TAMPEREEN TEKNILLINEN YLIOPISTO
TAMPERE UNIVERSITY OF TECHNOLOGY

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# SMARTPHONE UTILIZATION IN FREQUENCY CONVERTER APPLICATIONS

Master of Science Thesis

Examiner: Professor Hannu-Matti Järvinen
Examiner and topic approved by the Council of the Faculty of Computing and Electrical Engineering on 3 September 2014

# ABSTRACT

TAMPERE UNIVERSITY OF TECHNOLOGY
Master's Degree Programme in Information Technology
**MIKKO, KEMPPINEN**: Smartphone utilization in frequency converter applications
Master of Science Thesis, 48 pages
March 2015
Major: Embedded systems
Examiner: Professor Hannu-Matti Järvinen
Keywords: Smartphone, service business, frequency converter, wireless technologies, Android, User interface, Cloud services

Service business has gained popularity amongst enterprises as a new business model which is not affected by global market fluctuations. Competition drives the profits of the sold products to minimum and therefore reducing the corporation's profit. The existing installed base of devices is growing all the time and ageing at the same time. Companies have started to offer maintenance services to their customers, to improve the profit and the customer relationships. Better relations with a customer may eventually lead to a new deal of either new devices or maintenance deal or both. This thesis focuses on searching for new possibilities how to expand and improve the existing service portfolio offered for customers by ABB. The main focus being how smartphones could be utilized in different tasks performed with frequency converters.

What kind of applications can be and should be developed for smartphones? What kind hardware modifications are required for frequency converters? These aspects are examined from the business and technical points of view. Bluetooth is presented as a solution for the communication between a smartphone and a frequency converter. Bluetooth should be able to serve the planned applications data transfer requirements. Finally, an example solution is given how to develop an application for Android platform, where smartphone is used to read the fault codes of a frequency converter.

This thesis concludes that the presented Bluetooth based communication link can be used safely and reliably while fulfilling the data transfer requirements in electromagnetically noisy environments. The proposed Bluetooth adapter in a frequency converter enables the cheap implementation of a wireless connection, but for mass production, an in-house solution for the communication should be done. Growing smartphone markets and aging installed base gives the possibility to differentiate from competitors in a useful and profitable way. Further development of application areas should be started immediately and possibly with a potential customer to reduce the amount of misunderstandings, while making the maximal output potential from the application for both the customer and ABB.

# ABSTRACT (IN FINNISH)


TAMPEREEN TEKNILLINEN YLIOPISTO
Tietotekniikan koulutusohjelma
**MIKKO, KEMPPINEN**: Älypuhelimen hyödyntäminen taajuusmuuttajan sovelluksissa
Diplomityö, 48 sivua
Maaliskuu 2015
Pääaine: Sulautetut järjestelmät
Tarkastaja: Professori Hannu-Matti Järvinen
Avainsanat: Älypuhelin, huoltoliiketoiminta, taajuusmuuttaja, langattomat tekniikat, Android, käyttöliittymä, pilvipalvelut

Huoltoliiketoiminta on kasvattanut suosiotaan yritysten keskuudessa uutena suhdanneriippumattomana liiketoimintamallina. Koventuva kilpailu ajaa myytävistä tuotteista saatavat katteet pienemmäksi, ja siten pienentää yrityksen tekemää voittoa. Jo olemassa olevat laitteet ja niiden huoltaminen mahdollistavat asiakkuussuhteiden syventämisen, ja sitä kautta edesauttavat tulevien sopimusten solmimista omalle yritykselle edullisiksi. ABB:lla huoltoliiketoiminta on osa liiketoimintaa, joten tässä työssä etsitään uusia mahdollisuuksia, kuinka laajentaa asiakkaalle tarjottavaa huoltoliiketoimintasalkkua. Työssä keskitytään, siihen kuinka älypuhelinta voidaan hyödyntää osana taajuusmuuttajaa ja sen sovelluksia.

Tutkimuksessa esitetään liiketoiminnan ja tekniikan näkökulmista, minkälaisia sovelluksia olisi mahdollista ja kannattavaa toteuttaa älypuhelimelle, ja mitä laitteistomuutoksia vaaditaan taajuusmuuttajalta. Älypuhelimen ja taajuusmuuttajan väliselle kommunikoinnille esitetään Bluetooth-tekniikkaan perustuva ratkaisu. Yhteyden on kyettävä palvelemaan suunniteltujen käyttötapausten yhteysvaatimukset, koska taajuusmuuttajat toimivat yleensä prosesseissa, jotka vaativat ehdotonta eheyttä toiminnassaan. Lopuksi esitetään esimerkkitoteutus, siitä kuinka Android-alustalle voidaan toteuttaa sovellus, jossa älypuhelimella voidaan lukea vikakoodit taajuusmuuttajasta.

Työn tuloksena todetaan, että esitettyä Bluetooth-tekniikkaan perustuvaa kommunikaatioyhteyttä voidaan käyttää turvallisesti ja riittävän suurella tiedonsiirtonopeudella esitettyjen käyttötapauksien toteuttamiseen. Esitetty Bluetooth-adapteri taajuusmuuttajalle on mahdollista toteuttaa suhteellisen pienellä työmäärällä, että kustannuksilla taajuusmuuttajan ohjauskorttiin tai ohjauspaneeliin. Alati kasvavien matkapuhelinmarkkinoiden ja vanhentuvan laitekannan takia on kannattavaa differentoitua kilpailijoista ottamalla hyöty älypuhelimista ja niiden saamasta suosiosta maailmanlaajuisesti. Jatkokehitys uusista sovelluksista kannattaa aloittaa heti potentiaalisen asiakkaan kanssa, jotta kaikki mahdolliset toiminnallisuudet ja epäselvyydet tulee ratkaistua.

# PREFACE

This Master's Thesis was made at ABB in the Service R&D unit in Helsinki.

I would like to thank my supervisor professor Hannu-Matti Järvinen for his valuable feedback during the project. I appreciate the amount of work he did while teaching me how to write academic text. I would also like to thank my instructor M.Sc. Kalle Suomela for his patience during this thesis project which occurred to be way longer than it was thought to be, additionally I would like to thank my colleague Teemu Tanila for his feedback during the writing process.

Finally, I would like to present my gratitude towards my family and friends for believing in me during this project.

Mikko Kemppinen
Helsinki, March 2015

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## TERMS AND DEFINITIONS

| | |
|---|---|
| AC | Alternating Current |
| AP | Access Point |
| API | Application Programming Interface |
| DC | Direct Current |
| IDE | Integrated Development Environment |
| LTE | Long-term evolution networks |
| MCU | Microprocessor |
| OS | Operating System |
| PCB | Printed Circuit Board |
| SSL | Secure Socket Layer |
| UI | User Interface |
| UML | Unified Modeling Language |
| UX | User Experience |
| 3G | 3$^{rd}$ Generation networks |

# 1. INTRODUCTION

ABB is globally operating business in many industry segments, especially on the frequency converter markets ABB is one of the market leaders. Constant growth and increasing size of installed base leads to a more difficult customer field and how to preserve the old customers in the competitive market. Therefore ways how to better serve customers and the aging devices must be studied.

The role of industrial service business has grown in the developed countries due to the cheap manufacturing of products in non-developed countries. This leads to increased competition and decreased prices in the markets. Usually, companies tend to choose the cheapest possible option. Therefore companies with higher manufacturing costs automatically lose more money in the trade off. Companies have to start competing against the cheap products with something more. Industrial service business is at best the most profitable business for enterprise and it is not affected by economic fluctuations. By making long lasting agreements with customers, companies can keep their customers, and at the same time gain the profit.

ABB is selling hundreds of thousands of frequency converters to a variety of global customers, avoiding problems and misconceptions with such a large customer base is hard. Traditionally, ABB has to send an engineer to the job site to fix the problems, or send someone other from the supply chain. Both of these options are very expensive and time-consuming. In this thesis, a more sophisticated way to solve these problems is studied. Nowadays, almost everyone carries a smartphone. Combining smartphone capabilities with the frequency converter can possibly change many of the traditional ways of solving these problems. What then has to be studied for such a system to work between smartphones and frequency converters? The following objectives were identified, what at least has to be done for a proper proof of concept:

- The business point of view whether it is profitable or not to research applications for smartphones.
- The technological background behind smartphones and frequency converters: is it possible to create applications for co-operation.
- A bidirectional communication model for data exchange between a smartphone and a frequency converter has to be implemented.
- A communication model how to integrate cloud services as a part of the frequency converter applications has to be studied.

- An example design of mobile phone application for smartphone and frequency converter collaboration has to be designed.

All of these areas must be studied before a final answer can be given whether it is profitable or not to integrate smartphones as part of ABB's service portfolio. The outcome has to have potential profit incomes and it should be possible to implement it with reasonable amount of work meaning the used technologies must be mature enough to work flawlessly with frequency converters.

To cover all the aspects of this proof of concept the thesis is divided in the following areas: The business background is inspected in Chapter 2. This chapter gives the basic driving forces behind the connection of smartphones and industrial drive service in terms of value-added. Chapter 3 observes the characteristics of a smartphone with respect to the technical needs for applications. Chapter 4 is about frequency converters. The basic operating principle and structure are observed. The wireless communication interface possibilities of a frequency converter are also speculated. Chapter 5 describes the communication system between a frequency converter and a smartphone and inspects the possible applications where a smartphone could be utilized for a frequency converter. Chapter 6 presents example architecture and user interface design for an application based on the research done in the previous chapters. Chapter 7 concludes the thesis.

# 2. BACKGROUND

This chapter introduces the value-added motivation behind the study. The rapid growth of smartphone capabilities and industrial services provide an extensive new platform to create unique applications for adding more value to the business.

Last section introduces ABB's current service portfolio. As the objective of the thesis was to find application areas where a smartphone could be used, this section offers good insight what kind of applications could be done.

## 2.1 Mobile phone business

Mobile phone business has been rapidly growing through years. In 2011 total smartphone shipments reached 494.4 million units worldwide. The amount of shipped smartphones has doubled in the following years. This demonstrates strong end-user demand and vendor strategies to emphasize smartphones. The trend seems to continue strong over the year 2015 and increases the popularity of smartphones worldwide (IDC research). Figure 1 presents the actual amount (units in millions) of sold connected devices and gives the estimated amounts sold in the future. From Figure 1 can be seen that desktop computers are not gaining as much popularity as before the age of smartphones.

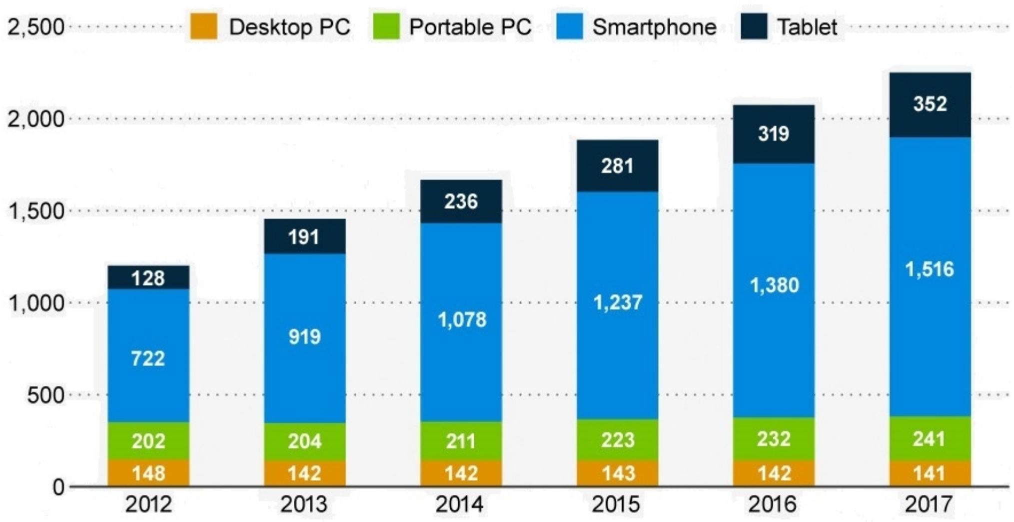



**Figure 1: Comparison of shipped connected devices worldwide (Adapted from IDC)**

In 2013, the whole industry shipped one billion units, which is 38.4% growth from the year 2012. From this amount, smartphones accounted 55.1% in total, making 41.7%

growth from the year 2012. This means that smartphones overrun the traditional phone business. (IDC research)

The huge growth of smartphones and the end-user demands drive manufacturers to create new unique and innovative smartphones and applications. One of the visible innovations is a display. The display size and resolution has grown from 1.5 inch displays to the biggest being around 7 inches. Another important factor is the low cost. Major amount of sold smartphones are in developing countries, and the price is set around 150$ per unit. (IDC research)

There are three operating systems, which almost control the whole market. Android dominates the market with nearly 85% of the market share in second quarter of 2014. Most of the Android market share comes from low-end models cheaper than 200$. This is expected since Android is free of license costs for the manufacturer, therefore it is the best choice for cheap smartphones. iOS, Windows Phone and the rest of the mobile operating systems share the remaining market share in a manner shown in Figure 2. (IDC research)

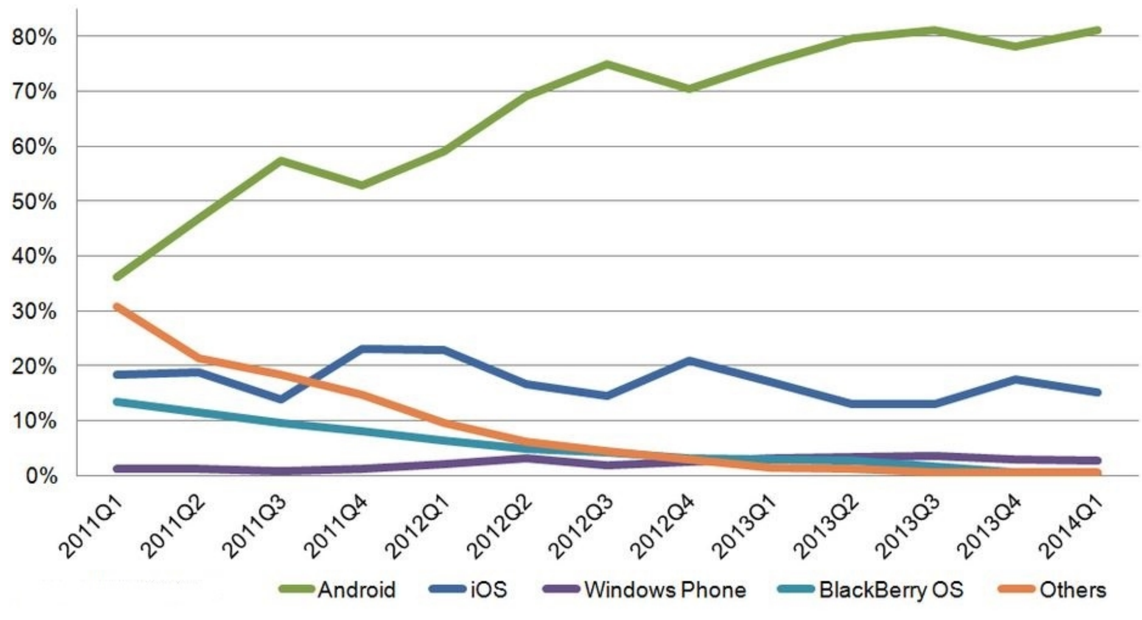



**Figure 2: Mobile operating systems market shares (IDC research)**

Both Apple and Microsoft (formerly Nokia) have their own challenges growing the market share, but they are still the two major players competing with Google's Android. The chart would look different if only high-end devices would be compared, since Apple has greater market share in high-end devices. Other platforms such as Samsung Tizen or Meego-based Jolla Sailfish OS are still minor operating systems and it is unlike that one of these would rise to the top three operating systems. The mobile ecosystem is built on various components. It has two main components: the infrastructural ones and the applications and services part. Infrastructural services, such as devices, platforms, networks, and cloud are essential in the forming of a functional mobile ecosystem. The applications and services part consists of an application store, social media, third party services and basic infrastructure services. Without having every component working, it is rather hard to build an ecosystem that would serve millions of people.

The main challenges the mobile phone industry is facing are related all the time to the rising data rates over the globe. The increasing demand for capacity that data intensive devices are driving consecutively put enormous traffic on the telecom networks. Not all the networks are designed to cope with such data amounts. This can be seen also as an advantage, because mobile operators must keep upgrading their network infrastructure consistently to remain in the competition. Other challenge coming with the enormous data transfers is the security of the data transfers and the contents' privacy. Security issues emerge and weak networks propose serious threats to users. Regarding enterprise applications and applications working with devices that require absolute reliability it should be considered well, which groups can access the application and what they can do with it.

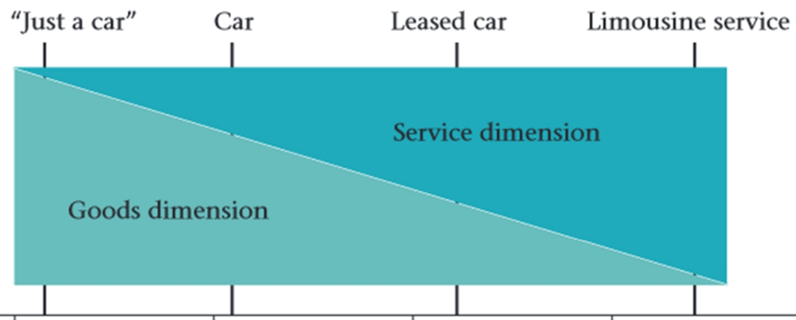
## 2.2 Industrial service business

In most traditional engineering and manufacturing companies service business has gained extensive support and is a fast-growing area. In the early stages of service business culture adoption, many companies failed to create successful service business with customers, due to proposed service models lacking the value creation for the customer and the cooperative supplier. (Grönroos, 2000)

Different economic and dynamic trends influence the business environment which leads to companies consolidate on a global scale. Customer requirements, deregulations, technological, and business innovations drive companies at the same time, therefore the total complexity of solutions what a company has to consider greatly increases. New products and service introductions are even more important and challenging, because the companies are heavily affected by other problems.

The engineering and manufacturing industry is facing challenges being the provider of customer value and product-related value-added services, no more the traditional product provider. The challenge of identifying customer critical processes is the most important part to succeed in the transition from traditional to a service provider. Many enterprises have failed in this transition, because some of the product-related services are only partly done. (Salminen et al, 2008)

The potential business growth lies in the making and capturing of these industrial services. The transition is named the framework of value transition. This framework contains everything from parts to the value provider. The main aspects where a company should point out are expressed in the framework of value transition. (Tushman et al, 1997)




| | | | | |
|---|---|---|---|---|
| **Physical** | Car | Car | (Car) | (Car) |
| **Service** | Delivery | Warranty<br>Service contract | Lease contract | Travel |

**Figure 3: Framework of value transition (Paloheimo et al, 2004)**

Figure 3 describes an approach how to understand the value framework. Value transition means that old products are changing in to complete solutions covering everything what a client could need, that is the product and all the related services to it. This creates a new basis for the new business, because customers have no capability to use these solutions without the solution provider. New co-operation models can then be created between the networked companies. (Salminen et al, 2008)

Products and service management of most businesses should be developed in open system architecture. Knowledge intensive and a value-critical approach over the product life cycle is the future of many business concepts. Value networks of companies are preparing to offer full-scale solutions. These full-scale implementations consist of service and product elements produced by various enterprises. A semantic structure of offering and further innovations needs to be developed. (Pallot et al, 2004)

### 2.2.1 Value creation

Value creation is the most important part for corporations since everything should be profitable. Creating profitable business segments increase the worth of the whole enterprise. Many companies focus on value creation both in creating better value for customers purchasing company's products and services, but as well for the shareholders who wants to see their stake appreciate in value. (Deloitte, 2006)

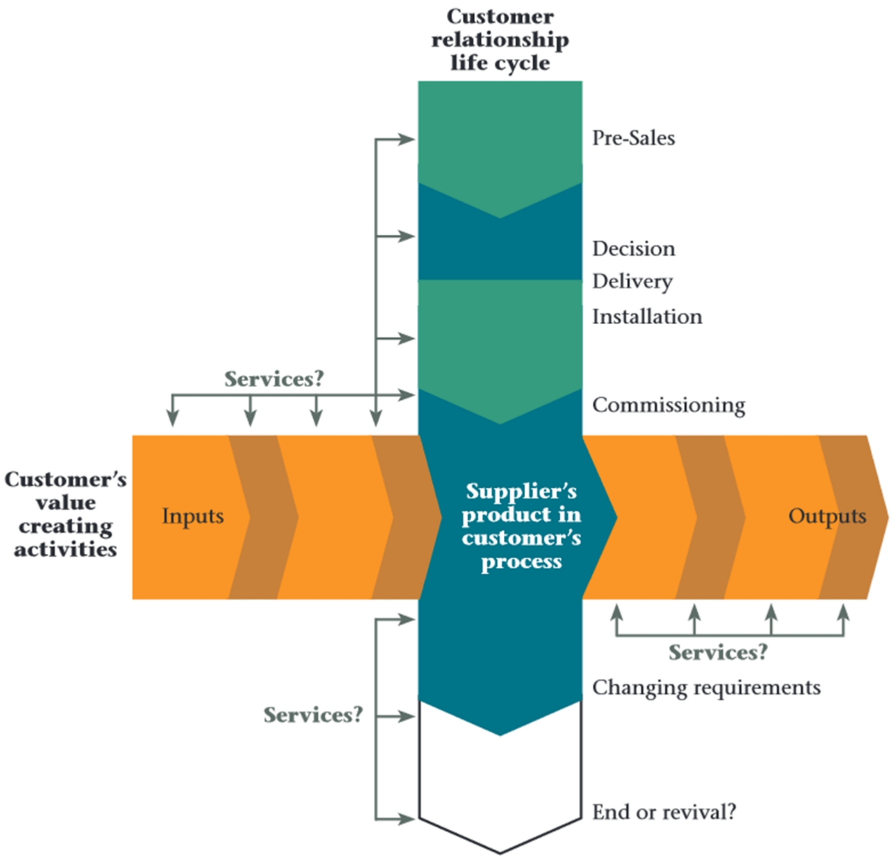



**Figure 4: Value creation possibilities (Paloheimo et al, 2004)**

Figure 4 describes product's network, where a value addition can be achieved. The figure makes clear that additional value can be achieved in almost every phase of a product, whether it is the customer or the supplier. Both provide and mutually benefit from each other's services in each stage of the product's life-cycle. As service business is traditionally thought to be everything after the supplier has delivered the product.

Reducing costs and time to market has become the priority of many customers in industrial automation, but at the same time there is pressure to improve the quality and safety. Usually making things cheaper and faster does not walk by with the quality and safety. At ABB, the direction has been towards selling performance services. This means tailoring the offered service exactly to the customer requirements. Automation performance management is a program where ABB guarantees the customer processes over the equipment lifecycle whether they are ABB equipment or not. Such service contracts are expected to set new standards for service excellence in the future. This can be ensured by the right pricing and cost effectiveness of such service contracts. (Deloitte, 2006)

### 2.2.2 Service portfolio for frequency converters and smartphones

Service business has already been developed for frequency converters at ABB. It has various advantages producing the critical customer value, for example, more information about the devices sold worldwide. Such information as what is the condition of one device and where it is installed are increasingly important with the growing installed base. Mobile phone integration could bring new ways to collect drive specific information.

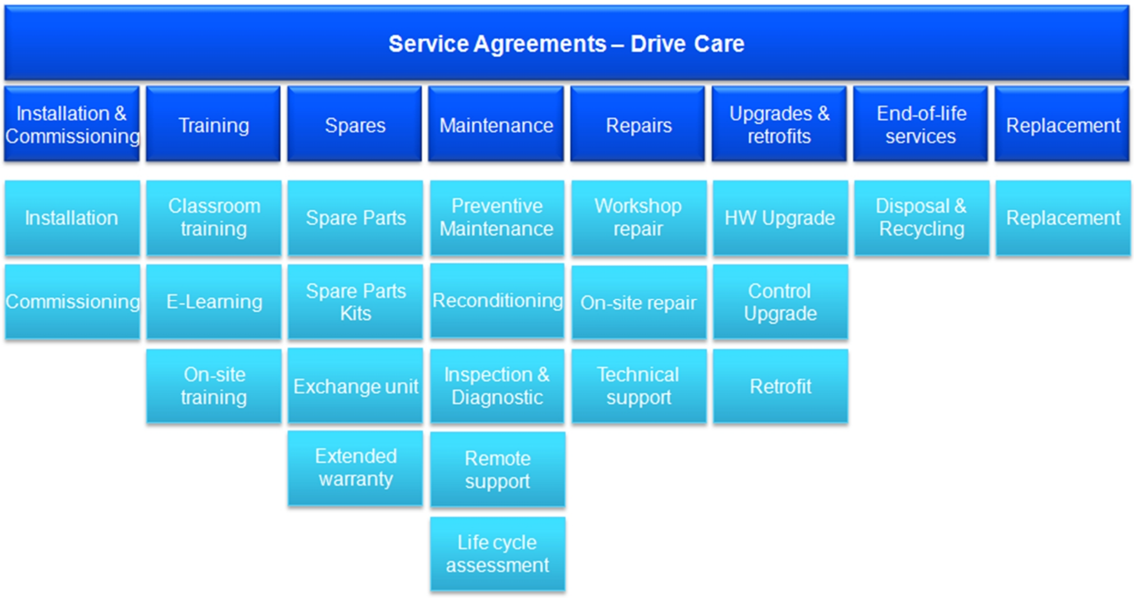



**Figure 5: ABB service portfolio for frequency converters**

Figure 5 describes the service portfolio for frequency converters offered by ABB. The portfolio consists of different services offered in frequency converters life-cycle. *Installing* and *commissioning* are related to how the frequency converter can be set up and running at customer's site. Either done by the customer, or ABB authorized technician. The *end-of-life services* could be integrated into this also in a way, if an old drive is broken or replaced, it can easily be commissioned with a smartphone. Regarding the research area of this thesis, one of the main purposes was to find application areas, where a smart phone could be utilized for better customer experience. Commissioning and registering the drive are promising areas to study, whether it is easy to implement such application for smartphone, so that it can directly control the drive. The last item on the figure *replacement* is linked to the installation and commissioning stage. This is because the old information from the replaceable device could be transferred to the new device as part of the commissioning.

*Training* is part of the offered service portfolio and it has a big impact on the handling and usage of frequency converters which reduces possible breakdowns caused by incorrect actions by humans. Smartphones offer an intelligent way to present information in a visually and more compact way than original classroom trainings.

Smartphone applications could provide access to the spare parts catalogue and directly show the correct parts for the drive model, perhaps the one where the smartphone is connected at the moment. It could also provide an easy way to order new spares directly to the customer's site. Maintenance, repairs, retrofitting and upgrades as an addition to spare parts services offer promising application areas, where the utilities of a smart phone could be used in a productive way, such as fault code checking.

# 3. SMARTPHONE CHARACTERISTICS

This chapter introduces the smartphone hardware evolution, how complex system can be designed now and in future. The three largest mobile operating systems are reviewed and their strengths and weaknesses are examined from technical aspect. Wireless communications are essential part of smartphones and the wireless connection to a frequency converter; therefore the wireless communications options in smartphone are introduced. Last subchapter introduces mobile security in general and what kind of threats' applications working in zero-fault-tolerant environments have to tolerate.

Smartphone hardware has developed rapidly. Therefore, companies, developers or consumers have had less time to fully maximise the potential of the hardware advancements. Such rapid advancements reduce the time to create unique and usable applications and shorten the life-cycle of mobile phone hardware drastically. The current smartphone hardware platforms are capable of running more complex and interactive applications than seen before. Therefore hardware is not seen as bottle neck for creating intended applications for smartphones and frequency converters.

## 3.1 Application environments

All three major operating systems (Android, iOS, WP) in mobile phone markets have different development tools, programming languages and simulators. This has led to the development of cross-compilation environments, where the same software code can be compiled to a working application in any mobile operating system. Such cross-compilation environments create less optimized code, therefore reducing the speed and increasing the battery consumption of a smartphone. Creating your own applications for every operating system in their native language and IDE requires more work and slower time-to-market.

### 3.1.1 Google Android

Open Handset Alliance is composed from over 80 manufacturers, software enterprises, a tele operator and Google. Google leads the development of Android operating system with the help from the alliance partners. First version of Android was published in the year 2008. Android is based on Linux kernel which means Android utilizes open source code manners. (Open Handset Alliance)

The main distributing channel for Android apps is Google Play store, but making and distributing of Android applications is completely free and any developer can share developed applications anywhere they want. Android applications are developed with Java programming language. The most famous development IDE is Eclipse, which integrates the required Android SDK plugin called ADT. By this way, applications can be emulated in Eclipse or in real equipment. Eclipse IDE also makes it possible to create fast and easy user interfaces through the graphical editor included in ADT. Android IDE is distributed for every operating system (primarily Windows, Mac and Linux). (Android Developer)

The application development platform is easy to learn and diverse. There are many differences in the operating hardware of devices using Android. Different CPUs and memories differ between price classes. The most visible feature is the screen size. High-end models have high resolution screens while the low-end models have small screen sizes with worse resolution. These features affect and bring challenges for Android developers.

The Android operating system architecture is based on four layers as illustrated in Figure 6. The applications layer contains all the operations offered by the operating system for applications, such operations are for example calling and messaging. The application framework layer offers a programming interface for applications layer applications to the lower layers. The library layer provides core functionalities for applications such as graphics and audio. Library layer also contains Dalvik virtual machine which executes the applications done for Android. The lowest layer is Linux Kernel which brings the Linux operating system core services to higher layers. Services like scheduling and memory management. (Maia et al, 2010)

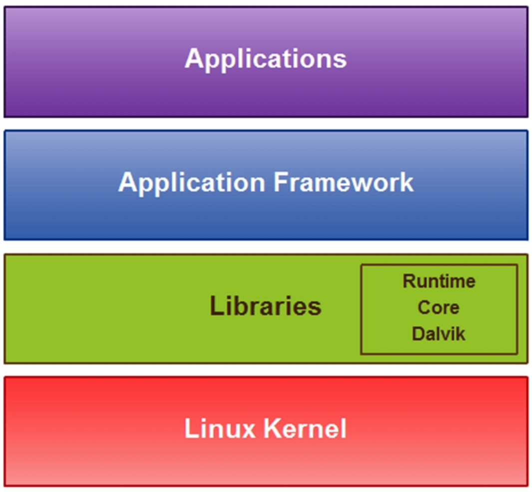



**Figure 6: Android system architecture (Adapted from Intel, 2014)**

Android’s greatest strength versus iOS is the formability of open source software, but at the same it is the greatest weakness of Android operating systems. Various manufacturers have published their own Android system, which do not support the latest Google-made operating system updates. This leads to huge amount of phones with not the latest software in them, causing security risks and phone hijacks.

### 3.1.2 Apple iOS

Apple iOS was introduced in 2007 in iPhone 3. Apple does not licence the iOS operating system to any third party manufacturer, unlike Microsoft Windows Phone and Google Android which are open ecosystems for every manufacturer. Using closed ecosystem, like iOS, has advantages such as Apple can do version control better, because Apple can decide when the updates are ready to install. This means the device base is usually always the latest version of the operating system. Disadvantages are related to freedom issues. Microsoft and Google give the freedom to the developer to create, but Apple restricts this by making different rules what kind of and how can you develop apps for iOS. (Apple iOS)

iOS operating system architecture consists of four layers represented in Figure 7. The Cocoa Touch layer contains the required frames for an iOS application. The media layer offers graphic, audio, and video libraries for applications. The Core Services layer contains the needed operating system commands and services. The lowest layer, Core OS, performs the low level task with the hardware, which most of the upper layer frames use. (iOS Technology Overview)

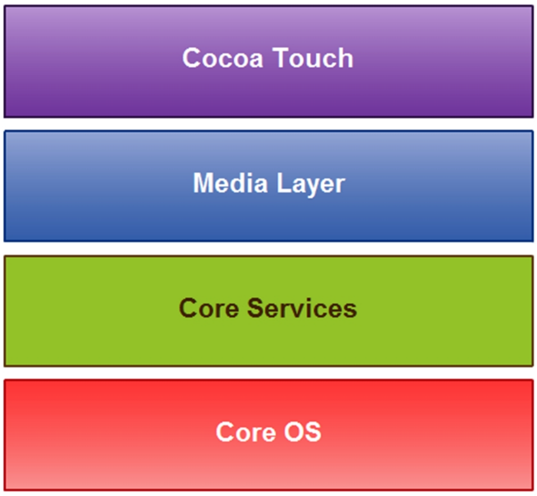



**Figure 7: Apple's iOS system architecture (Adapted from Apple)**

App Store application store is the only official distributing channel for iOS applications. Applications downloaded from other sources require jailbreaking the device to make applications from untrusted sources work (Apple iOS). iOS applications are developed with Objective C programming language with Apple specific SDK. Xcode IDE is the programming interface for iOS and it supports iPhone and iPad simulators. (iOS Technology Overview)

### 3.1.3 Microsoft Windows Phone

Formerly known as Windows Mobile, the operating system was designed for enterprises and is now replaced by Windows Phone operating system. The Windows Phone 7 operating system is based on Windows CE and its user interface is called Metro UI for better a response in consumer markets. Main visible differences between Windows Phone against it competitors Android and iOS, is that WP has dynamically updatable live tiles, which show the information on the screen live. For example, missed calls are shown on the phone live in the tile (Kokkonen 2012). Android has similar technology called Widget to present live information on home screen.

Windows Phone 8 operating system was changed from CE to NT based on better application development possibilities between desktop and mobile operating systems. Other features WP 8 brought were hyperdrive and support for SD cards. Due to these hardware requirement changes, old WP 7 phones are not compatible with new WP 8 based phones (Trew 2012). The newest Windows Phone 8.1 operating system hit the market at the end of Q2/2014 bringing new features like a command panel, new application framework and better support for faster hardware.

Figure 8 represents the Windows Phone architecture. The application runtime layer handles the applications when they are being executed. The modelling layer contains all the information related to modelling, transportation and connections. The kernel layer offers all the core services like scheduling.

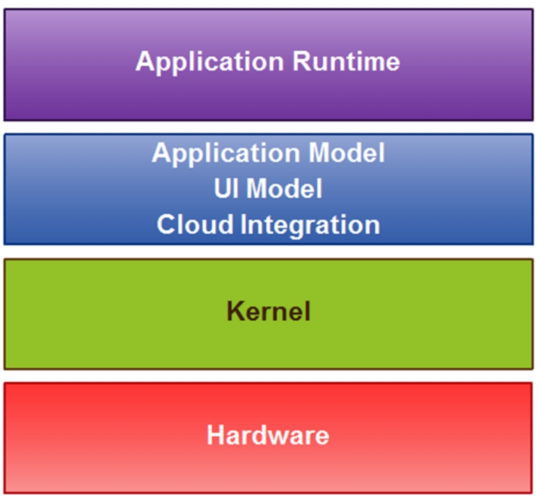



**Figure 8: Microsoft Windows Phone system architecture (Adapted from WP Developer)**

Apple iOS and Google Android are years ahead from Microsoft WP operating system. Not technically but in terms of application amount and their quality in the application stores worldwide. Therefore, Microsoft has to persuade more developers to develop for Windows Phone platform. The more applications there are the more possible satisfied customers. Even though Microsoft has dominated desktop markets decades already, it has not succeeded in breaking to mobile markets due to previously mentioned reasons.

The official WP applications distributing channel is Windows Phone Store. WP applications are developed with .NET and C# programming language with the help of Windows SDK. SDK contains Visual Studio Express IDE and WP emulator. WP 8 applications require 64-bit Windows 8 operating system, but WP 7 can be developed with 32-bit and Windows Vista or higher. (WP Developer)

## 3.2 Wireless technologies

Today's smartphones possess different kinds of wireless technologies. Most of them have established itself in the mobile phone business. In the following subsections, each of the technologies is studied. Features interesting for this study are interference sensitivity, security issues, connection establishment, and variety of qualities that define the usability of the communication channel, such as latency, throughput, and range. Technologies that make connection to Internet possible are reviewed in the sector 5.2, where cloud characteristics are more closely examined before introducing the concept of data transfers between a smartphone and a cloud.

### 3.2.1 Bluetooth

Originally, Bluetooth was developed to replace cables between connected devices. Created by Ericsson in 1994, later Special Interest Group (SIG). Bluetooth exchanges data over short distances using radio waves. Especially the industrial, scientific and medical (ISM) band which is 2.4 GHz. Bluetooth utilizes the band at 2.4 GHz to 2.485 GHz, using spread spectrum, frequency hopping and full-duplex data communication. The ISM band is available and unlicensed in most countries. (Gehrmann et al, 2004)

The original Bluetooth specification (Bluetooth 1.2) supported 1 Mbit/s data transfer rates. In the next specification, the data transfer rate was increased to 3.0 Mbit/s with a technology called Enhanced Data Rate (EDR), and even further with next version supporting technology called High Speed (HS) and Bluetooth 3.0 specification. The latest version of Bluetooth is called Bluetooth Low Energy (BLE), which is specifically designed to consume less energy. This Bluetooth 4.0 specification suits well for energy-constrained applications. (Prahbu et al, 2004)

Bluetooth range is always application and manufacturer specific. Only the minimum range is introduced in the Core Specification maintained by SIG. Manufacturers tune their devices so that the range fits in the application specification. The range may vary depending on the class of the radio used in the application. Class 3 radios have the range of up to 1 meter. Class 2 radios are the most commonly found radios in mobile devices and have the range of 10 meters. Class 1 radios are primarily used in industrial applications. Class 1 radios support ranges from 1 to 100 meters. All the radio classes can have shorter or longer range depending on the environment. (Bluetooth Core Specification)

Bluetooth utilizes technology called frequency hopping and spread spectrum to avoid interference sensitivity. Frequency hopping searches a free channel in the environment for data transferring. Frequency hopping with Division Multiple Access (FH-CDMA) and Error Correction and Received Signal Strength Indicator (RSSI) ensure the reliability of Bluetooth communication in challenging environments (Prahbu et al, 2004). Figure 9 illustrates the Bluetooth protocol logical view. The API offers core tasks for programmers. Such tasks are, for example, how to read and write data through the Bluetooth protocol. This is usually solution independent part of the Bluetooth implementation. Remaining layers are divided between software and hardware part, and are always part of the Bluetooth construction.

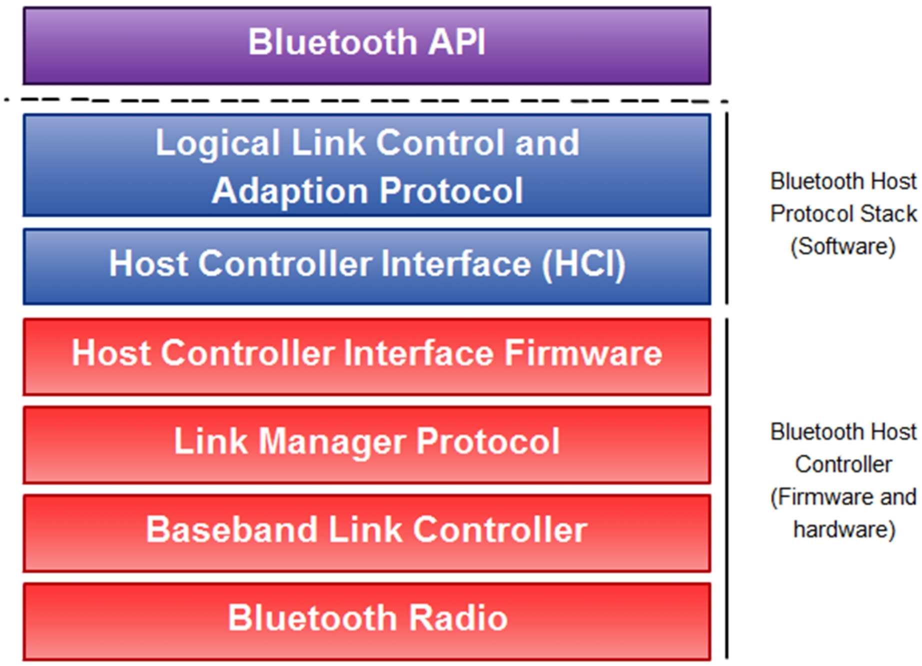



**Figure 9: Bluetooth protocol logical view (Adapted from Oracle, 2004)**

Bluetooth consists of three features which provide the basis for secure data and voice transmission, authentication, encryption and transmission level security. The authentication process prevents data corruption by preventing undesirable access to data being transmitted. The message originator identity cannot be falsified either. Data is encrypted before it is sent over-the-air (OTA), therefore possible eaves-dropping efforts are neglected. The message can be decrypted only with a proper key. Other extra methods preventing data eaves-dropping are the use of Frequency Hopped Spread Spectrum (FHSS) and the limited transmission range. (Prahbu et al, 2004)

### 3.2.2 Near-Field Communication

Near Field Communication (NFC) provides communication between electronic devices by manipulating the magnetic near-field between two devices. NFC is a short-range wireless connectivity technology. When a NFC transmitter and a receiver are brought together the data transfer occurs. The most common operating frequency for NFC devices is 13.56 MHz and data transfer rates ranging from 106 kbit/s to 424 kbit/s. NFC transactions can be considered safe due to the short-range although NFC devices are still vulnerable to eavesdropping with different mechanisms. NFC enables the networking platforms to interoperate seamlessly. Primary use cases for NFC are connection establishment between electronic devices, accessing to digital content and making contactless transactions. Connection establishment can be utilized in for example pairing two Bluetooth devices instantly using NFC touch. Therefore, no manual setup is required. Digital content can be easily accessed through embedded NFC RF tags. Contactless transactions are making their way to the market with the wireless payments. Figure 10 illustrates the NFC logical view. NFC API offers the core tasks for the programmers how to use the NFC protocol. These core tasks are dependent on the mode which is defined by the NFC Forum. The physical layers contain the actual hardware implementation of NFC.

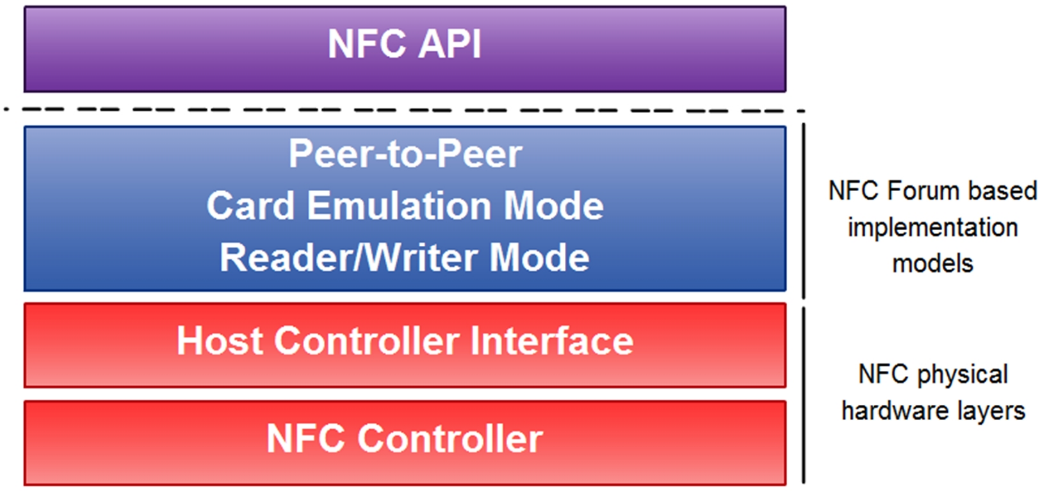



**Figure 10: NFC logical view (Adapted from EETimes, 2011)**

NFC technology could be considered as connection establishment utility for Bluetooth or other rather than the technology to implement the whole application data transfers.

### 3.2.3 IEEE 802.11 specifications

IEEE 802.11 family, better known as Wireless LAN (WLAN) or Wireless Fidelity (Wi-Fi), specify the local area network, which enables computers to exchange data wirelessly. Local area networks are considered as shared mediums, meaning everything in the network is accessible for anyone. Even though messages are encrypted and without valid key, the message cannot be decrypted in reasonable time, even though messages can be intercepted or blocked. (Geier, 1999)

WLAN uses 2.4 GHz ISM band. Many other equipment also work at this frequency and WLAN signals can occasionally be interfered with unwanted signals. WLAN uses DSSS (Direct-Sequence Spread Spectrum) and OFDM (Orthogonal Frequency-Division Multiplexing) to make the data transmission channel more interference resistant. WLAN is the fastest protocol in today's smartphones, but at the same time it requires higher infrastructure around it to work properly.

## 3.3 Security

Mobile security has become increasingly important in mobile computing. This is because more and more of the business and personal information is related to smartphones. Therefore, companies have to upgrade their policies regarding information security. This includes different rules how an employee can use a smartphone in work related subjects. Figure 11 represents the different parties involved in mobile device. As it can be seen there are various different people behind the mobile device which raise the risk of being attacked even higher.

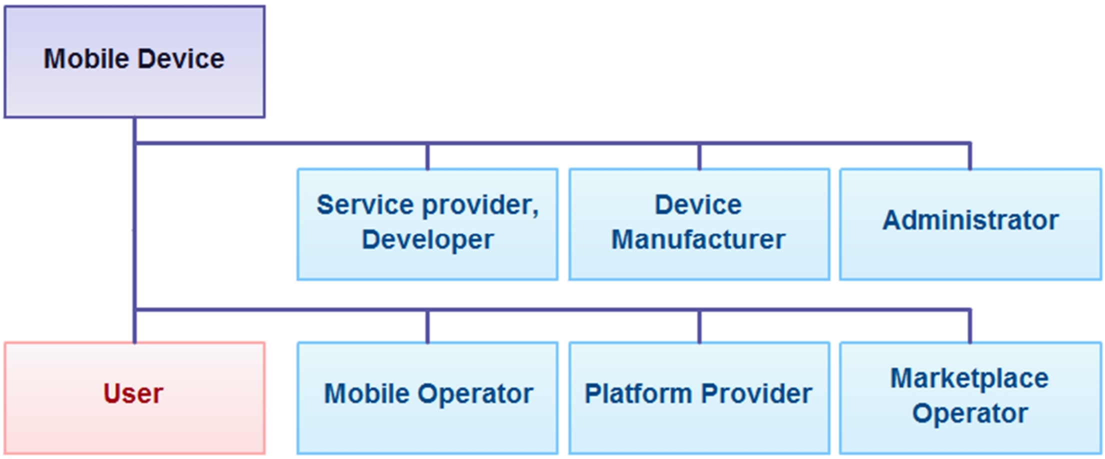



**Figure 11: Parties involved in mobile devices (Adapted from Asokan et al, 2014)**

All smartphones are plausible targets for attackers. Attacks exploit the different weaknesses in smartphone hardware, software or the user itself. Attacks can come through

Short Message Service (SMS), Multimedia Messaging Service (MMS), Wi-Fi networks, Bluetooth, NFC and GSM/GPRS networks. Software vulnerabilities can be found for example from the smartphone web browser. Still, users form the greatest threat for any system. User can, for example, allow malicious software to be installed on the smartphone, and then transmit or modify the phone content. For these reasons, the applications created must guarantee privacy and integrity of the information they handle. In the following, targets, attackers, consequences, and countermeasures are briefly considered.

Prime targets for attackers:

- data
- identity
- availability.

Smartphone's essential ability is to manage data and therefore the data itself can be very rich in terms of information. Such rich information can be credit card numbers, passwords or other private information. Many smartphone owners customize their smartphone to their personal interests; this can refer very much to your personality. For some attackers, your identity is the one they want to steal. The final prime target is the availability. Attackers may be using techniques to limit or deprive the users’ access to the phone. (Bishop, 2004)

The attackers:

- professionals
- thieves
- hackers.

The attacker can be anyone, but some main groups can be identified, such as intruders or hackers. Professional attackers mainly focus on the prime targets to steal sensitive data or the user's identity to do more attacks. Professionals are usually traced back to governments and militaries, hence, the name professionals. Usually, these parties undertake industrial espionage. Thieves differ from the professionals in a way that their priority is to make more profit. Stealing the identities or data to gain income is the main job. Hackers develop malware or viruses to damage the target, usually the device itself. Therefore their main goal is the availability of the device. On the other hand, hackers can be considered as some kind of a good guy since their goal could be to reveal the vulnerabilities of a system. (Bishop, 2004)

Possible consequences when a smartphone is infected:

- manipulation
- utility reduction
- theft.

If a smartphone is infected, it can be manipulated to do the same tasks as the user itself can perform. For example, the phone hijacker can send commands to the phone to perform certain actions like spamming. A large portion of worldwide traffic is e-mail or SMS spam. The attacker can also make phone calls using the victim device to call paid services in accordance to charge the original owner from usage of the service. This paid service can be directly or indirectly owned by the attacker. Espionage in terms of listening conversations between the victim phone and some other and then send this information to a third party. Manipulation eventually leads to crimes related to theft. For example, by impersonating the owner of the phone the attacker can access the owners' bank account or identity. Alternately attackers may want to delete the information in the phone, not just steal it.

Utility reduction is about reducing the capabilities of the phone. This can be, for example, battery life time. By installing such malware that constantly drains the battery by driving high CPU load applications the attacker can reduce the uptime of the smartphone. The attacker can also modify certain programs in the phone to prevent them from working. (Guo et al, 2004)

Countermeasures:

- security in operating systems and software
- resource monitoring in the smartphone
- network surveillance
- manufacturer surveillance
- user awareness.

The operating system of a device creates the first level of security. Usual operating system procedures, such as resource management and scheduling, must be protected from applications that are installed in the system. There are two methods how to protect the OS. Apple's way is to limit the access from applications in AppStore. Applications possibilities are restricted to the public API and a developer's application is checked before publication in the AppStore. Google's way is sandboxing. The application to be installed is driven in a sandbox to reduce the communication it can perform with OS. This way only a small portion of the OS can be shown to the application.

The next layer in security is the software security; in general this layer consists of antivirus software and firewall. These are the most common aspects of security in a smartphone. Such software consists of software components which prevent malware from functioning if the malware's way of working is known.

Surveillance of smartphone resources can be a way to discover malware. If certain applications draw great amounts of CPU time, consume memory, or use the 3G modem, and it is not known what for the application is functioning, it is possible identify such behavior as a malware. Using the same logic on network surveillance, the unwanted behavior of a smartphone can be traced in the telecom network. Manufacturer surveillance is also an important aspect of smartphone production and distribution. Manufacturers have the responsibility to build such products that are without vulnerabilities. (Guo et al, 2004)

The most important countermeasure is the user awareness. Almost everything what can be done with the phone is started by the user. The biggest factor is just simply carelessness. The usage of passwords, or more bullet-proof passwords, is still not at good level. Users should be more skeptical about what they install on their phones or what kind of permissions they give to the applications installed.

# 4. FREQUENCY CONVERTER

Frequency converters are designed to control the energy conversion in industrial processes. The electric energy from power supply or power grid is transformed to a mechanical energy in an electric motor. In the traditional scheme, the power grid feeds the motor directly. This approach is unbeneficial in terms of motor speed control and energy consumption i.e. the process is not optimal all the time. A frequency converter enables unique process control. The electric motor is driven exactly with the required speed and therefore the energy consumption can be optimized. Frequency converters can also work in another way. The excess energy from a process, i.e. when a motor is braking, is taken to the frequency converter and converted back to the power supply grid as electric energy. Frequency converters also include several other features such as control interfaces and protection mechanisms. (ABB, 2011)

This chapter introduces the basics of a frequency converter and its wireless interfaces.

## 4.1 Structure and operating principle

The frequency converters which drive an electric motor consist of four functional blocks: an intermediate DC link, a rectifier unit, an inverter unit, and a control unit. The Intermediate DC link decouples the rectifier and inverter units. (Kyyrä, 2008)

The rectifier unit takes the input energy from a power grid (AC) and converts it to DC quantity. The rectification is done by full-wave rectification bridge commonly implemented with diodes. The rectified DC voltage is further fed to the intermediate DC link which minimizes the voltage fluctuation. Energy from DC link is inserted into the switch-mode inverter and adjusted by controlling algorithms to fit properly for the process. Control algorithms adjust the frequency and magnitude of the signal. After the inverter, the voltage is near sinusoidal and it is inserted in to an AC motor, for example (Mohan et al, 2003). Figure 12 describes the block model of a frequency converter operating as motor driver.

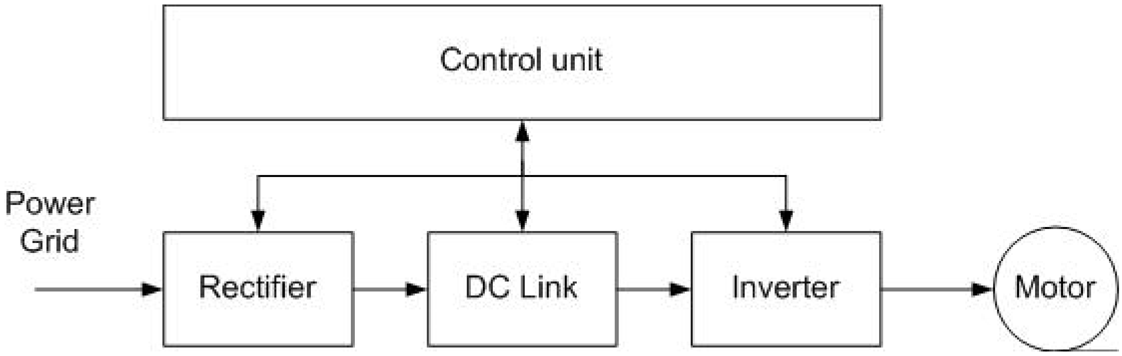



**Figure 12: Frequency converter block model**

Figure 13 illustrates a case where a frequency converter is used as a generator when the energy flow is controlled in the opposite direction. Meaning the energy from an industrial process is fed back to the power supply grid. In this operating mode, the rectifier bridge is replaced by a switch-mode inverter, which converts the DC voltage in the intermediate link to corresponding AC voltage in the power grid and then feeds it back to the grid. (Mohan et al, 2003)

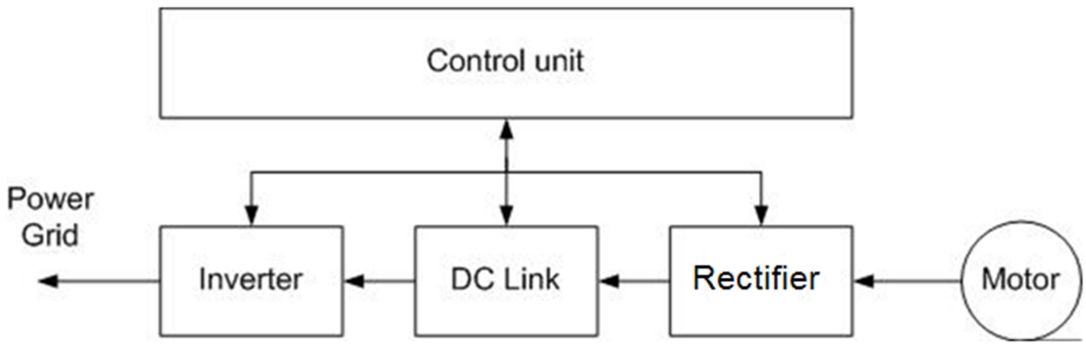



**Figure 13: Frequency converter as generator block model**

These two operating modes are the basic tasks done by frequency converters. Details of the electronics and software configurations are more complex and are not examined closer in this thesis.

## 4.2 Basic features

A frequency converter can be divided in to four basic components: motor control, electrical supply, process interface and user interface (ABB, 2011). The components are presented in Figure 14.

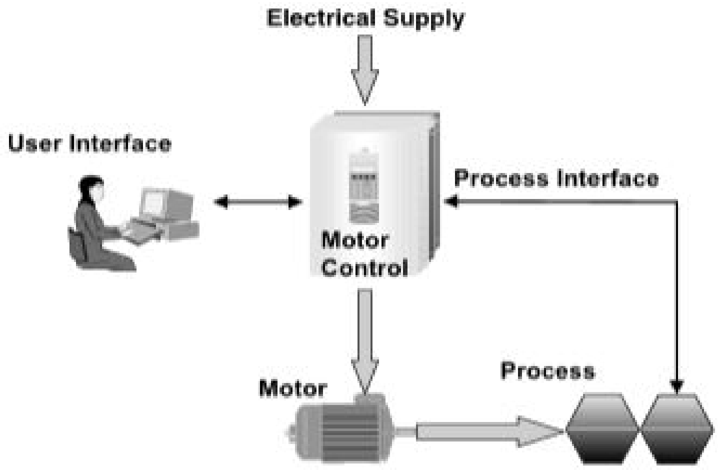



**Figure 14: Components of a frequency converter system (ABB, 2011)**

Behind these four main features lie many internal functionalities and features. The internal features are both implemented in to hardware and software. These features include diagnostic methods of different kind, mathematical analysis tools, and protection mechanisms against, for example, over-currents and earth-faults.

### User interface

The frequency converter and its operations can be controlled through a user interface. Basic operations for the frequency converter are for example start, stop, limit values, or direction change.

The user interface of a frequency converter is implemented in a variety of ways in practice. The access to a frequency converter requires either a control panel or direct operations through digital and analogue inputs. Other ways to implement methods for controlling the frequency converter are by field bus protocols or with a PC equipped with necessary software. These different methods for controlling the frequency converter require extensive support from the converter itself, such as adapters, hardware implementations and software solutions have to be provided for different access technologies. In addition to user interfaces, different interfaces for programmability are implemented. The programming interfaces include reprogramming of the device, i.e., firmware update, other software update for the frequency converter, or the adaptive programming of the device, where the end user can modify the software behavior after manufacturing. (ABB, 2011)

Specific requirements for different communication protocols and methods for a frequency converter are set. Requirements are set because the methods and protocols work in real-time environments to provide the latest information about the process for the user. The interfaces also have to meet with the requirements of soft real-time requirements. Feedback from the device should come in decent speed for the user to know the current state of the process. Other factors influencing the communication channel are, for example, electromagnetic interference, which may affect the hardware used in the communication. Finally, the communication channel has to be secure and fault-tolerant to guarantee correct operations.

## 4.3 Wireless interfaces

At the moment, the wireless connection from a smartphone to a frequency converter can be established over Bluetooth technology. The Bluetooth adapter used is presented in Figure 15. The all-in-one Bluetooth module can be designed in a way that all the parts inside Bluetooth module can be separately designed on the control board or the control panel's PCB of the frequency converter.

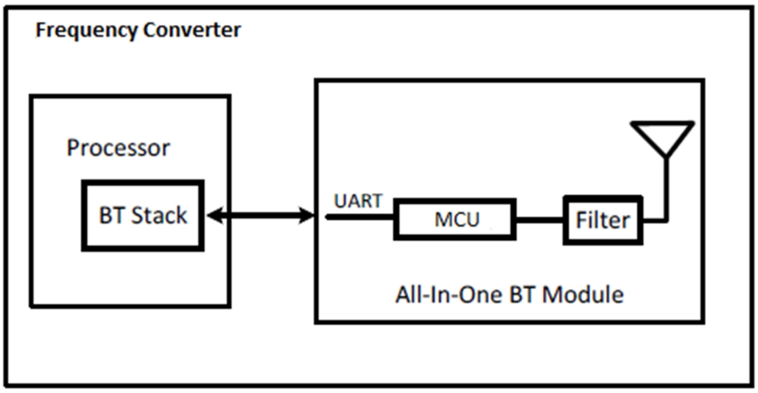



**Figure 15: All-in-one Bluetooth module**

While doing this thesis Bluetooth was the only reasonable technology to implement the connection between a smartphone and a frequency converter. In the following figures Wi-Fi and NFC are speculated as possible communication technologies in future. Following two figures represent two different configurations for implementing Wi-Fi capabilities into frequency converter control board.

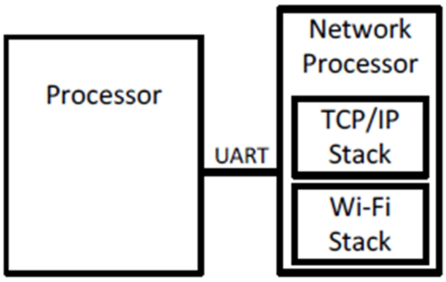



**Figure 16: Separate network processor**

Figure 16 represents a model where a separate communication processor is used. This implementation would not cause heavy overload to the already high load main CPU. This option would be the best in terms of differentiation and module based design, but on the other hand, the most expensive solution.

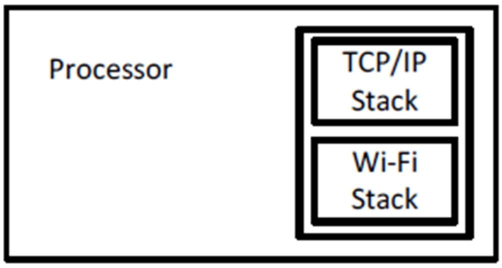



**Figure 17: Wi-Fi stack in the main processor**

Solution presented in Figure 17 would be full software implementation, but on a CPU already under heavy load, it is not a wise way implement the wireless feature. After all, software development may become more expensive than hardware even in high volume products.

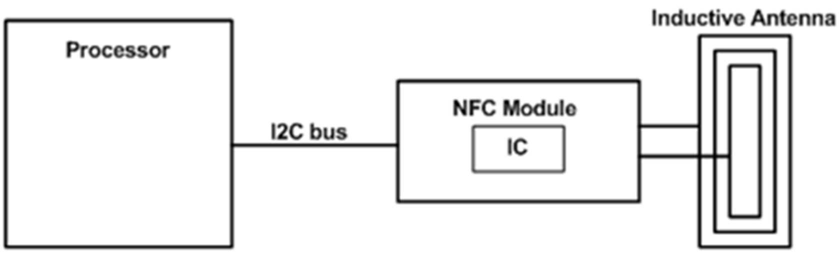



**Figure 18: NFC based communication**

NFC technology would allow the fast pairing of smartphone and a frequency converter rather than being the technology used for data transfer. Small amounts of data can be transmitted through NFC, but the short range of NFC could bring challenges for the user to keep the smartphone in close proximity of the frequency converter.

# 5. COMMUNICATION INTERFACES AND APPLICATION AREAS

In this chapter, the communication between a smartphone and a frequency converter is more closely examined. Bluetooth is chosen to be the protocol candidate for the proof of concept application. Section 5.1 describes the overview of the communication link between a smartphone and a frequency converter and defines general requirements for the data link. Use cases which are related to frequency converter and smartphone communication are presented in Section 5.2 and Section 5.3. The latter one introduces ABB specific use cases and the former one customer specific application areas. Different use cases and application areas give insight where a smartphone could be utilized to improve the usability of a frequency converter.

Section 5.4 introduces the basic characteristics of cloud based services. After basic information Section 5.5 introduces the concept of connecting and routing frequency converter specific data to a cloud through the smartphone. The last section gives insight to the use cases what can be performed through the presented data path.

The use cases are presented as separate, but the real application would be at the best, if all of these presented cases were implemented in one mobile application.

## 5.1 2-way communication between a smartphone and a frequency converter

Bluetooth was chosen to be the candidate wireless protocol for the communication. Partly due to the relatively simple Bluetooth adapter, that was retrofitted for the required purposes and partly due to the properties it offers. A secure connection in electromagnetic noisy environment, such as a factory environment, was an important part of the reliability of the communication.

The Bluetooth feature should be working with as many Bluetooth devices as possible on the market, which at least includes smartphones (iPhone, Android phones, Windows Phone), tablets (iPad, Android tablets), and computers (PC and Mac). The aim is to enable wireless data transmission with minimum end user effort. The wireless connection should be fast and reliable with a preferably long range (10+ meters). There is a requirement for the smart devices to be able to connect to several Bluetooth enabled frequency converters at the same time. This is used, for example, in the case where the user would like to instruct a group of frequency converters for data logging.

General requirements are as following:

- Initialization: Through the control panel menu settings, user should be able to initialize the Bluetooth radio and open it for scanning. This is comparable to a process when one wants to connect their mobile phone to a computer via Bluetooth. Users should then pair their smart devices to the control panel within some time limit (e.g. 2 minutes). After the pairing, the smart device should be able to communicate with a Bluetooth connection, e.g. using Serial Port Profile (SPP). Figure 19 shows an example connection scheme to ACS880 frequency converter using the Bluetooth adapter.

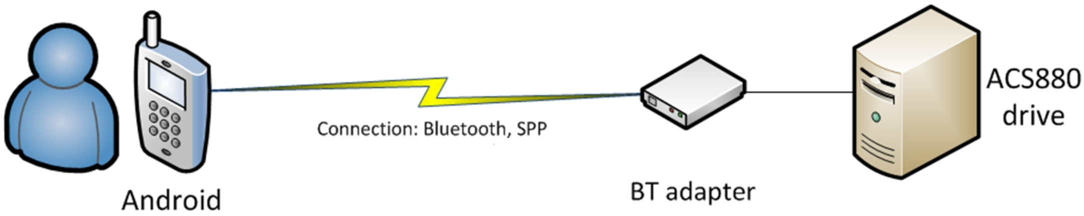



**Figure 19: Example connection parameters for the Bluetooth data link**

- Data logging: Upon initialization, user should be able to start an application in his/her smart device. This application is used to provide a user interface for data logging. After the smart device successfully downloads the data, it should check the integrity of the data and combine it with all the other relevant information and save them into the local folder of the smart device.
- Data transfer to the server: Initiated by the user, the application inside the smart device should be able to send the file that contains all the drive-related information to an ABB database server.
- Application should give indications when no mobile data connection is established or data is missing or corrupted.

## 5.2 Customer specific applications

This section describes the different use cases where a smartphone would bring more usability, speed, and easiness for handling a frequency converter from the customer point of view. The following list introduces use cases which were seen important during the research:

- commissioning
- registration

- parameter browsing and drive tuning
- fault code check and reset
- back-up and restore
- drive monitoring
- support
- reporting.

When the customer receives a frequency converter, it must be commissioned. At this stage, the frequency converter is set up to function the way it is wanted to. It includes the parameterization of the drive as well as possible specific application programming. After the set-up, the drive is monitored to guarantee it is completely working. Normally, these steps are done via the panel or the PC interface of the frequency converter, but utilizing smartphone for this could bring easiness for the commissioning. Hence a more interactive user interface can be designed for a smartphone to fulfil the required tasks. If, for example, the frequency converter breaks down the parameter set inside the broken device could be installed into the new device in the commissioning stage with smartphone rather easily.

Registration is the next step after commissioning. Gathering such information as the location of the drive, what application the frequency converter is driving, the customer details and the parameter set that helps both the customer and ABB to maintain the installed base. Creating mobile applications that enable fast and easy registration would decrease the gap for customers to do it.

Traditionally the frequency converter interface, i.e., the panel, is not very interactive and the screen is too small to show for example complete parameter names. If the parameters could be shown using full names, the user probably would not have to search for the drive manual to find out the correct parameters. The parameters are used to fine tune the frequency converter to better control the process. A smartphone with larger screen and more interactive functionality would bring new ways how to set and scroll parameter lists.

Application which enables easy and fast parameter back-up, fault code checking and resetting, and restoration back to any drive would ease the work load caused by malfunctioned devices and their replacement. Smartphone application with an integrated support and logging feature would help the customer in problem situations. The interactive support guide would be easier and faster to read and interpret than a traditional paper manual. The logging feature would give a good starting point where to, for example, search faults if the frequency converter does not operate in a correct way. Annual reporting like summary of use, fault logs, benchmarks which can be seen how the drive performed during the year, for example are there any better solutions for this phase of the production. Regular condition reports and predictive warning reports through the frequency converter data analysis give valuable information about the state of the converter. Depending on the amount of data, this can be a CPU power needing task, so it would be better to send the data to a cloud and perform the calculation there. Regular condition reports would include information like maintenance status and operating conditions and from this information the application could deduce what is the state of the frequency converter e.g. does the device need maintenance or is it running too hot and cause possible malfunction in the near future?

Most of the higher-end frequency converters have the control panel or are connected to a field bus network, from which the drive can be manipulated and monitored. Lower-end devices lack the options more often and, therefore, having an easy way to connect to the main board of the frequency converter for drive manipulation and monitoring makes the drive more beneficial.

## 5.3 ABB specific applications

This section introduces use cases which are aimed to improve the efficiency and cost-efficiency for ABB personnel, the same features as for ABB's customers are available for ABB’s personnel. The next items were seen as important features for different ABB personnel:

- diagnostic tool for ABB Service
- support tool for ABB Sales.

Mobile application that is designed especially for the ABB technicians working in the field tasks would give different maintenance tasks can be performed more effectively. The mobile application could offer services like: data logging, fault logging, history of use, or maintenance program.

Another ABB specific aspect is for salesmen who could easily acquire more detailed information about the customer or the frequency converter. Possibilities like ordering a new frequency converter for the customer or scheduling new maintenance program are promising ideas for the smartphone application.

## 5.4 Cloud characteristics

Cellular technologies such as GSM, GPRS or 3G/4G in the global telecom networks create the base for the internet connections of a smartphone, which it is a required feature to enable connections to clouds i.e. data storages and different servers. Cloud computing is constantly applied more throughout the business worldwide. The popularity it has gained makes it even cheaper. The vast amount of money spent in server hardware and software maintenance tasks can now be spent on other interests. Company may maintain its own server capacity, but on some tasks it could be a better idea to outsource the server capacity to third party cloud provider. (Bisong et al, 2011)

Essential characteristics that clouds provide are on-demand service, network access, resource pooling, elasticity, and measured service. The on-demand service offers the flexibility and scalability for users to automatically acquire more processing power or storage space if needed from the cloud. The benefit of the network (Internet) accessible cloud is that the service is available from anywhere. It also offers such an interface that makes the connection look the same whether the connecting device is a PC or a mobile client. Clouds offer diverse resource usage monitoring, for example, processing power, used storage, used bandwidth, user accounts can be monitored for both the transparency between the buyer and the cloud computing seller, and for measuring purposes. (DEi, 2012)

Companies can buy cloud service through different service models like infrastructure as a service (IaaS), platform as a service (Paas), network as a service (NaaS), and software as a service (SaaS). In IaaS model the consumer can access the cloud's processing properties to run own operating systems and applications. Hence, the consumer is paying for the infrastructure, where to execute programs. PaaS model differs from IaaS model in a way that operating system already installed by the cloud provider. Consumers need only to create and deploy their applications. In SaaS model the applications are already done by the cloud provider. An example of where SaaS model is used is, for example, a consumer buying web application to their website. The NaaS model is different from other three mentioned, it has the unique idea of sharing bandwidth to customers, using the principle, the one who uses the most, pays the most. (DEi, 2012)

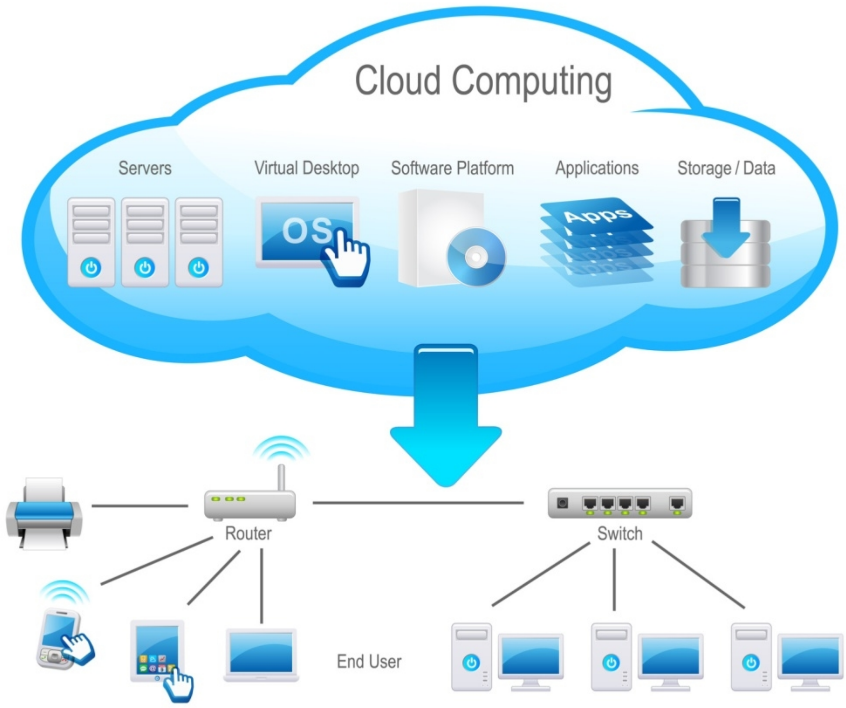



**Figure 20: General illustration of cloud infrastructure (DEi, 2012)**

Figure 20 shows an example configuration of a virtualized cloud environment. For example, this could represent company's site network where employees' computers are connected to the virtualized cloud, which consists of most of the tools employees need in their everyday work. Connections from and to cloud are encrypted and maintained by secure protocol (HTTPS) and proper authentication procedures.

Deployment models of clouds can be categorized in four groups: Private, community, public and hybrid cloud. Private cloud may be owned and managed by the owner, not only the cloud infrastructure owner. Usually private clouds are exclusively used by one organization, for example, company's business unit. Community cloud is designed for organizations having the same kind of need, such as security or policies. Community cloud can be operated by the organizations or the cloud owner. Public cloud is open for the general public. It could be managed by the government to offer library services for citizens. Hybrid cloud is a mixture of previously mentioned cloud deployment models. It is used to create unique environments where to deploy services. (DEi, 2012)

## 5.5 Smartphone application integration to cloud services

Smartphone capabilities to manipulate data between a frequency converter and a cloud offer more possibilities how the smartphone could be utilized in frequency converter application. Figure 21 presents the overview of the communication.


**Figure 21: Cloud utilizing system overview**

Smartphone can communicate with a server using a variety of different methods, primarily an internet connection using wireless cell technologies, such as 3G and LTE, but also wireless LAN if, for example, the factory site has WLAN routers installed. Depending on the connection and location, data transmission rates should be kept as low as possible to guarantee working in every environment. The connection should be based on a secure protocol like HTTPS on the application layer.

General requirements are as following:

- Scalability is the ability of the platform to scale both up and down to support varying numbers of users or transaction volumes. The application should be able to scale horizontally (by adding more servers) or vertically (by increasing hardware capacity or software efficiency).
- Flexibility is the ability of the application to adapt and evolve to accommodate new requirements without affecting the existing operations. This relies on a modular architecture, which isolates the complexity of integration, presentation, and business logic from each other in order to allow for the easy integration of new technologies and processes within the application
- Conceal data from unauthorized parties. All communication between data and mobile application is kept secure using Secure Socket Layer (SSL) encryption, essentially the same method banks use for secure online transactions.
- Ensure that system users are authenticated. All access to the system is centrally controlled, requiring password authentication. All user actions are fully audited (end-to-end) for traceability. Limit each user to specific data, views, and actions. Once authenticated, user actions are limited to the products for which they are responsible, and the level of access appropriate to their roles.

## 5.6 Cloud specific applications

This section introduces different use cases where a connection from a frequency converter to a cloud is established. The system overview was described in Section 5.5. The following cases were seen important:

- general frequency converter parameters transmitted to a cloud
- continuous monitoring, analysis and failure reports
- fine tuning
- troubleshooting and remote guidance
- parameter back-up and restoration.

The cloud services can be described as a large database which could contain all the specific data from each frequency converter in a factory. Usually, many frequency converters control the same process e.g. a conveyor belt in a factory. These frequency converter specific parameters can then be sent to the cloud from which they can be retrieved to optimize the process of one frequency converter to, for example, fit better in the conveyer belt process. Other general features can be for example: Alert notifications, for example, SMS or E-mail, when faults occur, historical data collection and storing in the cloud database, troubleshooting, guidance, summary reports on service, and audits of different kind. Cloud can also perform automated gathering of these features and the analysis which in turn can be sent to the user at any time if, for example, a fault occur. Clouds also give the freedom to a remote user to configure the frequency converter from a remote location through the smartphone link and therefore the configuration task does not need the person to be physically in the location.

Such cloud integration brings worth especially in cases where the factory infrastructure is poor i.e. there are no field buses connected to every drive. Factories where all the frequency converters are connected to field buses can be separately configured through the field bus network and therefore do not need a cloud connection because the same information can be sent through the field bus network. What about then factories where the infrastructure is not as good or there are many frequency converters without field bus interface? In such environments, a smartphone which can be connected to the specific frequency converter through, for example, Bluetooth connection and the same data can be routed all the way to the cloud gives the freedom to the factory owner to improve their processes without investing in better frequency converters or expensive field bus networks.

# 6. MOBILE APPLICATION DESIGN

This chapter describes how to implement one solution for fault code checking and resetting task on a smartphone. This is one of the use cases introduced in the Chapter 5 using the introduced Bluetooth communication channel from the same chapter.

The design flow should acknowledge some of the basic principles in software designing. The solid principle is introduced as the basis in the design principle framework. Five key elements of the solid principle are:

- Single Responsibility principle: Each class should have a unique responsibility or main feature.
- Open-Closed principle: A class must be open for extension but closed for modification.
- Liskov Substitution Principle: Sub-types must be able to be replaced by their base types (base class or interface).
- Interface Segregation Principle: The class interface implementers should not be obliged to implement methods that are not used.
- Dependency Inversion Principle: Abstractions should not depend on details; the details should depend on abstractions. (Metz, 2010)

User experience and user interface designs are important part of mobile applications. UX and UI are the first parts of the software, which counteract with the user and therefore have the impact on whether user sees the application is good or bad. Subsection 6.3 examines more closely how UX and UI design impact on user.

## 6.1 Cross-compilation environments and their benefits

There are many different platforms, and for every platform there is a tool chain to develop applications for this certain platform. Due to the amount of different platforms, cross-compilation platforms are the key answer to these. In the world of mobile, top three operating systems have their own native language and development environment. Therefore having to develop one application for all platforms, the application should be developed three different times. Using cross-compilation tools, the amount of development, in this case, can be reduced to only one time development. However, developing applications on cross-compilation environments has some disadvantages regarding the different screen sizes or memory requirements. Advantages of cross-platform application are that it runs on a different platform without behavioural or visual changes. (Dallera, 2011)

There is a debate between native development and cross-platform development. Cross-platform applications are not as fast as natively developed applications are. This is because native applications can take the most of the operating system's resources. However, the development of native applications is more expensive than just making one code which is then ported to every platform needed. Cross-compilation environments are gaining popularity and coming better all the time. Existing solutions (Qt 5) are capable of compiling mobile applications code to all major platforms (iOS, Android, WP), and therefore reducing the resources needed for the application development. Figure 22 illustrates visually how one good cross-compilation IDE can perform the compilation tasks for different platforms.

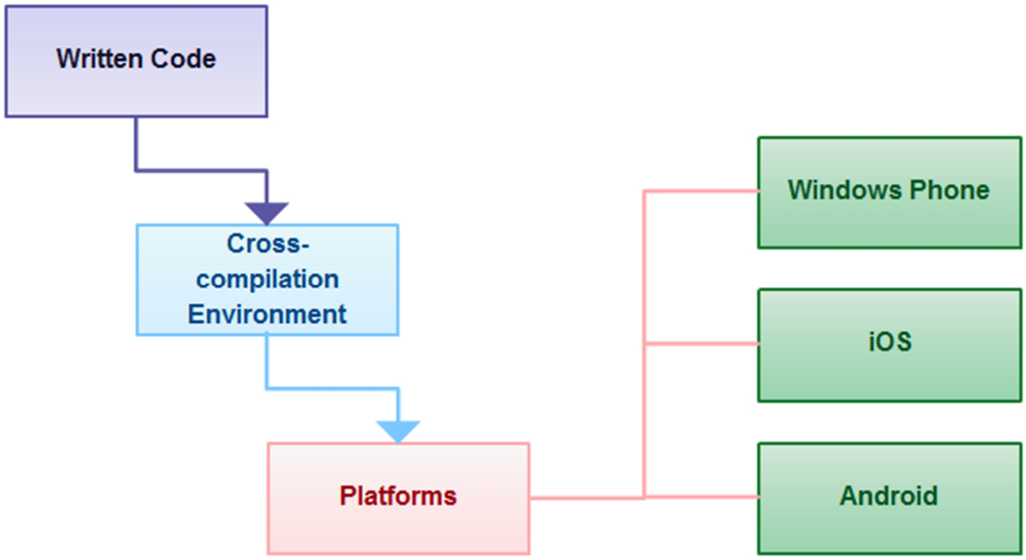



**Figure 22: Cross-compilation benefits**

## 6.2 Application platform and architecture design

Android was chosen to be the platform as Android is the most widespread mobile operating system and it has an extensive amount of libraries of different kind allowing the design of rich mobile user interfaces and functionalities. The following figures present the architecture between Android application and the Bluetooth adapter, the UML object model for the designed application, and a sequence diagram which represents the needed action and their order to accomplish the intended use case fault code checking and resetting.

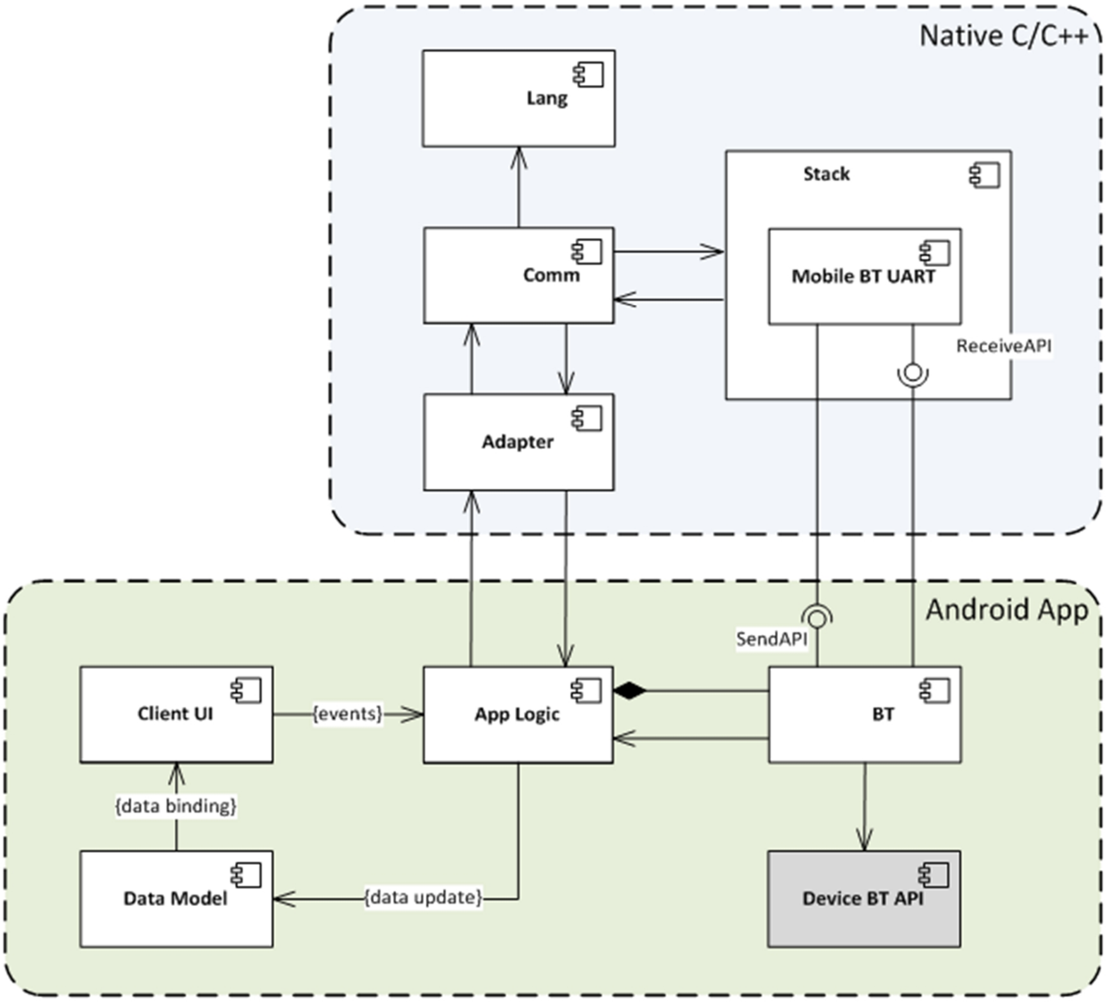



**Figure 23: Logical view for the communication between smartphone and Bluetooth adapter**

Figure 23 illustrates the logical connections between the applications and the Bluetooth adapter. Native C/C++ components are used for creating and translating the messages in the communication between the device and the transformer. In Android environment this set of components is executed in Java virtual machine using NDK. The native C++ APIs are published to Java *Android App* using JNI. Table 1 describes the components and their behavior with respect to the naming used in Figure 23.

| Component | Description |
| --- | --- |
| Stack | Protocol stack used by *Comm* for message creation, reading, sending and receiving. *Stack* is an existing component, which is reused with additions to the communication path by adding *Mobile BT UART* component to direct messages through *Android BT API*. |
| Mobile BT UART | Replaces Win32/Linux UART in *Stack* implementation to interact with *Android App's* BT service through *SendAPI* (data write) |

| | |
|---|---|
| | and *ReceiveAPI* (data read). |
| ReceiveAPI | The API is implemented within *Mobile BT UART* component. It is directly used by the App Logic's BT component for reporting the incoming messages from the BT connection for further decoding. |
| Lang | Handles local language file handling, e.g. used for getting a parameter name using the parameter's id. |
| Comm | An abstraction layer on top of *Stack*, including functionality e.g. for initializing communication to a drive and reading and writing parameters. |
| Adapter | An abstraction layer on top of *Comm*. Offers the API to the Android Java client for using the *Stack*, and thus the communication to the drive. |

**Table 1: Native C/C++ side i.e. frequency converter specific**

Android App part includes client's basic UI and application logic components running within Java's virtual machine. The components handle e.g. drawing the UI, handling user interface events and starting up the BT connection. The event handling interacts with the frequency converter side implementation, thus moving the user actions from the UI to BT connectivity. Table 2 describes all the components and their behavior with respect to the naming used in Figure 23.

| Component | Description |
|---|---|
| Client UI | Defines all the UI elements displayed on the Android's screen, gets displayed data from the *Data Model* through data binding, and forwards event handling from the user input to the *App Logic* (handled by Android platform). |
| Data Model | Contains the data structure of all the data that is displayed by the *Client UI*. The data is updated in the *Data Model* by the *App Logic*, when e.g. relevant information related to current UI interaction is received from the frequency converter. The updated data becomes visible on the UI through data binding. |
| App Logic | Contains the event handling from the user input and moves the actions to frequency converter communication using the *Adapter*'s API. Owns the BT connections, which it opens by user request, and passes the connection to the frequency converter to be used by the *Mobile BT UART*. Using *Adapter* and the user input, *App Logic* updates the *Data Model* content, thus displaying e.g. connection creation progress, parameter and group data on the UI. |
| BT | Handles BT connectivity by using *Device BT API* (Android com- |

| | |
|---|---|
| | ponent). The component is constructed and initialized by the *App Logic* and used by the *Mobile BT UART* for communication over BT. |
| SendAPI | The API is implemented within *BT* component. It is directly used by the frequency converter's *Mobile BT UART* component for sending the outgoing messages to the BT connection. |
| Device BT API | Device platform implementation of the BT API. Existing component in the Android platform. |

**Table 2: Android App side i.e. smartphone specific code**

Table 3 illustrates four function prototypes that describe what kind of function calls are happening inside the software in Android App and frequency converter. The first two are related to software code running in the Bluetooth adapter in frequency converter. The last two items are related to Bluetooth data traffic in Android application. The same functions can be found from the object diagram shown in Figure 24.

| |
|---|
| **void** sendAdapterMessage(**byte** id, **String** group, **String** parameter, **String** message)<br>**Parameters:**<br>*id:* Message type id<br>*group:* Group id<br>*parameter:* Parameter id<br>*message:* Message string |
| **void** receiveAdapterMessage(**byte** id, **String** group, **String** parameter, **String** message)<br>**Parameters:**<br>*id:* Message type id<br>*group:* Group id<br>*parameter:* Parameter id |
| **void** writeData(**byte[]** bytes)<br>**Parameters:**<br>bytes*:* Array of bytes to write. |
| **byte[]** readData(**int** timeout)<br>**Parameters:**<br>*timeout:* Timeout in microseconds.<br>**Returns:**<br>Array of bytes |

**Table 3: Function prototypes of used functions inside the application and frequency converter**

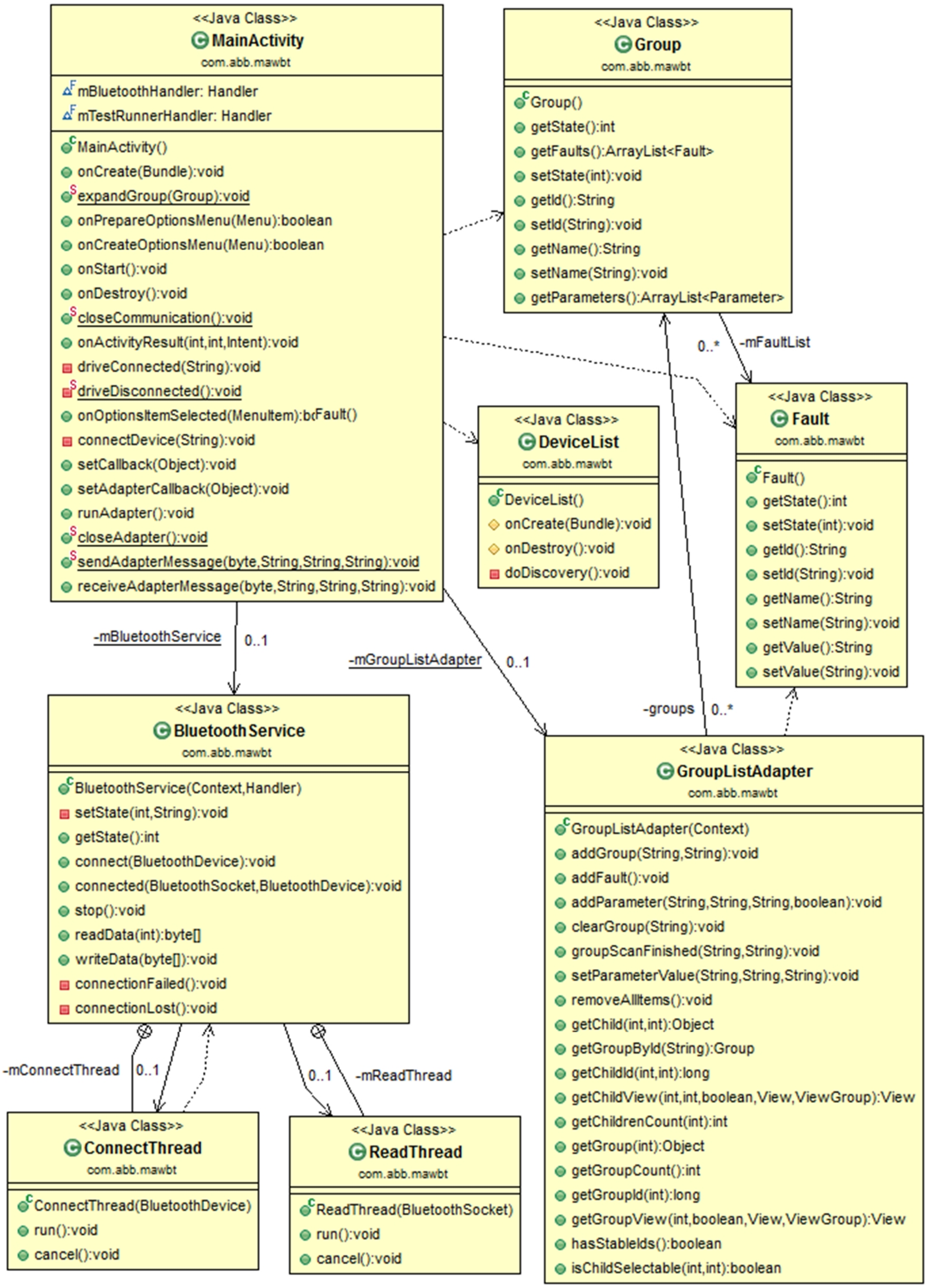



**Figure 24: UML object model for the application**

Figure 24 illustrates the UML object model for the application. The figure does not represent everything needed, but core classes and functions how the Bluetooth communication establishment works and how the *MainActivity* class gets the fault data from the frequency converter.

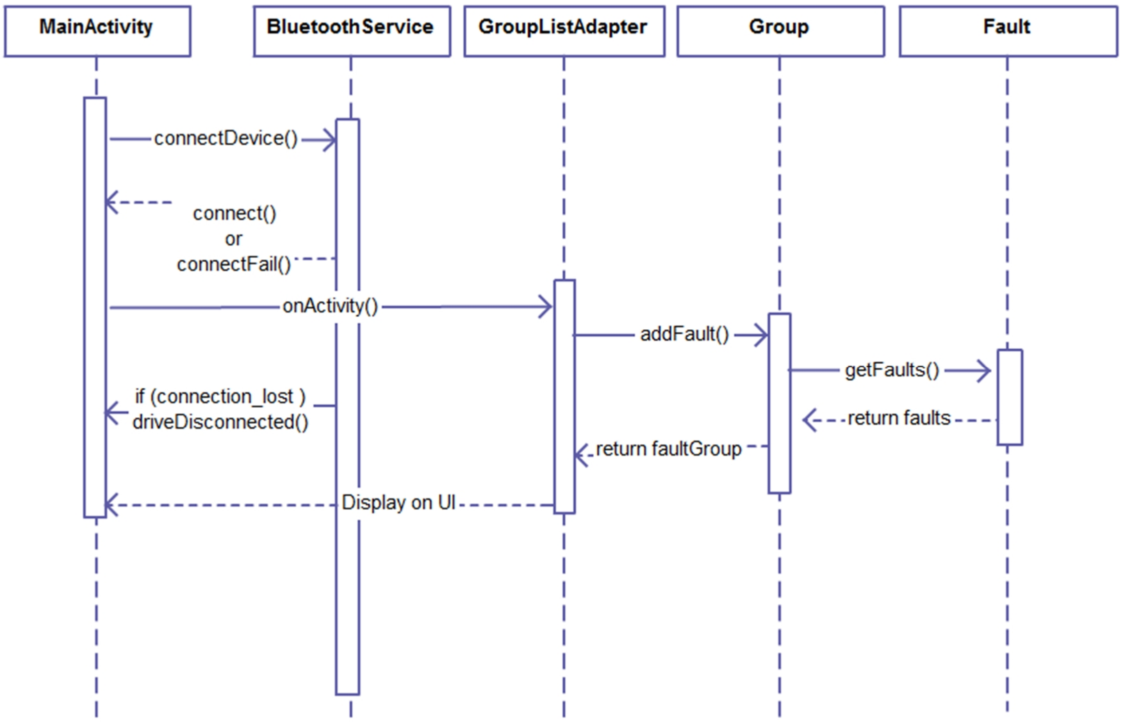



**Figure 25: Sequence diagram for basic fault code fetch**

Figure 25 illustrates the basic sequence over time, when the mobile application makes request to the frequency converter for the fault related data. At first, there is a connection period, where smartphone is paired with the drive's Bluetooth adapter. If the connection fails, the fault fetch process is terminated. Even after a successful connection, the link may break and the process is terminated. Link breaking may be caused by external factors, like interference, or user simply walking too far from the device. After pairing the devices, application can start the fetching process for fault code data. This happens through *GroupListAdapter* class, which translates the fault groups to human readable content.

## 6.3 Interface design

The user interface is the visible part of a computer system, where a user can see, hear, touch, talk or otherwise manipulate the computer system; it can be said that UI defines the usability of the system. There are three major considerations how to successfully create a mobile interface: development factors, visibility factors and acceptance factors. Development factors are focused on creating rich visual communication. The development tool defines how well and flexible the interface components can be designed and implemented. Visibility factors account for human factors, such as the identity and abilities of humans. Acceptance factors are related to politics, markets, documentation and training. The company itself can heavily influence on the acceptance factors by proving, for example, good documentation and training for the users.

The following figures present examples of how the interface for the application could look like.

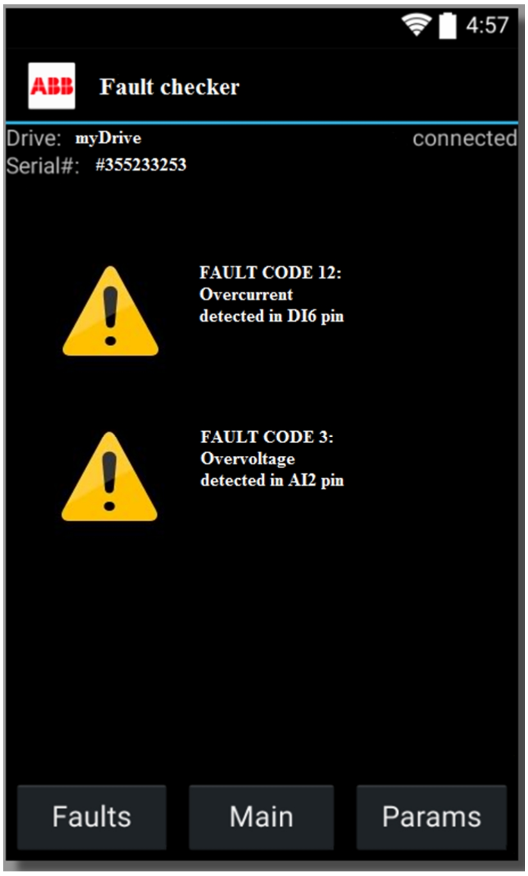



**Figure 26: Example look for the fault code check main view**

Figure 26 illustrates simple look and feel for the fault code check application. Connection status is always visible for the user to know whether the connection has broken or not. Information like the serial number should be displayed, because this is the identification tag for user to know which drive it is currently connected. The space in the middle is left for the faults. This simply shows current and active faults. Lower part of screen consists of buttons for different interactions. Buttons were chosen, because the application should support even the older Android versions, which do not support, for example, swiping. Even using swiping, more interactive user interfaces could be designed.

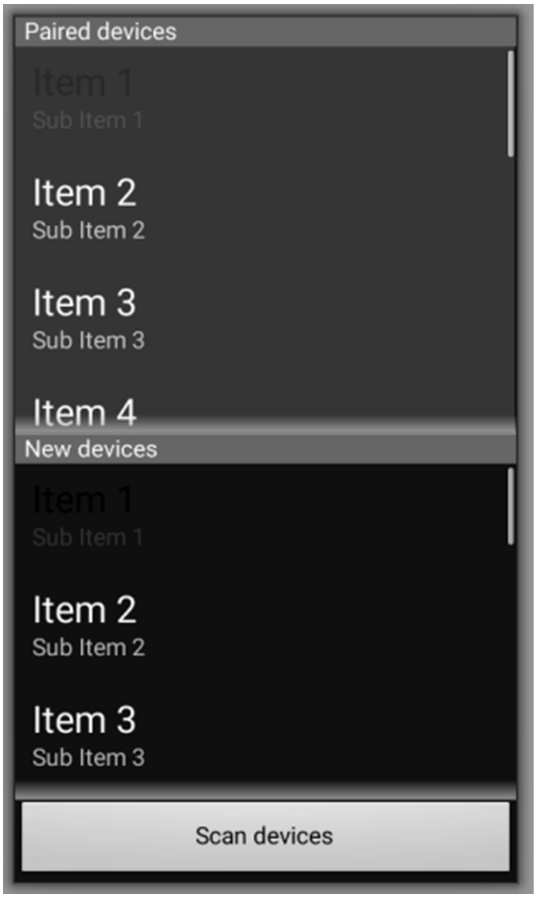



**Figure 27: Example look of the device list**

Figure 27 presents the view how different devices, the already known and still unknown could be simply shown on a mobile screen. The items are clickable, therefore reducing the amount of clicks and making the objects that appear on the screen larger, which makes the touch interface easier to use. One big problem in the user interface design is too small clickable objects. Applications designed to be used in a factory environment should be kept easy and icons as large as possible, because the diversity of users is large.

## 6.4 Analysis

This section evaluates how the application prototype succeeded. The prototype included the bidirectional communication link between a frequency converter and a smartphone, the application use case, where this communication link and the android application software were utilized.

The bidirectional Bluetooth link was designed to be smooth and consistent through the whole dialog between a frequency converter and a smartphone. Even though Bluetooth is designed to work in environments, where interference is present, the connection was tested in a factory environment where the communication link was exposed to interference originating in the 2.4 GHz spectrum and its multiples. No communication breakdown were detected, even though in heavy interfering environments the data throughput rates will degrade since the Bluetooth protocol have to do packet resends to cover the lost packets, but still the communication can be kept secure and reliable, which is exceptionally important regarding applications working with frequency converters.

The fault check use case is a simple case, where user needs to read the error codes from a frequency converter to determine what went wrong. After finding out the reason, the device can be driven to a reset mode, where it starts operating normally again, or it can be replaced if the malfunction is critical. The reason why smartphone is exceptionally good for this is the size of it. Usually in a factory environment the frequency converters are in tough locations which make the usage of larger computers hard. For simple tasks like fault code checking and resetting, smartphone offers simple and intuitive touch interface for the user to operate.

Application structure follows the Android developer design flow and SOLID principles, which ultimately lead to easier debugging and continuation of the development in the future. The environment is designed to be replaceable with new parts. For example, if a new communication interface like NFC is to be implemented, the Bluetooth communication part in application code can be easily turned to NFC equivalent model. Also the user interface was designed so that new features can be easily added to it, without compromising applications learnability and usability.

# 7. CONCLUSIONS

In the mobile phone business scene smartphones have overrun the traditional mobile phones in terms of quantity and capabilities. The exponential growth of smartphones and the possibilities what can be done with smartphones provide a solid base, where to start implementing smartphone applications that work with frequency converters. According to the latest IDC researches the growth trend in smartphones and the capabilities continue strong in the following years. Therefore it can be said, that smartphones have established itself in the pockets of almost every person, and can therefore be very well utilized for action. Important part to notice here is that this way only application development is required for the end user device, and therefore requires no proprietary end user device solution. Growing smartphone markets and the aging installed base gives the possibility to differentiate from competitors in a useful and profitable way. Further development of application areas should be started immediately and possibly with a potential customer, therefore reducing the amount of misunderstandings, while receiving the maximal output potential from the application functionality.

Today's smartphones possess powerful hardware with up to octa-core processors in the high-end models. The most widely spread wireless technologies can also be found in the smartphones. It also seems like these wireless technologies are here to stay, and it is reasonable to implement some of these technologies in the frequency converter to get the most of the smartphones. All of the top three application ecosystems are well documented, made reasonably easy to develop and to maintain the applications in-house, requiring no third parties, which increase the complexity and costs of the development and maintenance processes.

Cross-compilation environments should be tried, at least, while making the prototypes. Cross-compilation IDE’s make the application deployment process much faster and enable in-house development with relatively small resources. One person could be enough for the development process of smartphone application. More people are needed for frequency converter hardware development and the cloud back-end deployment.

Wireless options for frequency converters should be developed if smartphone integration is continued. The Bluetooth adapter provided a stable connection between the frequency converter and the smartphone and proved to be one possible option as an external wireless interface, before more integrated solutions will be developed. The proposed design requirements for the two-way communication between the frequency converter and the smartphone enable the integration possibility with clouds in the future which greatly expand the possibilities how to control and maintain the installed base and provide better services for customers.

Applications described, where smartphone could be utilized, are only a handful of many possibilities in the smartphone capabilities. Figure 5 on page 8 shows the current ABB service portfolio. For further development there are many areas where new solutions can be made to better serve customers and the installed base. All of these ideas bring a fresh feeling of ABB for the customers as a leading edge technology company, therefore giving advantage over competitors in the customers' decision making processes.

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