Tampere University

Moumita Roy

SURVEY OF THE INTERFERENCE SOURCES IN SEVERAL IOT TECHNOLOGIES

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ABSTRACT

Moumita Roy: **Survey of the interference sources in several IOT technologies**
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The main objective of this thesis is to study about several different IOT techniques like LoRa, BLE, NB-IOT, ZigBee and many other IOT techniques and to model the interference effect in one technique. Also, the goals included to add some analysis of several different environments, channels, and interference behavior. The thesis starts with a literature review about several IOT techniques and then NB-IOT is selected for interference studies. Then the thesis discusses about NB-IOT technology, giving an overview, signal, channel properties, and standardization. In the simulation part, firstly, a NB-IOT signal is generated without interference and then it is checked how it reacts in the presence of interference. it's the performance metric is the Bit Error Rate (BER). Observations are made at several interference power values. Then, a mitigation technique is suggested and open issues of NB-IOT are discussed.

Keywords: IOT, BLE, LoRa, NB-IOT, BER
The originality of this thesis has been checked using the Turnitin Originality Check service.

PREFACE

This Thesis is compulsory part to complete my master's degree in Information Technology. I would like to thank my supervisors to propose me this topic and provide me all support. Their clear guideline and friendly support help me to complete my thesis properly.

I am really grateful to God to give me patient during this time. I am also thankful to all my family members to give me mental support during this study period.

Tampere, 14.05.2019
Moumita Roy

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LIST OF ABBREVIATIONS

IOT	Internet of Things
ITU	International Telecommunication Union
IoP	Internet of People
IoWT	Internet of Wearable Things
EDA	Electronic device automation
ADS	Advanced design system
LoRa	Long Range IOT based technique
BLE	Bluetooth Low Energy
eDRX	Extended discontinuous reception
SNR	Signal to Noise Ratio
JSR	Jammer Source
NB-FI	*Narrowband Fidelity*
NB-IOT	Narrowband IOT
BLER	Block Error Rate
dB	decibel
WSN	Wireless Sensor Network
RSSI	Received signal strength indicator
L2CAP	Adaptation protocol
ATT	Attribute protocol
GATT	Generic Attribute Profile
SM	security manager
(GAP	Generic Access profile
HCI	Host Controller Interface
D7AAdvp	Dash7 advertising protocol
ALP	Application Layer programming Interface
DONAS	Data Over Non -Access Spectrum
PSM	Power Saving Mode
QPSK	Quadrature Phase Shift Keying
MIMO	Multiple Input Multiple Output
SC-FDMA	Single Carrier Frequency Division Multiple Access
MIB	Master Information Block
NPDCCH	Narrowband Physical Downlink Control channel
NPDSCH	Narrowband Physical Downlink Shared Control Channel
NPRACH	Narrowband physical random-access channel
NPRACH	Narrowband physical uplink shared channel
MME	Mobility Management Entity
EPC	Evolved Packet Core
NPSS	Narrowband Primary Synchronization Signal
DBPSK	Differential Binary Phase Shift Keying
FDMA	Frequency Division Multiple Access
CP	Cyclic Prefix
CRC	Cyclic Redundancy Check
MQTT	Message Queuing Telemetry Transport
RRC	Radio Resource Control

1. INTRODUCTION

1.1 Motivation

IOT is nowadays a most popular phenomenon. It helps software and hardware to work together without human interaction. IOT has a wide area of application domains, such as smart cities, smart parking, smart metering and healthcare issues.
Several different factors and technologies exist in IOT. Technologies are working different way comparing to each other. Their deployment and characteristics are also quite different.

1.2 Thesis objectives

This thesis shows an overview of several different IOT technologies, architectures and their deployment. Then it shows one specific IOT techniques brief explanation and its interference analysis. This thesis shows proper description of several different IOT techniques and their performance analysis and behavior and give some explanation about circumstances like ultra- narrowband, narrowband, wideband and licensed and un-licensed spectrum.
This thesis will help to analysis the interference performance of one IOT techniques and literature review help to understand several different IOT technologies. Further, discuss some open issues and mitigation based on analysis.

1.3 Author’s contribution

The topic choice was motivated by the desire to work on a new phenomenon which will be provide a great impact on near future. The thesis contributions are to explain several IOT techniques and their interference and brief overview of NBIOT techniques and idea how to mitigate interference in near future.

A wide part of this thesis is literature review and another smaller part is the simulation part, which describes briefly what will happen when interference occurs.

2. BRIEF OVERVIEW OF IOT

The Internet of Things (IOT) is nowadays so much a familiar word, which cause a revolutionary change in our modern IT sector. The term IOT consist of two words: one in called 'Internet' which is a standard internet protocol suite support worldwide people and another word is called 'Things', in this case, this word is basically used for wireless devices or any other electronic devices. IOT task is to establish a connection between these devices without human participation.

2.1 Definition of IOT

In 1999, Kevin Ashton, a British entrepreneur, proposed a RFID connected network object, he is primary inventor of "IOT". A proper definition of IOT is that, a network object which has certain capability to automatically synchronize data and resources, information sharing, can be part of several different environment.
Year review of IOT: Executive Director of Auto-ID center Of MIT (Massa chute Institute of Technology) invented IOT.
In 1999, Neil Gershenfield introduced his own book "When Things start to Think" about IOT.
In 1999, Kevin Ashton, David Brock and Sanjay Sharma proposed an electronic product code for IOT.
In 2000, Internet of Refrigerators Ideas are proposed by LG.
In 2002, David Rose and some other participants of MIT labs create ambient orb which published coordinated with NY times Magazines.
In 2003 -2004, The US department of Defense initialized RFID to their Savi program and commercial world wall Mart
In 2005 Internet of things in reported by The UN's International Telecommunication Union (ITU).
In 2008, The EU first gave recognition to IOT and first conference was held for IOT. In the same year, The IPSO Alliance was launched by a group of companies which use IP networks as smart objects and enable IOT. 'white space' spectrum was approved by FCC. The US National intelligence council also take IOT as their concerning issue. In 2008 -2009, Cisco's Business solution Group establish IOT. In 2010, Chinese premier wan Jiabao, a great proposal proposes for IOT that IOT will be an important phenomenon for china in future. In 2011, protocol allows for 340, 282, 366,920, 938,463,372, 607,431,768,211,456 addresses were launched by the IPV6 public.[1].
Internet of things consist of embedded intelligence, Internet of objects, web of things, corelated technology with devices, can also integrate physical and computational re-

sources, which can make a connection between imaginary and real world, here every imaginary object has power with connection to global network, calm technology or ubiquitous computing, machine to machine communication, human -machine interaction, ambient intelligence which provide sensitive and responsive environment. Internet of things must need to fulfil demand of dynamic resource, real time, application availability, security of user data, exponential growth, sufficient power consumption, cloud system access. An author also proposes that, three physical components need for IoT, hardware consists of actuators, Ip cameras and sensors, embedded communication. Middleware component for storage and computational analysis for Big Data solution, presentation component for application different visualization and tools interpretation.[1].

2.2 IOT Evolution

Internet of things nowadays achieve attraction of several different industries as they can be deployed anywhere, any environment without taking consideration of time and other factors. Related terms of Internet of things are Internet of People (IoP), Internet of wearable things (IoWT), Internet of Everything (IoE), Industrial Internet of Things (IIoT).

IOT evolution

Nokia provides some information about evolution of IOT to their article named IOT next step internet evolution. They show some step from previous IOT themes to modern IOT as like as-
Pre internet which consider Human to Human interaction as like fixed telephony, SMS. When pre internet consider to smart networks then, WWW-Email, information, entertainment, its beyond called Internet of content. Another term is called internet of services which consider smart IT platforms and services, Web 2.0- e -productivity, e-commerce, its beyond. A newer term added after internet of services which is called, Internet of people considers social media, skype, Facebook. Internet of things consider all such features like machine to machine, automation, metering, payment, actuation.

2.3 IOT Architecture

International Telecommunication Unit (ITU) proposes network architecture which include several different layer applications such as:

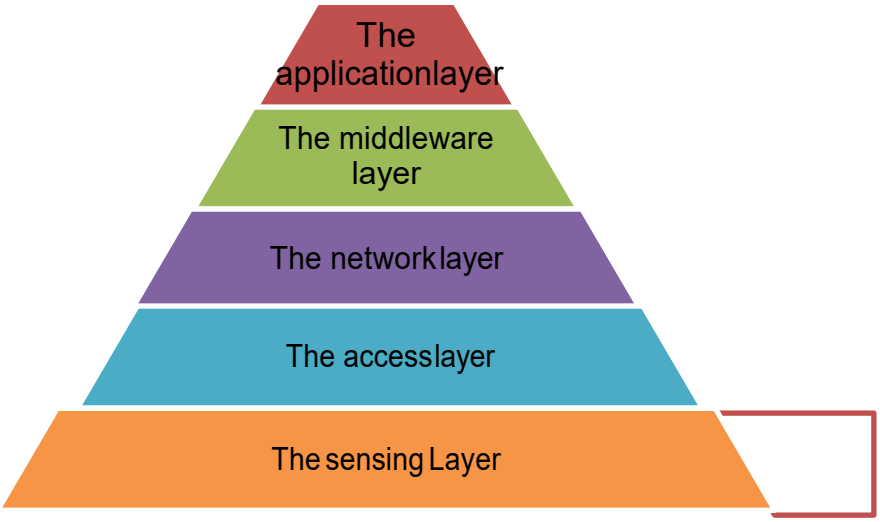

Figure 2-1 IOT Architectural View

a. The sensing layer, a physical layer co -existing with several different architectures depending on bandwidth such as Ultra narrow band, narrowband, spread spectrum and multicarrier. It changes with several different carrier frequencies.
b. The access layer, which introduce edge technology that initialize critical data and send receive data to data center and cloud network.
c. The network layer establish network connection between several different network.
d. The middleware layer, establish connection between several different heterogenous devices
e. The application layer which provide necessary support to users and provide services to network protocols.

2.4 IOT Topologies and Connectivity

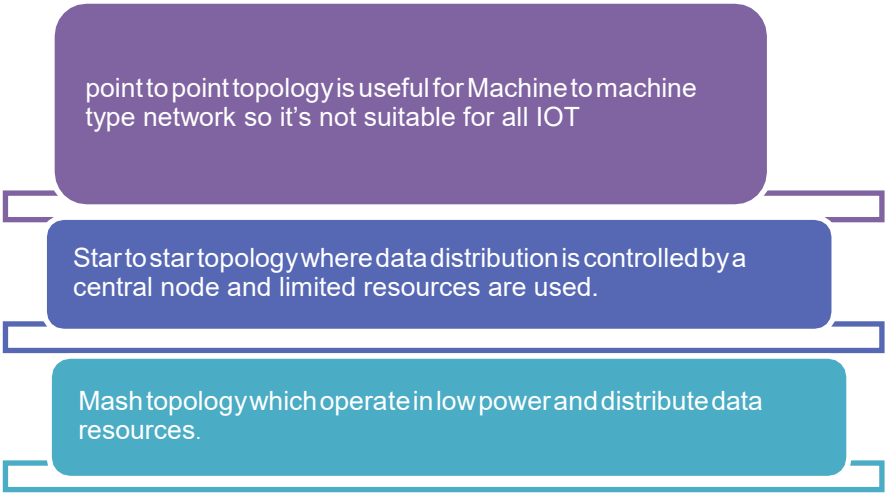

Figure 2-2 IOT topologies and connectivity

Machine learning and big data analysis are two main features of IOT. IOT supports machine to machine communication for initializing data and routing messages between several different intelligences and actuator and sensors. Topologies task is to establish connection from gateway to server. If simple gateways are used, then data routing will occur easily, and it reduces implementation costs. Either if complex gateways (included 'edge' and 'fog' program-based gateway) are used, then implementation requires high latency and costs [2].

2.5 Criteria or considerations for designing new IOT devices

Power efficiency maximization, electro thermal effect management, electromagnetic coupling needs to be taken into consideration for designing IOT device. Keysight technologies uses EDA (Electronic device automation) software for implementing new IOT device. EDA tool include circuit envelope, Golden gate RFIC simulator, harmonic balance, Em Pro 3D EM simulation environment, advanced design system (ADS) [3].

3. OVERVIEW OF MAIN IOT TECHNOLOGY

3.1 LoRa Overview

3.1.1 Overview

The goal of LoRa WAN is to transfer long range information by using low data rate. Its working principle is based on SS-spread spectrum modulation, which uses a chirp signal that depend on the frequency changes. Its operational time and frequency offsets are remaining same which helps them to reduce the complexity of receiver. As its operating principle is based on the Low power wide area network so it only connects bidirectional battery powered operating devices. It designing principle is based on star topology which can separate its structural view in two parts. One is back end part which collects sensors information and another part is front end part which consists of the end device nodes and the gateway modules.
Its end devices are divided into three parts. Class A device, Class B device and class C device.

Class A device
This device has highest energy efficiency because it can receive information only after the server end to send information. This it separates in two different time slots.

Class B device
The gateway can send a beacon types of message which is received by this device. It also follows time slots.

Class C device
Class C device can receive unlimited information which means that these devices can receive maximum number of information as they have capability to bidirectional communication and allocated time slots.
Another most valuable advantage of LoRa is that through encryption algorithm it can provide high level of security. Its scalable features and bidirectional communication help to adapt easily [4].

3.1.2 Lora WAN Architecture

LoRaWAN architecture consists of end nodes and gateway modules which connect with server network. WSN nodes can be connected directly to several gateway modules so it can offer remote control capabilities. A microcontroller is used for managing

Lora trans-receiver which is also helped to send configuration commands to the trans-receiver and send message to the gateway node.

3.1.3 LoRa mesh networking module

LoRa mesh networking module helps to transfer data from gateway to another destination in short time interval. For this feature, a beacon is sending by the gateway to another nearest node and then this gateway is considered as a parent and the gateway start to query data and send this to node as node can be able to join its network. LoRa devices cannot communicate wirelessly with gateway that's why this mesh networking module is needed. It's a kind of radio module like XBee where application processor is providing command for working [5].

LoRa mesh networking architecture actually includes a Nuvoton Nano100LE3BN, an ARM M0 microprocessor and a Semtech SX1278. A 5v USB adapters are used for maintaining power consumption of all nodes and gateways. A serial peripheral interface is used for establishing a connection between a microprocessor and LoRa trans-receiver. This architecture is based on LoRa PHY, data can be collected from IOT sensors, so it can be distributed in large area like campus by using only one gateway. In this architecture, LoRa devices act as a data router, to build a communication between indoor devices. Here, IOT sensors are working also in indoor environment. Deployment procedure of IOT sensors is not too much complicated, a single GW can do this deployment procedure successfully [6].

3.1.4 Example areas of LoRa

LoRa provides quite a huge benefit for vehicle monitoring system, temperature monitoring and Baltic water waste monitoring system. Baltic water waste monitoring system is used for to maintain water ecological environment. For this monitoring, it's also needed to ensure quality of services of LoRa through ensuring packet loss, throughput and delay. Clients sending data packet and gateways receiving data packets need to compare for measuring the packet loss. Certain amount of bit received by a certain amount of time shows throughput and delay means that how long it will take time to send a packet from client to gateway [7].

3.2 BLE

3.2.1 Overview of BLE

BLE (Bluetooth low energy) provides users data privacy, integrity and encryption. In order to achieve this security, it works as a pairing method through which the users share their information about identity, data to gain trust and suggest an encryption key for next step data transferring or sharing [8]. Most of this data is encrypted but some

over them also transfer through unencrypted channels, for this type of data security BLE works in another way. At first data is send to the protocol data unit and then receiving device verify this data and then PDU shows that this data is trusted.[9] Bluetooth low energy uses private addresses which means that these addresses will be changed by time to time which provides a higher security to track an LE device. These privacy features are work in two ways one is that there addresses directly send to the controller and here host provide all information like identity, authentication directly to the controller and another way is to after resolving this address, it directly send to the host [10].

3.2.2 Areas where BLE beacon can be used for indoor location estimation

Indoor location estimation technique is basically used in a store for tracking human be heavier in a store. The most common method for this indoor location estimation is to establish a RSSI (Received signal strength indicator) signal from beacon. But this signal is affected by surrounding environment and diffraction. So, when this RSSI values sometimes shows error. Actually, estimation technique using BLE beacon also shows error because of WIFI and movable obstruction. For this estimation a BLE receiver is needed for those customers who enter into that store then existing video camera in that sore can detect that object. This estimation shows less error then RSSI because that BLE beacons can work in static obstruction [9].

3.2.3 BLE protocol architecture

The controller, the host and the application are the three most common layer in BLE, where the controller has the two important functional layer one is the physical layer and another one the link layer, the host also includes logical link control and adaptation protocol(L2CAP),the attribute protocol (ATT), the Generic Attribute Profile(GATT), the security manager(SM) and the Generic Access profile(GAP). A Host Controller Interface (HCI)is needed for establishing a connection between a host and a controller. L2CAP layers can reassemble packets and perform segmentation. ATT shows the server and client activity while the SM is used to pair device, authentication and key distribution. Transmitting and receiving BLE data is store as a database which is call a GATT server. This data can be transmitted from one BLE node to another BLE node [10].

3.3 DASH7

3.3.1 Overview of Dash7

Dash7 alliance protocol is a LPWAN standard which is actually based on bi-directional wireless sensor and actuator network applications. This protocol is based on ISO/ IEC 18000-7 standard which operating band is sub-1 GHz. This protocol stack is actually make a relationship between RFID and WSAN.Dash7 is also called a BLAST networking technology where Bursty considers to send limited range of data sequence, light is called because of smaller packet size, asynchronous communication, no need of organized , scheduled beacon that's why it is stealth and because of mobility features it refers as transitive[11].

3.3.2 Architecture

Dash7 networking architecture includes sensor nodes, gateways and actuators and its supplier equipment is called wizziLab, which generates a wizzikit consists of wireless sensor actuator network. This protocol architecture also designs based on star network topology including end devices and gateways. At first this end devices connects with dash7 IP gateways and the MQTT protocol helps to connect this Gateways to wizzikit. The MQTT protocol is a kind of transmitting protocol which is actually make a connection with its client and establish a XL configuration with the cloud server. Thus, this procedure builds an actuator, sensors for monitoring the end devices and gateways data [11]. When a request is stored then a Dash7 advertising protocol (D7AAdvp) is used for ad hoc synchronization. In this overall procedure a command is also execute which consist read, write or execute file command is called Application Layer programming Interface (ALP) commands. This Dash7 advertising protocol (D7AAdvp) provides a framework containing estimated time of arrival of data and that ALP command. This overall architecture is helpful for low power consumption. [12]

3.3.3 Working Principle of DASH7

Dash 7 working principle can be classified in three parts as like as below:

Transmission procedure
A message is transmitting through CSMA / CA procedure from end devices and these end devices can connect with any of acknowledged gateway. The end devices broadcast their messages as if that connection is lost then procedure will not stop. If there are several gateways responding, then the end devices select only one among of them based on link budget [13].
Reception procedure
There are two types of communication procedure one is pull which is used for background frame reception, here gateways and end-devices send background frame. Another communication procedure is called push which is used for foreground frame, here request/response are detected between end devices and gateways. [13]
Reception of messages
End devices is waiting for a synchronized frame, if it finds than it starts to decode the frame and then subnet, CRC16 and link quality and ED address filters these frames are

transferred to the upper layers. If end-devices are not found a synchronized frame this process will be stopped [13].

3.3.4 Applications of DASH7

There are several applications of Dash7. Dash7 is used as ground sensors for searching parking lot. It is also used to detect food cart location and coffee cup temperature estimation. [14]

3.4 EC-GSM-IOT

3.4.1 EC-GSM-IOT Overview

EC-GSM-IOT provides an east solution to improve efficiency and specifies Maximum coupling loss (MCL) for better coverage. It's also a Low power wide area technology which operates on eGPRS and provides better capacity and wide range with low complexity architecture.

3.4.2 EC-GSM-IOT Architecture

EC-GSM-IOT shows a multi frame structure to synchronize the network. 51 frames with eight time slots are working on a Broadcast control channel (BCCH). There is also a synchronization channel (SCH) which can carry the identity code of base station and frame number. If there exist EC-SCH (extended coverage synchronization channel) then device will be able to decode the SCH. Existing EC_SCH indicates that EC_GSM IOT works in these above procedures. Secondary step is synchronization. For this step the initial task is to detect the Multi frame boundary and for this at first try to observe the start time of MF and EC-SCH position [15].

3.5 Ingenu/RPMA

3.5.1 Ingenu Overview

Ingenu is an unlicensed LPWAN technology which follows RPMA (Random phase Multiple Access) method which works in uplink.

3.5.2 Security analysis of RPMA

To establish a channel, RPMA needs end device and the network authentication, RPMA actually works as CDMA based method, which actually works in this that in a random delay transmission occurs and timeslots increases during that time. Traffic

attacks can be prevented by this way. Its main feature is multicast authentication. Firmware upgrade and message confidentiality is also working in this method [16]. Its Downlink signal strength proposed the spreading factor. RPMA works in 1MHz to 80 MHz band [17].
NBFI/WAVIOT WAVIOT is a low power wide area network which is based on Narrow-band Fidelity (NBFI) protocol. This protocol is actually working on physical and MAC layer [16].

3.6 NBFI/WAVIOT

WAVIOT is a low power wide area network which is based on Narrowband Fidelity (NBFI) protocol. This protocol is actually working on physical and MAC layer [18].
WavIOT works on 1GHZ ISM sub-bands and its modulation scheme is DBPSK and it support public, private, enterprise type networks. NB-Fi is based on star topology and all data from gateways is stored in the cloud server and then it sent to the API.XTEA 256 -bit key helps to encrypt all data [18]

3.7 SIGFOX

3.7.1 Sigfox Overview

Sigfox is an ultra -narrowband technology based on sub 1 GHz ISM bands. It doesn't need gateways, instead of gateways, a subscription is implied on each sigfox support related networking device. Network providers operates that Sigfox networks. Here, Gateways data are stored in the Backend server and customer can access that data by using a web portal. After that, callback implementation occurs[19].

3.7.2 Operating principle of Sigfox

Randomized-FDMA (R-FDMA) Channel access method are used in SIGFOX. Here, no prior transmission sensing of channel is needed. An uplink packet is sent, and end de-vice selects that packet and transmit it to the base station. This ensures delivery with less traffic attacks.
Uplink and downlink communication are not operating at the same time, so it is not work as a bi-directional communication. Uplink connectivity uses a BPSK modulation scheme for spectral efficiency, which support 12 bytes payload and downlink uses a GFSK scheme, which supports 8 bytes payload.
Sigfox is also working in MAC layer which working principle is based on ALOHA MAC protocol. Sigfox considers only selected transmitting messages which helps it to be more energy efficient. Medium sensing does not need energy, synchronization of time is not necessary. Here also need a subscription to tell the system that how many packets are sending.

Sigfox provides a web application interface which is helpful for device management and data integration. This application interface is based on Get or post, HTTPS Rest Requests. Metering sensors, tracking sensors are connected in Sigfox network. All callback messages are stored in the application server and an emulator is also placed in this sigfox network which main task is to send back those messages with HTTP protocols. [20]

3.8 Telensa

Telensa is also an ultra- narrowband based unlicensed LPWAN technology. Telensa is originally developed by UK company Plextek which operates in Sub-GHz bands. Its physical layer consists of Ultra narrow band and BPSK modulation and Frequency hopping spread spectrum technique. Application areas are smart city and street lighting.

3.9 Weightless N/P/W

3.9.1 Overview

Weightless special interest group (SIG) has proposed these three types of IOT techniques. There are three standard for weightless; i) weightless P is a bidirectional communication used for secure data exchange for industrial applications, working on frequency hopping a time slot procedure; ii) Weightless-W a whitespace wireless technology which is used for machine to machine communication; and iii) Weightless N is based on ultra -narrow band modulation which follows unidirectional communication that can provide a long battery life and wide area of coverage [16]

3.9.2 Operating principle of weightless devices

Here, the base station works as master and the end devices are consider as a slave. The server stores all key information and during the first connectivity it makes an authentication with the terminal. The slaves can communicate to its own databases and the base station also on the same databases [20].

3.9.3 Working procedure of weightless p

Weightless p can deliver a secured end- to end messages and acknowledgements. A Message Integrity Code (MIC) is used for encryption pf messages and that encrypted messages are send by the126 bits keys. It also uses 64 bits long signatures for authentication. A key wrap crypto graphic function is necessary to establish link for exchanging all keys. As a data counter is used for zero initialization so it is secure from relay attacks and wormhole attacks [16].

3.10 Wi-Sun

Wireless Smart ubiquitous network (Wi-Sun) is IEEE 802.15.4 g standard based technology which shows Wi- Sun specification. Its networking structure is based on star and mesh topology where every node connects to the network. Powered or battery powered both devices can use Wi-Sun. Its IPV6 protocols provides smarter utilities and use for Smart city.
It is backward compatibility features help it to high its networking performance. There are several companies who is working for Wi-Sun. Transmission of data includes AES, HMAC and certificates. Authentication is required for network access control.

Operational procedure
As it is based on mesh network topology so if it included more devices during operational time, then its reliability would be improved [21].

3.11 ZigBee

3.11.1 ZigBee Overview

ZigBee is working in Wireless Sensor Network (WSN) interfaces, which is basically implemented for Machine to Machine wireless communication. Its architecture is easy to implement and less expensive and it has great impact on automation and medical sector like patient monitoring and also some intelligence operation like enemy tracing [22].

3.11.2 ZigBee Architecture

There are certain types of devices working on ZigBee, such as Full Function Device (FFD) is responsible for tasks co-ordination and sensing, routing purposes. An AC-Fed power supply is needed to active these devices Another type of physical device is called RFD (Reduced Function Device) which is working with this FFD, but it has no impact on packet routing. ZigBee is also considered some logical devices like coordinator, router and end devices. Coordinator task is to make a network connection to others network. It can identify a unique identifier, radio frequency channel and also collect information about security keys [22].
Router can also make an interconnection with other devices by using re-transmission of the network. End devices (consider as a low power devices) also have huge impact to collect information from sensors and switches. ZigBee operates on star, tree and mesh topology[22].

3.12 Z-Wave

Z-wave is based on open standard ITU-TG9959 and z-wave alliance which is originated from Danish start up Zen-sys. It is deployed in non-licensed sub-GHz bands. Con-

trollers, mobile controllers, slaves, routing slaves these devices are used in Z-Wave. Application areas are home monitoring and control, smart and keyless locks, smart lighting and home monitoring and controlling [1].

3.13 RFID

Radio Frequency Identification Technology (RFID) is an oldest form of IoT. It is a transmission system which use radio waves and transmit person and object identity as a serial number. Tags, Active tags and passive tags these are the categories of RFID. Antenna, access controller, server, software, tag, reader there are the components of RFID. Application areas are patient monitoring, military apps, tracing and distribution [1].

3.14 Near Field Communication

NFC is deployed in ultra-short-range frequency bands. NFC tags and NFC readers are two main devices of NFC. Application areas are smart cards or contactless payments [1].

3.15 NB-IOT

NB-IOT is one of the most familiar IOT techniques as it saves cost and power efficiency due to its simpler designing and also several other applications. Unlike the previous ones, which are non-cellular IOT techniques, NB-IOT is a cellular IOT standard, which will be described in Chapter 4.

4. NB-IOT OVERVIEW

4.1 Overview

NB-IOT is an LPWA technology which is mainly deployed for low data rate applications, low power consumption and better coverage including indoor penetration and mobility. Minimizing congestion issue, it is deployed in licensed spectrum. Comparing to any other technologies like LTE, CAT-1, it does not have any hardware complexity. Its deployment cost is cheap because it can be co-existed with others existing LTE and GSM. It signaling cost is also not so high, so that it is beneficial for energy consumption. This is the highest benefit for this NB-IOT technology.

NB-IOT can provide massive connections which means that in one cell, there are quite many user can exist and their latency is not too much sensitive and can work at low frequency level. Both single tone and multi tone scheme can be supported by NB IOT. Including single tone scheme, NB-IOT can schedule 12 Sub carriers with 15 kHz sub spacing and 48 Subcarriers with 3.75 kHz sub spacing.

Its operational bandwidth is 180 kHz where uplink and downlink bandwidth are not possible. Here, device operation will be occurred in half duplex mode, so transmission and reception are not possible simultaneously. So, it can be reduced device cost.

Extended discontinuous reception (eDRX) and power saving mode (PSM) features is needed for reducing power consumption. In eDRX feature, the paging channel can be monitored by the user equipment periodically and in power saving mode device will be as same state as receiver.

To achieve wide area coverage, three classes CE level0, CE level1 and CE level 2 are defined to calculate the repetition number Through network bandwidth reduction there can be achieved 7 dB and repetition transmission it can be achieved 13 dB bandwidth.

NB-IOT does not contain higher modulation scheme like QPSK so it can minimize complexity and cost.

As it operates in licensed band, so security level is quite higher in this technique and due to higher capacity, it can reduce the chip area.

Signal optimization can be achieved by NB-IOT as it is based on data over non access spectrum (DONAS) which does not need user plane activation for data transmission and be able to support sporadic type transmission of data. It can also be deployed a Radio Resource Control for optimizing user plane which can easily reestablish the user plane.

NB-IOT also support channel quality indicator, handover, dual connectivity and intra RAT mobility and reporting features for cell selection process to transmit small number of messages on one cell.

4.2 Standardization

NB-IOT is working as NBIOT-OFDMA formats and NBIOT-M2M formats before standardization and together these two formats are called NB cellular IOT(NB-CIOT). After that a new format is proposed which is called NBIOT-LTE, which is compatible with existing IOT.[i]Also it takes quite a long time to standardize this NB-IOT and many other things is added for making this technique too much convenient. It's a machine type communication so it is more convenient to power consumption.

Standardization history

Table 1. Table 4-1 standarization history

Device history	**Features**
CAT (1-5), 2006-2009 release -8	Existing LTE features which include OFDM technique in Downlink and SC-FDMA features in uplink, antenna multiplication, broadcast and multicast both are possible, 64 QAM modulation technique is followed.
CAT (1-5), 2008-2010 release -9	Cell optimization is possible here. Beamforming is also an extended feature in this release. Broadcasting and multicasting of multimedia is also occurred here. Base stations are multi radio accessed.
CAT (6-9), 2009-20011 release -10	Its most important feature is carrier aggregation (CA). Deployed MIMO antenna. Support heterogeneous networks. Follow SC-FDMA technique
CAT (9-12), 2010-2013 release -11	Assuming location of user equipment, it can be enhanced packet data gateway. For reducing interference, it can transmit COMP. Integration of WI FI is also happened in this release.
CAT (13-14), CAT 0, 2011-2015 release -12(LTE A)	Reducing signal load as it can be enhanced throughput. Device to device communication is also possible here. 256-Quadrature Amplitude Modulation is following here. Managing congestion of data and radio internetworks. Heterogeneous mobility is quite enhanced in this technique.

	Power consumption is introduced in this release
CATM1 -CAT NB1,2012-2016, release -13(LTE advanced pro)	Device to device communication is enhanced in this release Sc-PTM, coverage of indoor environment, is also specified in this release.
CAT NB2 ,2014-2017, release -14(LTE advanced pro)	It is proposing new device class with shorter TTL and reduce latency and follow massive machine type communication
Release 15(just proposed)	Reducing interference and introducing UTRAN is the main challenge of this release.

4.3 NB-IOT Architecture

NB-IOT is based on EPC architecture which support lower data transmission rate by optimizing user plane and control plane. Here at first eNB connect with that user equipment and then this enodeB can establish a connection with evolved packet core (EPC). Several entities are evolved in this architecture like the packet data network gateway, the home subscriber server, the mobility management plane entity, the serving Gateway. This enodeB can transfer a message signal which is called non access stratum (NAS) (which is basically a protocol that can make communication between user equipment and MME by transferring non radio signal) through an S1 control plane which is efficient for handing of data. Then EPC transfer this to IOT and IOT forwards supported data form to the application server. There are two ways of transmission of data is possible one is IP based, which is more secure and another one is non - IP based which can reduce user equipment overhead.

Downlink frame structure

A radio frame is introduced in time domain where 2 slots are induced in each subframe and like this subframe there are 10 subframe and here OFDMA symbols have also seven time slots. This frame range is Up to 0 to 13 and here subframes are introduced which ranges are between 0 to 1023. A new hyper SFN is also establish if this SFN is reached across 1023 and this hyper sub frame number is also 0 to 1023.Subframes and slots both are signified as 0 to 9 number and 0 to 19 number. With 15kHz spacing 12 subcarriers are deployed in one physical resource block in frequency domain.

Uplink frame structure

There are 12 and 48 subcarriers based on two subcarriers spacing like 15 kHz and 3.75 kHz where slot duration is 5ms and 2ms

4.4 NB-IOT channel and signal overview

Here is showing channels of NB-IOT.

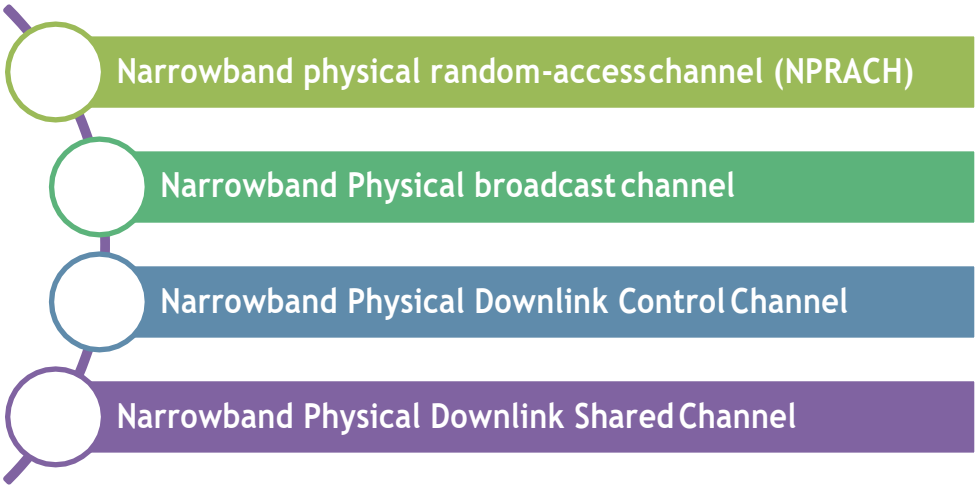

Figure 4-1Channel allocation of NB-IOT

Narrowband physical random-access channel (NPRACH)

The time frequency resource is referred by the NPRACH which is comprised with 12, 24,36 or 48 subcarriers which can be used to transmit random access preambles. There are four symbol groups in these preambles which is consisted of cyclic prefix and 5 symbols. Repetition of preambles during 0.04 s to 2.56s is also occur. The uplink timing can also calculate by this random-access preamble as it is sent by user terminal from eNB. The preamble transmission is starting during 5.6ms and 6.4ms time interval.66.67 micro second which is used for 8 km and 266.7 micro s cell which is used for 8-35 km is supported by the NPRACH. 3.75 kHz is modulated by all symbols. Frequency hopping between eNB and UE is used for better synchronization. Inner hoping and outer hoping are used for better time if arrival estimation and synchronization. The pseudo random hoping pattern is also used to reduce interference. For supporting 20dB GPRS, 128 times repetition of four symbol groups of preambles is occur.

Narrowband physical uplink shared channel (NPRACH)

Its operational principle is based on two formats one is to carry data to uplink with 1000 bits transmission block and it is following multitone transmission. It can decrease the average PAPR. Another format is used single tone transmission and carry control information and 1-bit UCI which retransmit hybrid automatic repeat request. It is better for longer battery life and wide coverage and better capacity.

Demodulated reference signal

Here user equipment transmits a demodulated reference signal for uplink channel estimation. It is consisted with NPUSCH symbols and three symbols as per SC-FDMA slots are used for transferring DMRS and this signal allocated 5^{th} symbols

Downlink channels and signals

To synchronize NBIOT cell, signals allow a device which is really complex

Narrowband Physical broadcast channel

NB-PBCH can carry Master Information Block (MIB) which exist in Subframe 0. It also contains system information bandwidth, information about system frame, estimation of antenna ports and operational mode information. Here, 8 blocks which is decoded at 80ms duration exist in Master Information Block.640ms time duration MIB works as same way. When MIB information start to demodulate than NB-IOT fixed cell antenna port number. Tail biting convolutional encoding and rate matching, scrambling, layer mapping, modulation, CRC generation and attachment these kinds of features are also get in this Narrowband Physical Broadcast Channel.

Narrowband Physical Downlink Control Channel

Downlink Control Information (DCI) is carried by this Narrowband Physical Downlink Control Channel (NPDCCH). There needs an external device for this channel to gather information. Information schedule can be transmitted by this channel and here packet-based transmission is occurred. Here, mapping of resource elements is possible because of existing Narrowband control channel elements. There are also three formats in this channel

- Format N0 which is used to schedule NPUSCH about certain criterion like resource assignment, coding, repetition and modulation of data.
- Format N1 which is used to schedule NPDSCH code word using one cell. It can notify the NPDSCH user data.
- Format N2 paging and direction is occurred in this format.

Narrowband Physical Downlink Shared Channel

Unicast data transmission, message and broadcast information all are the application of this channel. Upper layer transmits data segment to transmission block at a certain time. Mapping of resource element is also occurred here.680 bits Transmission Block (TB) is carried by this channel.

Comparison between NPDCCH and NPDSCH

In NPDCCH, two DCI message is responsible for resource multiplexing while no resource multiplex occurs in NPDSCH. If SIB1NB is transmitted in band mode NPDSCH act differently about OFDM symbol. After evaluation of 24-bit CRC, it is added to the transmission block and then tail biting convolutional coding encoder encoded this transmission block (TB).

Assigning NPDSCH subframes to transmission block, code word length can be fixed. Subframe number and transmission block size can regulate the code rate. Repetition of subframes is needed before encoded TB mapping. This bit is also surrounded with QPSK symbols and scrambled. This scrambling code is changed during every repetition. This code word must be decoded by any other external device.[23]

4.5 Connection procedure

These four steps which is required to establish connection between different cells [23].

Step 1- Identifying and Synchronizing a suitable cell is the main task of this cell selection procedure. procedure of cell selection- A protocol for cell selection is needed for cell selection and a device must be in active mode when it starts to search a cell. A device first gets some information. Time synchronization procedure is needed for CFO value estimation. For better coverage, NPSS frame synchronization is also needed. If CP length is less then latency, then detection of NPBCH might be degraded and it can also have a great impact on downlink OFDM orthogonality. To do this performance better, it needs to upgrade the device complexity.

Step 2- Estimation of Received power is the main goal of this random -access procedure. PRACH resource can detect Received signal received power which can determine the cell coverage and also maximum coupling loss of these certain coverage User Equipment transmit preamble to physical layer by using CE information. Device to eNodeB transmission time is by RA preamble. If eNodeB receive Random Access Response, it means that RA preamble transmission is OK. If not, UE need to retransmit preamble.

Step 3- RRC connection request is needed to establish a connection between UE and network. UE can also support multi carrier and multi tone. eNB transmit a RRC connection setup messages and UE send a connection setup complete message. Sometimes it needs a PDN connection that time NAS attach request needed. Authentication of EPS is introduced here.

Step 4- To transfer small data NB IOT do CIOT optimization which consider control plane optimization and user plane optimization. In Control plane optimization data packet is sent by the UE to NAS with a radio signal. User plane CIOT optimization is needed for larger data transfer.

4.6 NBIOT operational modes

Here are three operational modes of NB-IOT

Table 2. Table 4-2 NB-IOT operational modes

	Standalone	In band	Guard band
Deployment	Dedicated spectrum or spectrum which is used for GSM /UMTS radio access technology	Deployed in existing LTE carrier	Deployed in NB IOT carrier guard band of LTE carrier.
operation	Software and hardware upgradation are needed due to reframe spectrum	Need to share resource block for proper use of spectrum to increase capacity.	There is enough downlink, so it provides better downlink throughput.
Analysis of antenna system	Adding combiner antenna need to upgrade	Antenna can be re -used	Antenna can be re -used
Analysis of Baseband	Baseband unit must be upgrade	Baseband unit must be upgrade	Baseband unit must be upgrade
Analysis of repetitions	Number of repetitions is moderate.	Number of repetitions is excessive.	Number of repetitions is excessive.

4.7 NB-IOT power consumption

There are two important features are included in NB-IOT. One is called Power saving mode (PSM) which cannot receive any signal if it is in sleep mode. Registering with the network, this device can re-establish the connection when device will wake up. It can also avoid network congestion, which is also beneficial for power saving. Applications which requires sporadic transmission is required this PSM. Additional device which is showing timer (active timer and extended timer) is also added in in this PSM. Sometimes device is not reach over a long period, it's a challenging issue of PSM. That time it needs to consider device responsiveness and timer value.

Extended Discontinuous reception RX(EDRX) is another feature for power consumption. It can support downlink and reduce device periodicity in receive mode. As eDRX can be extended more so network and H-SFN (Hyper System Frame Number) is used for synchronization. Small paging transmission window is also helpful to save power. There is less complexity and less overhead to measure channel quantity, it can also reduce power consumption.

Table 3. Table 4-3 power and sensitivity analysis of NB-IOT

	Downlink (in-band and Guard band) Optimistic pessimistic		**Downlink (standalone) Optimistic pessimistic**		**Uplink**
Receiver sensitivity(dBm)	-118 dBm	-1o8.2 dBm	-118 dBm	-1o8.2 dBm	-138 dBm
Transmit power(dBm)	-30 dBm	-30 dBm	43 dBm	43 dBm	23 dBm
MCL(dB)	148 dBm	138.2 dBm	161 dBm	151.2 dBm	161 dBm

4.8 Example areas of NB-IOT

Due to increased efficiency and software implementation of existing LTE networks, Now -a -days it is one of the most promising technology. Utilize meter, automotive industry, management of waste, smart logistics and smart cities, to monitor agriculture and environment, personal task like pets or child monitoring, basement water, gas, electricity monitoring. Some companies are now use its utility feature to build modern cities. NB-IOT sensor can measure the trash bin level which is great benefit for minimizing cost. NB-IOT has also quite a great benefit in smart parking. Utility meter first collect information and then provides the available parking slot. For monitoring environment like environmental pollution intel chip NB-IOT is used. To monitor health, social, agriculture necessary automation and digitization of NB-IOT is necessary.

4.9 Resource allocation technique of NB-IOT

Inner and outer loop areas are introduced UL link adaptation scheme. Inner loop is beneficial for improving block error ratio and outer loop is working for selection of modulation and coding scheme, acknowledgement repetition factor and unacknowledged packets. This technique can utilize resource allocation. For handling massive connection, NB-IOT is used multi PRB design where Anchor PRB which satisfies raster of channel to achieve system information block and paging. Narrowband resource overloads reduce resource allocation. To overcome this issue, non -Anchor PRB use paging, which can improve source utilization.[23]

4.10 Challenges and critical issues of NB-IOT

NB-IOT is one of the best LPWA technology but still it has some problems:

- In band and standalone mode frequency allocation is asynchronous, which causes cell interference. This interference is mainly occurred among one cell to another neighboring cell. If macro cell is deployed in the same cell, then interference will occur during the same cell. It provides wrong value of SNR.
- Due to low power of NB-IOT, Signal transmission power will also low and sometimes interference and fading interrupt this connection, which reason its sometimes difficult to achieve better throughput.
- Resource allocation is not uniform because allocation is based on either coverage or power. So, this ununiform resource allocation sometimes provide worst impact on this technique. There is no appropriate algorithm is defined to overcome this issue.
- In resource allocation, packet synchronization, both uplink and downlink use several different types of latency. It needs a proper method to analyze latency.
- If multiple repetition occurred, then spectral efficiency will be reduced. To overcome this a better resource a better resource allocation technique is needed. For better channel capacity, the device absorbs more power which can reduce lifetime of battery.
- NB-IOT need to consider security attacks like active or passive attacks due to its low power. Other attacks like intruder injection of false data need to consider.[24]

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5. IOT INTERFERENCES

5.1 LoRa Interference

Lora's working principle is based on unlicensed ISM bands which is also working based on ALOHA medium access protocol, that's why co-technology interference and inter technology ISM interference is also occur. If multiple active LoRa devices work at the same time on the same communication channel, then co-technology interference occurs. If this technology shared same unlicensed ISM bands than Inter technology ISM interferences occurs [25]
Another two common type interferences also occur in LoRAWAN, if LoRa devices are established in an indoor environment then wideband interference occur, that time there happens too much packet loss and then another type of interference based on bandwidth performance is called narrowband interference [26]

5.2 BLE Interference

BLE's working principle is based on 2.4 GHZ bandwidth so it needs to face Wi-Fi interference because Wi-Fi is also working on same 2.4 GHz bandwidth. If there exist too many devices at the same time, then the interference ratio will be higher. If there are too many devices sharing the wireless channel at same time in nearer distance, some RF interference is also happening. To mitigate this RF interference, it needs to use devices which have strong output power because it is signaling level can work in the distance level of devices. Always try to deploy this device far from other RF based devices like router [27].

5.3 DASH 7 Interference

Dash 7 is an upload centric wireless technology which is supported a sub-GHz band. In Sub GHz bands there is not so much interference occurs because Sub GHz bands signal attenuation is lower comparing to other ISM frequencies [14].

5.4 EC-GSM-IOT Interference

In ECGSMIOT an inter symbol interference is occur due to its narrow channel bandwidth. This Interference can be minimized by channel bandwidth limitation. If an infinite bandwidth channel is used, then this channel can be passed in all signal. because the received signal is as same as transmitted signal. At this circumstances, transmitted data is not suffered from ISI. Wideband channel allocation is also a great solution be-

cause in this case a channel is so wide that a larger amount of signal power can be transmitted, and higher frequency can be rejected.
If channel bandwidth is lower than half of the symbol rate, then the received signal is suffered from a significant number of ISI. Signal processing algorithm and minimum channel bandwidth allocation is needed to recover this received data. If channel bandwidth is lower than the half of symbol rate than ISI is too much in this case and huge data loss is found [28].

5.5 Ingenu/RPMA Interference

RPMA is working based on unlicensed 2.4 GHz Band so it is suffered from surrounding channel interference. To mitigate this interference, RPMA works as like as Direct Sequence Spread Spectrum (DSSS) as it helps to avoid unwanted channel noise interference in same spectrum. Data acknowledgement with forward error correction (FEC) is needed to ensure that how much error free data is transmitted or received. If there is too much interference is occurred than RPMA can choose another via for communication [29].

5.6 WAVIOT Interference

Narrowband interference is occurred in WAVIO, the main drawbacks of this narrowband systems that it needs an error free RF crystal, which is mainly offset of RF frequency. For better performance WAV IOT supports high quality-based energy efficient component [30].

5.7 SIGFOX Interference

Sigfox working principle is based on unlicensed ISM bands, so it includes many devices to access spectrum, as a result those surrounding interference it needs to face. Receiver performance during this interference is quite remarkable. To mitigate this interference, data packet transmitted to the uplink several times by Sigfox for receiving at least one error free data packet completely. Transmitting power is also a huge impact to transmit and receive this packet and interferences. Without interference sigfox coverage is 96% but with interference its coverage is reduced. Comparing to the uplink, Sigfox provides better performance to downlink [31].

5.8 WEIGHTLESS N/P/W Interference

Weightless N: It’s a Nwave technology based on narrowband technology and differential binary phase shift keying (DBPSK). So here occurs some narrowband interference. To mitigate this interference, it provides FH algorithm which also works against fading.
Weightless p: To mitigate the interference it works with TDMA and FDMA techniques to synchronize time slots and frequency [31].

5.9 ZigBee Interference

ZigBee always faces some WLAN and Wi-Fi interferences as ZigBee networks is surrounded with many Wi-Fi networks. To mitigate Wi-Fi interference, channel allocation is an important criterion in ZigBee. There are 16 communication channels with 2.4 GHz band based is used but at a certain time only one of them can be used for communication with Wi-Fi channels. By that time, frequency is also a special concern to reduce interference between Wi-Fi and ZigBee. There is also another interference occurred which is called dynamic interference. This interference happens if there are more Wi-Fi channels are allocated then existing Wi-Fi channels. In that case, some steps need to follow to mitigate that interference like energy detection. Energy detection is something that router device check energy consumption of all 16 communication channels and determine which channel is suitable for communication at a certain range. Second step is to identify the interference impact. Main impact of interference is packet loss, which means that data is not successfully received. By this time some acknowledgement might be corrupted due to interference. [32].

5.10 Performance matrix of several techniques

This performance matrix table shows that features like channel, bandwidth, frequency etc of several techniques.

Here is describe LORA, Dash7 and ECGSMIOT features.

Table 4. Table 5-1 Performance matrix of LoRa, Dash7, Ec-GSM-IOT

	LoRa	Dash 7	ECGSMIOT
channel	for encoding and decoding in AWGN channel model bits are transmitted to a chrip signal because LoRa is using chrip spread spectrum modulation[1]	Its channel width is 25or 200kHz and 8 non-overlapping normal 55 kbps rate channels, 7 hi 200kbps channels and assuming 72 ,9.6 kbps channels.	Extended coverage synchronization channel implies that network supports EC-GSM – IOT, new logical channel comparing to GSM.
bandwidth(channel)	125kHz, 250kHz and 500kHz	433MHz	200 KHz per channel
Signal	ISM	RF wakeup signal is used for achieving low latency, low power and elegant architecture	GSM signal

bandwidth(if2.4GHz)	less interference than others but inter technology interference and co-technology interferences, narrowband interferences are found	In higher frequency ISM bands, there is no interference in Dash7 but in lower frequency ISM bands, Dash 7 has sideband interference occurred by another devices. not so much interference in 2.4GHz bandwidth due to lower data rate	adjacent and co-channel interference
Criteria used for avoiding interference	Frequency forcing filter is used as a zero-forcing filter for assuming ISM interferences to be zero	expanding more than 6 times through long range outside coverage to avoid interference in 2.4 GHz band	co- channel cell allocation must be in proper way that occupies minimum interval for ensuring isolated transmission and for adjacent channel interference channel allocation depending on frequency reuse is needed.
Network topology	star	node-to-node, Star, Tree	
ranges	few km in dense urban areas and 15-30 km in rural areas	1km (node to gateway) 2 Km (using sub controller)	less than 15km
power consumption	its varied of several devices' classes like Class A and class B devices works in normal battery power but class A has power saving capabilities, but class c device is not a battery powered device.	Certain devices take too much time for transmitting and receiving which absorbs more power [6].	low power wide area networks, reduce energy consumptions
Standard(IEEE)	802.11	ISO/IEC 18000-7	3GPP Release 13

Table 5. Table 5-2 performance matrix of RPMA, NBFI, NBIOT, Weightless n/p/w

	Ingenu/RPMA	NBFI(WAVIOT)	NBIOT	weightless n/p/w
channel	For rapid firmware updates it uses standalone broadcast channel and 40 channels are available		several type of channels	
bandwidth(channel)	1MHz	0.05 KHz	180kHz (200 KHZ carrier bandwidth)	12.5KHz weightless-p
Signal	signal is able to fit in Wi-Fi channels		uplink and downlink signals	coded signal with processing gain
bandwidth(if2.4 GHz)	WI-Fi interference		interference depend on power and guard bands	noise interference
Criteria used for avoiding interference	it is used forward error correction and interleaving and also DSSS technique for avoiding interference.		depends on channels and bands	
Network topology	star	star,mesh		star
ranges	upto 20 km	up to 10 km (urban) up to 50 Km(rural)	10-15 km	2 km (urban) weightless p 5 km for weightless n and w
power consumption	low power consumption but controlling transmit power has severe effect on interference issues	low	low	
Standard(IEEE)	3GPP	NBFI(Narrowband Fidelity)	3GPP	weightless SIG

There are features for BLE, ZigBee, Sigfox, Telnet, Wi-Sun like channel allocation, bandwidth, frequency etc.

Table 6. Table 5-3 Performance matrix of BLE, ZigBee, Sigfox, Telnet, Wi-Sun

	BLE	**ZigBee**	**Sigfox**	**Telnet**	**Wi- Sun**
channel	40	16	narrowband channel type		
bandwidth(channel)	2MHZ	3MHz	1GHz	1 GHz	Sub GHz/GHz
Signal	Narrowband	narrowband	Ultra-narrowband	ultra narrowband	Narrowband
bandwidth(if 2.4GHz)	no interference between coexistence of BLE and Wi-Fi, Bluetooth, ZigBee but other surrounding interferences are found	interference depend on this selected 16 channels	interference occurs frequently with high power		Channel bandwidth upto (200-1200)KHz
Criteria used for avoiding interference	FHSS (Frequency hopping spread spectrum) is used.	DHSS (Direct sequence spread spectrum) is used.	transmits each data package in uplink three times on different frequencies to maximize the probability of receiving at least one packet successful		Used Spread spectrum and OFDM modulation technique
	busy channels will be avoided for avoiding interference	Before transmission it measures in channel power and it also uses CSMA CA (Carrier sense multiple access with collision avoidance) to avoid interference			
Network topology	Tree, star	star, tree, mesh	star	Star	mesh
ranges	(1-100)m	10m	30-50 km (rural) 10 km (urban) 1000 km LOS	2 km	
power consumption	0.153 (microwatt/bit)	185.9(micro watt/bit)	low		
Standard(IEEE)	802.15.1	802.15.4	SIGFOX		IEEE802.15.4

6. COMPARISON OF DIFFERENT TYPES OF INTERFERENCE AND BANDS

6.1 Comparison between ultra-narrowband and spread-spectrum technologies

Ultra- narrow spread spectrum channel at a specific ultra- range is working on Ultra narrow band technology. Its great link budget and power consumption makes it remarkable to reduce noise and interference. Its longer-range coverage and long battery life and its higher power spectral density help it to mitigate interference and jamming. Its help to make a coexistence between a UNB and shared frequency bands. In UNB, many Narrow RF channels and neighboring sub carriers are working orthogonally due to the mitigation of interference and fading as it distributes the power among other subcarriers. Division of end users becomes limited in this narrowband channel which can minimize noise reception.

Spread spectrum is totally opposite than Ultranarrow band. It establishes wideband to send the data along spreading with larger bandwidth. Its carrier frequency is also changed during that time when data is transmitting. Spread spectrum signals are too wide to transmit data to lower spectral density. If there is a SS key used is a signal, then jamming signal can again resend.

LPWAN which is based on UNB, if it's possible to use extra channels which is suggested by base station and no divertive effect on process in two several different networks along with coexistence, the interference will be much more reduce. But in SS systems, this combination is much more difficult because neighboring channels in this case does not share their own spectrum. In LPWAN, Data rate is also an important concern for interference. Low data rate takes too much transmission time to transfer data packet which will sometimes increase the probability of interference, if it wants to connect with other LPWAN networks. UNB works with low data rate comparing to SS, at this point of view the interference is much higher than SS. If we consider other things as like as SS working principle is based on wideband and processing gain cannot totally minimize the implementation loss, then SS interference will be higher than UNB.

Capacity and coverage both are also important term. Capacity implies that how many operations can occur by using that link and coverage shows that area of transmission of data. Capacity does not concern about the data, it only concern about real data transmission. In SS technique if there are many users sharing the same channel it will cause self-noise. In this case an additional data needs to add, to reduce the extra noise, which will also have a bad impact on the capacity of SS. Another important term

is called link budget. Link budget concerns all important terms like transmit power, antenna gain, path loss, cable loss propagation loss, modulation, receiver sensitivity, gains and losses. If the link budget is too lower it means that the coverage and capacity is too much low for that particular technology, which can occur interference [32].

6.2 Uplink and downlink scenarios in UNB and SS

Uplink and downlink situation have a great impact on interferences.

Table 7. Table 6-1 Uplink and downlink scenarios in UNB and SS

Uplink and downlink	Case1(if UNB interferes to another UNB when data rate and channel bandwidth are the same)	Case2(if UNB interferes to another SS when data rate and channel bandwidth are the same)	Case3(if SS interferes to another SS when data rate and channel bandwidth are the same)	Case4(if SS interferes to another UNB when data rate and channel bandwidth are the same)
Coexistence of uplink	Here interference occurs due to both UNB use same channel	UNB which is active during that time can cause interference, but the processing gain can mitigate that interference	Here, SS which are active can cause interference, but the processing gain can reduce that interference.	Here, SS which are active can cause interference, but the processing gain can reduce that interference.
Coexistence of uplink(solution)	If there integrate huge number of channel and base station, then this interference problem will be solved	If Interference occurs in many UNB then it's really complexed to reduce that interference	Dividing users in many channels which can reduce the interference. In end points this processing is not possible.	Its little bit complex to reduce this interference in this case but if power control can be used in base station then situation will be better.
Coexistence of downlink	It is also same as uplink; interference occurs if both UNB uses same channel with same data rate	Its same as uplink, that all UNB which are active can cause interference	Here, Situations are also same that only active SS can occur interference and processing gain help to mitigate that interference.	SS which are active can cause interference, but the processing gain can reduce that interference
Coexistence of downlink(solution)	Solution is also same as uplink, like need to imply	Solution is same is uplink but in downlink that procedure	Dividing users in many channels which can reduce the	Its little bit complex to reduce this interference in this

	maximum number of channels and base stations.	is much easier	interference. In end points this processing is not possible.	case but if power control can be used in base station then situation will be better.

6.3 Comparison between narrowband and wideband Interference

Interference might be differed in every situation like narrowband and wideband. This table shows some comparison about this.

Table 8. Table 6-2 Comparison between Narrowband and wideband Interference

	Narrowband Interference	**Wideband Interference**
Spectrum	Mainly deployed in Unlicensed spectrum [33]	Mainly deployed in licensed spectrum
Techniques used to mitigate interference	IRC (Interference Rejection Combining) means that multiple antenna deployed in the receiver can mitigate this interference [33]	Try to find a source that can distribute the energy
Time domain analysis	Narrowband Interference is strongly related to time domain [33]	It is not strongly related to time domain, but it can be differed in center frequencies.
	Can be used Fast Fourier Transform to transfer data to time domain [33]	Used wider range of bandwidth
Transmission power	To overcome interference higher transmission power is needed	Lower transmission power is OK.
information	Narrowband channel does not contain so many information	It can contain so many information

6.4 Comparison between licensed and unlicensed spectrum.

Spectrum also have caused a great impact in interferences.

Table 9. Table 6-3 comparison between licensed vs unlicensed spectrum

Licensed Spectrum	**Unlicensed spectrum**
Need to purchase license	No need to purchase license-free
Owner who buy this license can only accessed it	Anyone can access it
Scheduling transmission	Unscheduled
Interferences can be centrally managed	During interference management will be distributed
700MHz, 800MHz,1.8 GHz,2.6 GHz,3.5 GHz	2.4 GHz,5.8GHz,600 GHz
High cost	Low cost

6.5 Comparison between open and proprietary standards

Open and proprietary standard also effect in interferences. A comparison is provided in Table 11.

Table 10. Table 6-4 Comparison between open and proprietary standard

Open standard	**Closed (Proprietary standard)**
Interoperable standard creation and provide facility to newcomer to be part of IOT technology.	Owner have only full control
Reliable and robust technology	Users must have full IOT chain
Shared and adopted by everyone	If de facto standard is not existing, then use this standard

7. SIMULATIONS

This narrowband IOT basically works as a machine type communication in LTE Advanced Pro Release 13. It does not need complex signal as other LTE based system.180KHz narrowband carrier is transmitted by the LTE system toolbox. NBIOTDownlinkWaveformGenerator is used full resource element grid and time domain waveform generation. This toolbox can generate all NBIOT modes such as standalone, Guard band and In-band.

In this simulation part, at first a NB-IOT downlink waveform is generated from Mat lab LTE toolbox. It was based on NB-IOT standalone features. it means that same spectrum is used as GSM or satellite communication. So, getting better result we need to convert standalone to In-band because In-band mode, carrier is deployed in existing LTE resource block. In –Band mode also act differently in two different criteria. of two different groups. Guard-band works little bit different way like between two LTE carriers

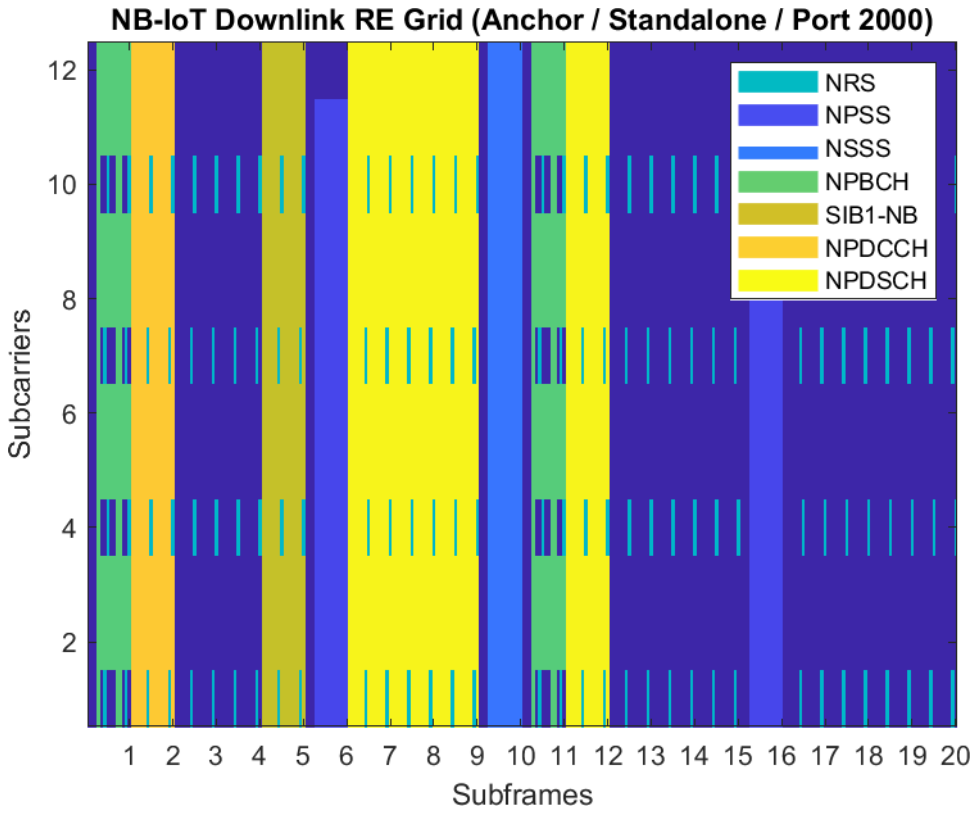


Figure 7-1 Standalone mode which is working on same spectrum as GSM or satellite communication

Figure 7.1 shows that standalone features of NB-IOT where it shows these physical channels and signals like

- Narrowband primary synchronization signal (NPSS)
- Narrowband secondary synchronization signal (NSSS)
- Narrowband reference signal (NRS)
- Narrowband physical broadcast channel (NPBCH)
- Narrowband physical downlink shared channel (NPDSCH)
- Narrowband physical downlink control channel (NPDCCH)

In band mode also works in two categories one is in band same PCI and another one is in band different PCI. One is In-Band same PCI, here physical layer cell identity is a as same as LTE and UE successfully do estimation of port and channel by using LTE signals.

This Figure 7.2 shows, that Inband-SamePCI introduce Master Information Block, which is useful to transmit necessary information to the User equipment. Also, two carrier mode anchor which task is to cell selection of primary NB-IOT, gather master information block information, ideal mode random access and transfer NPSS, NSSS, NPBCH information to the carrier. Non anchor mode can only use to share real data in active mode, but it cannot transfer information to the carrier.

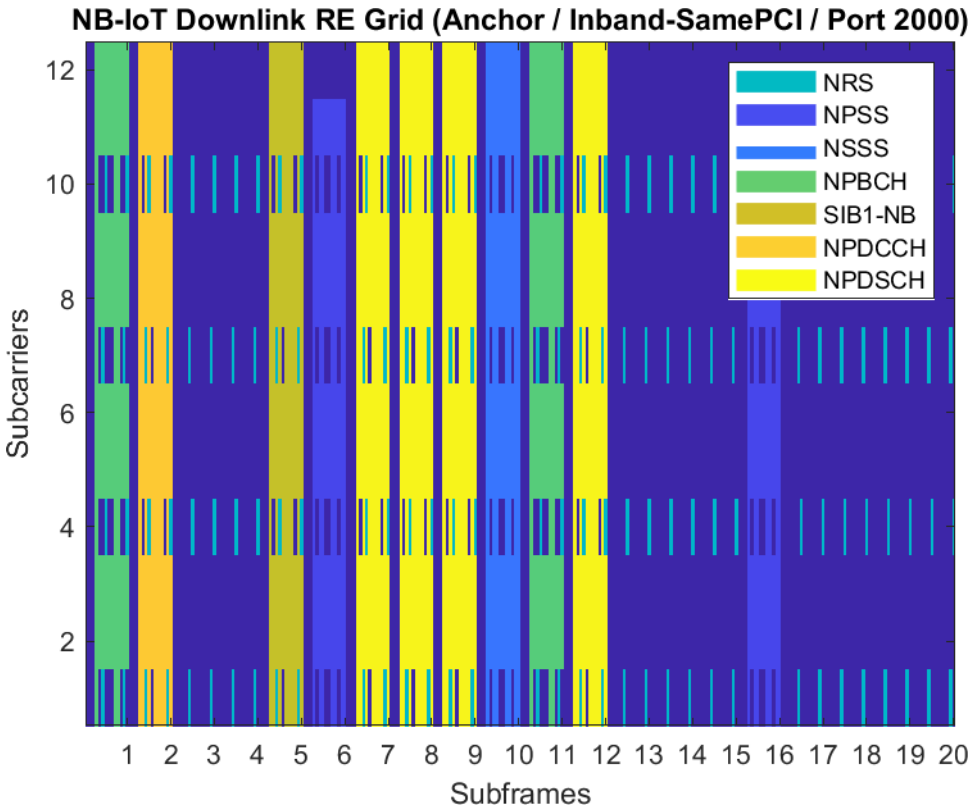


Figure 7-2 In Band same PCI

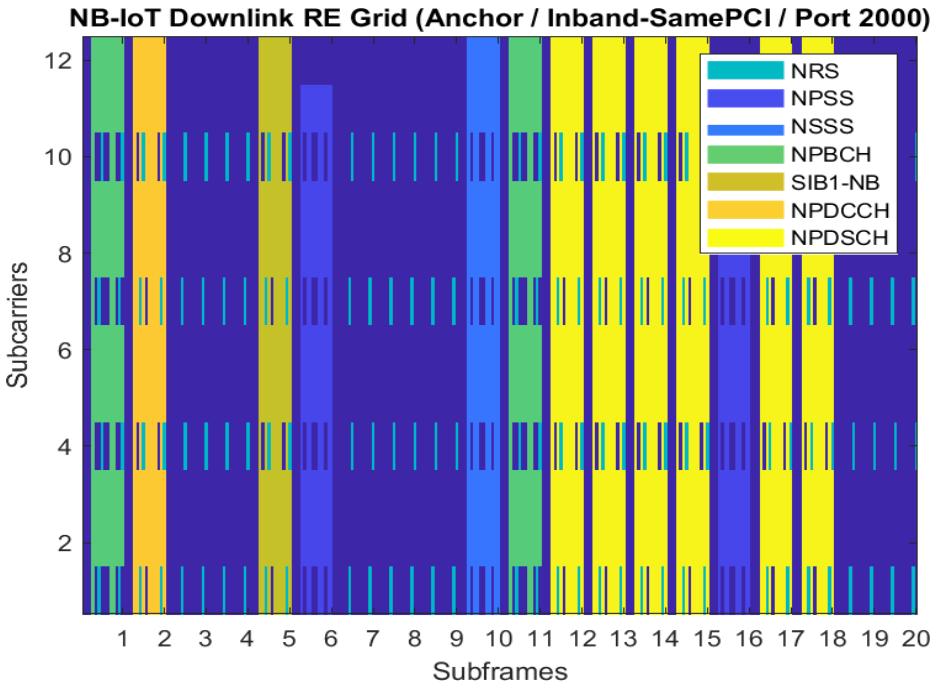


Figure 7-3 InBandsamePCI, when ready to transmit NPDSCH

Figure 7.3 also shows In-Band same PCI, but difference is that here, NPDSCH is ready to transmit.

Sub frame repetition and physical and logical channel mapping and the grid of several configuration are also a concern of this generator. In Figure 7.4, color represents three different subframes. This sub frame figure shows that here 3 sub frames are used, and 4 times number of repetitions occur so, 12 sub frames used to transmit this NPDSCH.

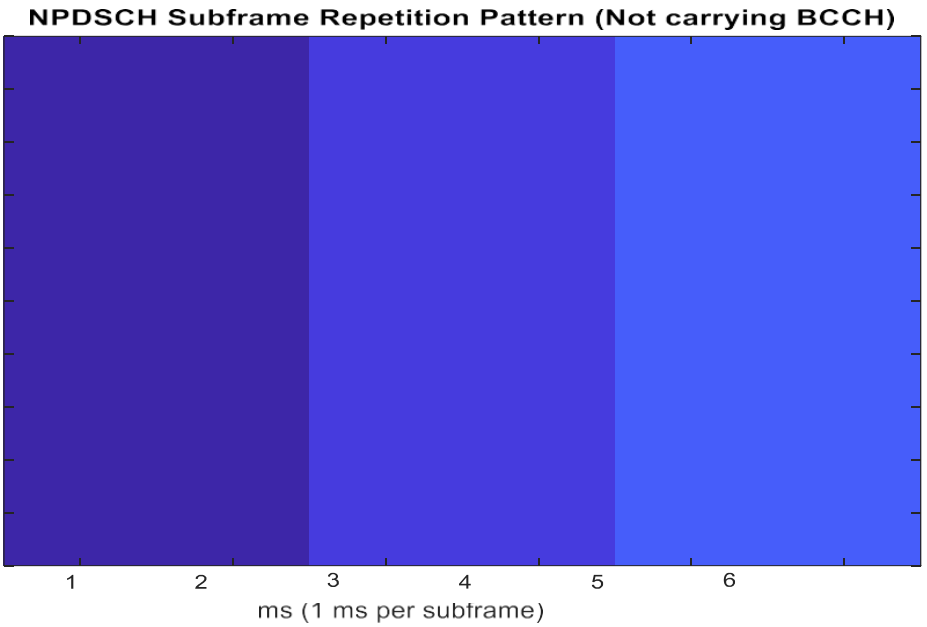
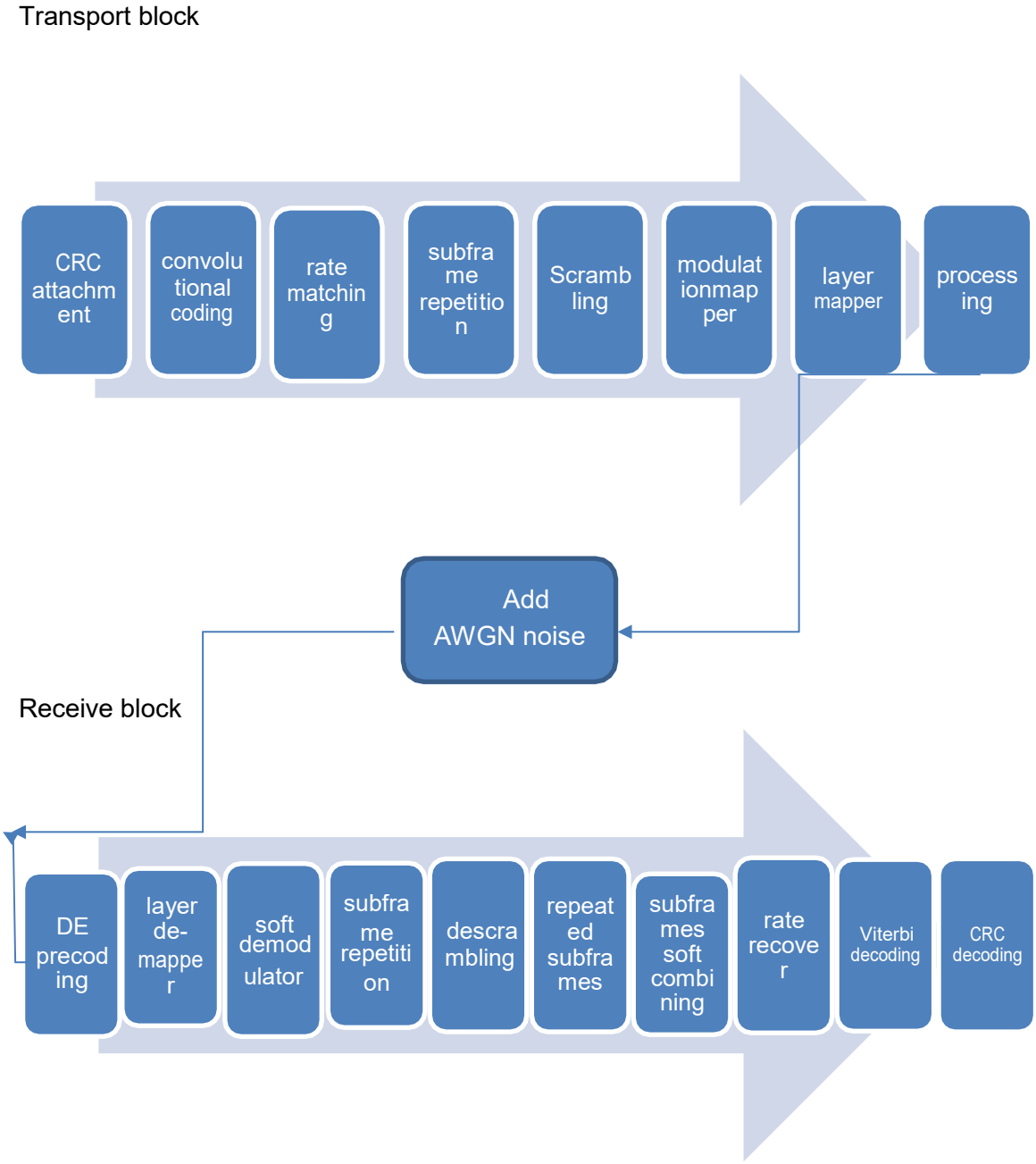


Figure 7-4 This figure shows that subframe repetition pattern of narrowband physical downlink shared control channel considering 1ms per subframe.

7.1 Block Error Rate Simulation Loop

Here, this Block Error rate simulation loops consider transmit and receive chain. In transport block which includes CRC attachment, convolutional coding, rate matching, subframe repetition, scrambling, modulation mapper, layer mapper and then precoding. At this point need to add an AWGN noise, and then start decoded block as this like DE precoding, layer de-mapper, soft demodulator, descrambling, repeated subframes soft combining, rate recover, Viterbi decoding, CRC decoding.

Block diagram of block error rate configuration



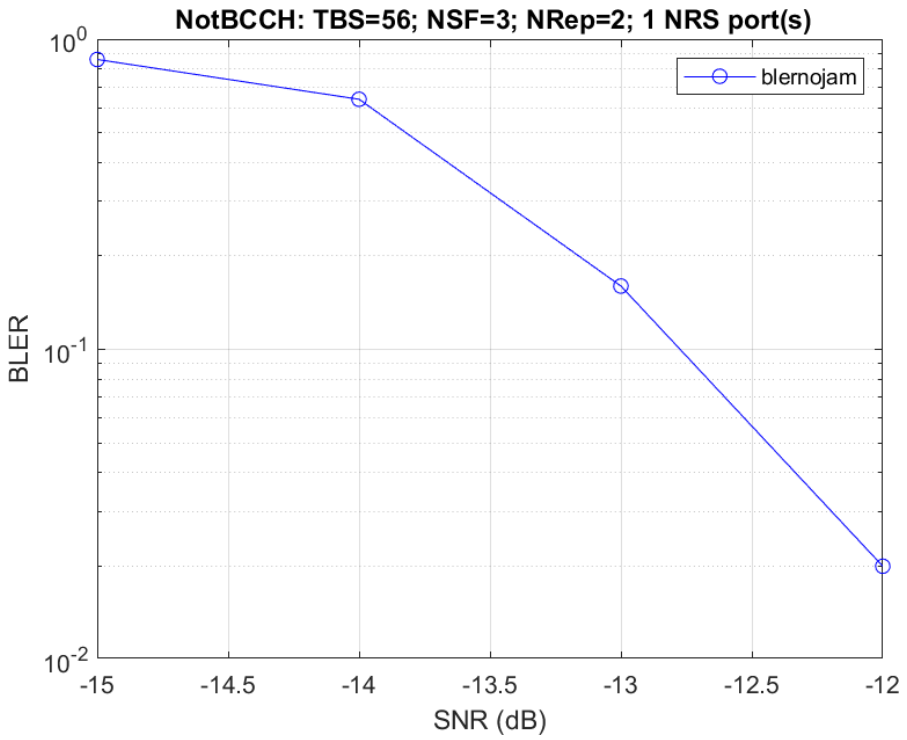


Figure 7-5 no jammer value with low SNR

Then in this same code with the received signal with noise, need to add an interference signal which is here considered as a sinusoidal signal. This interference signal further provides a great impact on BLER values.

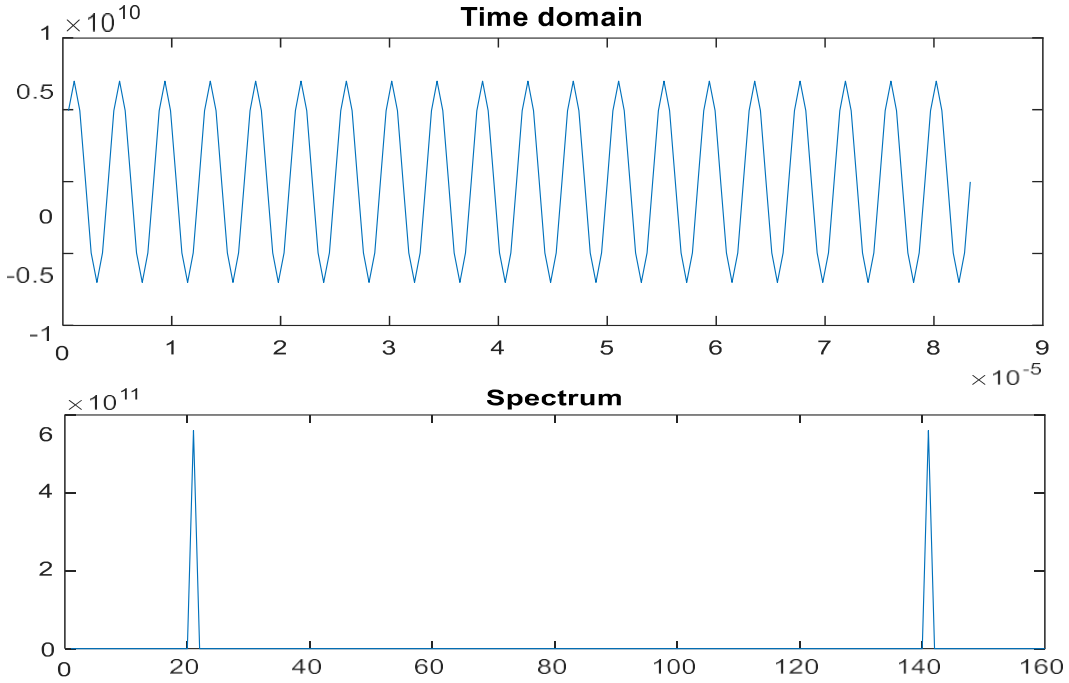


Figure 7-6 A sinusoidal signal here shows as an interference signal and this interference signal spectrum.

Now, we generate an interference signal and see its spectrum where JSR=power in dB=10:10:100 and see it's be heavier. JSR parameter here is basically use for jammer power in dB. Then add this interference signal to a sub frame to get receive symbol.

Then we add some JSR value such as 10, 20, -5, -20 dB and then we find that for positive JSR value, means if power consumption is better than Interference does not have so much impact on transmission. But for negative or positive power value channel BLER value is decreasing it means that if power consumption is low interference provide bad impact on channel.

This interference signal works here as a function specific jammer whose task is to either be proactive or reactive. Sometimes it does not concern regarding which channels functionality or channel throughput increases without considering the transmission power. This jamming can be occurred at multiple channels at the same time.

Channel based this jammer signals work differently like in PBCH channel, signals transmitted in the 1 MHz bandwidth might be work as a jammer signal and in that case highest power is required to detect that signal. Here, jammer is mostly occurred in narrowband cases [34].

In primary synchronization signal this is something different, like in that case, jamming only occur in that symbol which is responsible for transmitting the PSS. Here, Figure 7.7 we provide positive jammer value from 20 dB and then find this kind of curve. To detect the jammer in this case it needs to consider specific time management and jammer to signal ratio.

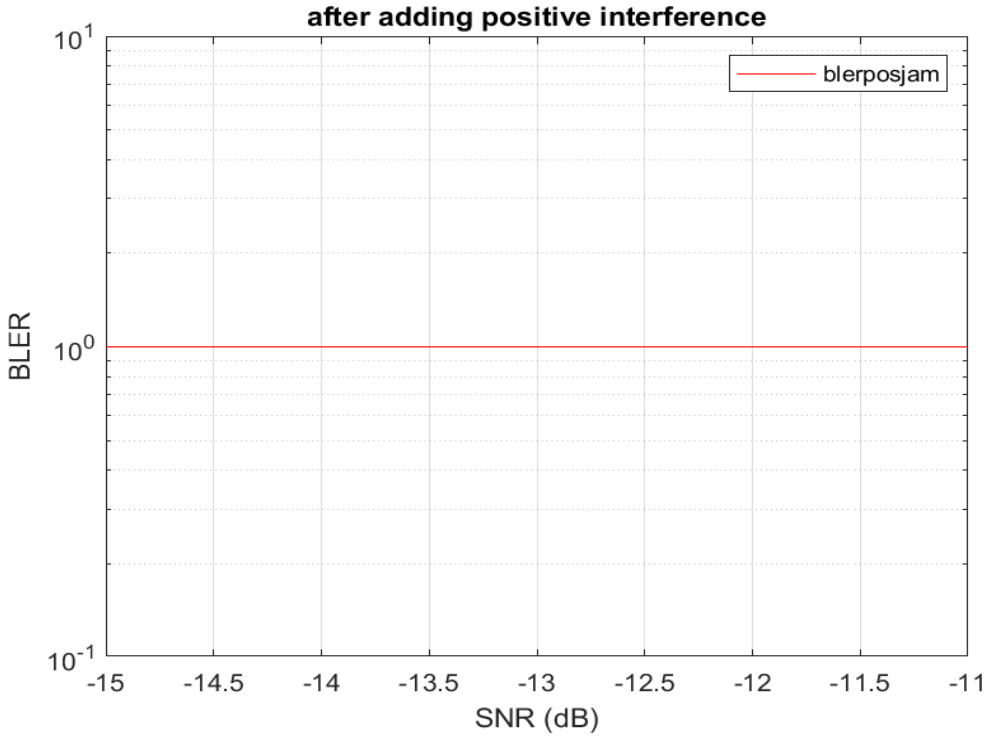


Figure 7-7 when JSR Value 20 and this SNR (dB) is including noise and interference both. This Block error rate is showing this figure due to its received signal is considering noise and interference both. Here, SNR value is low, that's why positive jammer BLER is higher than no jammer BLER.

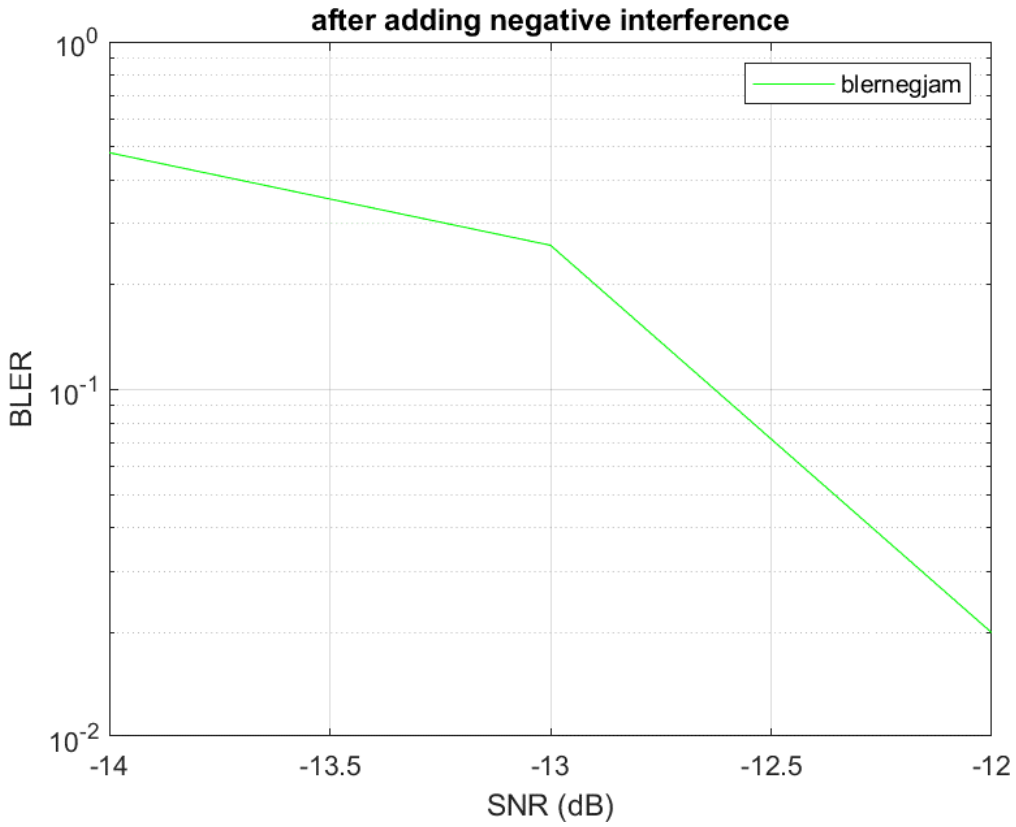


Figure 7-8 JSR Value -20, that Block error rate is still decreasing due to adding interference with noise.

Here, Figure 7.8, this BLER is decreasing because this it works versus those type of SNR which is considering already noise. Also, several other circumstances have a great impact for this case, inter cell or intra-cell interference. As NB-IOT is based on LTE, so it is also possible that there in some of jammer cases some of this channel are in active mode and some of them are in sleep mode.

some point has also might have some impact like channel overlapping or either some node might be shifted to one channel to another channel.

After that we will consider, negative value of jammer, where BLER curve is also decreasing.

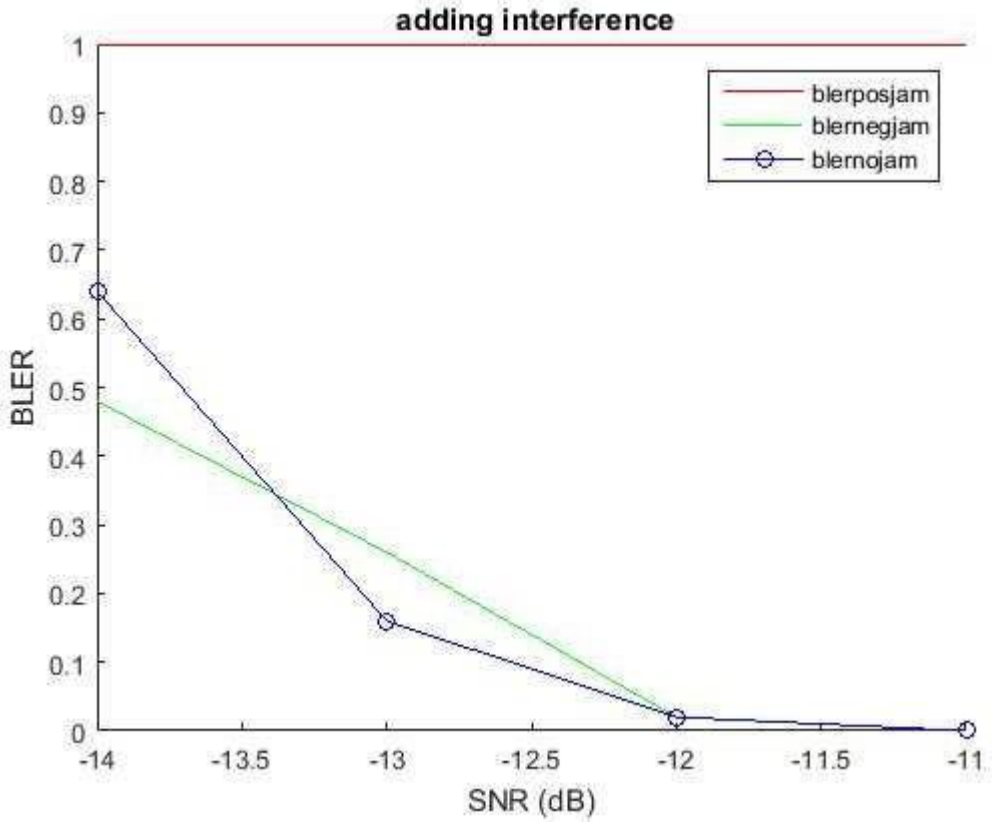


Figure 7-9 Differences between several different BLER values, where red curve is mentioning positive jammer value, green curve is for negative jammer value, blue curve is for without jammer

At last, from figure 7.9, it can be said that, for both positive and negative jammer values if SNR value is low and if that SNR value also consider interference than, BLER values will be increased and decreased.

Now, we see Block error rate with higher SNR values. At this point in figure 7.11, this BLER curve is for no jammer with lower SNR values. At this point, we see that, block error rate is low at this point.

This block error rate simulation loop is also similar as before simulation loop.

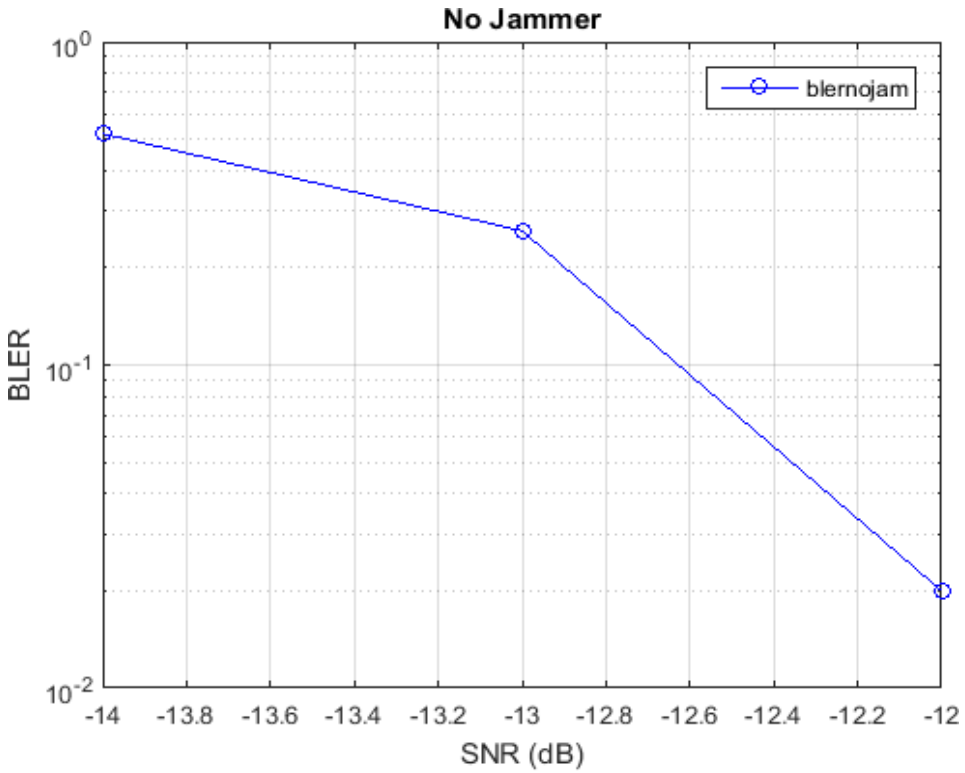


Figure 7-10 no jammer with lower SNR

At this point, we add interference signal and increase SNR value with negative JSR value-30. At this point in figure 7.12, we see that, BLER will be increased than no jammer value as because of higher SNR.

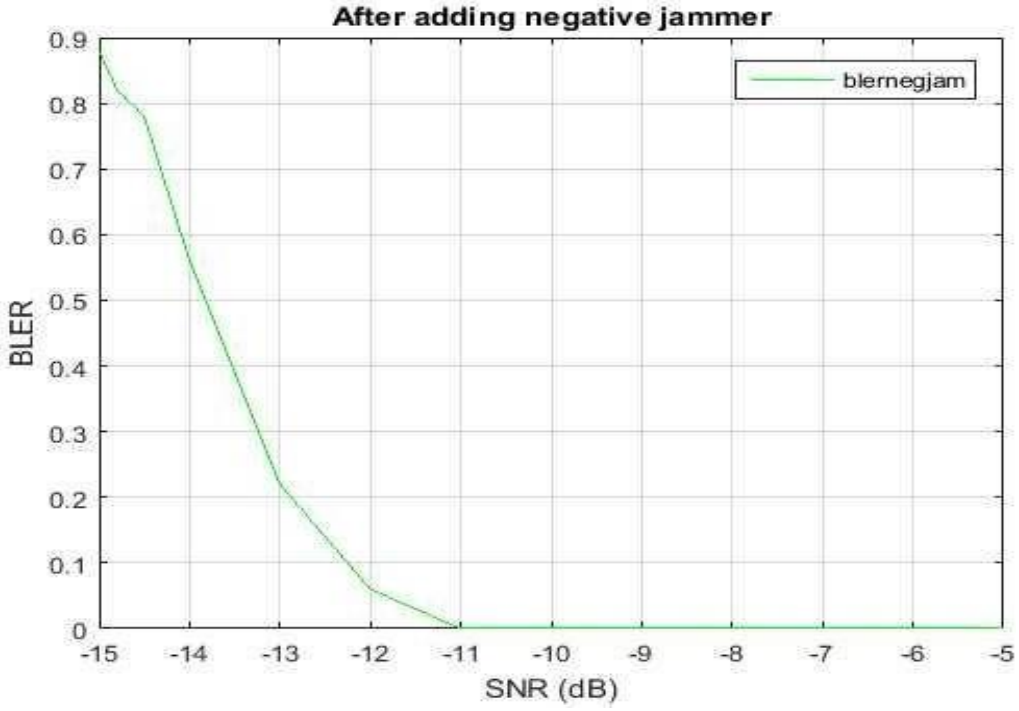


Figure 7-11 negative Jammer value -30 with little bit high SNR comparing no jammer

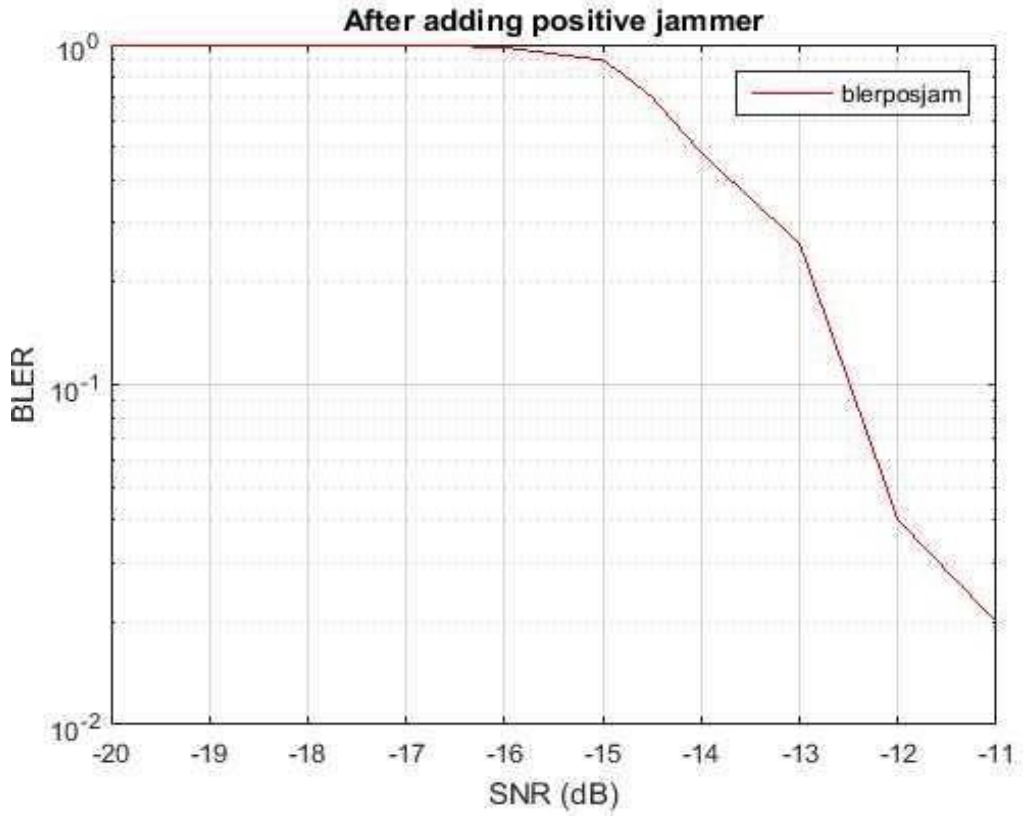


Figure 7-12 This figure both jammer is positive value 40 and SNR is also high

In figure 7.14, we see that both positive jammer value and higher SNR value BLER is higher than no jammer value.
Higher SNR value, interference affect more in any signals, that's why BLOCK error rate is high than low SNR value.
Jammer value is also causing a large effect, as we see that in positive jammer value both higher and lower SNR value BLER is high.
In Figure 7.14, is all BLER curve of higher SNR values. We see differences between all BLER values.

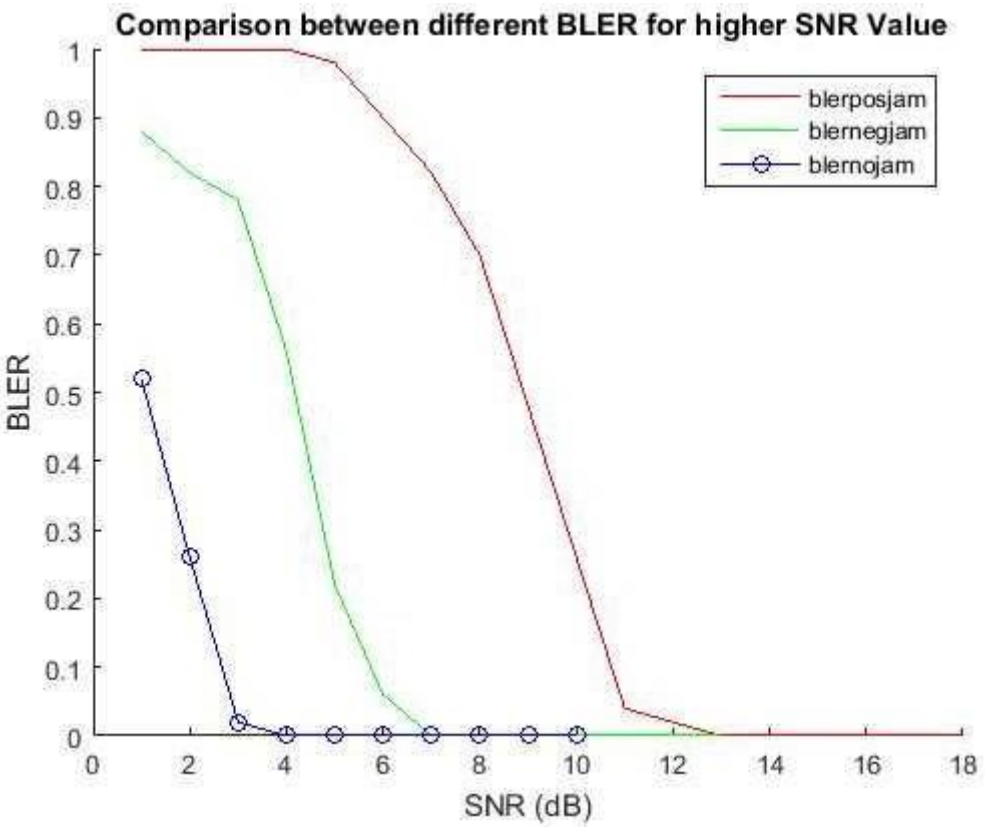


Figure 7-13 comparing between several BLER values with different value of SNR

Mitigation

Error vector magnitude(EVM) analysis might be a great solution for mitigating interference of NB-IOT. Error vector magnitude is equal to the number of interferers , if there is no fading occurs in these operational channels. EVM is a kind of symbol evel performance metric.

By using EVM analysis, we can find the signal degradation and identify the interference beheaviour. And after that we can add filter and try to fulfill power consumption, to get as much as error free signal.

8. CONCLUSION AND OPEN ISSUES

NB-IOT is nowadays most popular phenomenon. It has many applications in our modern areas like healthcare, parking and smart cities. In upper work we mainly focused on block error rate analysis of NB-IOT. There we see that how jammer value and SNR value impact on NB-IOT signals. From upper discussion, we reach a conclusion that if SNR value is high and also jammer value is high at the same time than, Block error rate will be high. But if SNR value is low and it takes interference at the same time, then its behaviour is changing due to channel and signal effect. In figure 7.9 and figure 7.13 we see this result.

In future work, we implement Error vector magnitude measurement to compare the BER performance of several different IOT techniques when Interference occurs and try to implement proper power consumption and filter for mitigating interference. Also, we can implement and analyse these type of interference analysis and mitigation techniques for several IOT techniques like BLE, ZigBee, those will helpful for future development of IOT.

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