electronic Service Guide (ESG) [49]. Next, the IP addresses are further mapped to service_ids within the INT, where it is possible to associate all the DVB-H services of an IP platform with only one service_id. The discrimination between different DVB-H services within one service_id, that is, association of elementary streams with IP streams, is done within the PMT by means of a combination of component_tag and service_id. Hence, within DVB-H, the service_id is just another parameter in the mapping of IP addresses to elementary streams.

The handover in DVB-H, as defined in [16], occurs when the receiver receiving a transport stream switches to another transport stream and continues the reception of the previously received IP streams. According to this definition, DVB-H handover can occur only within MFN networks, between two different SFN areas that are part of the same network and between two different networks. In other words, handover in DVB-H occurs each time the received transport stream and/or frequency changes. To be able to operate in such a situation, the receiver needs to regularly monitor adjacent cells that have currently consumed IP streams available. This monitoring can be done by means of the NIT and INT.

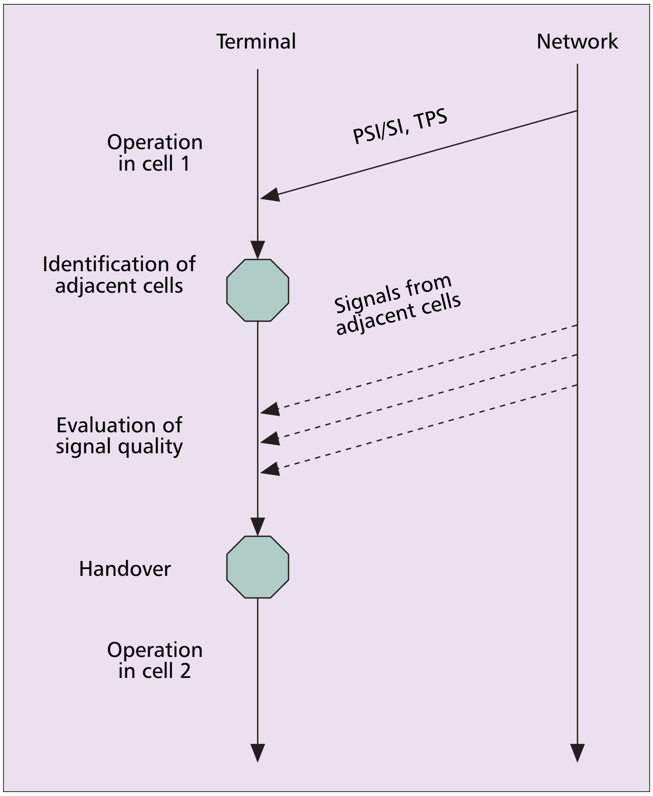
The less dynamic information is carried within the NIT, which maps each transport stream with one cell_id, one or more frequencies, and optionally with the transposer frequency and subcell_id. Also, the geographical coordinates of the cells and possible subcells are signaled within the NIT.

The level of invariability of the INT depends on the network implementation. Each INT may announce association of IP streams within all the transport streams of the network or just within the transport streams available within neighboring cells. In the case of an MFN, network capacity can be saved if each INT announces only the association of the IP streams available within the neighboring cells. From the receiver perspective this means that receiver needs to update INT each time after handover.

For the handover between two different DVB-H networks, the same procedures are followed as described above, except that the other NIT, that is, NIT_other, is needed for each network that is supported in addition to the current network.



■ **Figure 6.** *General handover situations in DVB-H networks.*



■ **Figure 7.** *Passive handover according to [36].*

Figure 6 shows the DVB-H handover schemes discussed above: handover between two DVB-H networks, handover between two subcells within a DVB-H network, handover between two cells within a DVB-H network, and handover between a subcell and the main cell within a DVB-H network.

It is expected that a DVB-H cell will usually be smaller than a DVB-T cell because of a low-gain receiver antenna, the low height of a transmitter antenna, building penetration losses, and fast fading in a mobile environment [40]. Thus, low-power transmitters serving a network operating in a multifrequency network (MFN) mode, in networks composed of one or more Single Frequency Network (SFN) areas or a mixture of these two topologies, are the main network structure types for DVB-H. One of the main factors that affect the selection of the network topology is the need for localized services. Depending on the density of the localized services, the network topology can vary from a MFN composed of single transmitter cells to networks composed of one or more SFN areas. If localized services are not supported at all within the network, the whole network can consist of a single SFN area where handover is not needed. All other network types, except the network type covered exclusively with one SFN area, result in handovers. The handover frequency is dependent on the size of the cells, terminal mobility, and environmental factors (such as rural or urban), which are similar to the handover frequency factors in UMTS/GSM and so forth.

The handover in DVB-H has unique features compared with that of cellular telecommunications networks (e.g., UMTS) such as its unidirectional nature, being mobile initiated, time slicing being utilized, and always being soft handover. Taking UMTS as an example, the base station will communicate with the mobile terminal in the handover procedure and the availability of an interaction channel between the network and the terminal is essential for the successful completion of the handover [50]. On the other hand, DVB-H networks have no information as to who is using their services at a given time and where the terminal is possibly going to perform handovers. Since the DVB-H transmitter cannot obtain information from the DVB-H terminals, the DVB-H terminals themselves based on their own decisions must perform the handover.

Although some convergence terminals have both DVB-H and telecommunication capabilities, it is not always possible for a terminal to get in contact with the network to perform handover. Handover without an interaction channel in DVB-H is called passive handover while handover in DVB-H utilizing an interaction channel such as a UMTS return channel is called active handover [51]. Illustrations of these two kinds of handovers are given in Figs. 7 and 8 [36]. Since DVB-H does not require a mandatory return channel, in this survey only passive handover in DVB-H terminals is considered where the terminal has no interaction channel with the network infrastructures.

Soft handover is not possible for single antenna DVB-T terminals [36], because single antenna DVB-T terminals cannot make seamless handover without interruption of the continuing service. On the other hand, DVB-H terminals can make seamless handover (soft handover) because of its time-slicing transmission nature. The DVB-H standard brings the possibility of soft handover for single antenna terminals. There are two main features that make soft handover possible in the DVB-H standard, one is time slicing and the other one is the mandatory cell id identifier [29]. Time slicing creates off times that can be used for the monitoring of the adjacent cells without interruption in the service consumption. Mandatory cell id identifiers assist the handover decision process and reduce the tuning failure probabilities.

Figure 9 shows the basic soft handover scenario in DVB-H networks.

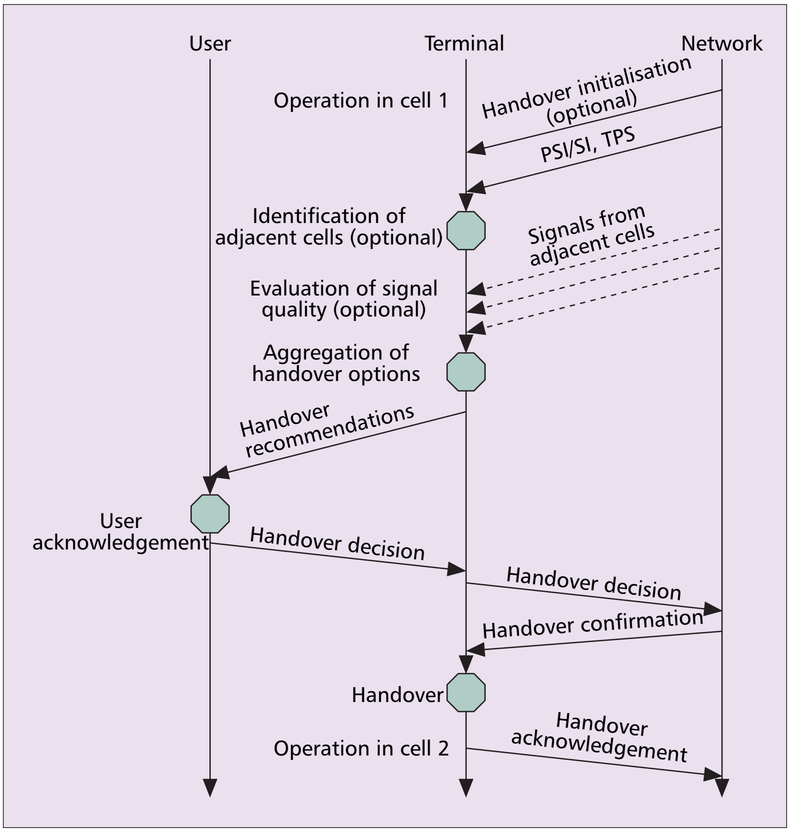


Figure 8. *Active handover according to [36].*

Approaches to the Handover Problems in DVB-H

Handover in DVB-H is a novel research issue. In order to evaluate the existing and the forthcoming handover solutions, a systematic categorization and evaluation method is needed. Two approaches are proposed here. One is to evaluate and categorize the handover algorithms based on the challenges that are introduced by the handover process of DVB-H. The other is to study DVB-H handover from different handover stages' points of view. In this way, it is believed, from the authors' own research experiences, that handover in DVB-H can be systematically studied and evaluated. These two aspects are described in detail in the following two sections.

Challenges in the Handover Process of DVB-H

Some challenges may exist in the handover process of DVB-H such as the Ping Pong effect, "fake signals," excessive power consumption, and packet loss. These are the challenges for DVB-H handover in general and the designed algorithms should cope with them. Also, the network planning has a big affect on handover in DVB-H.

Ping Pong Effect

Because the signal strength fluctuates in the real physical environment the DVB-H receiver has the possibility of detecting strong signals from other cells even though it is located in the original cell, especially in the transmitter shadow areas, for example, when high buildings are blocking line of sight signal transmissions. In this case, the receiver may have the possibility of repeated handover between different cells, causing a Ping Pong effect [30]. Since frequent handover increases power consumption that is critical for handheld battery powered terminals, reducing the occurrence of the Ping Pong effect is one of the key research areas for handover study in DVB-H. The Ping Pong effect should be reduced to the minimum possible in the handover decision-making stage.

Fake Signal Occurrence

The DVB-H receiver utilizes PSI/SI signaling and information acquired from the TPS bits to discover what services are available within the found signals. The PSI/SI maps IP streams to transport streams and subsequently transport streams with the different frequencies and cells. The cell identification information (i.e., cell_id) is also signaled within the TPS bits of each received signal. By utilizing these two signaling mechanisms, that is, PSI/SI signaling and TPS signaling, the receiver can verify that, with one exception, it always hands over to a valid signal. The exception mentioned above refers to [38], where the concept of "fake signals" is introduced. A "fake signal" is a signal that has the same frequency and cell_id as the

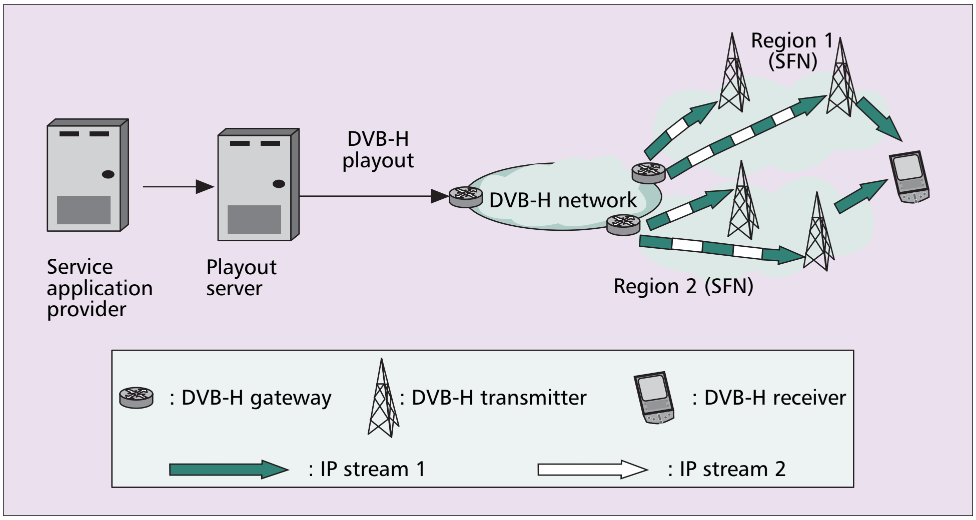


Figure 9. *Soft handover illustration.*

targeted signal, but which actually is from a different network; hence, it is very unlikely that the receiver is able to receive currently consumed IP streams from it. Such a situation may occur, for example, when a cell of another network is using the same cell_id and frequency as the cell that the receiver aims to hand over to, as shown in Fig. 10. The situation described above is possible even though it can be avoided by appropriate network design and co-operation between network operators.

POWER CONSUMPTION

In addition to the two main possible problems mentioned above in the handover process of DVB-H, power consumption is the most important concern. Power consumption has always been a critical challenge for mobile handheld terminals [52, 53]. In fact, reducing power consumption is the reason why the DVB-H standard was developed [29, 54]. Better handover algorithms in DVB-H can consume less battery power compared with other handover algorithms. Although the introduction of time slicing has reduced the power consumption of DVB-H to a considerable extent compared with that of DVB-T, the handover algorithm in DVB-H should be fully exploited to further reduce the power consumption of the terminal in different stages and to avoid unnecessary power consumption as much as possible when handover is present.

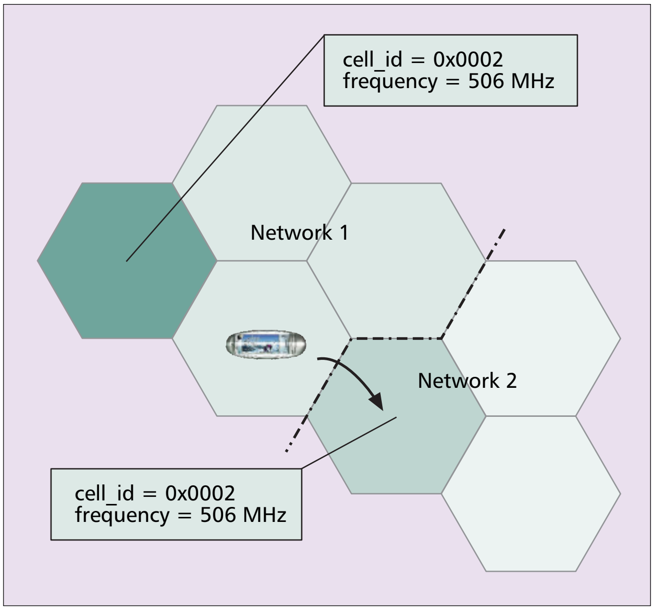


Figure 10. *Tuning failure or fake signals.*

PACKET LOSS

DVB-H is a unidirectional broadcasting network. If some packets are lost during the handover process there will be no retransmission of the lost packets. Packet loss will most probably happen when the terminal tries to synchronize to the target frequency and transport stream in the handover process. Delay and jitter are very common in the IP networks that are the service-feeding networks of DVB-H. Since even a single lost packet will have a disastrous effect for some IP Datacast services in DVB-H (e.g., file downloading), strict synchronization techniques must be used in the synchronization of the time sliced services of DVB-H. Further discussion of this issue can be found in [35].

HANDOVER STAGES IN DVB-H

Handover in DVB-H consists of three stages: handover measurement, handover decision-making based on the handover criteria, and handover execution [55]. All the previous research work on handover in DVB-H can be categorized into or was targeting these three stages.

HANDOVER MEASUREMENT

Handover measurement is the first of the handover stages. In DVB-H the handover measurement takes place in the off time of the time slicing mode. The terminal will switch off the tuner and the demodulator in the off burst period. However, the front-end receiver has to keep measuring the signal strength from neighboring transmitters in order to monitor the signal strength fluctuation. If the signal strength of the received signal is degraded to some degree, the handover decision-making process will be triggered. The wake up time for the next burst will be signaled in the current burst period. The detailed procedure is given in [42].

HANDOVER DECISION-MAKING BASED ON THE HANDOVER CRITERIA

In the second stage of the handover process, the DVB-H ter-

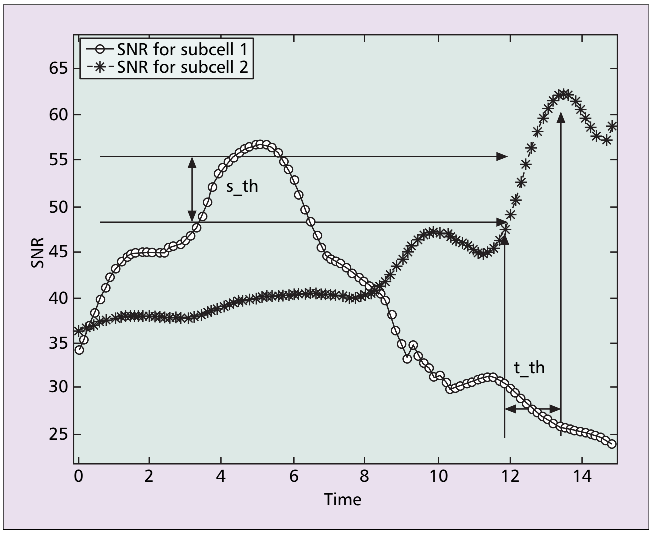


Figure 11. *SNR and time threshold for handover decision-making.*

minal will decide whether it should perform handover based on the predefined handover criteria. The most commonly used handover criteria parameters are the Received Signal Strength Indicator (RSSI) and the Signal Noise Ratio (SNR) [30, 38]. This survey article only considers MFNs, so the self-interferences between different transmitters in SFNs will not be considered. When the RSSI or the SNR is identified as degraded to some degree from the handover measurement of the first stage, the handover decision-making process will be triggered. Taking the SNR as the handover criteria for example, once the SNR threshold margin value s_th is reached for a certain threshold time t_th, the receiver will tune to the frequency with the strongest SNR value to continue service reception. The SNR and duration threshold are shown in Fig. 11. In addition to the physical layer parameters, it is increasingly important to take the quality of currently received IP streams as one handover criterion especially within a MFN network. This is also recognized in [48, 16].

Handover Execution

Handover execution is the last stage of the handover process. After the terminal has made the handover decision it will perform the handover execution stage. In this stage, the terminal attempts to synchronize to the handover target signal and to continue the reception of the currently received services without interruption. In order to validate whether the handover target signal is the correct one, the DVB-H signaling information contained in the TPS bits and the PSI/SI tables will be utilized.

Research Conducted on Handover in DVB-H

Handover in DVB-H is a novel issue. However, much research work has already been reported in this area at the time of writing this survey. In this situation, an attempt is made to survey as far as possible the work that has been reported and forecast the work that will be done.

An instantaneous Received Signal Strength Indication (RSSI) value based handover scheme was proposed in [38]. This handover scheme is the first for DVB-H published in the literature. This scheme uses the off burst time to measure the RSSI value. After comparing the current RSSI value with that of adjacent cells, it hands over to the cell with the strongest

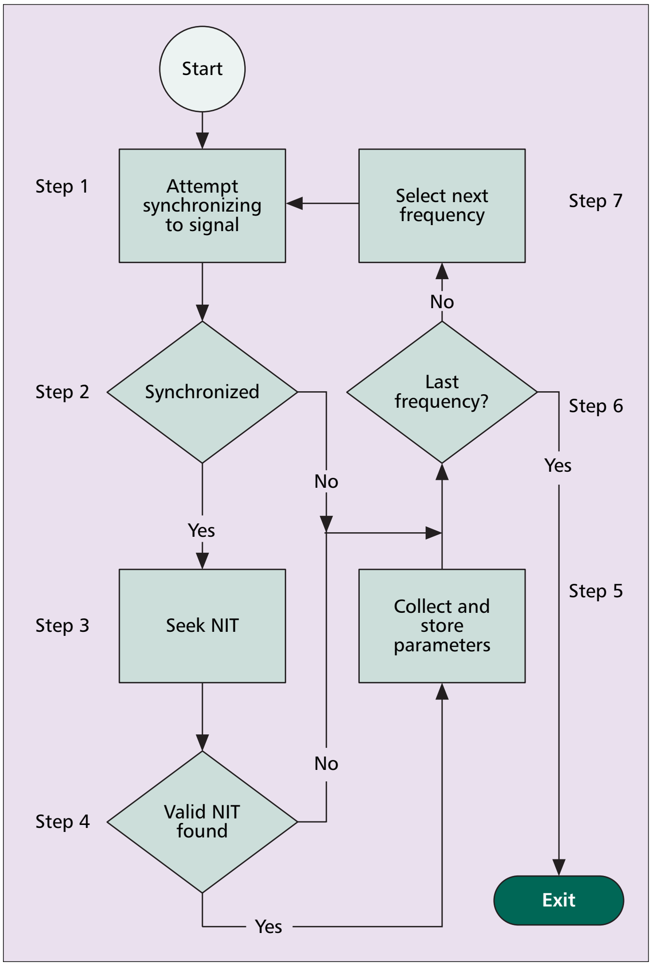
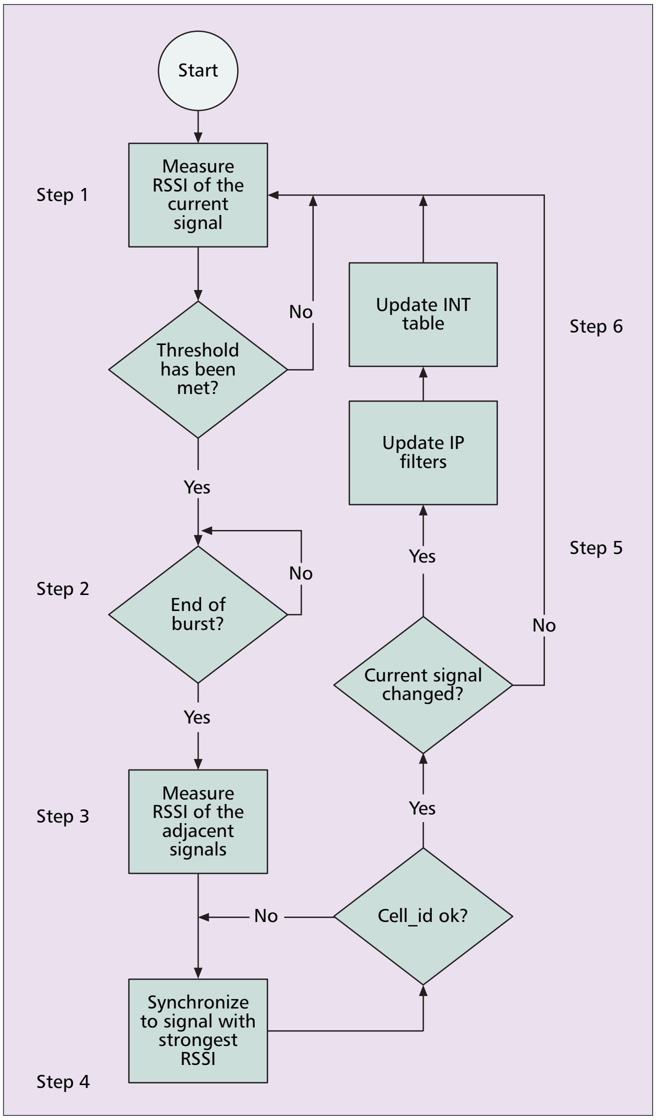


Figure 12. *Measurement stage of the handover algorithm according to [38].*

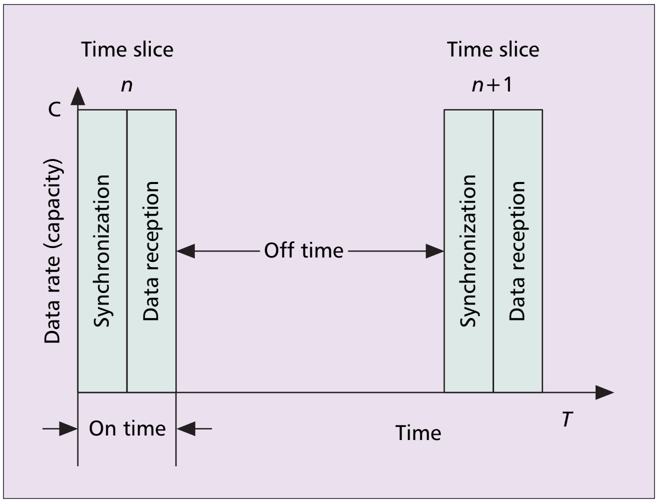
RSSI value. The handover stages for this handover algorithm are shown in Figs. 12 and 13. Since the RSSI value can vary due to multipath, interference or other environmental effects it may not give a true indication of the communication performance or the range and mistakenly measuring the RSSI value would result in the Ping Pong effect in handover measurement consuming power unnecessarily. The RSSI value could be measured many off burst times with the RSSI value being measured at least once every off burst time in the worst case. Constant measuring of the adjacent cells signal level without any handover prediction leads to more battery power consumption. In order to overcome these shortcomings, a better handover prediction algorithm had to be developed.

Hamara presented an enhanced version of the algorithm of [38] in his thesis [48] where, in addition to using the RSSI value as a handover criterion, currently consumed services and bit error rate were taken into account. This thesis is the first thesis about DVB-H handover in the literature. It gives an extensive analysis of the handover aspects within DVB-H in the light of the standard solutions at the time.

In [30] another handover scheme based on post-processing of the measured SNR value was proposed to avoid the Ping Pong effect and to get rid of the received “fake signals.” In the SNR-based handover scheme, the SNR is calculated from the RSSI and the noise characteristics and provides a more accurate estimate of the received effective signal than the RSSI. The main idea of post-processing the SNR values is to calculate the Cumulative Distribution Functions (CDFs) of all the SNR values. A CDF describes a statistical distribution. It gives at each possible outcome of the received signal SNR the



■ **Figure 13.** *Decision-making and execution stages of the handover algorithm according to [38].*



■ **Figure 14.** *Position of the synchronization duration in the time slicing mode.*

probability of receiving that outcome or a lower one. Because the CDF gives a probability value, its value depends not only on the current SNR value, but also on the SNR history of the signal. This not only eliminates the frequent handover phenomenon seen in instantaneous RSSI value-based handover, but also avoids the "fake signals" caused by frequency confusion. Although simulation has shown the feasibility of this simple algorithm, further studies and field trials need to be done to investigate the limitations of this algorithm.

Vare, Hamara, and Kallio [69] have proposed a new method for signaling cell coverage areas by means of bitmap data to improve the handover performance in DVB-H. A new table called the Cell Description Table (CDT) is proposed for the PSI/SI. By using a CDT, up to 256 different signal levels within the cell coverage area can be signaled to the receiver to inform it of the cell coverage. The terminal can make better handover decisions from the information about the cell coverage area to reduce the Ping Pong effect and "fake signals." However, in this proposed handover scheme more bandwidth and receiver memory consumption is needed to support the CDT information process. In addition, the DVB-H handheld receiver must have GPS support which will be an additional cost to the customer. This kind of cost cannot be neglected, especially in the early DVB-H roll out stage when potential customers are still not fully convinced of the benefits of DVB-H services. Transferring the cost from the terminal side to the network side is an alternative solution if the network can provide the same location information to the terminal as a GPS receiver does.

Yang *et al.* [55] investigated different handover decision-making algorithms and proposed a novel hybrid handover decision-making algorithm. The key idea of [55] is to reduce the frequency of handover measurement in the handover decision-making stage by designing a soft handover algorithm with prediction of the handover moment. The proposed handover decision-making algorithms are Context-Aware Handover Decision-making, Location-Aided Handover Decision-making, UMTS Aided Handover Decision-making, Repeater-Aided Handover Decision-making, and Hidden Markov Model Based Decision-making. A comparison of the different handover decision-making algorithms is presented in Table 1 according to [55]. As a conclusion to [55], a hybrid handover decision-making algorithm is proposed that can utilize the advantages of the different handover decision-making algorithms while eliminating the limitations of them by using a central management module to control the choice of one of the different handover modules in different environment scenarios. The feasibility and the limitations of the proposed handover decision-making algorithm need to be validated through field trials.

A more detailed description of different handover algorithms, especially of the different handover decision-making algorithms in dedicated DVB-H networks and in converged DVB-H/UMTS networks, is presented in [57]. The investigation and research of the handover in converged DVB-H and UMTS networks is thought to be one of the first in the literature.

Schwoerer [47, 56] and Vesma [47] target power consumption reduction by utilizing novel synchronization techniques in the handover execution stage of the handover process. The handover execution stage is equal to the signal synchronization, and the on time in the time slicing mode consists of both the synchronization time and the burst data duration time, as shown in Fig. 14; the main idea of [47, 56] is to try to minimize the synchronization time to further reduce the power consumption. The main exploitable synchronization time in the synchronization stage is the TPS synchronization, as shown in Fig. 15 [47].

Schwoerer and Vesma [47] proposed a new synchronization technique called correlation-based "Fast Scattered Pilot Synchronization" for DVB-H receivers to substitute the con-

Algorithms	Saved Power Consumption Compared with RSSI Algorithm	Advantages	Disadvantages
Context aware	60% in the worst case	Simple and efficient	Less robust to environment
Location aided	Up to 97%	Simple and efficient	Costly and only in motorway scenario
UMTS aided	Not determined	Simple and efficient	Complex and needs UMTS network
Repeater aided	Up to 63.22%	Simple and efficient	Costly
HMM based	Not determined	Simple, less costly, efficient	Needs Enough Measurements Data

Table 1. *Comparison between different handover decision-making algorithms according to [55].*

ventional TPS-based OFDM frame synchronization for finding the position of Scattered Pilots within an OFDM symbol in the handover execution stage. It exploits the temporally repetitive structure of the scattered pilots and Schwoerer and Vesma [47] showed using mathematical analysis that the synchronization time (until channel estimation) could be cut by 84 percent by using the new technique. Reducing the synchronization time means reducing the power consumption. Therefore, "Fast Scattered Pilot Synchronization" can reduce the power consumption in the DVB-H handover execution stage. Schwoerer [56] proposed another purely power-based "Fast Scattered Pilot Synchronization" method. It uses the fact that scattered pilots are amplitude-boosted by 4/3 to find the current Scattered Pilot Raster Position (SRPR) [43]. It is shown in [56] that 89 percent of the synchronization time can be saved using power-based "Fast Scattered Pilot Synchronization."

In [35] May focused on the handover execution stage of the handover process in DVB-H. Because the IP network delay and jitter may be different for different cells May proposed a technology called "phase shifting" to synchronize the signals of adjacent cells in IP Datacast over DVB-H networks in order to ensure loss-free handovers. When the terminal moves from one cell to another, synchronization techniques must be used to ensure that there is no packet loss caused by a time sliced burst overlap when the next time sliced burst arrives. There are three different possibilities for the types of synchronization. The first is no synchronization that of course will cause considerable packet loss. The second is in-phase synchronization where all the transport streams in different cells must be transmitted in perfect synchronization, that is, at the same universal time. This cannot be ensured without a buffer system in the network side. The third one is "phase shifting" synchronization where there is a time shift between adjacent cells to ensure that there is enough time between the neighboring time slices to avoid the possible packet loss caused by time slice overlap. The phase shifting principal for handover between any two cells as a four-color problem [58] is illustrated in Fig. 16 according to [35]. Analysis and simulation showed that the phase shifting synchronization techniques can achieve much better performance with respect to the packet loss probability compared with the no synchronization and "in phase" synchronization techniques.

The DVB Project technical reports [45] and [16] proposed a simple handover algorithm for handover in DVB-H based on the handover algorithm in DVB-T. The basic idea is for the DVB-H terminal to use the terrestrial_delivery_system_descriptor, the frequency_list descriptor, the original_network_id and the transport_stream_id together as a pair along with the service_list_descriptor to decide which frequency and transport stream the receiver should switch to in the handover process. Several methods to reduce the risk of tuning failures or "fake signals" are also presented. The first one proposed in [45] is called "local SI insertion" which makes each cell a separate network by individual Service Information (SI) insertion. In this case, there will be only one frequency per network. The second method utilizes the cell identifier so the terminal can know which cell it has entered. In this case, the terminal can determine and check the cell id of a signal from its TPS bits to see if it is in its cell id list of interest after checking the frequency thus reducing the tuning failure. The third method uses location data from GPS receivers to aid the handover so the terminal can determine the destination cell reducing tuning failure. The last method in [45] uses two front-ends including a second demultiplexer. In this case, the tuning of different frequencies can be done in parallel and the target cell frequency can be validated in advance so that the risk of tuning failure can be completely eliminated.

Designing a Better Handover Algorithm For DVB-H

The handover in DVB-H networks is the subject of on-going research and different approaches for designing handover algorithms by utilizing mechanisms defined in [16, 29] and in [10] are developed all the time. In this section, some key points are proposed as criteria for designing an efficient handover algorithm in DVB-H networks identified from the research conducted by the authors.

Handover Decision-making Stage

One of the key aspects in designing an efficient handover algorithm for DVB-H is to exploit the possibilities of reducing battery power consumption. The handover decision-making stage is the handover phase where the battery power consumption reduction can be fully exploited. The main objective in the handover decision-making stage is to try to predict the handover moment to reduce the number of off burst time intervals that are used for handover measurement.

Complexity and Compatibility

The design of a handover algorithm for DVB-H should not conflict with the already consolidated DVB-H standards and the complexity of the handover algorithm should be fully exploited to ease the difficulty imposed on the receiver design.

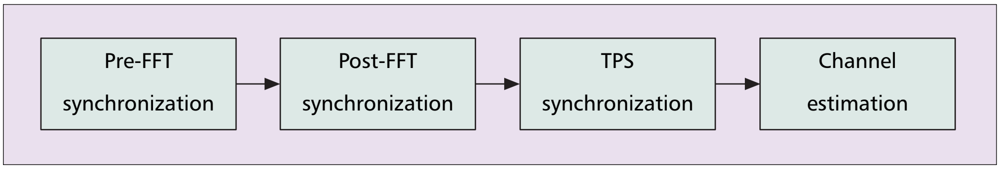


Figure 15. *TPS synchronization in the synchronization stages according to [47].*

Utilization of Additional Signaling Information

Additional signaling information should always be fully exploited by the handover algorithm. Handover in dedicated DVB-H networks has the characteristic of being passive where only the unidirectional transmission from the network to the terminal is possible. If additional signaling information is available, it should be used to help the handover process. Take the converged terminal as an example; converged DVB-H and GPRS/UMTS terminals have the advantage of having an interactive uplink channel. In this case, the uplink channel can be utilized to aid the handover process and this UMTS aided handover is a kind of active handover. The network parameters transmitted from transmitters and repeaters can also be fully utilized by the passive DVB-H receivers to aid the handover process.

Additional Equipment Cost

DVB-H terminals should be affordable for consumers. An additional attachment such as a GPS receiver can improve handover efficiency but can also increase the terminal price. The authors believe that DVB-H handover algorithms should focus on utilizing existed signaling information available in the DVB-H standard to avoid the extra cost of introducing new network equipment (such as expensive repeaters) or terminal attachments (such as GPS receivers) purely for handover purposes.

In addition, the handover challenges presented earlier should be carefully considered when a handover algorithm is designed. The challenges such as the Ping Pong effect, "fake signals," and power consumption are sometimes related each other. For example, because more Ping Pong effect means more power consumption, when the Ping Pong effect is solved, the power consumption is usually reduced as well.

Different handover algorithms have different characteristics. It is sometimes difficult for one algorithm to be used for all situations, for example, a handover algorithm utilizing UMTS interaction channels will not work when the UMTS network does not exist. While the above-proposed evaluation

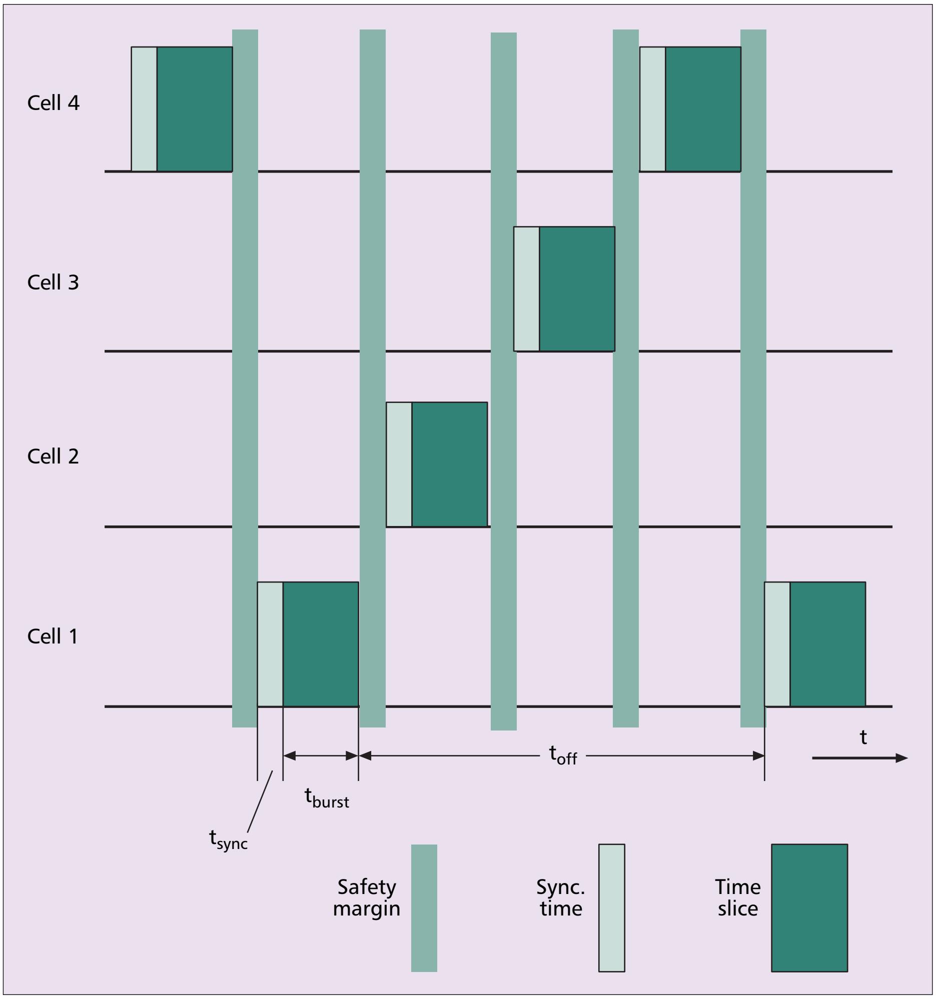


Figure 16. *Phase shifting as a four-color problem according to [35]*

Paper	Main Novelty	Handover Stages Target	Problem Target	Comments
[38]	First paper on handover in DVB-H	Handover measurement, Handover decision-making, Handover execution	Design a feasible handover algorithm	Without mechanisms to prevent the Ping Pong effect and "fake signals"
[30]	Post-processing of SNR values based handover algorithm	Handover decision-making	Ping Pong effect, "fake signals," and power consumption	Validation by further study and field trials is needed
[69]	Cell Description Table (CDT)-based handover algorithm	Handover decision-making	Ping Pong effect and power consumption	A trade-off between increased bandwidth (and memory) consumption and decreased power consumption should be considered.
[55]	Investigation and proposal of different possible handover decision-making algorithms	Handover decision-making	Ping Pong effect, "fake signals," and power consumption	Validation by further study and field trials is needed
[47]	Correlation-based "Fast Scattered Pilot Synchronization"	Handover execution	Power consumption	Validation by further study and field trials is needed
[56]	Power-based "Fast Scattered Pilot Synchronization"	Handover execution	Power consumption	Validation by further study and field trials is needed
[45]	Simple handover algorithm based on the handover algorithm of DVB-T and different methods to reduce or completely eliminate the tuning failures.	Handover measurement, handover decision-making and handover execution	Tuning failure or "fake signals"	The algorithm needs to be improved and validated by further study and field trials.
[35]	"Phase shifting" for synchronization of signals between adjacent cells.	Handover execution	Packet loss	The algorithm needs to be improved and validated by further study and field trials.

Table 2. *Summary of different handover algorithms.*

criteria should be considered in designing an efficient handover algorithm for DVB-H, the individual application situation must be taken into account. Designing an efficient algorithm usually implies a trade-off between power consumption, signaling information, and additional equipment cost under the condition that the complexity and compatibility problems are considered.

Conclusions

The different handover algorithms for DVB-H presented in the literature have been summarized in Table 2, which shows the different algorithms along with their corresponding handover stages and the problems they are focusing on. It must be noted that new handover algorithms are constantly being developed, so Table 2 may not be exhaustive, as it only relates to the algorithms that were reported at the time of writing of this survey.

Related Projects and Future Work

A myriad of projects on DVB-H are being carried out around the world. There are two main European research and development projects on DVB-H that have recently been in operation. INSTINCT is the acronym of a European project on IP-based Networks, Services and Terminals for Converging Systems, namely the converged network between Broadcast networks (DVB-T/H) and mobile cellular networks (GPRS/UMTS) [24]. Handover issues were considered by Brunel University, France Telecom R&D and TDF, in the INSTINCT project [24, 59] which completed its activities in March 2006. WingTV [25] is another European project supported by the European Research and Development program CELTIC [60]. The mission of the WingTV project is to contribute to speeding up the worldwide adoption of the DVB-H standard by validating the technology and providing adequate inputs to forums and standardization bodies. WingTV was planned over five years from 2004 to 2008.

Field trials of DVB-H have already taken place or are in operation in the cities of Helsinki, Berlin, Pittsburgh/USA, Barcelona, Oxford, Metz, and Amsterdam [61–64]. More field trials are taking place and are coming in many other cities around the world. The detailed validation report on the laboratory tests in Berlin and the field trials in Metz is given in the ETSI validation report [65]. All these trials are dealing with Single Frequency Networks; thus, no handover measurements for multifrequency networks have been done. Although there are some other technologies that are competing with DVB-H nowadays, such as T-DMB (Terrestrial Digital Multimedia Broadcasting) and MediaFLO (Media Forward Link Only) [66, 67], DVB-H has its unique advantages. Compared with MediaFLO, DVB-H is an open standard thus many more manufacturers support it. Compared with T-DMB, DVB-H has superiority in both technology and cost [68]. For the completion of the DVB-H validation work, the next logical step is the validation of handover that is prerequisite for the multifrequency DVB-H system.

Acknowledgments

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(ORIGINAL)
PUBLICATION P4

"A Prioritization Method for Handover Algorithm in IPDC over DVB-H System"

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A prioritization Method for Handover Algorithm in IPDC over DVB-H System

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Abstract

DVB-H (Digital Video Broadcasting for Handheld) is a standard that was developed to enable broadcast distribution of multimedia services such as MobileTV to the handhelds. The DVB-H standard was further enhanced by IPDC over DVB-H standard which defined complete end-to-end DVB-H system and hence maximized the interoperability between networks and terminals. Even though standards enable complete solutions for implementation, there are several different ways to realize the actual terminal implementation. One of the key features within DVB-H and IPDC over DVB-H standards is to ensure the reception of services when terminal switches the point of reception, i.e. performs handover. The latter has been a topic of research for a quite some time and several different approaches have been provided. This paper introduces another element for the handover and particularly for the implementation of handover algorithm. A prioritization method for handover algorithm in IPDC over DVB-H system is presented.

Keywords
DVB-H, handover, prioritizing, algorithm

1 INTRODUCTION

DVB-H (Digital Video Broadcasting for Handheld) [1] is the first standard defined for distribution of broadcast multimedia content to handheld devices. Actually the term 'handheld' was introduced as current context during the development of DVB-H, in order not to be confused, e.g. with mobile and portable. Since the DVB-H focused only the Physical and Data Link Layers, IPDC over DVB-H [2] was developed, in order to fully define the complete end-to-end system and hence enable global interoperability between networks and terminals.

Similarly as in any standard, the implementations may vary a lot. It is important to ensure that the first implementations provide reliable basic functionality. Later, with experience from different trials, the implementation optimization is a natural step forward. Optimization is also something which may be based on the customer needs and on the other hand it may be a distinguishing factor between different companies who are serving the same markets.

DVB-H markets are relatively young and only few companies have launched more than one DVB-H terminal. It could also be said that, at this point of time, the implementation optimization of the available terminals has not been pushed into the limits. The latter is understandable when acknowledging the fact that the basic functionality is already more than satisfactory to the end users.

So far, different aspects within DVB-H have been explored throughout several academic publications, which many relate back to the time before DVB-H standard was completed. For example handover and especially seamless handover within DVB-H has been studied already before the first publication of DVB-H standard in [3]. The transmission of PSI/SI signaling has been studied in [4] and in [5]. This paper introduces a method, which can be used for optimization of handover algorithm implementation in an environment where terminal is consuming several simultaneous services and needs to select one candidate from the several available ones. Chapter two describes the basic service discovery principle and handover in IPDC over DVB-H system. Chapter three explains the handover criteria relation to prioritization of services. The proposed method to implement service prioritization is described and analyzed in chapter four. Finally the paper is concluded in chapter five.

2 SERVICE DISCOVERY PRINCIPLE AND HANDOVER IN IPDC OVER DVB-H

Service discovery in IPDC over DVB-H is a process that resolves the parameters of the mapping of IPDC service with Elementary streams carried within transport streams which may be available within more than one network. It can be split into to levels (see Figure 1), which are ESG level service discovery and DVB level service discovery.

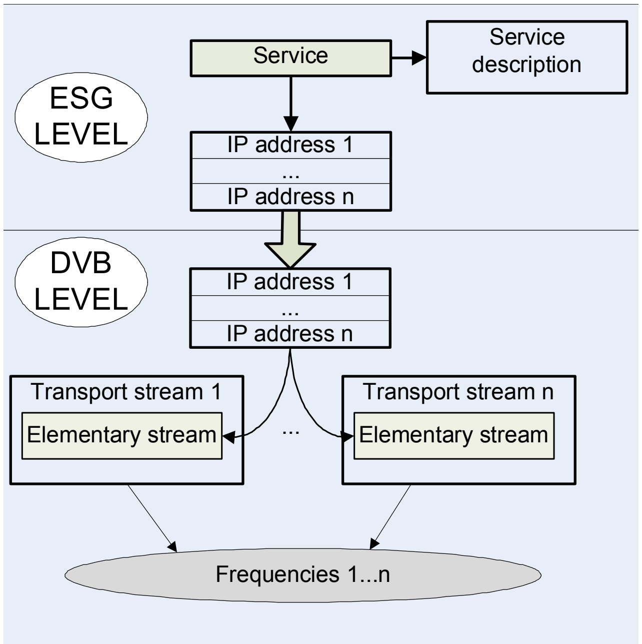

Figure 1. The service discovery principle in IPDC over DVB-H where the service is associated with the ESG level service description and with the IP addresses. The DVB level parameters, in turn, are associated with the ESG level parameters through the IP addresses.

The ESG level service discovery has been defined completely by the IPDC over DVB-H standard and it provides the service description and application related parameters. The DVB level service discovery, in turn, has been mostly adopted from that of DVB-T and enhanced with additional DVB-H specific signaling and functionality. The DVB level service discovery information associates services through IP addresses with the physical elements of the networks, i.e. signals, transport streams and different frequencies.

Service discovery information is used by a terminal to access into the new services and to maintain the service reception when terminal changes from signal to another, i.e. performs handover. The handover mechanisms in IPDC over DVB-H are fully terminal based, i.e., terminal makes the decision of when, and to which new cell it switches the reception. The role of network is only to provide sufficient signaling and hence enable handover for the terminal. Exhaustive explanation of service discovery and handover in DVB-H is provided in [6].

3 THE HANDOVER CRITERIA

The selection of handover candidate in DVB-H may be based on several criteria, depending on the implementation. Some of the most common handover criteria in DVB-H are explained in [6]. The handover criterion may be related to ESG level or to DVB level parameters. However, in minimum, the following is needed; First, the selected candidate signal needs to have at least one of the currently consumed services available. Secondly, the signal quality of the candidate signal needs to be sufficient enough for the service reception.

In the scenario, where terminal is receiving only one service at a time, a handover criterion is rather straightforward. The situation is different in the case where more than one services are consumed simultaneously. Such scenario can be realized, for example, in the case where one service is being recorded whilst another one is being watched at the same time. In the following, the handover decision in the ‘single service scenario’ and in the ‘multi-service scenario’, is described in greater detail. Finally, an example of the handover algorithm utilizing service prioritization is given.

3.1 Handover Criterion in the Single Service Scenario

In the case, where terminal is consuming only one service at a time, the handover will not happen if the consumed service is not available in any of the candidate signals. Hence, it is more optimal to first validate the handover candidates based on the availability of the currently consumed service, in order to avoid unnecessary signal measurements for such candidates, which do not carry currently consumed service. Figure 2 illustrates a principle of handover criterion in the single service scenario.

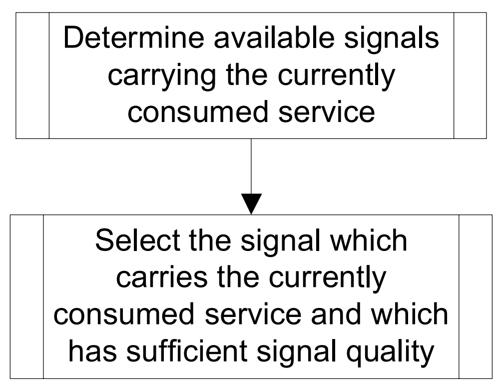

Figure 2. The principle of handover criterion of the single service scenario, where the handover candidate, which has the currently consumed service available and which has sufficient signal quality, is selected.

3.2 Handover Criterion in the Multi-Service Scenario

If the terminal is consuming more than one service simultaneously, it might want to select only such signals as candidates, which carry at least a subset or all currently consumed services. However, the situation might be such that the all candidate signals carry only partially same services that the terminal desires. In such case terminal needs to prioritize all currently consumed services in order to be able to decide which candidate it will select. In addition, terminal could prioritize such services which are currently not available, but which are available in some of the candidates. Figure 3 illustrates a principle for handover criterion in the multi-service scenario.

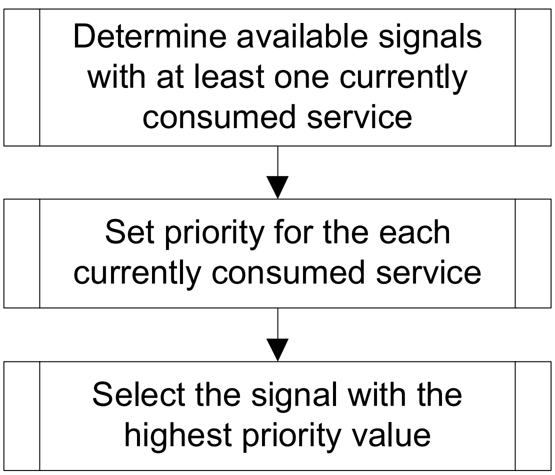

Figure 3. The principle of handover criterion of the multi-service scenario, where the handover candidate with the current service available and with sufficient signal quality is selected.

3.3 An example of handover algorithm utilizing service prioritization

There are several possibilities for the implementation of handover algorithms and for brevity, only a generalization is provided in Figure 4. In the described algorithm, two handover thresholds are used. The first threshold is purposed to give an early indication to terminal that it needs to start for searching new handover candidates. The second threshold, in turn, indicates that the actual handover needs to take place in order to guarantee the service reception. The steps of the algorithm are described as follows,

Step1: Terminal inspects that which of the currently consumed services are available within the neighbouring signals, as indicated by the signaling metadata. Next the availability of the neighbouring signals, containing at least one currently consumed service, is verified by measuring signal quality. If the signal quality is detected sufficient for service reception, the measured signal is accepted as handover candidate.

Step2: Each of the currently consumed services is prioritized by the terminal. This prioritization may be based on the end users desires.

Step3: The list of handover candidates is further ranked, based on the total priority value of each signal.

Step4: Once the second handover threshold has been met, terminal performs the actual handover.

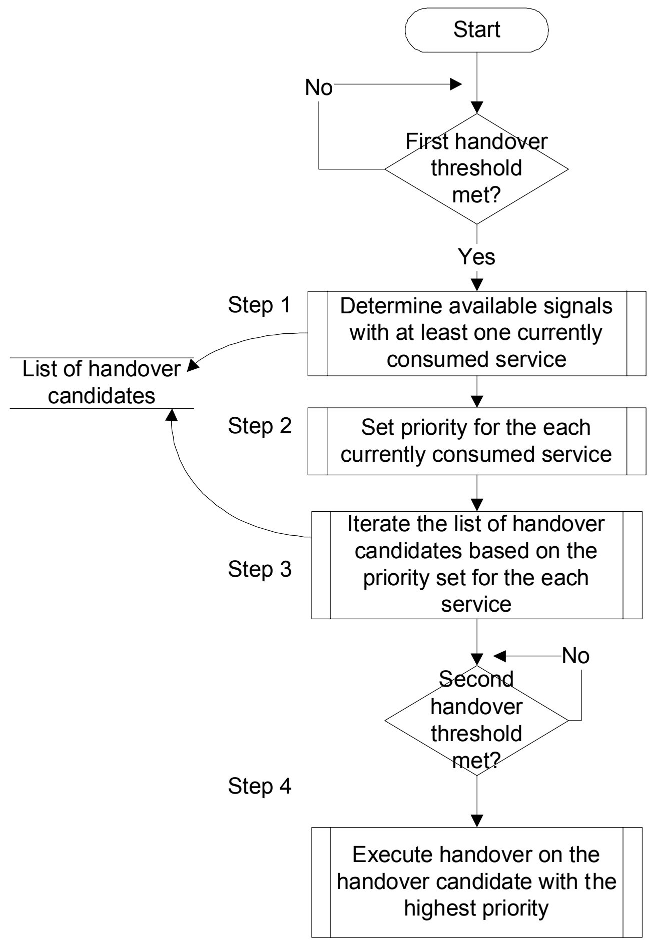

Figure 4. An generalized example of the handover algorithm utilizing the service prioritization.

4 PROPOSED PRIORITIZATION METHOD

In order to enable selection of such handover candidates, which have varying selection of currently consumed services available, receiver needs to prioritize each currently consumed service in such a way, that the best possible candidate can be selected. Based on the priority set for each service, the priority can be further calculated for the each candidate signal.

4.1 The Priority Determination Principle

The proposed prioritization method is based on the use of the *power of two, i.e.* 2^n, for determining the priority for each service. The value of n equals as zero for the service with the lowest priority. Respectively, the n determines directly the priority order of each service, i.e. the highest priority service has always the highest value for n. Finally, the priority of each candidate signal, i.e. HPCS, is the sum of the service priorities. The HPCS is calculated as follows,

$$HPCS = a^0 + a^1 + \ldots + a^{n-1} = \sum_{i=0}^{n-1} a^i \qquad (1)$$

where a equals two and n is the number of prioritized services.

4.2 Examples of the Priority Determination

Figure 5 depicts an example scenario, where terminal is moving out of the coverage area of signal C and needs to decide upon a handover, when there are two candidates, i.e., signal A and signal C. Terminal has prioritized four services, i.e. A, B, C and D, accordingly to Table 1.

Table 1. Terminal priority settings for the services A, B, C and D.

Service	Priority (n)
A	0
B	3
C	2
D	1

The signal A has three services available, which terminal is currently consuming or wants to have available within a new signal. The signal B, instead, has only two of such services available, but has better signal quality than the signal A. However, the signal quality within both signals is sufficient for the satisfactory service reception.

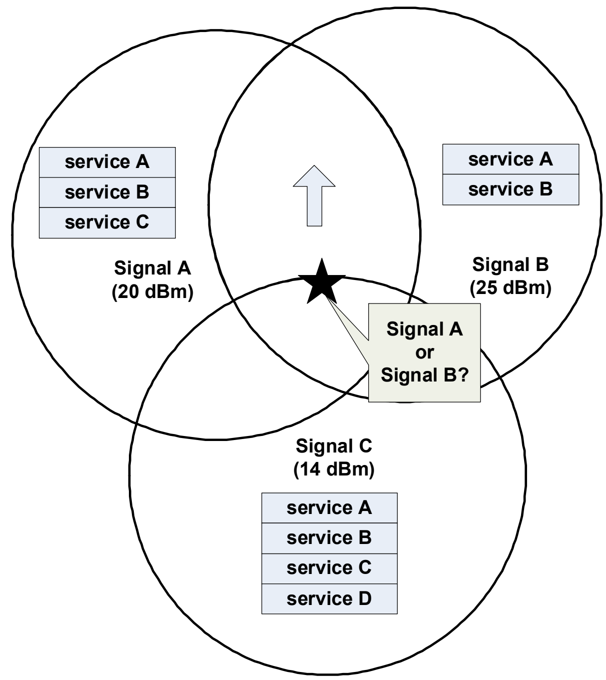

Figure 5. An example scenario of the handover situation where terminal needs to decide upon a two signals with sufficient signal quality and partially same set of services available.

The HPCS for the signals A and B, respectively $\boldsymbol{HPCS_A}$ and $\boldsymbol{HPCS_B}$ are calculated accordingly to (1) and are as follows,

$\boldsymbol{HPCS_A} = 2^0 + 2^3 + 2^2 = \underline{13}$

$\boldsymbol{HPCS_B} = 2^0 + 2^3 = \underline{9}$

Due to prioritizing, terminal would choose the signal A, even though the signal B would provide better signal quality. Figure 6 illustrates another example scenario, where situation is similar to that of depicted in Figure 5, except that signal B has all other services available except the service B, which has the highest priority. Signal A, instead, has only the service B available. The HPCS for the signals A and B are as follows,

$\boldsymbol{HPCS_A} = 2^3 = \underline{8}$

$\boldsymbol{HPCS_B} = 2^0 + 2^2 + 2^1 = \underline{7}$

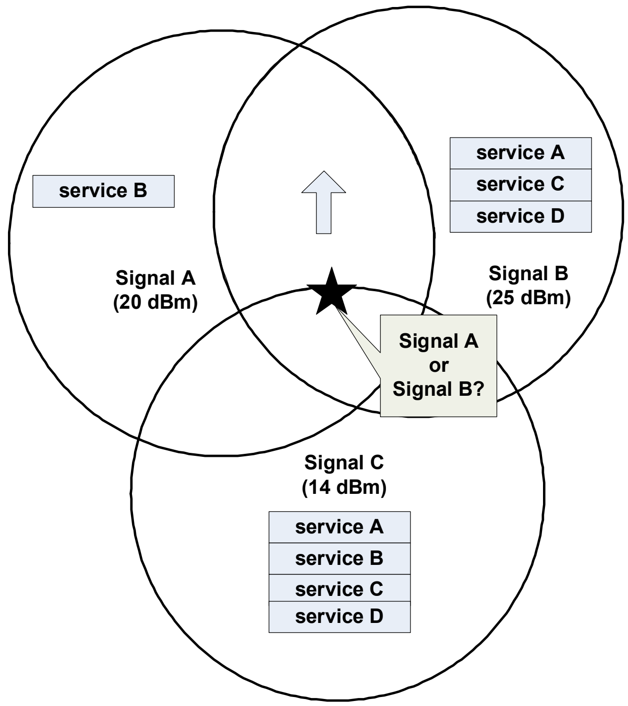

Figure 6. Another example scenario of the handover situation where terminal needs to decide upon a two signals with sufficient signal quality and partially same set of services available.

4.3 Analysis and Discussion

The proposed prioritizing method allows terminal to access into those handover candidates which do not have the best possible signal quality, but which have the highest priority determined by the available services. Hence the difference in signal quality between those handover candidates, which all have signal quality at sufficient level, becomes redundant.

Since the prioritization method is based on the allocation of *power of two* -sequences for the each set of prioritized services, the lowest value of such sequence is always 2^0 = 1. The highest priority value, in turn, is determined by the total number of prioritized services. The second example depicted in Figure 6, shows how the *power of two* -sequence, i.e. $2^0 + 2^1 + 2^2 + 2^3$, has been split into two candidate cells. Even though signal B had all other prioritized services, except the one with the highest priority, the HPCS remained lower than that of Signal A containing the highest priority service. The latter is due to characteristics of the *power of two* -sequence, where the highest *power of two* is always at least one greater than the sum of the lesser powers within the same sequence.

5 CONCLUSIONS

This paper presented a prioritization method for handover algorithm in DVB-H. Proposed method is based on the use of *power of two*-sequences, which are allocated for the sets of prioritized services. The proposed method guarantees the selection of such signal of all candidates, which offers the services with the highest priority possible. Furthermore, an example of the handover algorithm utilizing the proposed method was given. Practical implementation scenarios today could be for example cases, where terminal is recording another service while another service is being watched. Most importantly, the proposed method enables end user to influence on the service consumption, rather than selecting new signal, based on the signal quality.

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(ORIGINAL)
PUBLICATION P5

”Transmission Aspects and Service Discovery Strategy for Seamless Handover in DVB-H”

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PUBLICATION P6

“Optimization of PSI/SI Transmission in IPDC over DVB-H Networks”

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Optimization of PSI/SI Transmission in IPDC over DVB-H Networks

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Abstract
DVB-H and IPDC over DVB-H are the standards which enable mass distribution of services such as Mobile TV to handhelds. Technical and commercial field trials have already shown that a fully functional end-to-end system based on the two above-mentioned standards is a reality. However, as with all new systems, further optimization can be done in order to maximize performance. PSI/SI signaling is one of the key elements in the unidirectional service discovery of IPDC over DVB-H. This paper analyses PSI/SI signaling as defined in IPDC over DVB-H and proposes optimization of the implementation of PSI/SI transmission.

1.INTRODUCTION

The DVB-H (Digital Video Broadcasting – Handheld) standard [1] was provided by ETSI at the end of 2004. DVB-H, which was based on DVB-T (Digital Video Broadcasting for Terrestrial systems) [2], defines OSI layers 1 and 2 protocols. The IPDC (IP Datacast) over DVB-H standard [3] soon followed in 2005.

The IPDC over DVB-H standard comprises seven separate documents each focusing on specific protocols. The majority of the protocols in these specifications have already been defined in other standards, such as the Internet Engineering Task Force (IETF) standards. Therefore the main task of the [3] has been to adapt different protocols for IPDC over DVB-H. IP Datacast over DVB-H:PSI/SI [4] specifies the sub-set of Program Specific Information (PSI)/Service Information (SI) that has been defined in [5] and in [6]. Already during the specification phase of the IPDC over DVB standard, the technical and commercial trials took place in various locations around the world. The latter was giving guidance, for example, in the selection of the subset of PSI/SI, which was defined separately for the network and for the receiver in [4]. However, even though the trials gave valuable input for the standardization, there are still some aspects within PSI/SI that need further study. The robustness of PSI/SI is one such aspect.

This paper presents the results of a study that was done within Nokia, focusing on the robustness of PSI/SI signaling in the IPDC over DVB-H network. The study shows how poor robustness influences the receiver performance in service discovery and how it can be improved with different transmission methods of PSI/SI. The robustness of PSI/SI is analyzed with a selected error pattern, different repetition intervals and section sizes. The influence for network capacity consumed by the PSI/SI signaling and latency on the reception is analyzed. The paper is structured as follows: Section 2 gives an overview of the PSI/SI protocol. In Section 3 the network configurations and the basis of the analysis are described. The analysis of the default method is given in Section 4. Section 5 proposes an optimized solution for the PSI/SI transmission. A summary of results is given in Section 6 and the conclusions are presented in Section 7.

2.PROGRAM SPECIFIC INFORMATION (PSI)/SERVICE INFORMATION (SI)

PSI/SI information consists of tables which are carried within each Transport Stream (TS) of the DVB-H network. IPDC over DVB-H specific PSI/SI consists of the following tables: Network Information Table (NIT), Program Association Table (PAT), Program Map Table (PMT), IP/MAC Notification Table (INT) and Time and Date Table (TDT).

2.1. Principle

In [5], the PSI/SI table is defined as a high-level entity which consists of a collection of sub-tables identified with the same table_id. Each sub-table, in turn, may be composed of one or more sections with the same table_id_extension and version_number.

NIT is used to uniquely identify the network and to provide information of the multiplexes included in the network. It maps each multiplex, i.e., Transport Stream (TS) for the frequencies and other access parameters of the signals carried within one network. Examples of such access parameters are cell identification and cell coverage information. Furthermore, NIT provides linkage for locating the IP/MAC Notification Table (INT). Finally, a separate NIT table can be provided for each available network. NIT_actual is used for describing the current network and NIT_other can be used for describing all other existing available networks. NIT_other and NIT_actual can be mutually distinguished based on the different table_id. Respectively, a separation between two NIT_other sub-tables can be done based on the NIT network_id, which is a table_id_extension for a NIT sub-table.

PAT and PMT are used as a 'chain', where PAT maps each listed service_id with a PMT sub-table. Respectively, PMT sub-tables map each service_id with the PID value of the Elementary stream. Finally, each

Elementary stream may comprise one or more IP streams or INT tables. Figure 1 illustrates the mapping of the INT table through NIT, PAT and PMT.

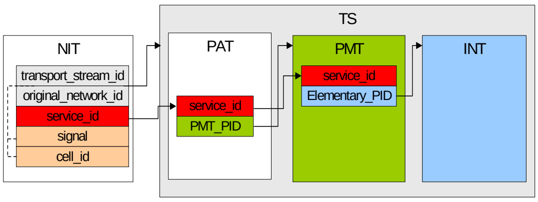

Figure 1. The mapping of INT table.

Each transport stream contains one IP/MAC Notification Table (INT) for each platform. Moreover, each INT provides the mapping for the location of the IP streams of the corresponding platform, for the current and adjacent cells (see Figure 2).

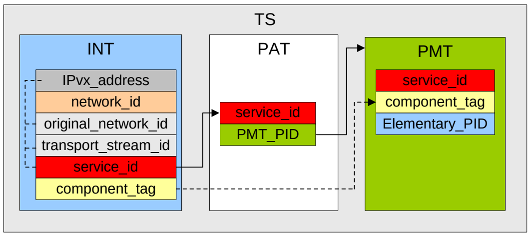

Figure 2. The mapping of IP streams.

As seen in Figure 2, the mapping between the IP streams and packet identifiers (PIDs) of the associated elementary streams is almost similar to that in the case of mapping the INT. The only difference between the mapping of INT and DVB-H service is the use of a component_tag. In the case where multiple PID values are announced within one PMT, a component_tag is used for distinguishing these from each other. Finally, TDT is needed for synchronizing the terminal with the network clock in transmitting IPDC over the DVB-H network.

2.2. Transmission

PSI/SI tables are transmitted periodically. These periods, i.e., repetition intervals, are table-specific. The maximum repetition interval, i.e., the maximum time from the beginning of the previous sub-table to the beginning of the next sub-table, is table-specific. However, the minimum repetition interval and the minimum and maximum time between sections of a sub-table have been clarified in [4] (see Figure 3).

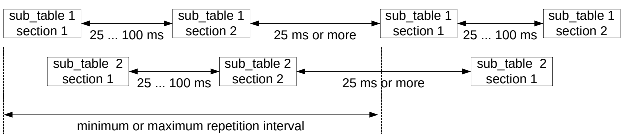

Figure 3. The minimum and maximum time between PSI/SI sections and sub-tables.

The PSI tables PAT and PMT do not have a mandatory maximum repetition interval. Only the recommendations have been given in [7] and in [4]. The normative maximum repetition intervals have been defined for NIT and TDT in [8] and for INT in [6]. Table 1 lists the minimum and maximum repetition intervals for different PSI/SI tables.

Table 1. PSI/SI table repetition intervals.

table	minimum	maximum	normative
NIT	25 ms	10 s	Yes
PAT	25 ms	100/500 ms	No
PMT	25 ms	100/500 ms	No
INT	25 ms	30 s	Yes
TDT	25 ms	30 s	Yes

The number of sections per transmitted sub-table depends on the used sections' sizes and the amount of signaled information. The maximum section size is 1024 Bytes for NIT, PAT and PMT. INT section size can be up to 4096 Bytes. For TDT, which comprises one section only, the section size is always 8 Bytes. PSI/SI sections are split into transport stream packets and hence the minimum network capacity reserved for one PSI/SI section is always calculated based on the size of one TS packet, i.e. 188 Bytes.

The robustness level of transmission is very important regarding PSI/SI, since unlike Multiprotocol Encapsulation (MPE), it does not have any Forward Error Correction (FEC) method, but only a Cyclic Redundancy Check (CRC). In addition, PSI/SI should have better robustness than MPE, since services cannot be accessed before access to PSI/SI. The time needed for accessing PSI/SI depends on the used repetition interval of different PSI/SI tables and the robustness of the transmission. Each erroneous section of a sub-table means that the receiver needs to wait for another transmission of that particular sub-table before it is able to perform full service discovery.

3. THE NETWORK CONFIGURATION AND CAPACITY CALCULATION OF PSI/SI SIGNALING

This document analyses PSI/SI transmission within the limits of current standard constraints and in the case when the robustness of transmission is optimized by adjusting section sizes and sub-table repetition intervals. Three different modulation schemes, one configuration scenario of IP services and one PSI/SI signaling scheme are used as a basis of the analysis. The required network capacity of PSI/SI is calculated for each modulation scheme based on the number of signaled IP services available within each scheme.

3.1 Network Configuration

Table 2 lists the parameters of the three modulation schemes Low cost, Typical and Max mobile.

Table 2. The parameters of the modulation schemes used as a basis of the analysis.

	Modulation scheme		
Parameter	Low cost	Typical	Max mobile
Transmission mode	8k	8k	8k
Constellation	QPSK	16QAM	16QAM
Code rate	1/2	1/2	2/3
Guard Interval	1/8	1/8	1/8
Bandwidth	8	8	8
Bitrate (Mbps)	**5.53**	**11.06**	**14.75**

The parameters in Table 2 are based on the configurations which have been used in IPDC over DVB-H trials and commercial networks [9] and in [10].
The IP service configuration scenario is based on the scenario where each service is composed of an IRD A class video stream and two other streams carrying audio and subtitles [11]. In addition, one stream is reserved for carrying files as best-effort, when network capacity is available from the fixed PSI/SI bitrate. Table 3 lists the IP streams and resulting TS level bitrate per IP stream within one service of such a scenario.

Table 3. The resulting bitrate per IP stream within one service.

IP stream type	Bitrate (kbps)
IRD A video	106
Audio	68
Subtitles	5
Filecast	0
∑	179

The used PSI/SI signaling scheme is based on the network components listed in Table 4. A network consists of 11 cells which provide different TS. The number of IP streams per service is as defined in Table 3 and all services are available through one platform. Finally, each INT advertises the services of six neighboring cells.

Table 4. The network components.

Network component	Amount
Platform	1
Cell	11
IP streams per service	4
Transport stream (TS)	11
Announced neighboring cells per TS	6

3.2 Network capacity calculation of PSI/SI signaling

Since the IP configuration scenario and the PSI/SI signaling is the same in all three modulation schemes, the network capacity consumption of PSI/SI signaling is determined by the number of signaled IP streams. The latter, in turn, is calculated based on the available service bitrate B_S, within each scheme.
The B_S is constrained by the bitrate consumed by the PSI/SI signaling and the bitrate reserved for MPE-FEC signaling. Since the network capacity for PSI/SI signaling cannot be accurately calculated before the number of signaled services is known, and vice versa, 1% of total capacity is reserved as a fixed bitrate for PSI/SI signaling. Since the latter is significant as regards the number of signaled services, it cannot be exceeded. The coefficient of 0.75 is used for reserving extra network capacity for the MPE-FEC coderate. Hence, the number of services S within the three modulation schemes is calculated as follows:

$$S = \left(\frac{B_{TS} - B_{FPSISI}}{B_S} \right) \times MPE\_FEC_{CE} \qquad (1)$$

where B_{TS} is the total bitrate of TS, B_{FPSISI} is the fixed bitrate reserved for the PSI/SI and B_S stands for the bitrate of one service. Finally, MPE_FEC_{CE} is the coefficient for the bitrate reserved for MPE-FEC support.
Ultimately, the actual bitrate of PSI/SI is determined by the size and repetition interval of each sub-table. Hence, the total network capacity consumed by the PSI/SI sub-tables ${}_cPSI\_SI_{tot}$ is calculated as follows:

$${}_cPSI\_SI_{tot} = {}_cNIT + {}_cPAT + {}_cPMT + {}_cINT + {}_cTDT \qquad (2)$$

where ${}_CNIT$, ${}_CPAT$, ${}_CPMT$, ${}_CINT$ and ${}_CTDT$ equal network capacity consumed by NIT, PAT, PMT, INT and TDT sub-tables, and are calculated as follows:

$${}_cSUB = \frac{{}_{sTS}SEC \times {}_{sc}SUB}{{}_{ri}SUB} \qquad (3)$$

where ${}_{sTS}SEC$ equals the size of one PSI/SI section in the TS level and is calculated by

$${}_{sTS}SEC = Round\left(\frac{{}_{ss}SUB}{184} \right) \times 188 \qquad (4)$$

where ${}_{SS}SUB$ indicates the maximum section size of the sub-table and *Round (x)* rounds upwards to the next integer. Respectively, ${}_{SC}SUB$ indicates the number of sections per each sub-table. Finally, ${}_{ri}SUB$ is the repetition interval of the sub-table.
Table 5 lists S and ${}_cPSI\_SI_{tot}$ in all three given modulation schemes, when the maximum repetition intervals listed in Table 1 and maximum section sizes are used. The B_{FPSISI} is also given for each scheme as a reference.

Table 5. S, $_C$PSI_SI$_{TOT}$ and B$_{FPSISI}$ of the given modulation schemes, when maximum repetition intervals and section sizes are used.

	Low cost	Typical	Max mobile
S	22	45	61
${}_cPSI\_SI_{TOT}$ (kbps)	47.23	62.95	63.69
B_{FPSISI} (kbps)	55.3	110.6	147.5

4. THE ANALYSIS OF THE DEFAULT METHOD

The robustness is analyzed based on the success probability in the reception of sub-tables PSI_SI_{SP} in simulation where TS packets of the transmission are corrupted with an error pattern. The used error pattern is based on the averaged error rate of transport stream packets TS_{PERR}, which is assumed as 0.15. In theory, MPE-FEC is able to correct up to 25% of erroneous TS packets, if a typical MPE-FEC coderate of ¾ is used. On average 15% TS_{PERR} leads to a 5% MPE-FEC Frame Error Rate MF_{ER} reception, with typical high quality receiver implementation, when the mobile channel model (TU6) is used. [9] The MF_{ER} of 5% is the failure criteria set in MBRAI specification [12] leading to acceptable picture quality. Therefore an average TS_{PERR} target of 15% was selected.

It is assumed that the receiver implementation is 'intelligent', i.e., it is able to parse PSI/SI tables immediately after all sections of each sub-table have been received, even if these are received in reverse or random order. Since 100% PSI_SI_{SP} is not reasonable, the minimum PSI_SI_{SP} was set at 0.95. As well, other confidence levels could be used for the comparisons, with minor effect on the results. The PSI_SI_{SP} is calculated as follows:

First we get the probability of unbroken TS packets TS_{pok} by

$$TS_{pok} = 1 - TS_{PERR} \qquad (5)$$

The probability of N consecutive unbroken TS packets $SEC_{pok.}$ is calculated as follows:

$$SEC_{pok} = (TSpok)^{TS_{count}} \qquad (6)$$

where TS_{count} is the number of TS packets per one PSI/SI sub-table. Respectively, the probability for N consecutive TS packets SEC_{PERR} is calculated with the following

$$SEC_{PERR} = 1 - SEC_{pok} \qquad (7)$$

Finally, the PSI_SI_{SP} can be derived from the following

$$\frac{\left((n \ over \ k) \times a^{k} \times b^{(n-k)}\right)}{(a+b)^{n}} \qquad (8)$$

where $k = PSI\_SI_{SP}$, n is the number of trials, $a = SEC_{pok}$ and $b = SEC_{PERR..}$ Next, the PSI_SI_{SP} and receiver latency is calculated separately for each sub-table when the maximum section sizes and repetition intervals are used.

4.1 Network Information Table (NIT)

The NIT is identical within all three schemes, since it is unaffected by the number of signaled IP streams. The size of NIT sub-table $_{STS}NIT$ is 756 Bytes.

Figure 3 illustrates the PSI_SI_{SP} for NIT where the minimum 95% requirement is met after five transmissions. Hence, with the repetition interval of 10 s, the receiver latency in NIT reception equals 50 s. Finally, the c_NIT is calculated with (3) and equals 0.67kbps.

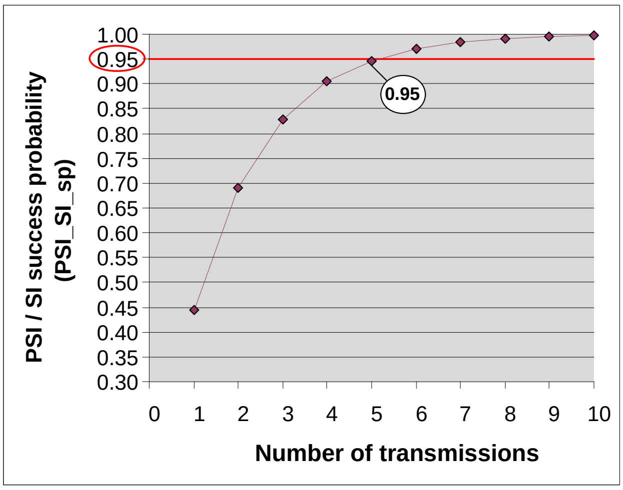

Figure 3. PSI_SI_{sp} of NIT.

4.2 Program Association Table (PAT)

As in the case of NIT, PAT is similar in all three schemes. PAT signals only one PMT and hence equals 16 Bytes in length, i.e., 188 Bytes since the minimum transmission unit is one TS packet. The results of PSI_SI_{SP} for PAT in Figure 4 show that the 95% target is met with two transmissions. Hence, with the repetition interval of 0.1 s, the receiver latency equals 0.2 s. Finally, the c_PAT equals 14.69 kbps.

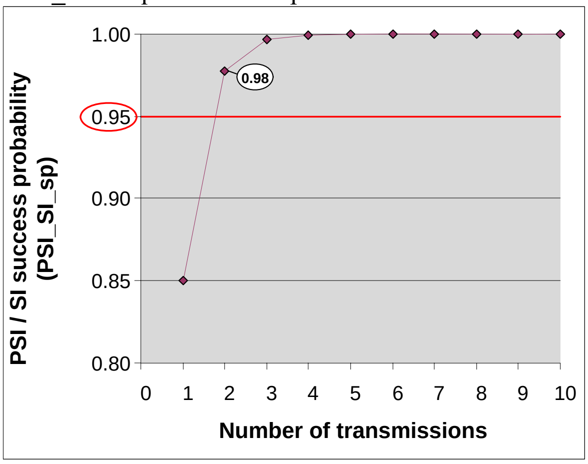

Figure 4. PSI_SI_sp of PAT.

4.3 Program Map Table (PMT)

PMT sub-table size varies within three modulation schemes due to the different number of signaled IP services and hence elementary streams. The sub-table sizes of PMT $_{STS}PMT$ and $_{C}PMT$ in different configurations are listed in Table 6.

Table 6. Sub-table sizes of PMT within different schemes.

Configuration	$_{STS}PMT$ (Bytes)	$_{C}PMT$ (kbps)
Low cost	210	29.38
Typical	394	44.06
Max mobile	522	44.06

The PSI_SI_{SP} for PMT is illustrated in Figure 5. In networks configured according to the Low cost configuration, the receiver may need to wait 3x $_{ri}PMT = 3x0.1s = 0.3$ s before it is able to receive the sub-table correctly. In the networks configured according to the Typical and Max mobile configurations, the waiting time is in the worst case 4x $_{ri}PMT = 4x0.1s = 0.4$ s.

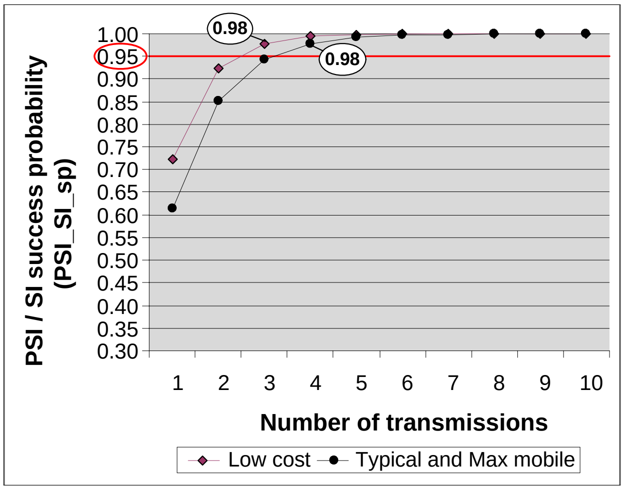

Figure 5. PSI_SI_sp of PMT.

4.4 IP/MAC Notification Table (INT)

The sub-table size of INT varies between three schemes due to the different number of allocated services per scheme. The sub-table sizes and number of sections for INT in Low cost, Typical and Max mobile configurations are listed in Table 7.

Table 7. The sub-table sizes and $_{C}$INT in different schemes.

Configuration	Sub-table size	$_{C}INT$
Low cost	3689	0.96
Typical	7683	2.00
Max mobile	10515	2.74

The PSI_SI_{SP} for INT is illustrated in Figure 6. As the results show, the PSI_SI_{SP} = 0.95 in the case of INT needs many times more transmissions than in the case with other sub-tables. The minimum number of transmissions *mnt* for the PSI_SI_sp =0.95 within each configuration can be derived from (8). In the networks configured according to the Low cost configuration, the *mnt* equals 111, i.e. the receiver needs to wait 111x $_{ri}INT = 111x30s = 3330$ s before it is able to receive the sub-table correctly. In the networks configured according to the Typical configuration, the *mnt* is 153 and requires $153x\ _{ri}INT = 153x30s = 4590s$ waiting time before INT can be received. Finally, in the Max mobile configuration where the *mnt = 170*, the receiver may need to wait in the worst case $170x\ _{ri}INT = 170x30s = 5100s$.

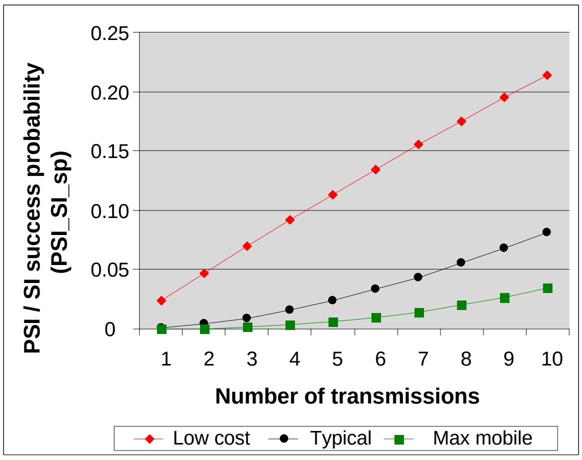

Figure 6. PSI_SI_sp of INT.

4.5 Time and Date Table (TDT)

Similarly as PAT, the TDT is under 188 Bytes long and hence the target PSI_SI_{SP} is met after two transmissions and $_{C}TDT = 0.05$ *kbps*. The receiver latency in the case of receiving TDT equals $2x_{ri}TDT = 2x30s = 60s$.

5. OPTIMIZED SOLUTION

Two methods were used to investigate the transmission robustness optimization possibilities. Both had the same goal, i.e., the receiver should receive all PSI/SI tables correctly with a PSI_SI_{SP} of 95%, within the time-frame constrained by the maximum repetition intervals that were used within the default transmission in Section 4.
The first optimization method is called "Simple optimization", in which only repetition intervals are changed to meet the goal. The "Advanced Optimization" is the second method, in which repetition intervals and section sizes are changed. Finally, the results in Section 4 showed that in the cases of PAT and PMT, there is no need to optimize transmission, since in both cases the sub-tables can be received in less than 500 ms with the PSI_SI_{SP} of 95%. Also, TDT is left out of the advanced optimization, since the section size of TDT cannot be decreased.

5.1 Simple Optimization

The simple optimization determines the optimized repetition interval of each sub-table $_{ori}SUB$ that is needed in order to achieve PSI_SI_{SP} of 95%. The $_{ori}SUB$ can be calculated by means of *mnt* as follows:

$$_{ori}SUB = \frac{_{ri}SUB}{mnt} \tag{9}$$

where the $_{ri}SUB$ stands for the repetition interval of the sub-table. Furthermore, the required network capacity for each sub-table $_{c}SUB$ is calculated as follows:

$$_{c}SUB = \frac{\left(\frac{_{sts}SUB}{_{ori}SUB}\right) \times 8}{1024} \tag{10}$$

where $_{sts}SUB$ equals the total size of sub-tables including TS overhead. Table 8 summarizes the $_{ori}SUB$ and $_{c}SUB$

calculated with (9) and (10) for the sub-tables in the case of the three modulation schemes. Also the input parameters derived from Section 4 are included within the summary.

Table 8. Summary of $_{ori}SUB$, $_{c}SUB$ and input parameters of NIT, INT and TDT.

	Sub-table	$_{sts}SUB$ (Bytes)	*mnt*	$_{ri}SUB$ (s)	$_{ori}SUB$ (s)	$_{c}SUB$ (kbps)
Low cost	NIT	940	5	10	2	3.67
	INT	3948	111	30	0.27	198.41
	TDT	188	2	30	15	1.47
Typical	NIT	940	5	10	2	3.67
	INT	7896	153	30	0.19	569.20
	TDT	188	2	30	15	1.47
Max mobile	NIT	940	5	10	2	3.67
	INT	10904	170	30	0.17	871.46
	TDT	188	2	30	15	1.47

5.2 Advanced Optimization

As the simple optimization solved the robustness problem by decreasing the repetition intervals, the resulting increase of the network capacity needed for the PSI/SI signaling may not be acceptable.

Advanced optimization aims to find an optimized setting which improves robustness and maintains the network capacity consumed by the PSI/SI signaling on a reasonable level. The goal is to find a combination of section sizes and repetition intervals which result in robust transmission whilst the network capacity consumed by the PSI/SI signaling is maintained at a reasonable level.

In the following the $_{ori}SUB$ and the optimal section size of sub-table $_{oss}SUB$ are sought for each sub-table.

5.2.1 Network Information Table (NIT)

It is assumed that each NIT section carries information of at least one transport stream, and hence the minimum section size for the NIT sub-table with the given configuration is 96 Bytes. The minimum network capacity per section is calculated based on the payload of the TS packet, i.e. 184 Bytes.

Figure 7 illustrates the PSI_SI_{SP} of the NIT in the case of different section sizes. The graph shows that the *mnt* for NIT varies from three to five.

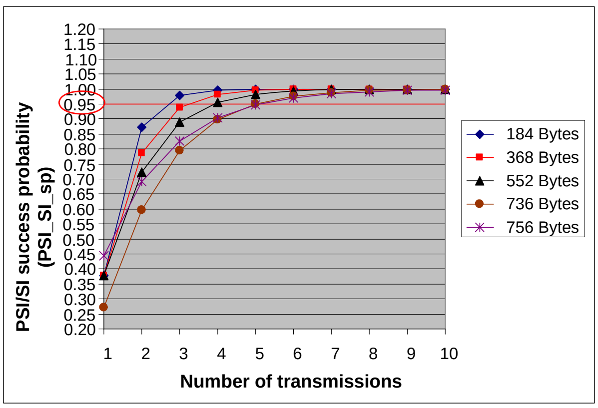

Figure 7. PSI_SI_{sp} of NIT sub-table in the case of different section sizes.

The $_{c}NIT$ in the case of different section sizes can be calculated with (9) and (10) (see Figure 8).

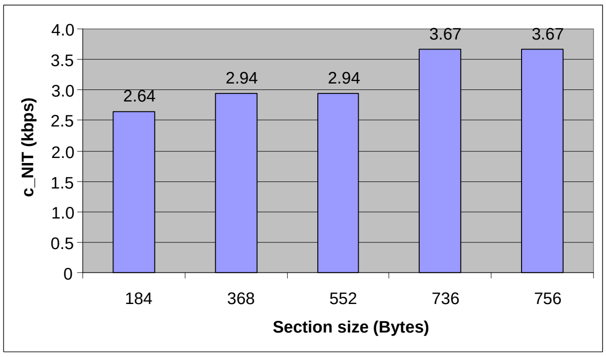

Figure 8. $_{c}$NIT in the case of different section sizes.

The results in the above figure reveal that 184 Bytes is the most optimal section size for the transmission of NIT.

5.2.2 IP/MAC Notification Table

The minimum size for one INT section is 203 Bytes, in the case where only one IP service is carried within each INT section. The maximum section size used in the calculations is the standard maximum 4096 Bytes. Figure 9 illustrates the relation of needed transmissions and PSI_SI_sp as a function of section sizes. Each set of curves presents the number of transmissions and PSI_SI_{sp} for Low cost, Typical and Max mobile configurations, when read from the left.

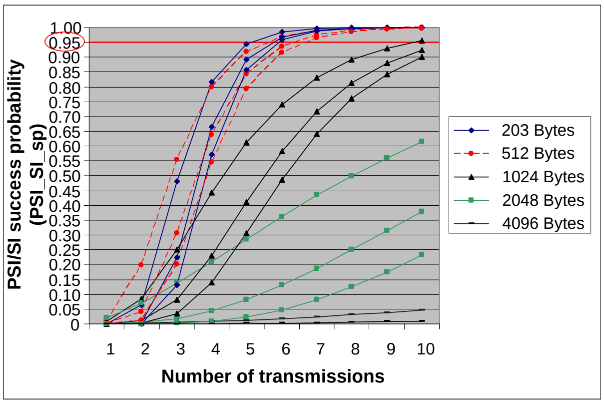

Figure 9. PSI_SI_{sp} of INT sub-table in the case of different section sizes.

The results in Figure 9 show that with the section sizes of 203 and 512 the number of transmissions is under 10, until the PSI_SI_sp of 95% is met. For the larger section sizes the number of needed transmissions is beyond 10 and hence results in excessive share of network capacity.

The resulting network capacity consumed by the NIT sub-table in the case of different section sizes is illustrated in Figure 10, where the section size of 512 Bytes is the most feasible from the network capacity point of view.

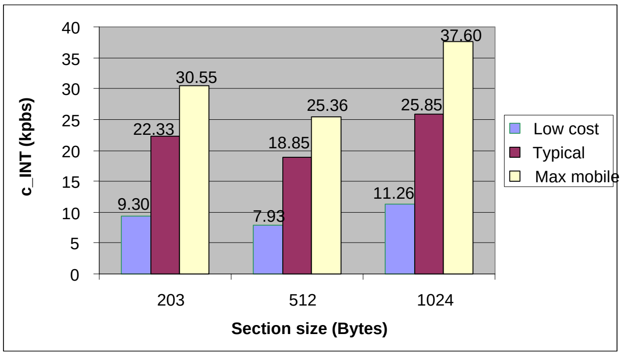

Figure 10. c_INT in the case of different section sizes.

6. SUMMARY OF RESULTS

The results showed that the latency in the default transmission was unacceptably high for some of the sub-tables, such as INT. As well, even though the simple optimization succeeded in decreasing the latency to the minimum, the network capacity required for PSI/SI signaling was too high, exceeding many times the 1% B_{FPSISI}. The advanced optimization provided the best trade-off between receiver latency and PSI/SI network capacity consumption. Finally, the PAT and PMT did not need any optimization due to the initially low repetition intervals which allow multiple re-receptions until the maximum repetition intervals are exceeded. Hence, the concluded *'Optimized transmission method'* is a combination of *'Default transmission'*, *'Simple optimization'* and *'Advanced optimization'*. Table 9 lists the composition of the *'Optimized transmission method'*.

Table 9. The composition of the 'optimized transmission' method.

	NIT	PAT	PMT	INT	TDT
Default transmission		X	X		
Simple optimization					X
Advanced optimization	X			X	

Next, the comparison of total network capacity consumed by the PSI/SI signaling $_{C}PSI/SI_{TOT}$ and total receiver latency according to the 'Default transmission' and 'Optimized transmission' is illustrated separately in Figure 11 and Figure 12. The total receiver latency is the total time consumed when each PSI/SI sub-table is received at least once. Also the fixed bitrate reserved for the PSI/SI signaling is also included in the comparison. As can be seen from the results, the total receiver latency can be decreased significantly with the optimized transmission. Moreover, the total increase in network capacity of PSI/SI in the optimized transmission is negligible. Finally, the 1% limit in the reserved PSI/SI network capacity is not exceeded in any configuration.

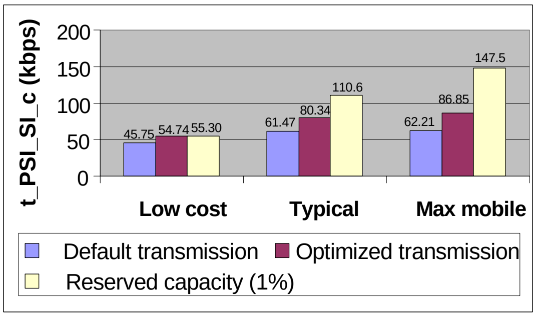

Figure 11. The $_{C}$PSI/SI$_{TOT}$ in default and optimized transmission.

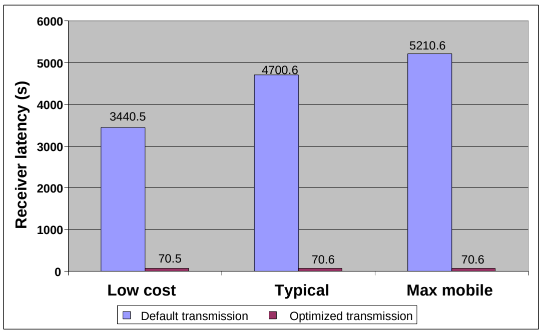

Figure 12. The total receiver latency in default and optimized transmission.

7. CONCLUSIONS

This paper provided an analysis of the robustness of PSI/SI transmission in the IPDC over DVB-H network when extremely poor reception conditions prevail. An error pattern based on [9] was selected and the robustness of PSI/SI transmission was analyzed from the receiver perspective, when the success probability of PSI/SI reception was set to 95%. Three modulation schemes and one PSI/SI configuration was used as a basis of the analyzed transmission. The total receiver latency was used as a measure of the robustness level of transmission. The results showed that if PSI/SI transmission is implemented according to maximum standard section sizes and repetition intervals, the resulting latency is beyond acceptable and the service discovery within IPDC over DVB-H is not optimal. As a solution to the problem, two optimization methods were proposed by which the optimized implementation was discovered. The optimized transmission setting was a combination of all three methods: default, simple optimization and advanced optimization.

The present study revealed several issues. First, due to the flexibility of IPDC over DVB-H standard, robust transmission of PSI/SI is possible even in the worst case scenario and there is not need for additional forward error correction mechanisms within the transmission of PSI/SI. It also showed that by changing section size, vast improvements can be done for the robustness and hence receiver latency. In addition, network capacity consumption of PSI/SI signaling is negligible. Finally, guidelines are needed for the transmission setting of PSI/SI in IPDC over DVB-H to maximize the robustness of PSI/SI transmission, even when the worst possible reception conditions prevail.

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(ORIGINAL)
PUBLICATION P7

“Simulations of PSI/SI Transmission in DVB-H Systems”

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Simulations of PSI/SI Transmission in DVB-H Systems

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Abstract

The robustness of the transmission of application data in DVB-H systems has been investigated in several papers. However, the transmission of Program Specific Information/Service Information (PSI/SI) necessary for the service discovery within DVB-H is not that well examined. While the data carried inside MPE and MPE-FEC sections is protected at the link layer by MPE-FEC, the PSI/SI is not and its transmission relies solely on periodic retransmission. There is a question whether the transmission of the PSI/SI is practical in mobile environment as it is done presently. In this paper results of computer simulations on PSI/SI transmission in a mobile multipath channel are illustrated together with analysis of the results.

Keywords
Mobile TV, DVB-H, IP datacasting, signaling, PSI/SI

1. INTRODUCTION

DVB-H (Digital Video Broadcasting for Handheld terminals) is a data broadcasting standard [1] that enables delivery of various Internet Protocol (IP) based services to mobile receivers. The DVB-H standard, which is based on and is compatible with DVB-T (Digital Video Broadcasting - Terrestrial) [2], introduces solutions to the problems caused by the mobility of the handheld terminals receiving digital broadcast. A good overview of DVB-H systems can be found in [3].

PSI/SI (Program Specific Information/Service Information) [4][5][6] is an essential part of service discovery in DVB-H systems. The PSI/SI access time has a direct effect on the total latency in service access. From the end user point of view, the fast service access time is preferred and hence the PSI/SI access time should be minimized. In DVB-H the PSI/SI information is carried in MPEG-2 private table structures [4]. These structures are tables that are segmented into sections and carried inside transport stream (TS) packets. PSI/SI is transmitted with a certain retransmission interval to enable tapping into the network. The sections contain CRC (Cyclic Redundancy Check) information allowing the receiver to check the correctness of the received sections. If the receiver detects that some sections carrying one subtable during one transmission are in error it has to wait for the next transmission to receive the missing sections. Although the application data is protected at the link layer by the MPE-FEC to combat the effects of mobility, the transmission of the PSI/SI information is left uncoded. Therefore a question arises, whether the transmission of the PSI/SI information in its present form is robust enough for mobile receivers. The issue of robustness is briefly touched upon in [7] and further studied in [8], but needs still further research.

In this document, simulation results of PSI/SI transmission using three different decoding methods with mobile multipath channel model TU6 [9] are presented. First the simulated network configurations are discussed. Then, in section 2.1, the performance comparison of the decoding methods is done with uniform error distribution. The simulation results in TU6 channel model are presented in section 2.2. Here the effects of repetition interval and section sizes for different configurations are presented. Further, also network capacity issues considered in [8] are analyzed in mobile channel in section 3. Section 4 presents the results of simulations on field measurements. Finally, in section 5 concluding remarks are given.

2. SIMULATIONS

The simulations cover the transmission and reception of the PSI/SI. The physical channel model between the transmitter and receiver is commonly used TU6 [9] mobile multipath channel model. Three different network configurations were considered. These configurations are named “Low Cost” (LC), “Typical” (T) and “Maximum Mobile” (MM) and their network parameters are given in Table 1. These configurations are similar to the ones considered in [8] except for the different Guard Interval (1/4 instead of 1/8 of pure OFDM symbol duration).

Table 1: Simulated Configurations

Configuration	LC	T	MM
Mode	8k	8k	8k
Constellation	QPSK	16-QAM	16-QAM
Conv. Coderate	1/2	1/2	2/3
Guard Interval	1/4	1/4	1/4
Bandwidth	8 MHz	8 MHz	8 MHz

2.1 Decoding Methods

The simulator simulates three different decoding methods for the PSI/SI tables. The first one we call “intelligent” decoder. It is capable of keeping all correctly received sections in memory until all the sections are correctly received and the table can be reconstructed. The second decoder is “correct order” that requires the correct sections to be received in correct order. The third decoder is the least intelligent and called “all ok at once”. It requires that all sections of a table must be received correctly during one transmission for correct reception. The most important output of the simulations is the percentage of users that have received the table correctly with certain number of retransmissions (from now on this is called coverage). The performance difference of the decoders for a table of size 8192B (Byte) transmitted in 512B sections is illustrated in Figure 1 for TS PER (TS Packet Error Rate) 15% and uniform error distribution. It is seen that to obtain user coverage of for example 95%, eight transmissions are needed for “intelligent” decoder. For “correct order” decoder this number is 20 and for “all ok at once” it is rather large. It is easy to see and deduce that in any situation the intelligent decoder is the best of these three and its use is therefore recommendable. This is the reason why our main focus in the following sections is on the intelligent decoder, unless otherwise stated.

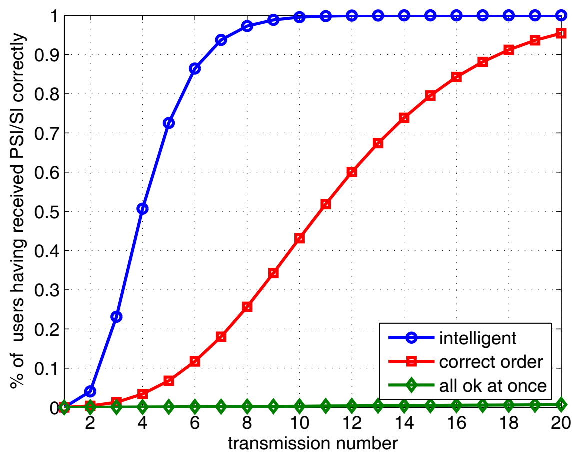

Figure 1: Performance of different decoding methods for PSI/SI in the receiver

2.2 Mobile channel simulations

The TU6 simulations were performed with recorded TS packet error traces that are receiver dependent. To obtain the error traces the transmitted signal has been generated, modulated and ran through a channel simulator with TU6 channel profile. Then the signal was received by a DVB-T receiver supporting mobile reception (8-tap channel estimation in time direction) and the transport error indicators (TEI) were collected. Transport error indicators directly inform us whether each TS packet was decoded correctly by the physical layer RS (Reed-Solomon) decoder or not, i.e. are there errors left in the packet. With TU6 error traces the effect of the motion of the receiver on the PSI/SI transmission can be studied. Traces were available for Doppler frequencies f_D = 2 Hz, 10 Hz, 30 Hz and 80 Hz and C/N values corresponding to TS PER from around 40 % to nearly error free transmission with 1 dB resolution. Simulated table and section sizes together with repetition intervals for all three network configurations and decoding schemes are given in Table 2. The simulation matrix is rather large to reveal the behaviour of the transmission in this environment. 10000 users were considered to be enough for each simulation.

Table 2: Simulated Parameters

Table B	Section lengths (B)	Rep. Intervals (s)
16384	64, 128, 256, 512, 1024, 2048, 4096	1, 5, 10, 15, 30
8192	64, 128, 256, 512, 1024, 2048, 4096	1, 5, 10, 15, 30
4096	64, 128, 256, 512, 1024, 2048, 4096	1, 5, 10, 15, 30
1024	64, 128, 256, 512, 1024	1, 5, 10, 15, 30
768	64, 128, 256, 512	1, 5, 10, 15, 30
512	64, 128, 256, 512	1, 5, 10, 15, 30
256	64, 128, 256	1, 5, 10, 15, 30
16	8, 16	.025, .05, .075, .1
8	8	.025, .05, .075, .1

2.2.1 The effect of repetition interval on C/N requirement

The repetition interval has only a slight effect on the C/N requirement to obtain certain reception coverage with different numbers of transmissions. The percentage of receivers receiving a table of size 8192B with 512B sections correctly with three transmissions is presented in Figure 2 for typical (T) configuration and Doppler frequency $f_D = 10$ Hz. It is evident that the curves differ very little from each other. This means that having the same channel conditions, the repetition interval has almost no effect on the reception coverage percentage. The network capacity required by the transmission and the time for the receiver to obtain the table, on the other hand, are directly affected by the repetition interval. Sending tables more frequently naturally increases the used network capacity and shortens the time receiver has to wait before acquiring all the sections correctly. More on this section 3.

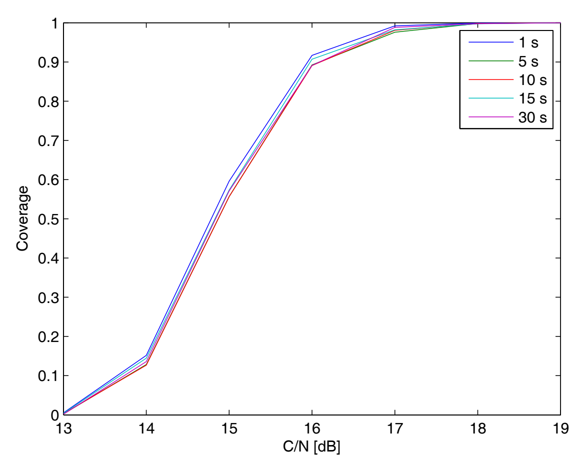

Figure 2: The effect of repetition interval for 8192B table transmitted with 512B sections (T)

2.2.2 The effect of section size

Let us begin by considering two Doppler frequencies $f_D = 10$ Hz and 80 Hz with typical (T) network configuration as an example. Consider that intelligent decoder is used and 95% user coverage is necessary. The curves for transmission of the table with sections of sizes 64B, 1024B and 4096B are shown in Figure 3.

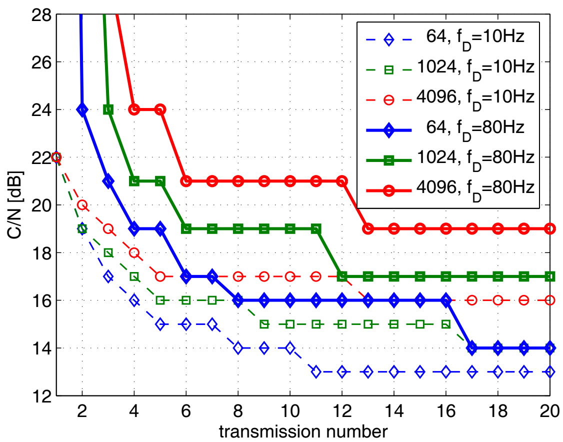

Figure 3: The effect of section length to obtain 95% coverage for 16384Bb table (T)

From Figure 3 it can be observed that using 64B sections instead of 4096B ones gives us approximately 2-3 dB gain in TU6 channel with $f_D = 10$ Hz in T network configuration. For $f_D = 80$ Hz the gain is even 4 dB. Similar order with different gains is observed also with other network configurations. The effect of total table size is not as remarkable as the effect of the section length, but naturally when transmitted with similar length sections a smaller table consisting of fewer sections can be received correctly more quickly.

Let us further investigate the effect of Doppler frequency on the transmission of PSI/SI as compared to the transmission of the data protected by MPE-FEC with 512 row frame and code rate 3/4. Comparison to the datapath is informative, since at least when the datapath is operating above some certain error criteria, the PSI/SI transmission should work as well to enable service discovery. For all PSI/SI results here the total table size used is 16384B and it is required to obtain the coverage using 6 transmissions with 5s repetition interval. This could be a realistic size for the largest table INT (IP/MAC Notification Table) used in the DVB-H systems being in the same time the most error prone. The maximum repetition interval for INT is 30s [10]. Let us decide that 95 % user coverage should be obtained during this time. So, if repetition interval of 5s is used, six transmissions should be enough to obtain the wanted coverage. If the network is planned according to the MFER=5% (MPE-FEC Frame Error Ratio) criteria, the curves lying above (at higher C/N values) the corresponding MFER curve cannot be considered viable.

For example, in Figure 4 for LC configuration correct order and all-ok decoders require higher C/N to obtain 95 % user coverage than is designed and only intelligent decoder is a working option in this example. This further justifies the fact that intelligent decoder is the best of the three decoding methods presented here. Yet again, the results are valid for the receiver used in the generation of the TS error traces. The performance of other receiver implementations at different Doppler frequencies can differ from the receiver used here, but most likely the general behavior is of the same kind. For T configuration the effect of section size is presented in Figure 5.

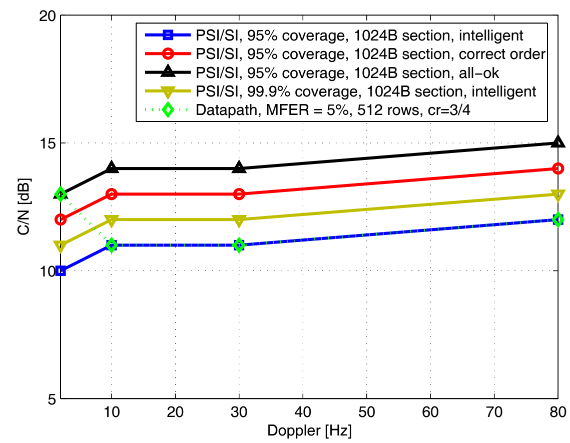

Figure 4: Comparison of decoding methods and required coverage percentage (LC)

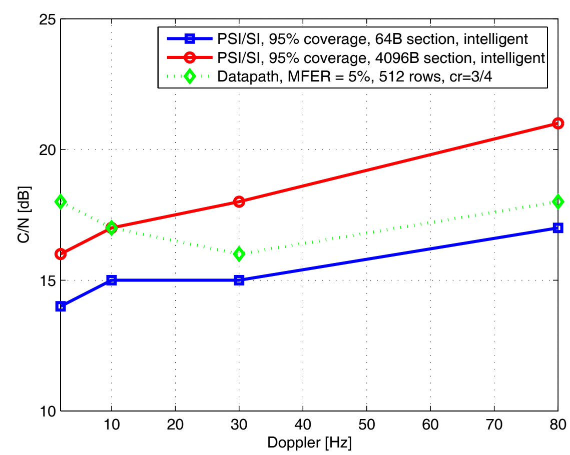

Figure 5: Comparison of different section sizes (T)

The gain of using the smallest sections instead of the largest ones is observed to be approximately 3 dB in T network configuration. The values for Doppler frequencies $f_D = 10$ Hz and 80 Hz can also be seen in Figure 3. With the 64 byte sections it can also be observed that obtaining the required coverage is possible with smaller C/N value than for obtaining MFER=5% in the datapath, so the PSI/SI transmission is more robust than the datapath in this case and it can be considered to be working. The curves for section sizes between 64B and 4096B lie between the curves for these section sizes. It must be noted that the exact shape of the Doppler curves could not be obtained, since error traces only for $f_D = 2$, 10, 30 and 80 Hz were available.

In reality using shorter sections with some subtables increases the total size of the subtable (this situation is considered in section 3). In these simulations hypothetic table and section sizes given in Table 2 were used meaning that the variation in section size doesn't introduce any changes in the total table size. This was done to obtain more general insight into the behavior of the PSI/SI transmission in mobile multipath channel. It is evident from the simulations that to obtain similar coverage for large tables with longest sections as with the shortest ones, several dB higher C/N is required. For the small tables (8B and 16B) there is no visible difference between the different section sizes. Of the four measured Doppler frequencies $f_D = 80$ Hz is the most challenging, i.e. highest C/N is required to obtain 95% coverage and respectively $f_D = 2$ Hz is the least demanding.

3. NETWORK CAPACITY CONSIDERATIONS

If the effect of varying section size on the total table size is taken into account (as is done in [8]), the shortest sections are not necessarily the best from the reserved network capacity point of view. The increase in total table size with decreasing section size is caused by the additional overhead induced by the increased number of sections. Let us consider here the T configuration. The necessary numbers of required transmissions to obtain the 95% coverage in T network configuration for the PSI/SI at the C/N where the MFER=5%, are shown in Table 3. For different section lengths the worst case of the Doppler frequencies needs to be considered (marked with bold face font in Table 3), i.e. the largest amount of transmissions is the limiting factor for each section size, since while planning the network worst case velocities of the receivers should be taken into account. For example, INT with 512B sections needs to be transmitted 5 times to obtain the required coverage.

The required network capacity for the transmission of the tables can be calculated if we assume that it is necessary to reach the coverage of 95 % of users within the maximal repetition intervals given in Table 4 (collected from the standards) at any Doppler frequency. The acronyms for the tables are: INT (IP/MAC Notification Table), NIT (Network Information Table), PAT (Program Association Table), PMT (Program Map Table) and TDT (Time and Date Table). These form the main PSI/SI necessary in DVB-H IP-datacasting [7]. Figure 6 presents the reserved network capacity as a function of the section length for INT and NIT. From the network capacity point of view, the optimal section length for INT is 512B and for NIT it is 756B.

Table 3: Necessary number of transmission to reach 95% coverage at C/N corresponding to MFER = 5% (T) for different section lengths

Table				
INT	f_D=2Hz	f_D=10Hz	f_D=30Hz	f_D=80Hz
203B	2	3	**5**	4
512B	2	3	**5**	4
1024B	2	3	**6**	4
2048B	2	4	**9**	6
4096B	2	4	**19**	10
NIT				
96B	1	2	**3**	2
128B	1	2	**3**	2
256B	1	2	**3**	2
512B	1	2	**3**	2
756B	1	2	**3**	2
PAT				
16B	**1**	**1**	**1**	**1**
PMT				
394B	1	**2**	**2**	**2**
TDT				
8B	**1**	**1**	**1**	**1**

Table 4: Repetition interval ranges [5],[7],[10]

Table	Min	Max
NIT	25 ms	10 s
PAT	25 ms	100 ms
PMT	25 ms	100 ms
INT	25 ms	30 s
TDT	25 ms	30 s

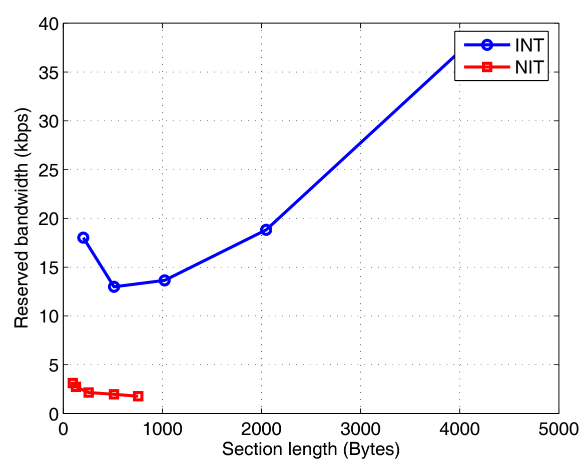

Figure 6: Network capacities reserved by INT and NIT

The overall network capacity reserved by the five tables using these optimal section sizes is calculated to be:

$$\frac{9971 \times 8}{(30s/5)} + \frac{756 \times 8}{(10s/3)} + \frac{394 \times 8}{(0.1s/2)} + \frac{16 \times 8}{0.1s} + \frac{8 \times 8}{30s} \approx 77.6 \text{ kbps},$$

that is less than 1 % of the total network capacity of 9.95 Mbps in T network configuration. Most of this network capacity is reserved by PMT that requires 61.6 kbps due to the short repetition interval. The total sizes for the tables using sections of these sizes are: INT 9971B, NIT 756B, PMT 394B, PAT 16B and TDT 8B.

4. SIMULATIONS BASED ON FIELD MEASUREMENTS

The field measurements were performed in the city of Turku on a non-hierarchical DVB-H signal with the center frequency 498 MHz in two-transmitter SFN (Single Frequency Network), with the transmitters located approximately 4 km from each other. Physical layer parameters measured were 16-QAM modulation with convolutional code rate 1/2 and the 8k OFDM mode. The guard interval of 1/4 of the OFDM symbol duration was used. In the measurements four use cases were considered: Pedestrian outdoor (3 km/h), Pedestrian indoor (3 km/h), Vehicular urban (30 km/h) and Motorway (100 km/h). The block diagram for the measurement setup is shown in Figure 7.

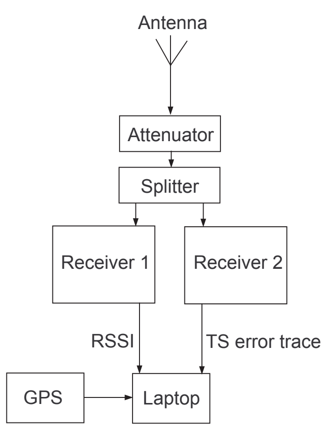

Figure 7: Measurement setup

In the pedestrian use cases the measurement system was carried in a backpack with the antenna outside the pack and in the vehicular measurements the antenna was located on the rooftop of the car. The indoor measurements were performed in a shopping center with a variation of open squares with glass roofs and narrow passageways. Measurements in both pedestrian use cases were performed close to the transmitter in the city center; the vehicular urban use case was measured between the two transmitters and the motorway use case in the coverage area of the further transmitter.

The results of simulations on PSI/SI transmission in the four usage scenarios are presented in Figure 8. The INT table of total size 7683B in T network configuration with 4096B sections was simulated. Attenuator was used to obtain such a signal level that errors do occur in the reception. During one measurement the attenuation was kept constant. The MFER values for the measurements used in the simulations are: Pedestrian indoor = 53%, Pedestrian outdoor = 10%, Vehicular urban = 5% and Motorway = 35%. Important notion of the figures is that even when the reception of the application data can be considered to be impossible, for example in the pedestrian indoor case with MFER=53%, 95% coverage for the PSI/SI can be reached already with 6 transmissions. It is clear that the distribution of TS errors is different in the use cases and, for example, in pedestrian indoor measurements there are error bursts of duration reaching up to several seconds and sometimes the reception can be perfectly clear resulting in quite good overall PSI/SI transmission. As a contradictory example, in the motorway measurements TS errors are rather evenly distributed and the performance of PSI/SI transmission is quite poor. The curves in the figure are not directly comparable to one another since there are fluctuations in signal strength, but it can be verified that PSI/SI transmission actually works in real mobile environment also.

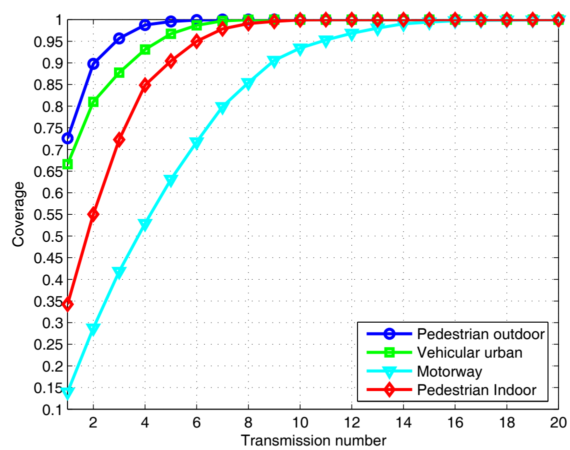

Figure 8: PSI/SI transmission in real environment

5. CONCLUSIONS

In this paper simulations on the performance of PSI/SI transmission in DVB-H systems in a mobile environment were presented. The effects of repetition interval, section size and decoding method on different channel conditions and network configurations were presented. Also, a comparison to the theoretical calculations presented in [8] was made on the side of network capacity usage optimization.

First of all, intelligent decoder should be used due to its superior performance over the other two decoding methods. Based on the simulation results it is also advisable to use as short sections in the transmission of PSI/SI as possible. If the transmission of PSI/SI is optimized with respect to the used network capacity and the impact of varying section size on the total subtable size is taken into account, the smallest section size is not necessarily the best option, but some optimal section size can be found. It seems according to the simulations with TU6 channel and field measurements that the PSI/SI transmission as it is organized presently is able to provide robust enough transmission presuming that some effort is put on the selection of the PSI/SI transmission parameters.

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(ORIGINAL)
PUBLICATION P8

"Laboratory Measurements and Verification of PSI/SI Transmission in DVB-H Systems"

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Laboratory Measurements and Verification of PSI/SI Transmission in DVB-H Systems

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Abstract

PSI/SI is the core part of service discovery within all DVB systems. The PSI/SI needs to be received by the receiver, before it is able to start to consume the services. In the fixed reception, the robustness of PSI/SI is not as important as it is in the handheld systems, such as in DVB-H. Some studies have been carried out to investigate the robustness of PSI/SI and especially the mechanisms to guarantee the robustness on the same level as it is within the data transmission. This paper completes the earlier studies on PSI/SI robustness, by providing the results of the laboratory measurements where the robustness of PSI/SI was investigated.

1. Introduction

The MobileTV [1] is a widely adopted concept in the telecommunication industry. Today, several standards have already been defined or are under development as enablers for the MobileTV. The DVB-H (Digital Video Broadcasting – Handheld) standard [2] [3] was one of the first standards that provided broadcast MobileTV services. The end-to-end DVB-H systems in the current commercial implementations are all based on [2] [3] and on the IPDC (IP Datacast) over DVB-H standard [4] and OMA-BCAST [5]. The majority of the current commercial implementations have adopted these three standards as follows; The DVB-H standard defines solely the OSI layer 1 and layer 2 protocols. In [6] the IPDC over DVB-H standard defines the DVB-H specific sub-set of Program Specific Information (PSI)/Service Information (SI) signaling [7] and some rules for the MPE encapsulation and MPE-FEC transmission. Finally, the OMA-BCAST standard defines the higher layer protocols from OSI layer 3 and above, relating to the ESG and higher layer transmission protocols.

The verification of the DVB-H standard was carried out immediately after the DVB-H standard was approved by the ETSI in 2004 and it has been documented in [8]. The verification process was seen important as it gave guidance to the network operators and for the terminal vendors in optimizing the implementation. However, the verification process was not complete, since the PSI/SI signaling, which is the core part of service discovery procedure in DVB-H system, was not covered. This drawback was brought up first time in [9], where a theoretical analysis of the robustness of PSI/SI transmission was provided. The studies on the same topic were continued in [10], where the PSI/SI was analyzed by means of simulations and wider selection of error patterns. Finally, in 2007, the work for the verification of the robustness of PSI/SI transmission was established in the Celtic B21C project [11] as one task force. This paper presents the results of the laboratory measurements, which were carried out on the B21C laboratory sessions and also on the internal laboratory sessions carried out by Nokia. The results are compared with the earlier theoretical calculations and simulations. The paper is organized as follows. The chapter two provides an overview of the PSI/SI transmission principle. In chapter three, the network configurations and receiver settings are defined. The chapter four presents the measurement results of the laboratory tests. In chapter five, the results of the past studies on PSI/SI and the results of the laboratory measurements are summarized and concluded. Finally the paper is concluded in chapter six.

2. PSI/SI

PSI/SI information consists of tables which are carried within each Transport Stream (TS) of the DVB-H network. IPDC over DVB-H specific PSI/SI consists of the following tables: Network Information Table (NIT), Program Association Table (PAT), Program Map Table (PMT), IP/MAC Notification Table (INT) and Time and Date Table (TDT).

2.1. Principle

The PSI/SI table is defined as a high-level entity which consists of a collection of sub-tables identified with the same table_id. Each sub-table, in turn, may be composed of one or more sections with the same table_id_extension and version_number. Finally, the sub-tables are composed of sections which are carried within the transport stream packets. The maximum size of the sub-table varies between 1024 and 4096 Bytes, depending on the table type.

2.2. Transmission

PSI/SI tables are transmitted periodically. The period between the transmissions of the same sub-table is determined by the repetition interval. The actual duration of a sub-table transmission depends on the offset between the two consecutive sections of a sub-table and on the number of sections. Figure 1 illustrates an example of the sub-table transmission, where sub-table composed of three sections is transmitted. The parameters depicted in the figure are defined as follows,

T_{trans} = The time consumed for the transmission of a sub-table.

T_{sto} = The sub-table offset is the time between the two consecutive transmissions of a same sub-table, calculated from the end of the last section of the previous transmission to the start of the first section of the next transmission. According to definition in [6], the sub-table offset shall be set to the value of 25 milliseconds or more.

T_{so} = The section offset is the time between two consecutive sections of a sub-table calculated from the end of the previous section to the start of the next section. As defined in [6], the section offset shall be always set to the value between 25-100 milliseconds.

T_{rep} = The repetition interval is the time between the two consecutive transmissions of a sub-table calculated from the start of the first section of the previous transmission of a sub-table to the start of the first section of the next transmission of a same sub-table.

The repetition interval between the two consecutive transmissions of a sub-table is table-specific. The PSI tables PAT and PMT do not have a mandatory maximum repetition interval. Only the recommendations have been given in [6] and in [12]. The normative maximum repetition intervals have been defined for NIT and TDT in [13] and for INT in [3].

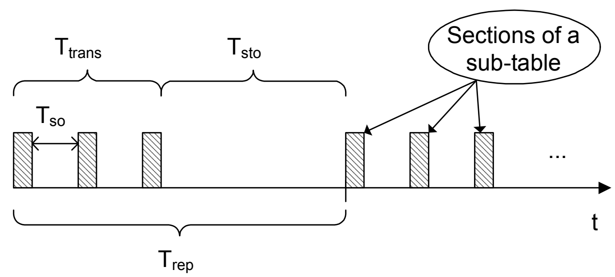

Figure 1. The minimum and maximum time between PSI/SI sections and sub-tables.

The robustness level of transmission is very important regarding PSI/SI. Multiprotocol Encapsulation (MPE) is the protocol, which is used to encapsulate the services within DVB-H, is protected by MPE-Forward Error Correction (MPE-FEC). However, PSI/SI does not have any Forward Error Correction (FEC) method in OSI layer 2, but only a Cyclic Redundancy Check (CRC) at section level. However, PSI/SI should have better robustness than MPE, since services cannot be accessed before access to PSI/SI. The time needed for accessing PSI/SI depends on the used repetition interval of different PSI/SI tables and the robustness of the transmission. Each erroneous section of a sub-table means that the receiver needs to wait for another transmission of that particular sub-table before it is able to perform full service discovery.

3. The laboratory measurement set-up and configuration description

The preconditions in the network configuration and in the receiver implementation are crucial when fair and consistent comparisons are desired. Hence, the settings for the network configurations and receiver implementations used in the laboratory tests are aligned with that of used and investigated in [9] and in [10]. An overview of the laboratory measurement set-up is described in section 3.1. The network configuration settings are described in section 3.2 and receiver configuration in section 3.3.

3.1. Overview of the laboratory set-up

The illustration of the end-to-end test set-up can be seen in Figure 2, followed with the description of the crucial elements.

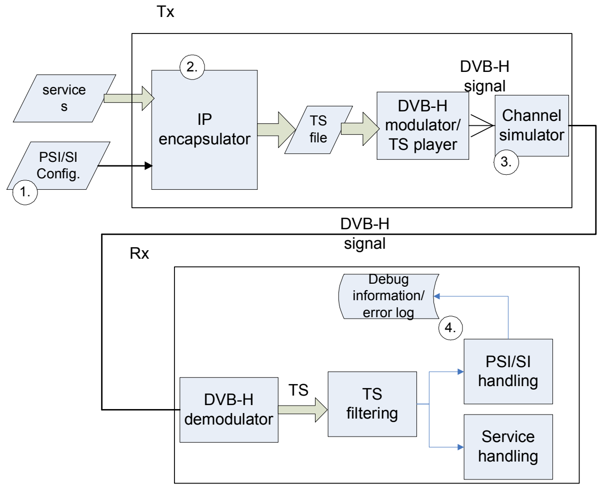

Figure 2. The end-to-end test set-up and all crucial elements.

1.) The PSI/SI configurations which were used within the test set-up, were based on the [9] and [10]. More detailed description of the used PSI/SI configuration is explained in section 3.2.

2.) The IP encapsulator was used to generate the transport stream (TS) which combines the services and PSI/SI data.

3.) The channel simulator was used to generate impairments into the radio channel, which in turn resulted as errors within the received transport stream. The used channel model was Typical Urban (TU6) with six paths, which has been defined in [14]. The used degradation criteria was 5% errors in the MPE-FEC frames (MFER5%). Figure 3 illustrates the DVB-H receiver behavior in the mobile reception conditions with Doppler. The measurements were done in the measurement points TP1 and TP3. The TP1 presents the minimum C/N requirement for the receiver in low Doppler conditions and TP3 presents the Doppler performance with C/N increased by 3 dB from the minimum value of TP1. Typically the TP3 is the practical maximum operating point of the receiver. The minimum receiver performance in terms of C/N and Doppler is specified within the MBRAI specifications. [15][16]. The receiver calibration is further explained in section 3.3.

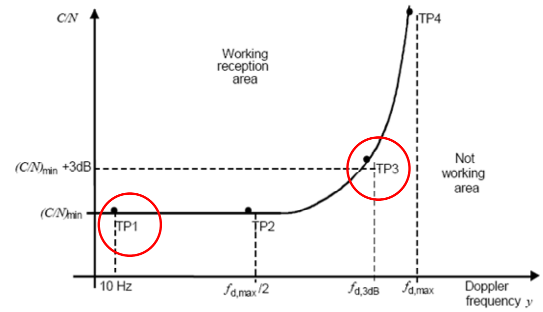

Figure 3. The mobile DVB-H receiver behavior and the the measurement points used within the tests.

4.) Receiver, which generated a log of the PSI/SI reception, each time when it was able to receive PSI/SI section. The time which was consumed to receive the complete sub-tables was stored.

3.2. The network configurations

In [9] the PSI/SI transmission was analyzed with the two different settings. First, the PSI/SI transmission was set to the standard maximum settings, where the largest possible section sizes and the longest possible repetition intervals were used. Next, the PSI/SI transmission settings were optimized, by configuring the most optimal combination of section size and repetition interval. In both cases, the goal was to maintain reasonable balance between the reception latency and network capacity consumption of PSI/SI transmission. It was discovered that both, the reduction of repetition interval and small section sizes improved the robustness of PSI/SI transmission. The findings were confirmed by the more extensive simulations in [10], were the impact of section size and repetition interval, especially in the case of INT table, was seen remarkable.

Hence, the network configuration settings for the laboratory measurements were based in [9] and in [10] and were focused only in the INT reception in case of the 'worst case'-scenario configuration, i.e., Maximum Mobile configuration. The two different settings used for the Max Mobile were Max Mobile Maximum Repetition (MMMR) and Max Mobile Optimized Transmission (MMOT). While the MMMR had the maximum repetition interval and maximum section size, the MMOT had the optimized setting for the repetition interval and section size, as discovered feasible in [9] and [10]. The maximum section size, repetition interval and the number of sections of the MMMR and MMOT configurations are listed in table 1.

Table 1. The section sizes and repetition intervals of the MMMR and MMOT configurations.

Parameter	Value	
	MMMR	MMOT
Repetition interval (s)	30	6
Maximum section size (Bytes)	4068	501
Number of sections	4	28

The section size of the all sections within the configurations was approximately equal with the respective maximum section size, except for the last section. The size of the last section within MMMR was 117 Bytes while within the MMOT it was 453 Bytes.

Next, the modulation parameters used in the configurations are described in Table 2 and the description of the network configuration is summarized in Table 3.

Table 2. The modulation parameters of the configurations.

Parameter	Value
CR	2/3
Constellation	16QAM
Transmission mode (FFT)	8k
GI	1/4
Bandwidth	8 MHz

Table 3. The description of the network configuration.

Parameter	Value
Number of transport streams and cells	11
Number of neighbouring cells	6
Number of services	45

3.3. The receiver calibration and configuration

Two different receivers, i.e. receiver A and B, were used in the laboratory measurements. For the both receivers C/N and Doppler performance was measured in the TP3 to meet the MFER5% criteria. In addition also the TP3 performance values, which were taken directly from the [16], were used with the receiver B. Table 4 lists the C/N and Doppler frequencies for the receivers A and B at TP3. The used RF input level was -50 dBm.

Table 4. The C/N and Doppler frequencies for the receivers A and B @ 50 dBm.

Receiver	TP3 Values	
	C/N	Doppler frequency (f_d)
A	21.50	147 Hz
B	17.80	110 Hz

The calibration point for the receiver B according to [16] were as follows; C/N =18.5 + 3 = 21.5 dB, f_d=95 Hz.

Three different receiver algorithms were tested in the measurements, based on the ability to parse complete PSI/SI sub-table from the set of partially corrupted sub-tables. The algorithms were named as *intelligent*, *semi-dummy* and *dummy*. The *intelligent* algorithm is able to parse sub-tables, regardless of the order of the received sections and regardless of the number of transmission from where it picks different sections. The *semi-dummy* algorithm is also able to pick different sections from different transmissions, but it is required, that the sections of the each particular sub-table are collected in consecutive order. Finally, the *dummy* algorithm insists that all sections are transmitted at once, within the same transmission.

The characteristics of the latter algorithms have been further clarified by means of the following description and Figure 4, which illustrates an example of transmission where one PSI/SI table is partially corrupted in three consecutive transmissions, while the fourth transmission is error-free.

The intelligent algorithm is able to receive the sub-table A after the second repetition, since the transmission order of the sections doesn't have any influence. The *semi-dummy* algorithm is able to collect all sections only after the third repetition, since only after then all sections can be received in correct order. Finally, the *dummy* algorithm needs to wait until all sections are transmitted within the same transmission, in correct order and are all error-free.

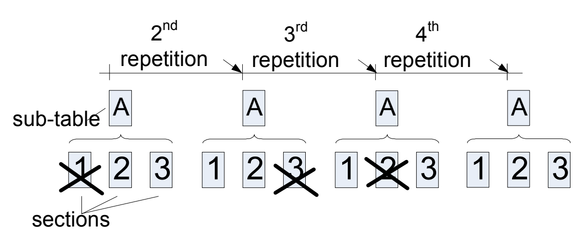

Figure 4. An example of the four consecutive transmissions of a PSI/SI table, where the first three transmissions have corrupted sections and the fourth is error-free.

4. The results of the laboratory measurements

The laboratory measurements were done by using TP3 point and several other measurement points, which were obtained by varying the required C/N and keeping the Doppler constant. In addition, also a few MBRAI2 measurement points were used as well for the MMOT configuration. For brevity and due to the fact that the overall measurement results were very similar in case of both receivers, only the measurement results of the receiver B are presented in this paper. Table 5 lists the MBRAI measurement points and C/N in case of receiver B where the reception of INT sub-table was inspected. The equivalent values to the Table 5 of the MBRAI2 measurement values are listed in Table 6.

Table 5. The measurement points and C/N of receiver B in MBRAI measurement points.

Measurement point	C/N
TP3 – 3 dB	14.80
TP3	17.80
TP3 + 3 dB	20.80
TP3 + 5 dB	22.80

Table 6. The measurement points and C/N of receiver B in MBRAI2 measurement points.

Measurement point	C/N
MBRAI2 – 3 dB	18.50
MBRAI2 – 6 dB	15.50

The measurement duration in each point was approximately 45 minutes. The reception duration of complete sub-tables was inspected in all four MBRAI measurement points with three algorithms in case of MMMR and MMOT configurations. In addition, two MBRAI2 measurement points were measured from the transmission based on MMOT configuration.

4.1. Max Mobile Maximum Repetition

Figure 5 illustrates the minimum, maximum and average reception durations in case of the transmission based on the MMMR configuration in the three MBRAI measurement points, when the intelligent receiver algorithm is used. The measurement results from the measurement point TP3 – 3 dB has intentionally left out from the figure, since no sub-tables could be received at this point. The dashed line within the Figure 5 indicates the maximum repetition interval of the INT table, which is targeted as satisfactory reception duration for the 95% of the transmitted INT sub-tables.

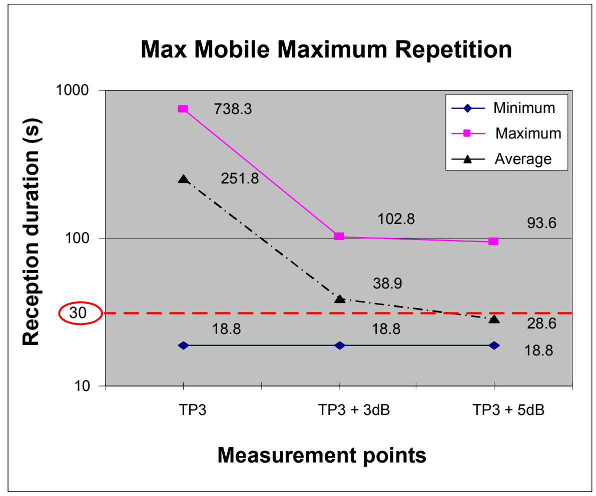

Figure 5. The minimum, maximum and average reception duration of the complete sub-tables in case of the transmission based on the MMMR configuration.

The curve of minimum reception duration in Figure 5 reveals that the receiver has been able to receive at least once a full INT table in all measurement points. On the contrary, it also reveals that the maximum reception duration is multiple times higher than the desired 30 second limit set by the maximum repetition interval. The average reception duration further hints, that only in the TP3 + 5dB measurement point the reception duration could be satisfactory, i.e. equal or less than 30 seconds. However, the further analysis of the measurement point TP3 + 5dB results revealed, that from the total of 194 received sub-tables, only 73.7% was received within or under 30 seconds.

4.2. Max Mobile Optimized Transmission

The MMOT configuration was tested against the MBRAI and MBRAI2 measurement points. First the results of the MBRAI test points are presented in section 4.2.1, followed with the results of the MBRAI2 measurement points in section 4.2.2.

4.2.1. MBRAI measurement points. The results in MMOT were radically different to that of in MMMR. The 95 % of the sub-tables were received within 30 second limit in almost all measurement points. Figure 6 illustrates the minimum, maximum and average curves of the reception duration in MMOT. Only measurement point where the 30 second limit was completely failed with all sub-tables was measurement point TP3-3 dB. Instead, within the measurement points TP3, TP3 + 3 dB and in TP3 + 5 dB, the average reception duration of the sub-tables was remarkable lower than the targeted 30 second limit. The percentage of sub-tables received within or under 30 seconds in the TP3 measurement point was 98.6 %. In the measurement points TP3 + 3 dB and TP3 + 5dB the 30 second limit was achieved with 100% of the sub-tables. Even the maximum reception duration within the TP3 + 5dB point was two times lower when compared to that of 30 second limit.

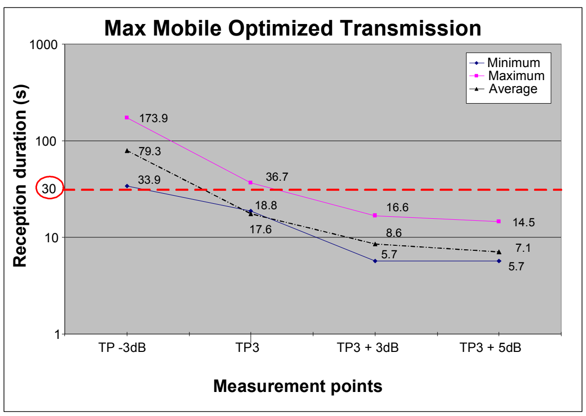

Figure 6. The minimum, maximum and average reception duration of the complete sub-tables in case of the transmission based on the MMOT configuration.

4.2.2. MBRAI2 measurement points. The results in the two MBRAI2 measurement points were mutually contrast. While the 30 second reception limit was by passed by 100% of the tables in the MBRAI2 -3 dB measurement point, in the MBRAI2-6 dB measurement point the amount of satisfactorily received sub-tables was only 16.5 %. The minimum, maximum and average reception durations of the MMOT in MBRAI2 measurement points can be seen in Figure 7.

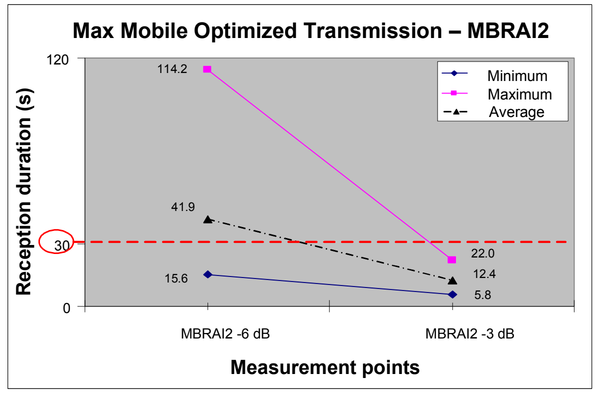

Figure 7. The minimum, maximum and average reception duration of the complete sub-tables in case of the transmission based on the MMOT configuration in MBRAI2 measurement points.

4.3. The impact of the receiver algorithm on the reception duration

The results indicated also that, in addition to the combination of section size and repetition interval, the implementation of receiver algorithm is essential, when the duration of sub-table reception is considered. Figure 8 depicts the reception durations, when dummy, semi-dummy and intelligent algorithms are used in the reception of MMOT in MBRAI2 – 3 dB.

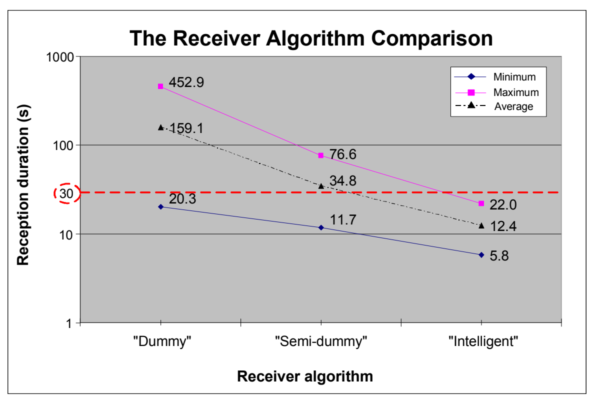

Figure 8. The minimum, maximum and average reception duration of the complete sub-tables with the three different receiver algorithms in case of the transmission based on the MMOT configuration and MBRAI2 – 3 dB measurement point.

The curves in Figure 8 indicate clearly that the reception duration is decreased, when more intelligence is added into the receiver algorithm.

4.4. The network capacity consumption within MMOT and MMMR

The difference in the network capacity consumption was negligible between the MMOT and MMMR configurations. The MMMR had four sections with the maximum section size of 4068 Bytes, which equals as the total network capacity of 3.2 kbps. The MMOT had 28 sections with the maximum section size of 501 Bytes, which equals as the total of 18.16 kbps. When the network capacity consumed by the MMOT and MMMR are compared mutually, the relative difference between the two may seem high. However, when the network capacity consumed by the MMOT is compared to the total network capacity, it is negligible with only 0.14 % of the total capacity. Also the network capacity consumption of the all PSI/SI was clearly under 1 % of the total network capacity.

5. The comparison of the results

The PSI/SI robustness has been studied before in [9] and in [10]. The main findings of the latter publications are summarized in sections 5.1 and 5.2. Finally, the summary and comparison between the earlier work and the results of the laboratory measurements is given in section 5.3.

5.1. The results based on the theoretical calculations

The theoretical calculations within [9] inspected the robustness of PSI/SI in the transmission based on TU6 mobile channel, which is used for determining the MFER 5% error criteria for the data transmission. The transmission of different configurations was compared against 95 % success probability for the receiver to receive all sections of the sub-table. The receiver algorithm was assumed as '*intelligent*'. The main findings were that the optimal section size for INT was 512 Bytes and the needed number of transmissions per sub-table to achieve the PSI/SI_{SP} of 95% was between 6 and 7. If the reception is assumed to be possible within the maximum repetition interval of 30 seconds, with the 7 repetitions the repetition interval would equal as 4.29 s. The network capacity consumption of the optimized PSI/SI transmission was below 1% of the total network capacity and hence considered negligible.

5.2. The results based on the simulations

In [10], the target was to verify the results achieved in [9] and to further investigate for example the impact of the section size for the robustness in PSI/SI. As in [9] the results were based on the theoretical calculations and probability analysis, now simulations were used instead. The findings turned out to be very similar to those of found in [9]. In the worst case scenario, the INT with section size of 512 Bytes would require 5 transmissions to meet the MFER5% error criteria. Hence, the optimal repetition interval was 6 s. Similarly as in [9], the network capacity consumed by the optimized PSI/SI transmission was found to be less than 1% of the total network capacity.

5.3. The summary and comparison of all results

The results discovered within the laboratory measurements were well in line with the previous work done in [9] and [10]. The most optimal section size discovered within the all three studies was ~ 512 Bytes. The repetition interval was slightly pessimistic within [9] with 4.29 seconds. However, the 6 second repetition interval was found satisfactory in [10] and that was also verified by the laboratory measurements. The network capacity consumed by the PSI/SI in the optimized configuration was below 1 % in all three studies. Finally, the laboratory measurements verified also that there is a significant difference between the three receiver algorithms. Almost in all configurations and reception conditions, the MFER5% criteria could be met only with the receiver supporting *intelligent* receiver algorithm.

6. Conclusions

The robustness of PSI/SI had been studied previously by theoretical calculations in [9] and by the simulations within [10]. The results achieved from these latter studies were indicating that the robustness of PSI/SI would not be satisfactory in all configurations, especially in those cases where the sub-tables are composed of one or more sections with the maximum section size of 4096 Bytes. The robustness was compared against the requirements defined for the data reception in [15]. This paper presented the results from the laboratory measurements which were carried out in conjunction of B21C Celtic project. The laboratory measurements were focused on the transmission of INT, which was found as the bottleneck in the previous studies. The results verified the findings made within the earlier studies. It was shown that the robustness of PSI/SI and especially that of in INT can be improved by using small section sizes and by reducing the repetition interval. The optimization in the repetition interval and section sizes has negligible effect on the total network capacity consumption. Finally, it was also discovered that the intelligent algorithm should be always used within the receivers in order to further improve the robustness and minimize the receiver latency.

Hence, it would be highly recommended for the network operators to consider using 512 Bytes as the maximum section size and not to use the maximum repetition intervals defined within the standard. In case of INT table, the 6 seconds should be the maximum repetition interval. Finally, the receiver vendors should always implement *intelligent* algorithms to maximize the robustness of PSI/SI reception and hence to minimize the receiver latency.

7. Acknowledgements

The authors of this paper would like to express their sincere gratitude to the B21C project and especially to the Project leader Mr. Gerard Faria for opening the opportunity to investigate the robustness of PSI/SI in wider scope.

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