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NB-IoT Narrowband Physical Uplink Shared Channel Performance Analysis for Low Power Cellular Communication

تحليل أداء القناة المشتركة الضيقة في الوصلة الصاعدة لإتصالات إنترنت الأشياء ضيقة النطاق الخلوية ذات القدرة المنخفضة

A Thesis Submitted in Partial fulfillment for the Requirements of the Degree of M.Sc. in Electronics Engineering (Communication Engineering)

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الإستهلال

بِسۡمِ ٱللَّهِ ٱلرَّحۡمَٰنِ ٱلرَّحِيمِ

قال تعالى:

﴿وَيَسْأَلُونَكَ عَنِ الرُّوحِ قُلِ الرُّوحُ مِنْ أَمْرِ رَبِّي وَمَا أُوتِيتُمْ مِنَ الْعِلْمِ إِلَّا قَلِيلًا﴾

سورة اَلإسْراء الآيه رقْم (٨٥)

Dedication

I dedicate this piece of work to my father and mother who have always been of endless support and to my teachers and everyone who helped me in completing this thesis.

Acknowledgment

I am very grateful to Prof.Dr. Rashid A. Saeed who helped me a lot to prepare this thesis. He gave me many suggestions both about the overall plan and about the details of the writing.

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Abstract

Narrowband-IoT (NB-IoT) is a standards-based Low Power Wide Area Network (LPWAN) technology developed to connect a wide range of new Internet of Things (IoT) devices and services. NB-IoT bandwidth is limited to a single narrow-band of 180 kHz. Although NB-IoT provides low-cost connectivity, it provides channel to large number of smart IoT installed in households, building etc. However, In NB-IoT systems, repeating same signal over additional period of time has been taken as a key technique to enhance radio coverage up to 20 dB compared to the conventional GPRS. Performance of NB-IoT system optimization and modeling is still challenging particularly coverage improvement in the case of real applications. For example, the narrow bandwidth in IoT and low power have led to diffectly in communication between IoT devices and network station, which results in low quality transmitter channel. Repetition process used enhanced coverage while increase number of repetitions leads to bandwidth consumption. So, Cooperative relay is used with repetition to solve this problem. In this thesis, we proposed an enhanced repetitions cooperative process of NPUSCH transmission channel. Results shows dramatical enhancement uplink NB-IoT channel quality when applied in to LTE networks. In addition, this thesis describes the analytical simulation to evaluate the proposed repetition of cooperative process (RCP) performance for LTE-NPUSCH channel.

المستخلص

إنترنت الأشياء ضيقة النطاق تعتبر من أحد التقنيات التي تندرج تحت الشبكات واسعة النطاق ذات الطاقة المنخفضة التي تعتمد على عدد من المعايير تم اعتمادها لتمكين الإتصال بين مجموعة واسعة من الأجهزة و خدمات إنترنت الأشياء المختلفة. تمتاز إنترنت الأشياء ضيقة النطاق بعرض نطاق ترددي ضيق يحدد ب 180 كيلو هيرتز لتمكين من توفير إتصالات قليلة التكلفة بقنوات إتصال قادره على تشغيل عدد كبير من أجهزة إنترنت الأشياء الموجودة بالمنازل و المباني وما إلى ذالك. تعتمد إنترنت الأشياء ضيقة النطاق على عملية تكرار نفس الإشارة على مدار فتره زمنية محدده تساعد على تعزيز التغطية الراديوية حتى تصل ل 20 ديسيبل مقارنة مع خدمة حزمة الراديو التقليدية. لا يزال أداء تحسين ونمذجة نظام إنترنت الأشياء ضيقة النطاق يمثل تحديًا خاصًا لتحسين التغطية في حالة التطبيقات الحقيقية. على سبيل المثال ، أدى النطاق الترددي الضيق في إنترنت الأشياء والطاقة المنخفضة إلى اختلاف في الاتصال بين أجهزة إنترنت الأشياء ومحطة الشبكة ، مما ينتج عنه قناة إرسال منخفضة الجودة. استخدمت عملية التكرار تغطية محسنة بينما تؤدي زيادة عدد التكرارات إلى استهلاك عرض النطاق الترددي. لذلك ، يتم استخدام التتابع التعاوني مع التكرار لحل هذه المشكلة. في هذه الأطروحة ، اقترحنا عملية تعاونية مكررة معززة لقناة إرسال قناة المشتركة الضيقة في الوصلة الصاعدة. تُظهر النتائج تحسينًا كبيرًا لجودة قناة إنترنت الأشياء ضيقة النطاق للوصلة الصاعدة عند تطبيقها على شبكات تطور طويل المدى. بالإضافة إلى ذلك ، تصف هذه الأطروحة المحاكاة التحليلية لتقييم التكرار المقترح لأداء العملية التعاونية.

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List of Symbols

Υ	Average SNR.
I_L	Identity matrix.
I_{Rep}	Repetition number indicator.
$M_{identical}^{NPUSCH}$	Number of repetitions of identical slots for NPUSCH.
M_{rep}^{NPUSCH}	Scheduled number of repetitions of a NPUSCH transmission.
MAX_{th}	Maximum throughput variable with SNR index = 1: numel (SNRdB).
N_{ID}^{Ncell}	Narrowband physical layer cell identity.
N_{RU}	Number of scheduled UL resource units for NB-IoT.
N_{Rep}	Number of repetition.
$NSTB_{ER}$	Number of simulated transport blocks.
NTB_{ER}	Number of transport blocks with errors.
N_{sc}^{RU}	Number of consecutive subcarriers in an UL resource unit for NB-IoT.
N_{sc}^{UL}	Number of subcarriers in the frequency domain for NB-IoT.
N_{slots}^{UL}	Number of consecutive slots in an UL resource unit for NB-IoT.
N_{symb}^{UL}	Number of SC-FDMA symbols in an uplink slot.
$\mathrm{PL}_{\mathrm{Co-relay}}$	Free-space path loss for cooperative relay in dB.
$\mathrm{PR}_{\mathrm{co-relay}}$	Received power for cooperative relay in dB.
SIM_{th}	Simulation throughput function with variable SNR index.
T_{slot}	Slot duration.

List Abbreviations

3GPP	3rd Generation Partnership Project.
8PSK	8-ary Phase Shift Keying.
ACK/NACK	Acknowledgment/Non-Acknowledgment.
bit/s/Hz	Bit per Second per Hertz.
BLER	Block Error Rate.
BPSK	Binary Phase Shift Key.
BS	Base Station.
CCH	Control channel.
CSS	Chirp Spread Spectrum.
D2D	Device-to-Device.
dB	Decibels.
DBPSK	Differential Binary Phase-Shift Keying.
DCCH	Dedicated Control Channel.
DR	Data Rate.
DSTC	Distributive Space Time Coding.
DT	Delay Transmission.
DTCH	Dedicated Traffic Channel.
EC-GSM-IoT	Extended coverage GSM IoT.
eDRX	Extended Discontinuous Reception.
eGPRS	Enhanced GPRS.
eMTC	Enhanced machine-type communication.
EPC	Enhanced Packet Core.
EPHYL	Enhanced Physical Layer.
E-UTRAN	Evolved Universal Terrestrial Radio Access.
FDMA	Frequency-Division Multiple Access.
FEC	Forward Error Correction.
FS1	Frame Structure 1.
FSPL	Free-Space Path Loss.
$\mathrm{Gain}_{\mathrm{BS}}$	Gain of base station in dB.
$\mathrm{Gain}_{\mathrm{IoT}}$	Gain for IoT devices in dB.
GFSK	Gaussian Frequency-Shift Keying.
GSM	Global System for Mobile communication.

GSMK	Gaussian Minimum Shift Keying.
HARQ	Hybrid automatic repeat request.
IoT	Internet of Things.
IP	Internet Protocol.
Kbps	kilo bits per second.
LoRa	Long Range.
LPWAN	Low Power Wide Area Network.
LTE	Long-Term Evolution.
LTE-MTC	Machine-Type Communications.
m	Meter.
M2M	Machine-to-Machine.
MCL	Maximum Coupling Loss.
MCS	Modulation and Coding Scheme.
MGF	Moment Generating Function.
MHz	Megahertz.
MIMO	Multiple-Input Multiple-Output.
MME	Mobility Management Entity.
ms	Milli-seconds.
NB-IoT	Narrowband Internet of Things.
NPBCH	Narrowband Physical Broadcast Channel.
NPDCCH	Narrowband Physical Downlink Control Channel.
NPDSCH	Narrowband Physical Downlink Sharing Channel.
NPRACH	Narrowband Physical Random Access Channel.
NPSS	Narrowband Master Sync Signal.
NPUSCH	Narrowband physical uplink shared channel.
NRS	Narrowband Reference Signal.
NSSS	Narrowband Subsidiary Master Sync Signal.
OFDM	Orthogonal Frequency Division Multiplexing.
OFDMA	Orthogonal Frequency Division Multiple Access.
PRB	Physical Resource Block.
PSM	Power Saving Mode.
PT	Transmitted power for IoT device in dB.
PUCCH	Physical Uplink Control Channel.
QPSK	Quadrature Phase Shift Keying.

RBs	Resource Blocks.
RU	Rescource Unit.
RVseq	Redundancy Version Sequence.
SE	Spectral Efficiency.
SIR	Signal-to-interference ratio.
SNO	Sigfox Network Operators.
SNOW	Sensor Network over White Spaces.
T_{BL}	Transport block length.
TDMA	Time-Division Multiple Access.
TH	Throughput.
UL-SCH	Uplink Shared Channel.
UNB	Ultra NarrowBand.
WSN	Wireless Sensor Network.

Chapter One

Introduction

Chapter One

Introduction

1.1 Introduction

For the Internet of Things (IoT) future growth and development in mobile industry, the Third Generation Partnership Project (3GPP) has standardized new class technologies for Low Power Wide Area Network (LPWAN) applications. These standards are referred as mobile IoT. They are designed for licensed spectrum and to support devices with requirements of low power consumption, long range, low cost and security [1].

The variety of LPWA IoT applications are emerging and their requirements are differing from each other. One LPWAN technology cannot address the requirements of all low power IoT applications and for this reasons, two complementary licensed 3GPP standards; Narrowband-Internet of Things (NB-IoT) and LTE-M have been proposed and are built on the Long Term Evolution (LTE) [2]. LPWAN is an emerging network technology for IoT and Machine-to-Machine (M2M) applications which suitable for long-rang performance and cellular M2M networks. traditional technologies in IoT landscape such as Short-range technologies like Bluetooth, Zigbee, Z-waves and Wi-Fi are not suitable for applications that required long range and the cellular communication used for long range connectivity but they consume high-power, this resulting to low energy efficiency for long range IoT network [3]. The integration of IoT and M2M devices connected by the LPWAN technologies will generate a global IoT in anywhere and anytime to interacts with any kind of environment issues such as range, penetrability of thick objects, long battery life, security and scalability all will be adequate by the LPWAN technologies.

NB-IoT is a standard-based LPWAN technology developed to connect a wide range of new IoT devices and services. NB-IoT will improve the power consumption of user devices, system capacity and spectrum efficiency. It’s able to be loaded by major mobile equipment and module manufacturers and indeed it will be existing to be adaptable with any cellular mobile network’s generations. Also, it has benefits at security and privacy features of mobile networks. From these features, NB-IoT has enabled many kinds of applications not only in smart monitoring but also will exceed the expectations to promises great benefits in tracking applications, energy services great industrial applications and for smart cities.

According to the cooperative networking paradigm, IoT nodes terminals could help each other by relaying data towards the base station. This technique established by using device-to-device (D2D) links, with same cost of existing infrastructure for the network operator [4]. This work investigated the adoption of cooperative relay techniques and repetition number of subframe in NB-IoT uplink to optimize the performance of the overall network.

1.2 Problem Statement

Although NB-IoT needed to provide low-cost connectivity channel to a large number of smart IoT installed in households, bulding etc., but The narrow bandwidth in IoT and low energy have led to difficulty in communication between the IoT and the Network Station, This results in low quality transmitter Channel, Repetitions process of NPUSCH transmission and cooperative technique , can enhance the quality of channel in NB-IoT in LTE Networks.

1.3 Proposed Solution

To achieve Enhanced Physical Layer for cellular IoT (EPHYL) specially for NB-IoT uplink, this research is configuring eNB PHY with different NPUSCH repetitions varying across simulation time, with cooperative relay that to improve the performance of overall network.

1.4 Research Aims and Objectives

The general aim of this research is to enhanced physical layer for NB-IoT uplink by utilize number of repetitions subframe in uplink NB-IoT with cooperative relay to achieve an improvement in coverage, overall quality for the user as well as improving the utilization of the network performance**.** The detailed objectives include:

A. To provide the necessary specification support to efficiently realize the benefits of number of repetition per channel with cooperative relay in NB-IoT uplink and related work.

B. To derive mathematical equations and parameter that used in system model with number of repetition per channel and cooperative relay for NB-IoT uplink entered by using Matlab simulation.

C. To implement system model in network scenario to enhance Block Error Rate (BLER), data rate, throughput, delay of transmission and spectrum efficiency.

1.5 Methodology

The Methodology of this project is composed of four phases:

- **First phase:** concerning deep study and investigation of the specification of number of repetition with cooperative relay in NB-IoT uplink scenario.
- **Second phase:** mathematical model to calculate performance such as BLER, throughput, data rate, transition delay and spectral efficiency for number of repetition with cooperative relay to prove enhanced physical layer for NB-IoT.
- **Third phase:** includes simulation by using Matlab platform for mathematical model. A Matlab code has been written to simulate the system performance for NB-IoT uplink.
- **Fourth phase:** the simulation result output of MATLAB is in form of figures represent performance evaluation as BLER, data rate, throughput, spectral efficiency and delay transmission. The output of the simulation is in graphs form; it shows the amount of improvement in each parameter.

1.6 Thesis Outlines

The thesis work is divided into five chapters including this chapter, the remaining part of this thesis is outlined as follows:

- **Chapter two** present theoretical background of LPWAN, NB-IoT uplink relevant physical layer channels and signals and LTE system. Also, this chapter presents the related work done.
- **Chapter three** describe working principle of the system and the flowchart of the software program to achieve the goals.
- **Chapter four** contain simulation results and analysis highlight several simulation result and discuss the obtained result.

- **Chapter five** concludes the thesis by summarizing the work that was done followed by recommendation for future work that can be done in this direction.

Chapter Two

Background and Literature Review

Chapter Two

Background and Literature Review

2.1 Background

The main purpose of this chapter is to survey the motivation from existing M2M communication to cellular LPWAN, type of LPWAN, LTE system, cooperative communication system model and provides a comprehensive review of current literature on repetition, cooperative relay communication, focusing specifically on the requirement of a cooperative relay communication in NB-IoT and repetition in NPUSCH. In section 2.2 determine the motivation from existing M2M to cellular LPWAN, followed by highlighting type of LPWAN in Sections 2.3 and 2.4. Finally, explore the related work in section 2.5.

2.2 M2M Cellular LPWAN

M2M communication refer to allow intelligent devices with specific application to communicate with each other for exchanging the data or perform action, without any manual input from humans to achieve better cost efficiency and time management. Sensors and other intelligent devices can be connected through wired or wireless communication. M2M solutions allows terminal such as a sensor, actuator or meter to capture an event such as temperature, inventory level. Then, transmit data that was captured through wired or wireless communication. After that, received captured event by an application to translating the data captured into meaningful information. M2M has been able to deploy in various application scenarios such as remote monitoring and control of enterprise assets of various types or to provide connectivity of remote machine-type devices. In general, M2M solutions don't enable broad sharing of data or connect devices directly to the internet [5].

IoT define as interconnection between various things through internet to exchange data without any human interaction. IoT applications have specific requirements including wide range, low data rate, long battery life and cost effectiveness [6] [7]. The 3GPP has defined a new radio access technology called LPWAN which provide main features which are extended coverage and low power consumption [8]. After 2020 expected that more than 50 billion devices will be communicated in massive long-rate long-range connectivity which will requires novel communication paradigm, to able integrate and operate the traditional cellular and short-range wireless technologies in addressing diverse requirements of IoT applications.

LPWAN is an emerging network technology for IoT and M2M applications which provide long-range, low-power consumption, low cost for devices and infrastructure and massive number of devices connectivity. Figure (2-1) shows required data rate vs. range capacity of radio communication technologies [7]. LPWAN overcomes challenges: the range limit, power consumption and scalability that appeared in traditional short range wireless sensor networks (WSN) [9]. Due to their escalating demand, several technologies are developed such as Long-Range Low-Power Radio (LoRa), SigFox, DASH7, Weightless-P, Weightless-N, Sensor Network Over White Spaces (SNOW), LTE-M, EC-GSM-IoT, NB-IoT and 5G [10].

LTE technology and evolved LTE technology, which support different categories of terminals (e.g., LTE-M, Extended coverage GSM IoT (EC-GSM-IoT), NB-IoT) and 5G. These technologies developed by international standards organizations such as 3GPP and 3GPP2 [8]. It can be easy to deploy across business sectors including manufacturing, automotive, energy, utilities, agriculture, healthcare, wearables (for humans or animals), or transport. LPWAN technologies raise a number of challenges in terms of spectrum limitation, coexistence, mobility, scalability, coverage, security, and application-specific requirements which make their adoption challenging [10].

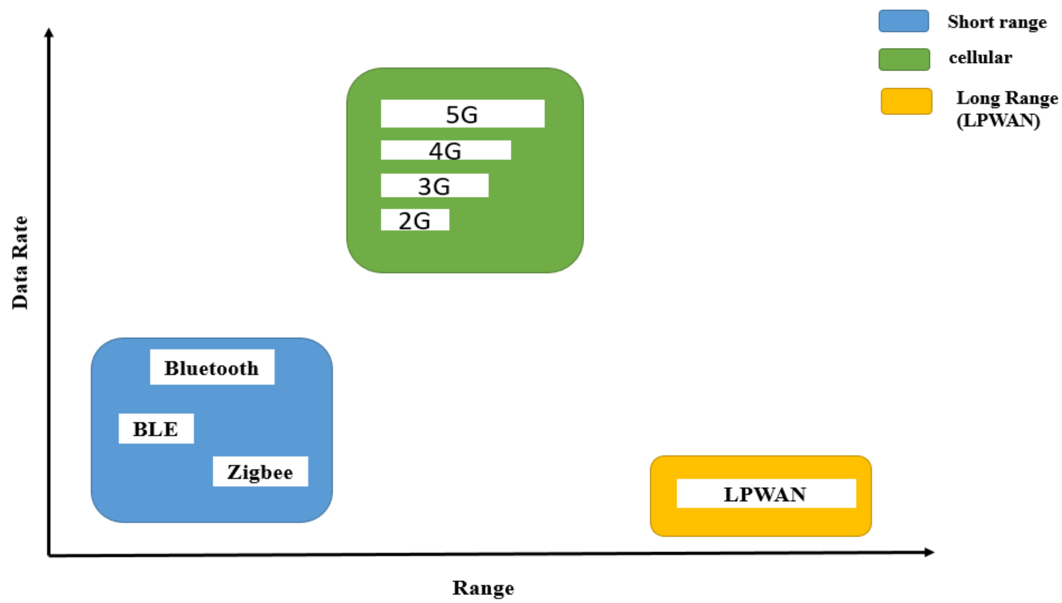


Figure (2-1): Required data rate vs range capacity of radio communication technologies.

2.3 LPWAN

LPWAN is a new wireless technology suited for long rang performance and cellular M2M networks since all other technologies like Wi-Fi, Bluetooth, Zigbee, Z-waves and LTE or other cellular systems does not concern to such long-range properties because of their high-power consumption and low energy efficiency for long range IoT network. LPWAN supports various applications such as smart city, smart grid, agriculture, home automation, logistics and industrial operations. It has a several characteristics such as large coverage area, low power consumption, low deployment, low operation cost and more reliable. The LPWAN features will mentioned in more details in section 2.3.1. LPWAN is not only one technology, it is a set of various LPWAN technologies that have many shapes and forms. It has two categories unlicensed LPWAN and licensed LPWAN will mentioned in details in section 2.3.2.

2.3.1 LPWAN Features

The main features of LPWAN that overcome from other technologies are:

A. Long-Range Connectivity

In comparison with traditional short-range WSN, the goals of designing LPWAN is to support wide-area coverage at low-power and low cost. Most LPWANs achieve long range and thus form a star topology where the terminals directly communicate with the base station (BS), most unlicensed LPWANs operate on Sub-GHz band (low frequencies) which provide long range (1-5 km in urban areas and 10-40 in rural areas). Lower frequencies have better propagation over obstacles. Due to this features, Sub-GHz band become attractive for LPWANs technologies [10].

B. Low-Power

IoT devices are expected to work for a several years (5 to 10 years) without replacing the battery. LPWAN achieves low power operation by using several methods. First, usually connectivity in form a star topology. Second, keep node design simple by offloading the complexities to the BS or gateway. Third, they utilized narrowband channels where noise-level is decreased and transmission range is extended [10].

C. Low Deployment and Operational Cost

Low cost is the major factor that contribute to the rise of using LPWANs. Non-cellular LPWANs no need of infrastructure and work on unlicensed band which providing an excellent alternative to the cellular network. Moreover, due to the advances in the hardware design and the simplicity of end-devices makes LPWANs economically feasible [10].

D. Reliability and Robustness

Most LPWANs used robust modulation techniques and spread-spectrum techniques to increase the signal to interference ratio (SIR) and provide a high level of security. In spread-spectrum, the narrowband signal is spread in the frequency domain with same power density resulting in a wider bandwidth signal [10].

E. Scalability

The LPWANs avoids multi-hop topology this will gives a high potential to scale in LPWAN. Also, LPWANs use narrowband to provide a massive number of devices in efficient utilize of limited spectrum. Furthermore, some LPWANs such as LoRa use multiple antenna systems for allowing BS to support large number of end-users, thus providing high scalability. Moreover, scalability in LPWANs can be affected by several factors like reliability, duty cycle and media access control (MAC) protocol [10].

2.3.2 LPWAN Technologies

LPWAN has two categories unlicensed LPWAN and licensed LPWAN. For unlicensed LPWAN run in an unmanaged spectrum such as Sigfox and LoRa as defined in the following below, whereas licensed LPWAN runs in a managed spectrum with an existing cellular network (2G,3G,4G and 5G), types of licensed LPWAN such as EC-GSM, LTE-M and NB-IoT as defined in the next subsection.

I. Unlicensed LPWAN

This section summarizes the views of different entities focusing on unlicensed spectrum.

A. SigFox

SigFox itself or in collaboration with other network operators provides an end-to-end LPWAN connectivity solution depends on its patented technologies. SIGFOX Network Operators (SNOs) deploy its proprietary BSs equipped with cognitive software-defined radios and connect them to the backend servers using an Internet Protocol (IP)-based network [11]. Due to Ultra-NarrowBand (UNB) modulation, power of each message's is focused in a very narrow bandwidth due to that reason why this technology is resilient to interference and noise levels as illustrated in Figure (2-2) [12]. SigFox uses efficient frequency bandwidth and very low noise levels leading to ultra-low power consumption, high receiver sensitivity and low cost for antenna design at the expense of maximum throughput of only 100 bps.

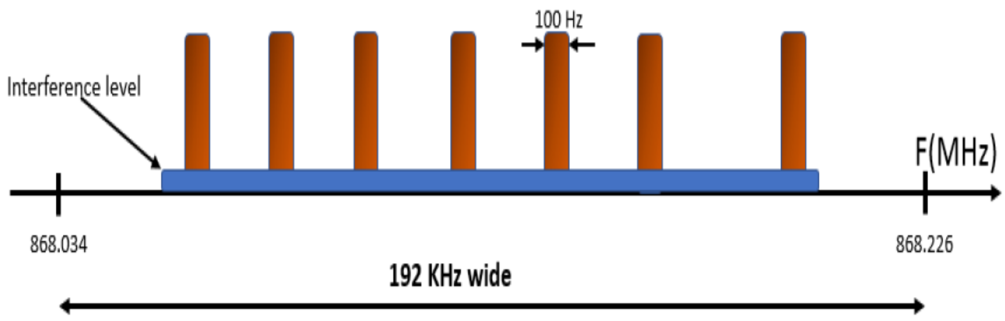


Figure (2-2): UNB Modulation Technique and Interference Resilience [12].

In uplink transmission, Sigfox uses Differential Binary Phase-Shift Keying (DBPSK) modulation and in downlink, Gaussian Frequency-Shift Keying (GFSK) technique is used [11].

When Sigfox developed, it was only support uplink communication but later develop to offers bidirectional technology with an asymmetry link. The number of messages for the uplink is only 140 messages per day and maximum payload length for each uplink message is 12 bytes. In downlink transmissions, number of messages is limited to 4 messages per day and maximum payload length is 8 bytes. Not exist downlink acknowledgment for every uplink message [11] [12], As shown in Figure (2-2), that 99% of the time for channel are not using, means that devices are in sleep mode resulting in saving a lot of battery-life [12].

SigFox takes feature of frequency and time diversity to compensate the lack of acknowledgments for each uplink message. Each end-device send same message multiple times (three by default) using 3 different time slots over different frequency channels.

B. LoRaWAN

LoRaWAN stands for Long Range Wide Area Network which invented by Semtech Corporation and developed by LoRa Alliance as a wireless communication standard. It operated in unlicensed bands. It is important to know different between terms LoRaWAN and LoRa. LoRaWAN is a definition of MAC protocol that provide long range, high capacity and low power in LPWA networks, while LoRa is the part of physical layer and realize the modulation [12].

The key feature in LoRaWAN standard is LoRa. LoRa is a part of the physical layer and determine the modulation that has ability long-range in LoRaWAN. LoRa is based on Chirp Spread Spectrum (CSS) technique which spreads a narrow-band over a wider channel bandwidth. Also, LoRa use Forward Error Correction (FEC) with the spread spectrum technique to increase the receiver sensitivity. LoRa holds low level of power consumption and achieves longer range communication [7] [12]. The advantage of using LoRa that it can covered a whole city or region by deploying only one gateway. In addition, LoRaWAN provides three different device classes (A, B and C) for low power consumption. Figure (2-3) illustrate the three classes, in Class-A, end-devices provide a bi-directional communication. It has low power consumption. The uplink transmission could be transmitted randomly at any time. Uplink transmission is followed by two slots of downlink transmission as shown in figure (2-3) (a) [7] [12]. But in Class-B, it made an adjustment in term of receiving slots that open extra receive slots at scheduled time. To do that by one more downlink transmission slot could be dedicated by the gateway according to its demand in a predefined time and synchronized by using Beacon frames as shown in figure (2-3) (b) [7] [12].

While in Class-C, it allows continuously receive windows after uplink transmission. End-devices consume more power but has less latency in the system. This class useful for applications that need more downlink transmission as shown in figure (2-3) (c) [7].

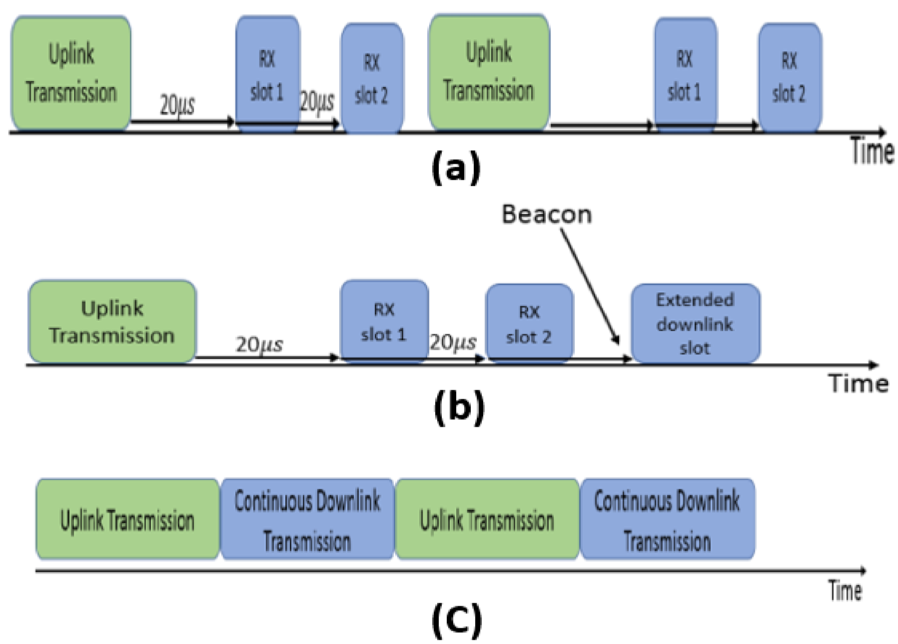


Figure (2-3): Three classes device LoRaWAN, (a) Class-A, (b) Class-B, (c) Class-C [12].

LoRaWAN provides scalable bandwidths 125, 250 or 500 kHz depending on the region or the frequency plan. SRD860 band is unlicensed and could be utilized by anyone without paying money, while the usage of the SRD860 band is regulated by the regional government that puts restrictions on the frequency and transmitted power [12].

II. Licensed LPWAN

This part summarizes the views of different entities focusing on licensed spectrum.

A. EC-GSM

EC-GSM-IoT also known as EC-GPRS is a LPWA technology based on eGPRS (Enhanced GPRS) and designed to provide a high capacity, long range, low power consumption and low complexity cellular system for IoT. It is developed by 3GPP as release 13. The optimization of EC-GSM that can be deployed on existing Global System for Mobile communication (GSM) with a software upgrade on the radio network and core network by defining new data and control channels mapped over GSM network. It offers enhanced coverage up to 20dB, a massive number of devices connectivity up to 50K devices per cell, device complexity is reduced, long battery-life up to 10 years of operation for a wide range application and low latency [11] [13] [14].

It also benefits from all the security and privacy features compared to conventional GSM such as entity authentication, user identity confidentiality, data integrity, confidentiality and mobile equipment identification [15]. The Spectrum bandwidth used in EC-GSM same as used in GSM spectrum (850-900 MHz and 1800-1900 MHz) bands. A link budget in the range of 154 dB to 164 dB it is depends on the transmission power [14]. Multiple access that used in EC-GSM-IoT same as in 2G, i.e, FDMA (Frequency-Division Multiple Access) and TDMA (Time-Division Multiple Access) [14].

Two modulation techniques used in this technology are Gaussian Minimum Shift Keying (GMSK) and 8-ary Phase Shift Keying (8PSK) offers variable data rates and the peak rate of 70kbps (GMSK) and 240 kbps for (8PSK) and latency is 700 ms to 2 seconds [11] [14].

B. LTE-M

LTE enhancements for Machine Type Communications (eMTC) also known as CAT-M1 or else known as LTE-MTC (Long Term Evolution-Machine Type Communication) or just LTE-M. LTE-M is the one of three proposals developed by 3GPP for cellular LPWAN applications. It is a bi-directional, it provides several characteristics such as long battery-life, carrier-grade, security, low data needs and low cost modules. The main idea of LTE-M IoT devices are wirelessly connected to existing LTE network means no need for a new base stations or additional network infrastructure for deployment [9]. LTE-M application used in efficient way in Smart Metering and Asset Tracking [12].

In uplink, LTE-M utilized Single Carrier-Frequency Division Multiple Access (SC-FDMA) medium access scheme with 15 kHz tone spacing and turbo code and modulation technique is 16QAM, while in the downlink, it used Orthogonal Frequency Multiple Access (OFDMA) with 15 kHz tone spacing and turbo code. Also, the modulation technique is 16QAM. 3GPP specifications show that LTE-M devices batteries-life up to 10 years and can extend coverage to 156 dB of Maximum Coupling Loss (MCL) and data rates modified according to coverage [12]. To extend the battery lifetime in LTE-M. 3GPP provides two features are Power Saving Mode (PSM) and Extended Discontinuous Reception Mode (eDRX). In PSM mode, LTE-M UE most of the time in sleep mode and only wakes up for a specific time slot to transmit data in the network, after sending the data, the device remains active in receiving mode for four specific time slots, if it needs to reach the network while, In LTE-M eDRX mode, it adds extended windows of sleep mode between LTE paging cycles time from 10.24s to 44 min. this mode has a less power saving than LTE PSM due to device more of the time slots in on mode [12] [15].

LTE-M use an existing LTE network architecture. The only additions are that software upgrade on the eNB base stations of the LTE network and LTE-M UE integrates chipset and antenna for desired sensors. A SIM card is needed to enable transmission and authentication over the network and it connects directly to the LTE network without requiring to any other gateways.

The LTE network consists of the Evolved Universal Terrestrial Radio Access (E-UTRAN) and Enhanced Packet Core entities (EPC). The eNB is responsible for provide a resource allocation to the UE in both uplink and downlink transmissions and change the state of transition from idle to active mode of the UE. The Managed Services core network existent allows a secure and protected monitoring environment for all the data that is received. In the end-user's side, data and applications can be recover from the application server supported by the network operator of the area [12]. A new Technology driven from the LTE-M is known as NB-IoT which is generally use the same features of power saving mechanism but it differs in using the multiplexing and modulation techniques. The following section will review a brief concept and details about the NB-IoT.

2.4 NB-IoT

NB-IoT is a new standard known as massive LPWAN to support wide range and low data rate for IoT applications. It has several characteristics such as ultra-low power consumption, wide coverage and massive connection. Also, NB-IoT has a several novel characteristics for LPWAN deployment to overcome shortcomings like poor security, poor reliability and high operational and maintenance costs. NB-IoT able to be loaded by major mobile equipment, and module manufacturers, and indeed it will be existing to be adaptable with 2G, 3G, 4G and 5G cellular networks [3]. It enables to operate traditional IoT businesses and open up new opportunities for industry applications and other aspects, in addition it promises a strong market trends pointing at growing demand for different smart applications. Due to features and deployment of NB-IoT make it more realistic and more reliable in the most applications.

2.4.1 NB-IoT Downlink/ Uplink Approaches

In downlink, NB-IoT based on Quadrature Phase Shift Keying (QPSK) modem and OFDMA technology with 15 kHz subcarrier spacing. Each Orthogonal Frequency Division Multiplexing (OFDM) symbols consists of 12 subcarriers with bandwidth of 180 KHz. OFDMA symbols are occupied in slot.

The slots are summed up into subframes and radio frames is in the same manner as in LTE. A frame in NB-IoT uplink/downlink consists of 10 sub frames, each sub-frame duration time is 1 ms and divided into two slots with 0.5 ms [16].

The aim of 180-kHz downlink transmission bandwidth it needs to enhance the coverage. Downlink physical channel for NB-IoT is reduced and re-building part of downlink physical channel, reference and synchronized signals such as Narrow-Band Physical Broadcast Channel (NPBCH), Narrow-Band Physical Downlink Sharing Channel (NPDSCH), Narrowband

Physical Downlink Control Channel (NPDCCH), Narrow-Band Master Sync Signal (NPSS) / Narrowband Subsidiary Master Sync Signal (NSSS) and Narrowband Reference Signal (NRS). Moreover, it does not provide Physical Control Format Indicator Channel and physical mixed retransmission indicator channel [16].

Retransmission mechanism introduces in downlink physical channel and enhanced demodulation threshold via merged gain and diversity gain of retransmission for enhancing the downlink coverage. The periodic downlink transmission interval is introduced to solve resource blocking problem of enhanced coverage. If resource block is frequently occupied by NPDCCH and NPDSCH, then the uplink/downlink authorization or downlink packets traffic transmission of other devices will be blocked [16].

In uplink transmission, adopted Binary Phase Shift Key (BPSK) or QPSK modem and SC-FDMA technology. NB-IoT supports both multi-tone and single-tone transmissions. single-tone transmission supports two subcarrier spacing 15 KHz and 3.75 KHz [16]. 15 kHz of subcarrier spacing is same as in LTE and hence it provides the best co-existence performance with LTE, while in single-tone subcarrier spacing of 3.75 kHz, the slot duration uses 2 ms and support 48 continuous sub-carriers [16] [17].

In Multi-tone transmission, it is based on SC-FDMA with 15 kHz subcarrier spacing same as in LTE and supports 3,6 or 12 continuous subcarriers [17][18]. Due to higher power spectral density for 3.75 kHz subcarrier spacing than 15 kHz spacing the coverage in 3.75 kHz is higher than in 15 kHz [8] [19]. In the time domain, single carrier transmission the resource unit is 8 ms for 15 kHz and for 3.75 kHz is 32 ms. For multiple subcarrier spacing the resource unit is 4 ms for spacing with 3 sub-carriers, 2 ms for spacing with 6 sub-carriers, and 1 ms for spacing with 12 sub-carriers [8] [19]. NB-IoT network modified and re-design uplink physical channel such as Narrowband Physical Random Access Channel (NPRACH) and NPUSCH. But it does not support Physical Uplink Control Channel (PUCCH). Aiming to enhance coverage in uplink, retransmission mechanisms in uplink physical channel is defined in NB-IoT system and this mechanism is a low cost.

NB-IoT terminal has a crystal oscillator which is low cost. Due to long continuous uplink transmissions, the consumption of terminal power amplifier causes temperature change of transmitter then the result will be in frequency variation in crystal oscillator and that will impact uplink transmission performance and reduce efficiency of data transmission [17] [18]. To solve this frequency deviation, the uplink transmission interval is defined in NB-IoT to allow the terminal to suspend during long continuous transmission in uplink transmission, switch to downlink during that period and using NPSS/NSSS. NRS signal can make synchronous tracking and frequency offset compensation After a specific period of compensation (for instance, the frequency deviation is less than 50 Hz), the terminal will go back to uplink and continue to transmit data [18]. Figure (2-4) shows NB-IoT Uplink and Downlink Channels and Figure (2-5) shows NB-IoT Uplink Downlink Transmission Mode.

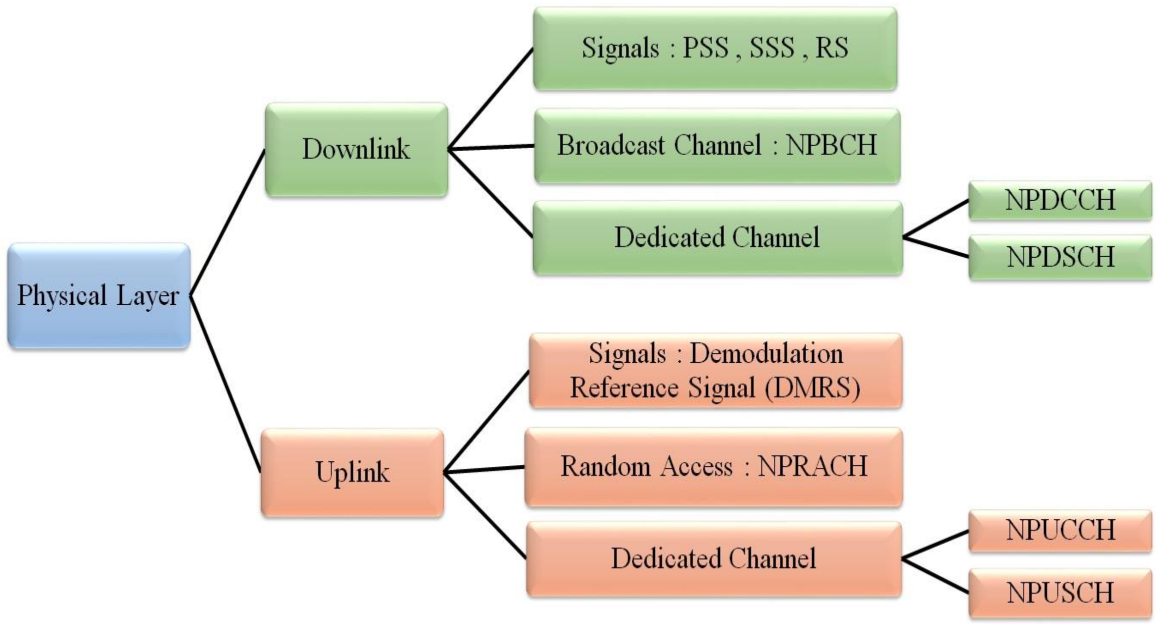


Figure (2-4): NB-IoT Uplink and Downlink Channels.

Figure (2-5): NB-IoT Uplink Downlink Transmission Mode.

2.4.2 NB-IoT Operation Modes

Currently, NB-IoT supports only Frequency Division Duplex (FDD) transmission mode with bandwidth of 180 kHz. The three deployment scenarios for NB-IoT as shown in Figure (2-6):

- **Independent deployment mode (Stand-alone mode):** which utilize a frequency band outside LTE bands, it utilizes in current GSM/EDGE frequency band with 200 kHz and guard interval is 10 kHz on both sides to replace the existing single or multiple GSM carrier wave and this deployment mode depends on available spectrum in city, country or carrier [16].
- **Guard-band deployment (Guard-band mode):** This used free Resource Blocks (RBs) within LTE carrier's guard band.
- **In-band deployment (In-band mode):** it uses a RB within an LTE frequency band. This band required a software upgrade for the eNB.

  In-band operation defined two modes of operation. The first mode is defined as Same-PCI mode where NB-IoT carrier has identical parameters, which are the physical cell ID (PCI) and number of transmit antennas as the LTE. The second mode is named Different-PCI where it considers options of having different cell ID and number of transmit antennas [20].

In conclusion, independent and Guard band deployment mode tend to provide best indoor coverage, also, use FDMA (GMSK) offers lower cost and saving power consumption about 20% [18].

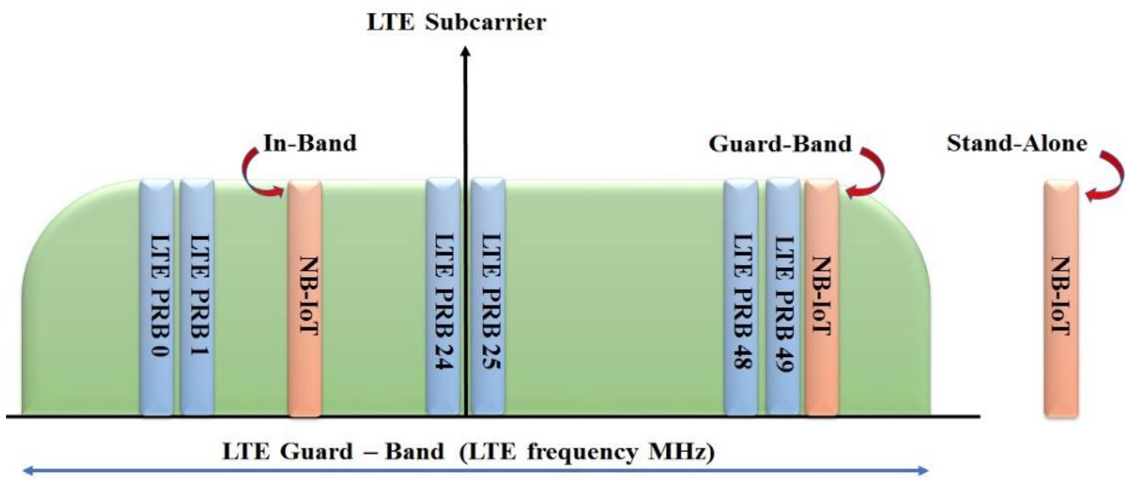


Figure (2-6): NB-IoT operation modes.

According to operation options, the deployment of NB-IoT should be transparent to UE when it is turned on and searches for NB-IoT carrier. It is only requires to search for carrier on 100 KHz for facilitating the UE initial synchronization referred to anchor carrier. Figure (2-6) showing the process of NB-IoT assign to a selected carrier from LTE spectrum based on three operation options [21]. Given LTE carrier frequency in MHz, the Physical Resource Block (PRBs) indexes that are the best range with the LTE frequency grid can be used as an NB-IoT anchor carrier. PRBs indexing starts from index 0 for the PRB occupying the lowest frequency within the LTE system bandwidth. NB-IoT anchor carrier in in-band and guard-band deployment required to have a center frequency no more than 7.5 kHz from that 100 kHz carrier for a UE to synchronize to the network [21].

2.4.3 NB-IoT Network and Frame Structure

NB-IoT technology used FDD half-duplex Type-B as a duplex mode also support full duplex mode. In FDD half-duplex, means frequency in uplink and downlink are separated with at least one guard subframe when switch between uplink and downlink and the user can either transmits or receives, i.e., cannot do both operations simultaneously. The downlink of NB-IoT eNB provides E-Utran wireless Frame Structure 1 (FS1). Also, uplink supports FS1 for 15 KHz sub-carrier space. But, a new type of frame structure is defined for sub-carrier spacing of 3.75 kHz.

Mini-packet transmissions are target services of NB-IoT. In general, mini-packet transmissions do not support long-term and continuous channel quality change indication. Hence, NB-IoT depends on selecting Modulation and Coding Scheme (MCS) and repeat times of data transmission according to the coverage level instead of design a dynamic link adaptation scheme. Commonly, there are three kinds of coverage levels which are normal coverage, robust coverage, and extreme coverage, which correspond to link losses of 144 dB, 154 dB and 164 dB, respectively [18]. The NB-IoT network architecture is mainly consists of five parts:

- **NB-IoT terminal:** It is IoT devices in all industries such as sensors and IoT devices can access to NB-IoT network through installed corresponding SIM card.
- **NB-IoT base station:** It refers to the base station, mainly refers to the LTE base stations (eNB). It has deployed by telecom operators and it supports three types of operation modes (Stand-alone, Guard-band and In-band).
- **NB-IoT core network**: function of this layer is to enable connection between NB-IoT base station and NB-IoT cloud.
- **NB-IoT cloud platform**: function of this layer that various processing for various services can be completed and results could be forwarded to the vertical industry center or NB-IoT terminals.

- **Vertical business center:** It can obtain NB-IoT service data from center itself as well as made control to NB-IoT terminals.

Communication between the NB-IoT terminals and the eNB via air interface based on functions which describe the interface access processing and cell management. The S1 lite interface represented as an optimized version for control plane based on S1 AP protocol, interface between eNB and IoT management core. User plane data is carried the modified S1 AP messages to support small data handling in an efficient manner and optimized security procedures in C-IoT and NB-IoT. The collection of data and voice in NB-IoT is performed by EPC which is a framework unifies voice and data on an IP service architecture as a Mobility Management Entity (MME), and voice is treated as just another IP application. This mechanism will allow operators to deploy and operate one packet network for all cellular networks in addition to WLAN, WIMAX, LTE and fixed access with the NB-IoT applications [8].

2.5 Related Work

Table (2-1) shows some literature works which are used in optimizing the network and its corresponding performance analysis in term of power efficiency, delay transmission, throughput, Bit Error Rate and probability of the message loss. The forthcoming paragraph will be discussing the concepts mentioned in Table 2.1.

In [22], the authors proposed analyzed NB-IoT uplink repetition number and bandwidth allocation and proposed analytic expressions in term of SNR, bandwidth, and energy per transmission bit that can be derived by Shannon theorem in order to illustrate the influence of the repetition number and bandwidth allocation to different User Equipment (UEs). Moreover, their work proposed an algorithm for link adaptation. The algorithm exploits resource unit (RU) number, bandwidth and repetition. Their numerical and simulation results show that reducing bandwidth and performing repetitions could enhance the coverage. However, this work did not determine the actual impact of channel parameters as well as NB-IoT UE impairments.

In [20], the authos presented of using number of repetition in NPDSCH to enhance coverage at weak signal area and improve signal quality. Performance of NB-IoT system for NPDSCH is evaluated for three operation modes (standalone, guard band and in-band modes). When number of repetition increase it will achived better performance as well as standalone and guard band modes perform better compared to in-band mode.

In [4], the authors investigated an extended NB-IoT architecture and the adoption of cooperative relaying paradigm. It determines an optimal relay selection algorithm that minimizes the overall power consumed in a NB-IoT cell. Also, propose a greedy algorithm which that reaches the same aim with a lower computational complexity. System level simulations clearly to demonstrate that cooperative relaying brings to an energy saving up to 30% and the greedy approach achieves only 10% for average overall energy consumption which is higher than the optimal strategy.

In [23], the authors determine in details an opportunistic crowdsensing application scenario in which traffic from a large number of connected sensors is transmitted over NB-IoT technology. The analytical model across both urban and rural deployments. Moving vehicles assist in relaying sensor traffic to the NB-IoT BS was addressed to resolve difficulty of baseline infrastructure to handle the massive amounts of short messages from thousands of battery-powered IoT devices. They proposed concept to bring significant improvements to both network-centric as well as device-centric performance indicators, thus offering a smart alternative to static NB-IoT deployments. The simulation results show the effects of vehicle-based relays on network performance, expressed in terms of connection reliability, transmission latency and communication energy efficiency.

In [24], the authors present a cooperative communication as a proposed scheme to increase the throughput and transmission rate. It contains two terminals (terminal A and terminal B) and destination. There is a collaborate between two terminals in order to improve performance. They used OFDMA as a multiple access and channel is AWGN. A decoding scheme is proposed as well.

In [25], the authors discussed solutions, challenges and future work in cooperative communications in M2M.

In [26], the authors show the performance analysis of average symbol error probability (ASEP) for the multiple-mobile-relay-based decode and forward relaying in M2M system over N-Nakagami fading channels. The method that used to obtain the ASEP performance for different modulation called the Moment Generating Function (MGF). They present Monte Carlo simulation to confirm system model and using MATLAB and MAPLE to find the result output which are comparison of the DF, AF relay and direct transmission. Also, shows the parameters fading coefficient, number of cascaded components, relative geometrical gain, power-allocation parameter, and number of mobile relays have an effect in the ASEP performance.

Table (2-1): Summarization for related work

Ref. No.	**Problem**	**Methodology**	**Results**
[22] Pilar A. Maldonado et al [2019]	Poor coverage	- Shannon theorem analytical for Tx repetitions bandwidth allocation in NPUSCH - Link adaptation in uplink transmission.	A. reduction Tx power, Greater number of RUs means low Tx energy, good SNR. B. Higher MCL in UE increases delay transmission
[20] Nurul Aizati Ahmad et al [2019]	Poor coverage at weak signal area	- The performance of using repetition in NPDSCH will be presented by BLER simulation under AWGN. - Configured NPDSCH to carry SIB1-NB. - Calculate BLER for using repetition in NPDSCH for three modes.	A. When Increasing number of repetitions, it will achive better performance of NB-IoT system. B. It shows standalone and guard band modes have perform better performance when compared with in-band mode.
[4] Davide Di Lecce et al [2018]	energy consumption	- Cooperative relaying techniques in NB-IoT for energy-saving. - optimal and greedy approaches in uplink transmission.	A. optimal approach up to 30% energy save. B. greedy approach higher than optimal by 10%
[23] Vitaly Petrov et al [2017].	Poor coverage	- mathematical analysis for opportunistic crowd sensing applications in NB-IoT.	A- reliable data transfer in urban for connected sensors per Km. B- For the anticipated density not able to delivering delay-sensitive data in the massive deployments. C- in a rural with the cell's radius 30 km. best energy efficiency than conventional LTE.

			D- radio resource depends on optimal value of Fraction of channels allocated to the vehicles
[24] Eui-Hak lee et al [2015].	Low Tx rate in cooperative communication	Evaluating OFDMA as a multiple access and channel is AWGN for cooperative communication	A- increases the throughput, increased transmission rate
[25] Juma w. Raymond et al [2018].	Survey	Solutions, challenges and future work in cooperative communications in M2M.	A- escalating complex scheduling design, increased intra and inter network interferences, increased end-to-end latency and redundancy increased message overheads. B-future use; full duplex relays, utilization of non-regenerative mode of relay operation, cross layer optimization, designing of hybrid clustering techniques.
[26] Lingwei Xu et al [2016].	Nakagami channel fading in M2M system	- moment generating function (MGF) for ASEP performance in modulations. -presents Monte Carlo simulation for system model for evaluate DF, AF relay and direct transmission.	A- ASEP performance affected by; fading, coefficient m, number of cascaded components, power-allocation, relative geometrical gain number of mobile relays. B- ASEP performance of DF relaying is better than that of AF relaying. C- ASEP performance of DF and AF relaying is better than that of direct transmission. D- ASEP performance improved by increase in fading coefficient. when cascading increases, performance degraded. E- ASEP performance is improved with the SNR increased.

2.6 Summary

This chapter presented LPWAN as a new wireless technique that can provide several features like large coverage area, low power consumption, low cost and more reliability than other types of technologies. It addressed the concept of LPWAN along with more details in it is features and categories. Cooperative relay is allowing relays to cooperative with BS and users to enhanced power efficiency, data rate, mobility, throughput, network deployment, system throughput, extend cell-edge coverage and guarantee QoS. Finally, presented a review of literature works about the most important aspects for using repetition and cooperative relay in NB-IoT.

Chapter Three

System Model and Formulation Approach

Chapter Three

System Model and Formulation Approach

3.1 Overview

The main motivation behind NB-IoT feature was to support IoT devices where power and energy is the basic concern while maintaining low data rates with an equivalent bandwidth. As we mentioned in chapter 2, NB-IoT is a new air interface developed by 3GPP for low data rate MTC in LTE-Advanced Pro release 13. It will improve the power consumption of user devices, system capacity, spectrum efficiency and low cost as it avoids the requirement of complex signal overhead required for eNBs system. The bandwidth for uplink NB-IoT is 180kHz narrowband carrier.

NB-IoT can be implemented in three operation scenarios: standalone, guard-band and in-band scenarios. In standalone, with no cellular services offering narrowband spectrum availability such in cellular GSM, the scenario can establish by formatting one or more GSM carriers with bandwidth of 200 kHz and guard interval of 10 kHz on both side spectrums to carry NB-IoT traffic with ensuring smooth transition to the LTE massive machine communications. The operation of guard-band scenario with cellular services positioned the NB-IoT traffic in the guard-band of the LTE carriers without allocating LTE resources and avoiding possible interference.

In-band scenario will let the NB-IoT in the LTE carrier sharing the LTE resources which will efficiently uses spectrum resources for LTE or NB-IoT services based on demand from mobile users or devices and more cost effective and it requires that eNB software should be upgraded. The NB-IoT uplink physical channels and signals are Narrowband demodulation reference signal (DM-RS), Narrowband physical random-access channel (NPRACH) and Narrowband physical uplink shared channel (NPUSCH) [28].

The methodology of this thesis based on simulation scenario by applying the NB-IoT physical layer parameters with number of repetition in NPUSCH with/without cooperative relay, where NB-IoT is a new feature introduced in release 13 and 14 of 3GPP LTE network this scenario is implemented in NB-IoT uplink with number of repetition (number of repetition=1, 16, 32) compact with cooperative relay in NPUSCH to achieve high performance. This scenario will describe in more details in this chapter.

3.2 Narrowband Uplink Shared Channel Analysis

Here, we will describe how the NPUSCH gets mapped into the NB-IoT uplink slots. The NPUSCH can carry the uplink control information or Uplink Shared Channel (UL-SCH) according to the two formats:

- NPUSCH format 1 for carrying the uplink shared channel (UL-SCH).
- NPUSCH format 2 for carrying uplink control information.

A transmitted physical channel or signal in a slot is illustrated by one or more resource grids of N_{sc}^{UL} subcarriers and N_{symb}^{UL} SC-FDMA symbols. The number of slot in a radio frame is known as n_s where n_s (for Δf = 15 kHz)∈{0,1,...,19} for and n_s (for Δf = 3.75 kHz)∈{0,1,...,4}. Table (3-1) shows that time slot duration T_{slot} for each case uplink bandwidth in terms of subcarriers (N_{sc}^{UL}).

Table (3-1): NB-IoT parameters.

Subcarrier spacing	N_{sc}^{UL}	T_{slot}
Δf = 3.75 kHz	48	61440·T_s
Δf = 15 kHz	12	15360. T_s

Where: T_s: Basic time unit. Resource units (RUs) are used to defined the NPUSCH mapping to resource elements. In time domain, RU is denoted by $N_{symb}^{UL}, N_{slots}^{UL}$ consecutive SC-FDMA symbols while in frequency domain, N_{sc}^{RU} consecutive subcarriers, the N_{sc}^{RU} and N_{symb}^{UL} are given by table (3-2).

Table (3-2): Supported combinations of N_{sc}^{RU}, N_{slots}^{UL} and N_{symb}^{UL}

<table>
<tr><th></th><th>Δ f</th><th>N_{sc}^{RU}</th><th>N_{slots}^{UL}</th><th>N_{symb}^{UL}</th></tr>
<tr><td rowspan="5">1</td><td>3.75 kHz</td><td>1</td><td>16</td><td rowspan="7">7</td></tr>
<tr><td rowspan="4">15kHz</td><td>1</td><td>16</td></tr>
<tr><td>3</td><td>8</td></tr>
<tr><td>6</td><td>4</td></tr>
<tr><td>12</td><td>2</td></tr>
<tr><td rowspan="2">2</td><td>3.75 kHz</td><td>1</td><td>4</td></tr>
<tr><td>15 kHz</td><td>1</td><td>4</td></tr>
</table>

The NPUSCH is transmitted on one or more resource units (RUs) and each of these RUs are repeated until 128 times to enhance coverage and transmission reliability with low power and low complexity requirements to meet ultra-low end IoT use cases. RU is a smallest mapping unit in NPUSCH. It can be found by equation (3.1):

$$\text{RU in time domain} = 7 \times N_{slots}^{UL} \tag{3.1}$$

Where: RU is representing the Resource Unit, $N_{symb}^{UL}$is Number of SC-FDMA symbols in an uplink slot in the time domain successive, N_{slots}^{UL} is number of consecutive slots in an UL resource unit for NB-IoT and N_{sc}^{RU} consecutive subcarriers in the frequency domain. Equation (3.2) shows the formula RU in frequency domain and equation (3.3) shows the calculation of $M_{identical}^{NPUSCH}$ (Number of repetition of identical slots for NPUSCH) with respect to N_{sc}^{RU}

$$\text{RU in frequency domain} = N_{sc}^{RU} \tag{3.2}$$

$$M_{identical}^{NPUSCH} = \begin{cases} \min\left(\left\lceil M_{rep}^{NPUSCH}/2 \right\rceil, 4\right), & for\ N_{sc}^{RU} > 1 \\ 1 & , for\ N_{sc}^{RU} = 1 \end{cases} \tag{3.3}$$

Where: M_{rep}^{NPUSCH} : Scheduled number of repetitions of a NPUSCH transmission.

The NB-IoT UL-SCH may carry Common Control Channel (CCCH), Dedicated Control Channel (DCCH) or Dedicated Traffic Channel (DTCH) and maps on to the NPUSCH physical channel. The NPUSCH could be mapped to one or more than one RU. (Total duration depends on number of repetitions, Number of consecutive slots and Number of repetitions of identical slots in NPUSCH). Total duration is linearly proportional with number of repetitions that when number of repetitions increase the total duration will increase. Figure (3-1) shows the repetition pattern with N_{Rep} = 4. Table (3-3) show value for N_{Rep} depends on I_{Rep}.

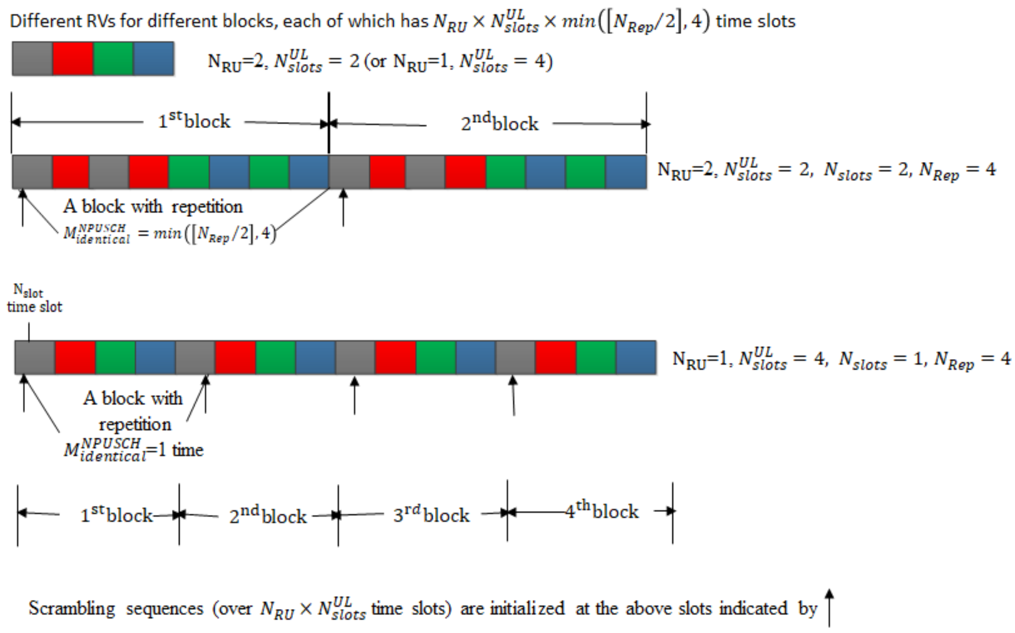


Figure (3-1): Repetition pattern with N_{Rep}= 4.

Table (3-3): Value of repetition number indicator (I_{Rep})Number of repetitions (N_{Rep}) for NPUSCH

I_{Rep}	N_{Rep}
0	1
1	2
2	4
3	8
4	16
5	32
6	64
7	128

In NB-IoT uplink communication, total duration for transmitting a block of data is find by equation (3.4):

$$\text{Total duration} = N_{RU} \times N_{slots}^{UL} \times M_{identical}^{NPUSCH} \tag{3.4}$$

Where: N_{RU}: Number of scheduled UL resource units for NB-IoT, N_{slots}^{UL} : Number of consecutive slots in an UL resource unit for NB-IoT, $M_{identical}^{NPUSCH}$: Number of repetitions of identical slots for NPUSCH.

In the first case, each transport block is transmitted over N_{RU} = 2 and each of these N_{RU} consist of two UL slots specified by N_{slots}^{UL}. After mapping to N_{slots}, these slots will be repeated $M_{identical}^{NPUSCH}$ = 2 (assumption number of consecutive subcarriers in an UL resource unit for NB-IoT (N_{sc}^{RU})> 1) times. For the second case, assumed that N_{sc}^{RU}=1 and hence $M_{identical}^{NPUSCH}$ =1 and integrated with N_{slots}= 1 results in the transmission pattern where each block is transmitted without internal repetitions. In all cases, the scrambling sequence is reset at the start of the codeword transmission or retransmission.

3.2.1 NB-IoT Uplink Slot Grid

This part shows the RE allocation in a slot related to the NB-IoT uplink transmission. Grid contains one or more frames for NPUSCH and corresponding DM-RS.

A. NPUSCH: as we know before, bandwidth in NPUSCH provides single tone and multi-tone (12 subcarriers) bandwidth. Single tone transmissions use either the 15kHz or 3.75 kHz subcarrier spacing while the multitone transmissions can utilize the 15 kHz subcarrier spacing. For 3.75 kHz the slot duration is 2 ms but for 15 kHz, the slot duration is 0.5 ms. The first slot in transmission codeword initiated the scrambling sequence. If repetitions enabled, then after every $M_{identical}^{NPUSCH}$ transmission of the codeword the scrambling sequence is reinitialized. The modulation type used to modulate codewords is BPSK/QPSK and the precoded process occurs before mapping to one or more RUs. Remain resource element from the resource element that used for demodulation the reference signal, are used for transmission in NPUSCH. If higher layer signalling indicates the presence of the SRS symbol, these symbols are counted in the NPUSCH mapping, but not used for the transmission of the NPUSCH.

B. Narrowband demodulation reference signal *(*DM-RS): for every NPUSCH slot, the DM-RS is transmitted in the same NPUSCH bandwidth. The reference signals depend on the Narrowband physical layer cell identity (N_{ID}^{Ncell}), NPUSCH format (NPUSCHFormat) and the number of subcarriers (N_{sc}^{RU}). Position of RE depend on subcarrier spacing and NPUSCH format. In NPUSCH format 1 with subcarrier spacing of 3.75 kHz, the DM-RS is transmitted on symbol 4 but for NPUSCH format 1 with 15 kHz subcarrier spacing, the DM-RS is transmitted on symbol 3. For NPUSCH format 2 with subcarrier spacing of 3.75 kHz, the DM-RS is transmitted on symbols 0,1,2 while NPUSCH format 2 with subcarrier spacing of 15 kHz, the DM-RS is transmitted on symbols 2,3 and 4 in the slot.

3.2.2 Generate Block Error Rate (BLER)

The following flowchart (figure (3-2)) will explain how to generate an NB-IoT NPUSCH BLER curve according to a number of SNR points and transmission parameters.

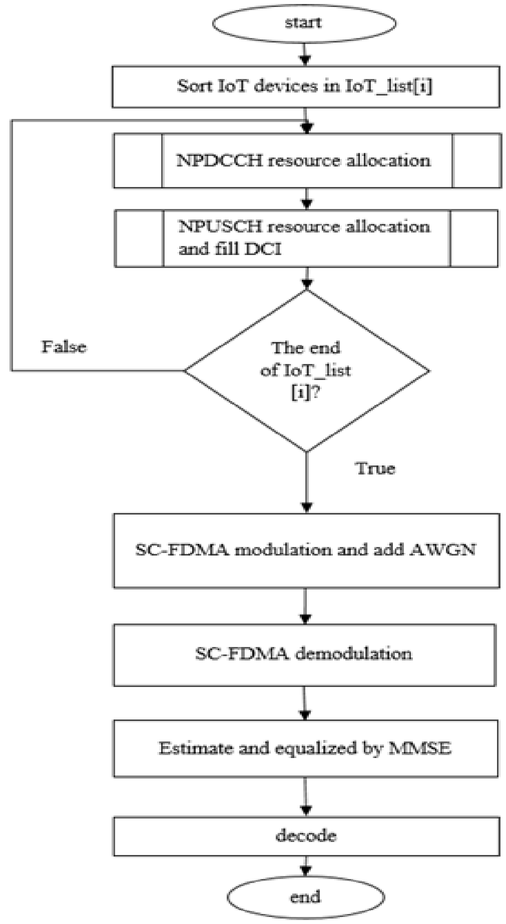


Figure (3-2): NB-IoT NPUSCH BLER.

3.3 Simulation Configuration

The simulation length of UL-SCH transport block for SNR points is 5 for different repetitions (sim_{Reps}= 1, 16 and 32). SNR in dB and simulation for number of Repetitions can be a specified as a scalar or a numeric array. A larger number of transport blocks ($\mathrm{Tr}_{\mathrm{Blks}}^{\mathrm{num}}$) should be used to calculate throughput.

3.3.1 NPUSCH Configuration

In this section will explain how to configure the parameters needs for NPUSCH generation. There are two types of payload for NPUSCH transmission which are format I and format II data and control respectively. In format I, UE used combination of modulation and coding scheme (MCS) and resource assignment signalled by DCI to determine the transport block size. In format II, NPUSCH carries the 1-bit Acknowledgment/non-acknowledgement (ACK/NACK). The parameter of channels for NPUSCHFormat used to specify format payload and information length parameter used for specify transport block length.

Hybrid automatic repeat request (HARQ) operation has one or two UL HARQ processes and HARQ operation is asynchronous for NB-IoT except for NB-IoT UE configured with a single HARQ process and for the repetitions within a bundle. Bundling operation depends on HARQ entity to invoke same HARQ process for every transmission formulate a part of the same bundle.

Within a bundle HARQ retransmissions are non-adaptive and are triggered without waiting for feedback from previous transmissions according to repetitions. An uplink grants corresponding to a new transmission or a retransmission of the bundle is only received after the last repetition of the bundle. A retransmission of a bundle is also a bundle. Figure (3-3) shows the HARQ process in NB-IoT. Which is an asynchronous.

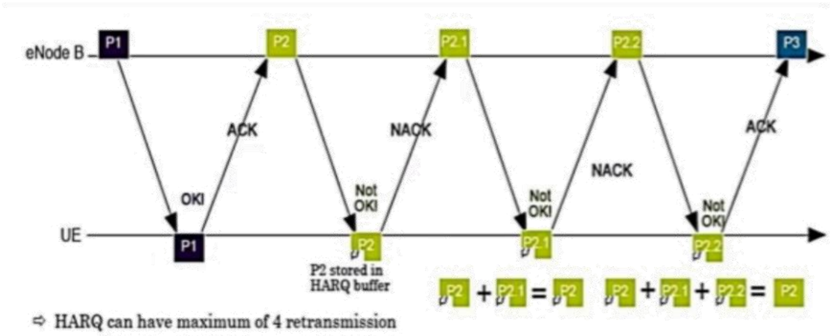


Figure (3-3): HARQ retransmission in NB-IoT.

3.3.2 Configuration of Propagation Channel Model

For the simulations, the channel model configuration parameters those should be set are shown below:

- channel struct: To initialize structure channel.
- channel.Seed: Channel seed
- channel.NRxAnts: Number of receive antennas (here defined 2 Rx antennas).
- channel.DelayProfile: Define delay profile.
- channel.DopplerFreq: Doppler frequency, unit in Hz.
- channel.MIMOCorrelation: Correlation for multi-antenna (MIMO)
- channel.NTerms: Number of oscillators used in fading model
- channel.ModelType: Choose type of Rayleigh fading model.
- channel.InitPhase = 'Random': Random initial phases
- channel.NormalizePathGains: Normalize delay profile power
- channel.NormalizeTxAnts: Transmit antennas normalization.

3.3.3 Configuration of Channel Estimator

A perfect channel estimator is used which returns the channel modelled by the functions for Multipath fading MIMO channel and High-speed train MIMO channel. The function Uplink perfect channel estimation offers a perfect MIMO channel estimate after OFDM modulation. This is done by setup channel to the required configuration and set of known symbols transmitted through this channel for each antenna transmission in turn. DM-RS signals in NPUSCH format I. the sequence group hopping (Seq_Group_Hopping) parameter used to enable or disable sequence-group hopping.

We used MMSE as a channel estimation and equalization, MMSE is a perfect estimation technique that use the knowledge of the channel statistics and channel covariance matrix. For the conventional MMSE estimator shown in equation (3.5)

$$\widehat{H}_{MMSE}^{con.} = F_L\left(F_R^H F_R + \sigma_{\widehat{H}_R}^2 \Lambda^{-1}\right)^{-1} F_R^H \widehat{H}_R \quad (3.5)$$

Where $\Lambda = \mathrm{E}[HH^H]$ is the auto-covariance matrix of H. MMSE is a modified form of conventional LS estimator, but it is very complicated to obtain the exact knowledge of the channel covariance matrix. The channel estimates $\widehat{H}_{MMSE}^{prop.}$ for the proposed MMSE estimator can be estimated as shown in equation (3.6)

$$\widehat{H}_{MMSE}^{prop.} = F_L\left[F_R^H F_R + \left(\frac{\sigma_{\widetilde{H}_R}^2}{\sigma_R^2}\right) I_L\right]^{-1} F_R^H \widehat{H}_R \quad (3.6)$$

Where: I_L represent identity matrix, σ_R^2 is the average power of the NDMS symbols the MSE of the proposed method $\varepsilon_{MMSE}^{prop.}$ can be computed as in equation (3.7)

$$\varepsilon_{MMSE}^{prop.} = E\left[\left\|\widehat{H}_{MMSE}^{prop.} - H\right\|^2\right] \quad (3.7)$$

Subsequently, equation (3.8) is the simplified form of (3.7) can be represented by the following form:

$$\varepsilon_{MMSE}^{prop.} = \left\| \Lambda - \Lambda \left(1 + \frac{\Gamma}{\Upsilon} (\Lambda^{-1})\right)^{-1} \right\| \tag{3.8}$$

Where ϒ is represent the average SNR. Equation (3-9) is used to defined ϒ as

$$\Upsilon = \frac{\sigma_R^2}{\sigma_{\hat{H}_R}^2} \tag{3.9}$$

And equation (3.10) to find Γ:

$$\Gamma = \mathrm{E}[|R(N_{sc}^{RU})|^2]\ \mathrm{E}\left[\left|\frac{1}{R(N_{sc}^{RU})}\right|^2\right] \tag{3.10}$$

where Γ is represent the modulation scheme dependent constant , for QPSK, Γ = 1.

3.3.4 Block Error Rate Simulation Loop

In order to generate the loop of block error rate, two formats were used which they represent NPUSCH format I used to carry uplink data transfer and NPUSCH format II used to carry uplink control information. Figure (3-4) shows the NPUSCH format I which use turbo code for error correction same as LTE, a random bit stream with a desired size for transport block is encoded by CRC, turbo encoder and rate matched to generate the NPUSCH bits. These bits are interleaved per resource unit to apply a time-first mapping to generate the codeword.

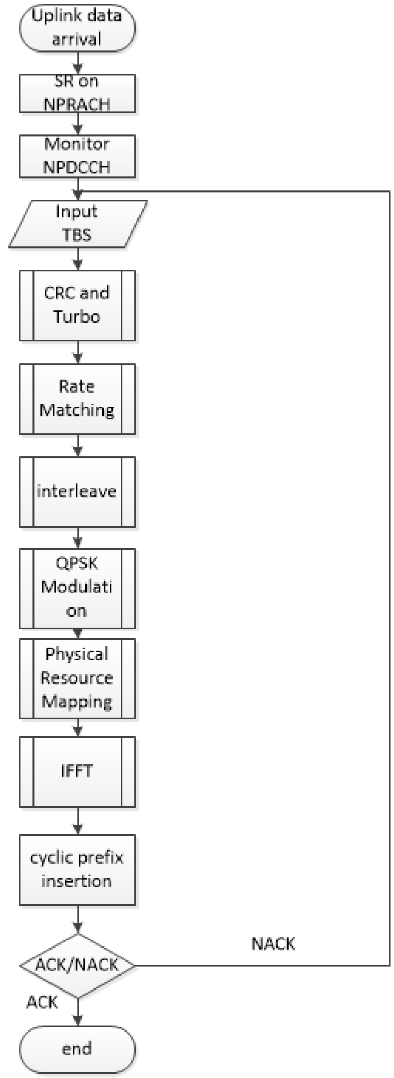


Figure (3-4): NPUSCH format I.

Figure (3-5) describe the NPUSCH format II which used for signalling HARQ Ack for NPDSCH, transport channel encoding contains bit repetitions to create the codeword. The Scrambling, modulation, layer mapping and precoding are applied to the codeword to form the complex symbols. After that, NPUSCH symbols and DM-RS are mapped on to the resource grid and the grid is SC-FDMA modulated to the time domain waveform. The time domain waveform is then passed through a fading channel and AWGN.

The noisy waveform is synchronized and a perfect channel estimation is calculated used to perform MMSE equalization for recovering the transmitted grid. After that, NPUSCH symbols are extracted, demodulation and channel decoding executed to recover the transport block following by de-scrambling, the repetitive slots are soft-combined before rate recovery. The transport BLER is calculated for all SNR points. The evaluation of the BLER is based on the assumption which is all the slots in a bundle is used for decoding the transport block at the UE.

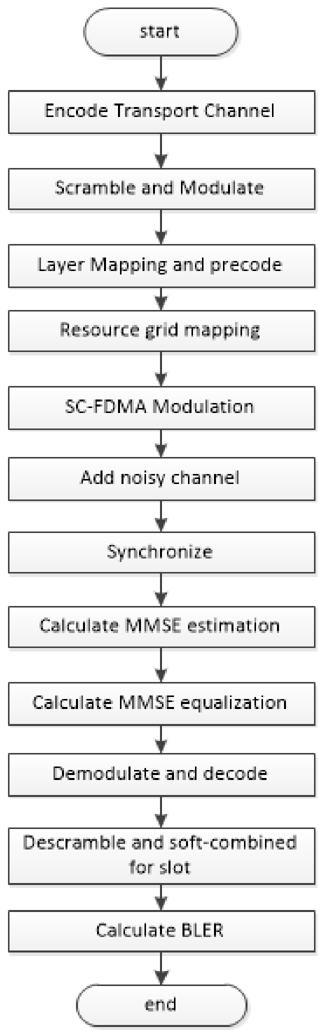


Figure (3-5): NPUSCH format II.

3.4 Simulation Scenario

The main method of this project is that assuming there are three users and one base station as shown below in Figure (3-6), where radiation is uplink (radiated from three UE to the BS). Two UE are in active mode which contains both user's data and each user needs to fetch its own data according to its distance from BS. Strong and weak signal user is simulated as near and far user according to end-user position in the BS cell. The third UE in idle mode and act as relay to help UE that position far from the BS to send the data. The data path through AWGN and fading channel.

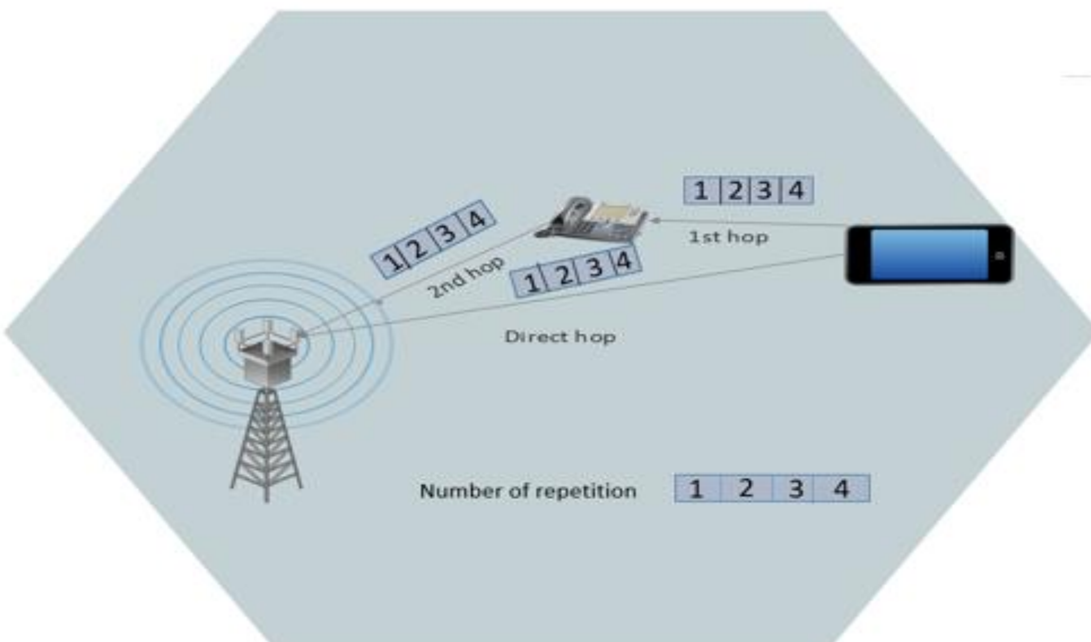


Figure (3-6): Simulation scenario topology model.

This project confined in NPUSCH only. The number of repetition that used are 1, 16 and 32. We use repetition with/without cooperative relay. In NPUSCH used the QPSK/BPSK modulation. In this scenario we use QPSK modulation, number of subcarriers are 12. Repetition with cooperative relay communications improves BLER, spectrum efficiency, delay, throughput, data rate and signal-to-interference-pulse-noise ratio. The mathematical model shows in section (3.5).

3.5 Mathematical Model

In this part, we will illustrate the simulation equation to find the simulation result.

A. Redundancy Version Sequence (RVSeq)

Redundancy version (RV) indicator used by all HARQ processes. RVSeq is a one- or two-row matrix for one or two codewords, respectively. The number of columns in RVSeq equals the number of transmissions of the transport blocks associated with a HARQ process. The RV sequence specified in each column is applied to the transmission of the transport blocks. RVSeq used according to the RV offset. To Create the codewords corresponding to the RV values used in the first and second block by using equation (3.11)

$$rv_{idx}(j) = 2 \times \text{ mod}(rv_{DCI} + \text{j}, 2) \tag{3.11}$$

Where: rv_{DCI}: RV in the DCI, $j = 0,1, \dots, \frac{N_{Rep}}{L} - 1$,

L=1 if $N_{sc}^{RU} = 1, otherwise\ L = min\left(4, \lceil N_{Rep}/2 \rceil\right)$

Here: j=0,1.

B. Frame number and slot number within the frame

The calculation of the frame number and slot number within the frame can be calculated according to the following equations:

$$F_n = Fix\left(\frac{s_{idx}}{NS_f}\right) \tag{3.12}$$

where F_n is frame number, s_{idx} represented by SNR index equal to 1: numel (SNR dB). The NS_f is number of slots per frame.

$$S_{nf} = mod(s_{idx}, NS_f) \tag{3.13}$$

Where S_{nf} represents the slot number within the frame.

C. Initialize channel time for each slot

The calculation of channel time initialization for each slot can be expressed as follows:

$$CH_{IT} = S_{idx} \times Sd \tag{3.14}$$

where CH_{IT} is representing the initialize channel time, S_{idx} is slot index and Sd represents the Slot duration.

D. Noise Gain

Equation (3-15) shows how to calculate the noise gain

$$SNR = 10^{\left(\frac{SNRdB(SNR\ index)}{20}\right)} \tag{3.15}$$

E. Normalize noise power

The normalize noise power to take account of sampling rate, which is a function of the IFFT size used in SC-FDMA modulation is given by equation (3-16):

$$N_0 = 1/(\sqrt{2\ X\ double(scfdmaInfo.Nfft))}\ xSNR \tag{3.16}$$

Where: N_0 is the normalized noise power, scfdmaInfo: is SC-FDMA modulation.

F. Adding AWGN to the received time domain waveform

We describe how to add AWGN to the RX in time domain waveform in equation (3.17):

$$RX_{wf} = RX_{wf} + noise \tag{3.17}$$

where: $RX_{wf}$is the received waveform.

G. Free-space path loss (FSPL)

The path loss in decibels calculated by using equation (3.18)

$$\text{FSPL (dB)} = 20\log_{10}(d) + 20\log_{10}(f) - 27.55 \tag{3.18}$$

where: d is represent the distance between two users in meters, f is the frequency and unit is megahertz. the constant -27.55 due to frequency and distance in megahertz and meters, respectively.

H. Power receive cooperative relay

The power receive in cooperative relay formulated as in equation (3.19)

$$\text{PR}_{\text{co-relay}} = \text{PT}_{\text{IoT}} + Gain_{BS} + Gain_{IoT} - PL_{Co-relay} \tag{3.19}$$

Where: $\text{PR}_{\text{co-relay}}$ is received power for cooperative relay in dB, PT is represent the transmitted power for IoT device in dB, $\text{PL}_{\text{Co-relay}}$ is the free-space path loss for cooperative relay in dB and it is in minus because it is destroyed the signal, Gain_{BS} is gain of base station in dB and Gain_{IoT} represent gain for IoT devices in dB.

I. Block Error Rate

Blok Error Rate is a ratio of blocks error to the total number of blocks that transmitted. Equation (3-20) shows the BL_{ER} calculation.

$$BL_{ER} = \frac{\mathrm{NTB}_{ER}}{NSTB_{ER}} \tag{3.20}$$

Where: NTB_{ER} is Number of transport blocks with errors and $NSTB_{ER}$is Number of simulated transport blocks. To calculate The maximum throughput could be calculated by using equation (3.21):

$$MAX_{th}(SNR\ index) = T_{BL} \times NSTB_{ER} \tag{3.21}$$

Where MAX_{th} is maximum throughput variable with SNR index = 1: numel (SNRdB), T_{BL} is transport block length. To calculate Simulated throughput by using equation (3.22)

$$SIM_{th}(SNR\ index) = T_{BL} \times (NSTB_{ER} - NTB_{ER}) \tag{3.22}$$

Where SIM_{th} is simulation throughput function with variable SNR index.

J. Data Rate

Data rate is the average number of bits per unit time. The unit of data rat is bits per second (b/s). Equation (3.23) calculates the Data rate (DR)

$$\mathrm{DR} = \mathrm{Bw} * \mathrm{M} * \mathrm{C} \tag{3.23}$$

Where: DR: Data Rate in (b/s), BW: Bandwidth in (Hz), M: type of modulation. (number of bits per symbol) and C: coding rate.

K. Throughput

System throughput is defined as the total number of bits correctly received by all users. mathematically expression for calculate the Throughput (TH) by equation (3.24).

$$\mathrm{TH} = \sum_{n=1}^{n} (\mathrm{DR}(1) + \mathrm{DR}(2) + \mathrm{DR}(n)) \quad \mathrm{Bits/second} \qquad (3.24)$$

Where: TH: Throughput in (b/s), SINR: Signal to interference noise ratio in (dB) and N: number of symbols.

L. Spectral Efficiency

Spectral Efficiency is referred to information rate that can be transmitted over a given bandwidth in a given system(bit/s/Hz), Equation (3.25) calculate the Spectral Efficiency (SE)

$$\mathrm{SE} = \frac{\mathrm{DR}}{\mathrm{Bw}} \qquad (3.25)$$

Where: SE: Spectral Efficiency in (bit/s/Hz), DR: Data rate in (bit/sec) and Bw: Bandwidth in (Hz).

M. Delay transmission

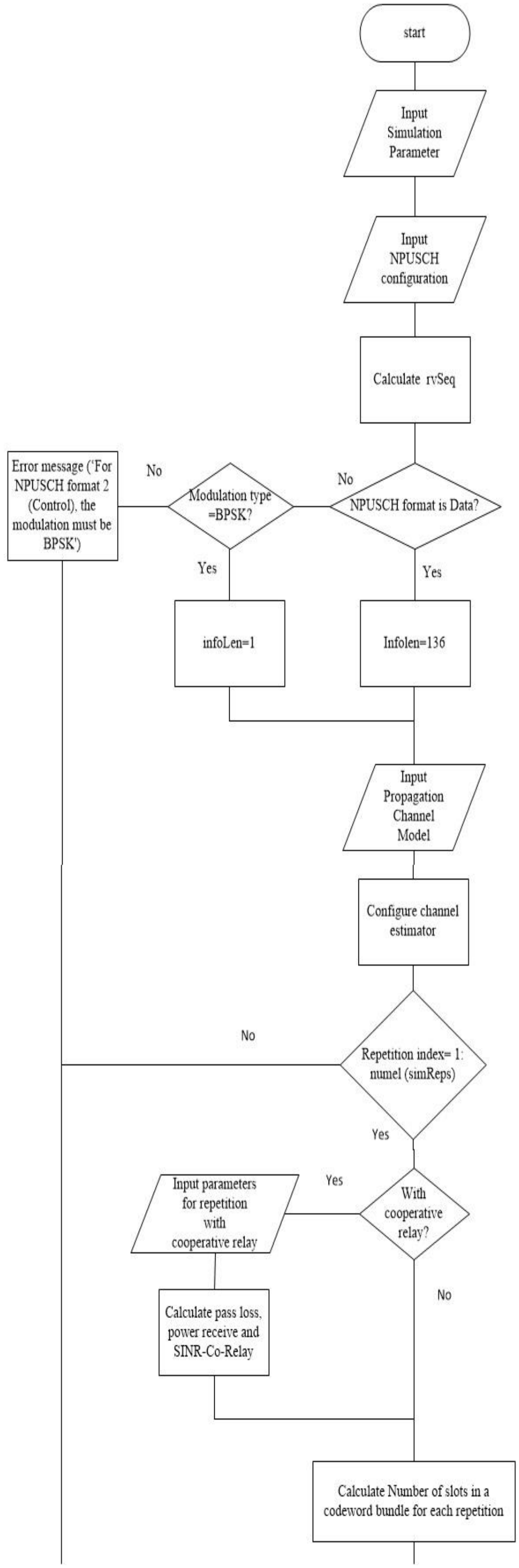
System delay gives the average of the total queuing delay of all packets in the buffers at the NB-IoT eNBs, System delay can be mathematically expressed by Equation (3.26)

$$\mathrm{DT} = \frac{\mathrm{data}}{\mathrm{DR}} \ \mathrm{Sec} \qquad (3.26)$$

Where: DT: Delay transmission in (sec), Data: data transmit in (bit/sec), DR: Data rate in (bit/sec).

3.6 Simulation Model

In order to evaluate the performance of enhancing the physical layer for NB-IoT by using number of repetition with/without a cooperative relay, the system-level simulator has been implemented to inspect on the performance of this communication. The detailed system-level simulation chain and parameters are illustrated as flow chart in the following Figure (3-7).


start
Input Simulation Parameter
Input NPUSCH configuration
Calculate rvSeq
NPUSCH format is Data?
No
Modulation type =BPSK?
No
Error message ('For NPUSCH format 2 (Control), the modulation must be BPSK')
Yes
infoLen=1
Yes
Infolen=136
Input Propagation Channel Model
Configure channel estimator
Repetition index= 1: numel (simReps)
No
Yes
With cooperative relay?
Yes
Input parameters for repetition with cooperative relay
Calculate pass loss, power receive and SINR-Co-Relay
No
Calculate Number of slots in a codeword bundle for each repetition

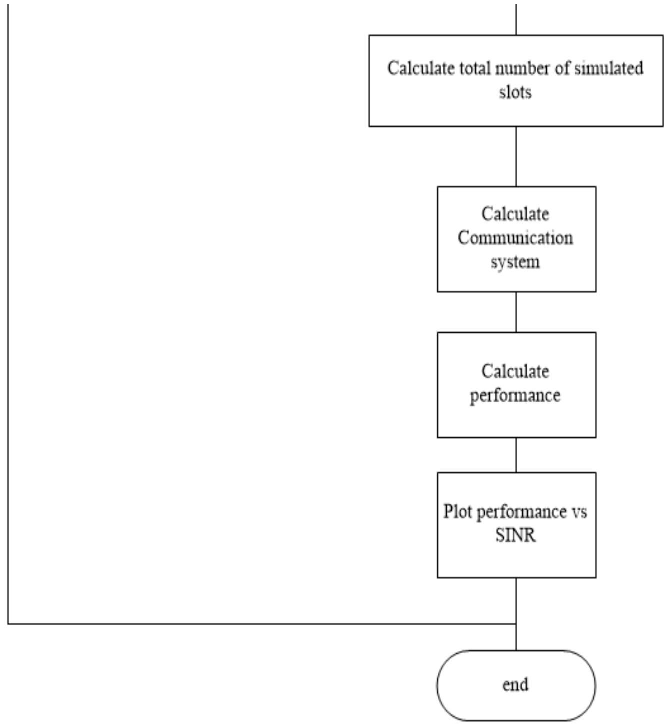


Figure (3-7): System-level simulator chain.

The simulation models of our proposed contribution are to implement number of repetition (1, 16 and 32) with/without a cooperative relay and to do comparison between them to show when using the repetition only, number of repetition increase, the performance of the overall network will increase but there is a threshold value for number of repetition when it increased than this value the performance will degrade. Moreover, when using repetition with a cooperative relay, less number of repetitions will give the high performance of the network. We calculate the performance of overall network in NPUSCH only.

The performance that we calculated are block error rate, data rate, throughput, spectral efficiency and delay transmission. The system of NPUSCH built in the transmitter side, receiver sides and the signal will pass through noisy channel (AWGN and fading channel).

3.7 Simulation Flow

In this section will show the steps that took to obtain the simulation result. Firstly, input simulation parameters such as SINR with repetition, SINR with repetition and cooperative relay, NB-IoT bandwidth, number of repetitions here we used the number of repetitions 1, 16 and 32, modulation type is QPSK, etc. After that, start the uplink channel connection between the IoT devices and eNB. The physical channel used for the uplink is NPUSCH which is physical channel to transfer data from UE to eNB. Then, using the AMC-CQI thresholds. There is a condition for the scenario that if used repetition with a cooperative relay then calculate free-space path loss, power receive and SINR for cooperative relay. After that, calculate the BLER, data rate, throughput, spectral efficiency and delay transmission. Then, plot the calculation results according to SINR else used the SINR for repetition only and calculate BLER, data rate, throughput, spectral efficiency and delay transmission and plot the calculation results as well.

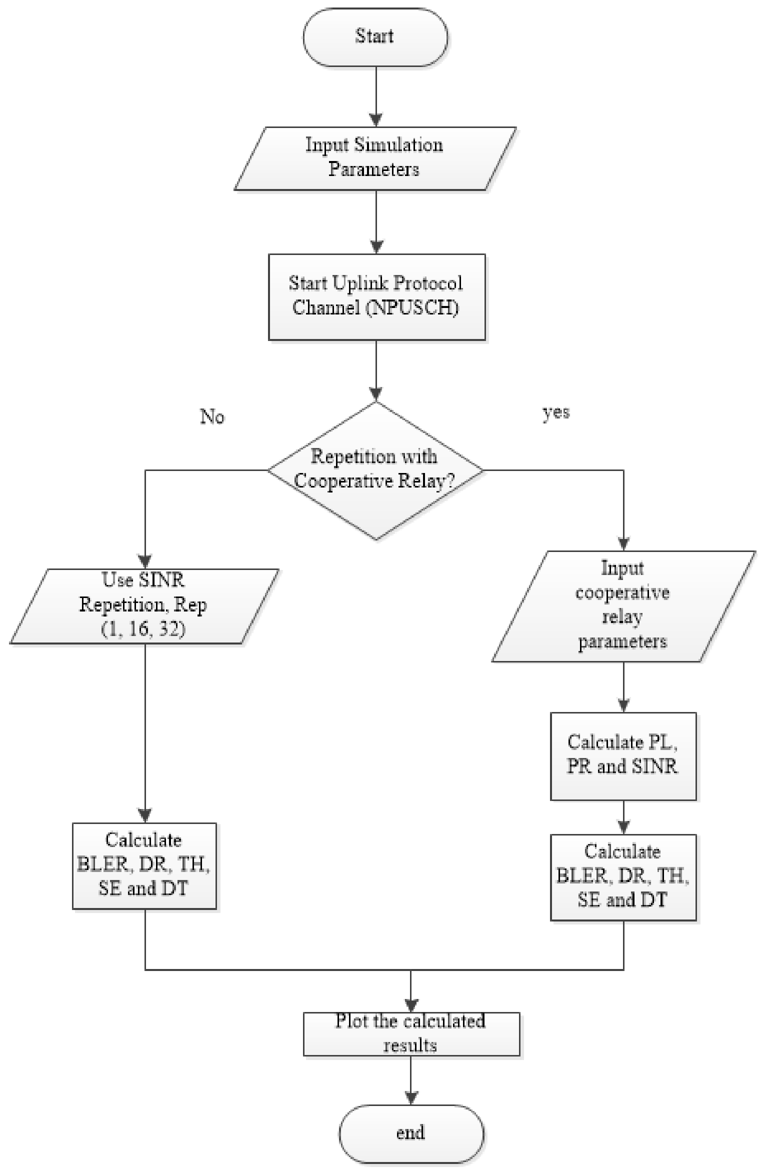


Figure (3-8): Flow chart of the simulation process.

3.8 Summary

In this chapter, we have performed an elementary analysis on using number of repetitions only and number of repetitions with cooperative relay in NPUSCH between two points in a BS cell. A comparison is made in terms of the BLER, data rate, throughput, spectral efficiency and delay transmission. We have used a noisy channel (AWGN and frequency-selective fading channel). The SNR for using repetition with cooperative relay is greater than the SNR for repetition only. Also, we describe the methods of design the simulation of using the number of repetition with/without cooperative relay in NPUSCH. Finally, equations of performance analysis were illustrated.

Chapter Four

Results and Discussion

Chapter Four

Results and Discussion

4.1 Introduction

This chapter will explain the simulation model, simulation parameter, results of the simulations and discussion for each result. The simulation scenario was done by using a Matlab simulation. The proposed NB-IoT network is consist of three IoT devices and one eNB. The IoT devices radiates an uplink which contains both IoT's data and each IoT devices needs to fetch it is own data according to its distance from BS. Strong and weak signal user is simulated as near and far (edge) user which refers to location of user inside the BS cell. We use repetition with a cooperative relay to enhance NPUSCH in NB-IoT.

NPUSCH used to carry the uplink control information or uplink shared channel (UL-SCH) according to the two formats as follows:

- ❖ Format 1 used to carry the uplink shared channel.
- ❖ Format 2 for carrying uplink control information.

Repetition is a key solution adopted by NB-IoT to achieve enhanced coverage with low complexity. In addition, for one complete transmission, repetition of the transmission should be applied to both data transmission and the associated control signaling transmission. In NB-IoT systems, before each NPUSCH transmission, related control information, including RU number, selected MCS and repetition should first be transmitted across a NPDCCH. Particularly, repetition for NB-IoT can only be selected among

{1, 2, 4, 8, 16, 32, 64, 128}, the number means the repetition number of the same transmission block (TB). The maximum number of repetition in NPDSCH is 2048 and in NPUSCH is 128. Figure (4-1) describe repetition in NB-IoT for both NPDCCH and NPUSCH transmission block with same content are repeated four times during one transmission [29].

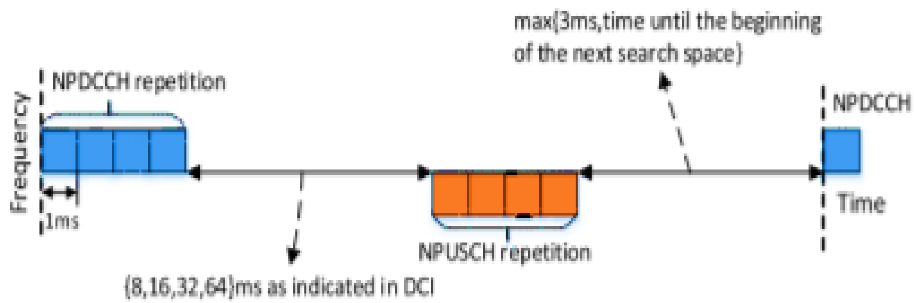


Figure (4-1): Illustration of repetition during one transmission [29].

4.2 Simulation Parameters

NB-IoT is simulated according to its specifications and features specified by 3GPP Release 13 and 14, parameters used are mentioned in the table (4-1).

Table (4-1): Simulation Parameter.

Parameter	**Description**
Bandwidth (KHz)	180
Number of simulated transport blocks	5
Number of repetition in simulatation	1,16,32
Subcarrier spacing (kHz)	15
Number of allocated subcarriers	12
Modulation	QPSK
Channel model	AWGN + Frequency Selective Fading

Number of turbo decoder iterations	5
Power transmit for IoT in cooperative relay (dBm)	23
Base Station (BS) gain	17
IoT gain	10
Frequency (MHz)	2100

4.3 Simulation Results

The evaluation metrics that took are block error rate, data rate, system throughput, spectral efficiency and delay transmission. This network performance calculated for both techniques when using repetition only and repetition without a cooperative relay in NB-IoT. The simulation results are shown in the following section in form of line graphs.

4.4.1 Block Error Rate

Blok Error Rate (BLER) is a ratio of blocks error to the total number of blocks that transmitted. The result of BLER of the repetition effects with and without cooperative relay are shown in the following figures.

Table (4-2): BLER for Repetition without and with a Cooperative Relay.

Repetitions	**BLER Case**	**SNR**			
		-20	**-15**	**-10**	**-5**
1	**Without Cooperative Relay**	**1.0000**	**1.0000**	**1.0000**	**1.0000**
1	**With Cooperative Relay**	**0.2000**	**0**	**0**	**0**
16	**Without Cooperative Relay**	**1.0000**	**0.8000**	**0**	**0**
16	**With Cooperative Relay**	**0**	**0**	**0**	**0**
32	**Without Cooperative Relay**	**1**	**0.6000**	**0**	**0**
32	**With Cooperative Relay**	**0**	**0**	**0**	**0**

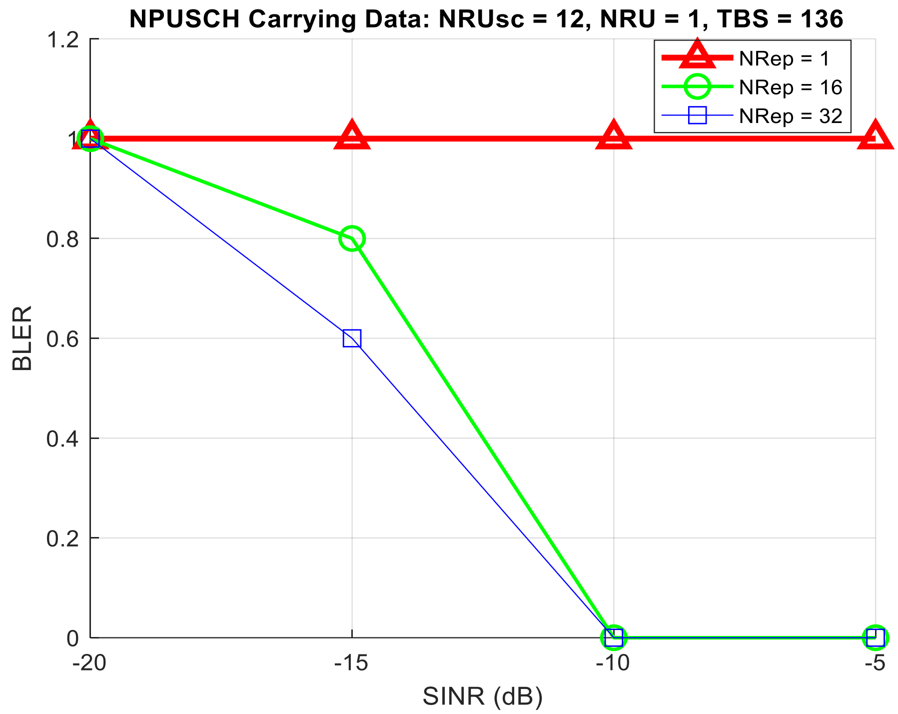


Figure (4-3): BLER for Repetition without Cooperative Relay.

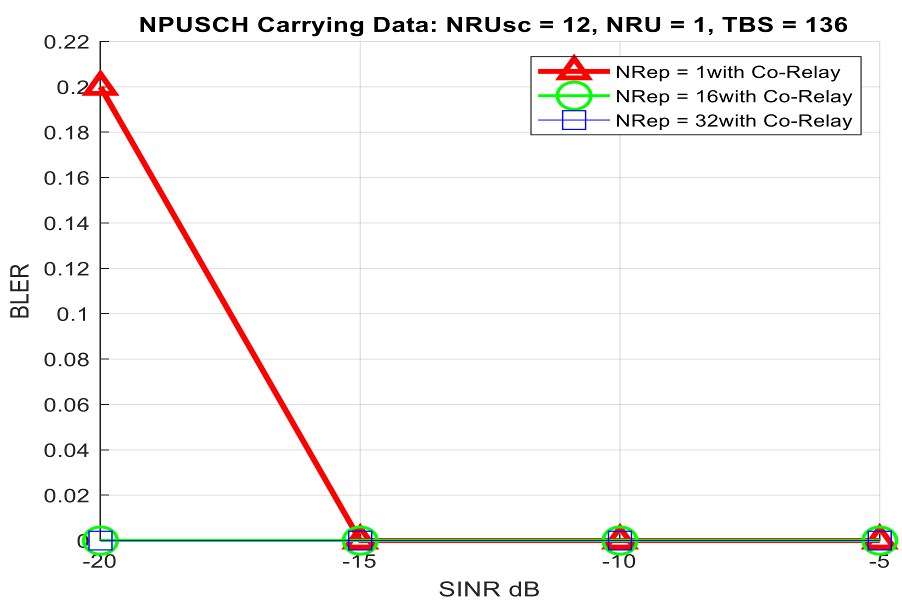


Figure (4-4): BLER for Repetition with Cooperative Relay.

As shown in the figure (4-3) (4-4) and table (4-2), In case of using repetition only, its observed that BLER in NRep=1 is 100% which means that all data received is corrupted. While BLER is enhanced when NRep=16 and 32. Rate of enhancement in BLER when NRep=16 is approximately to 40% and in NRep=32 is 67%. In other word when number of repetition increase, the BLER decrease. Whenever, in case of using repetition with cooperative relay, when number of repetition increase, the BLER will decrease as well. In NRep=1 with cooperative relay, BLER= 0.20 when SINR=-20 dB but for other SINR values the BLERs are equal to zero which mean that there is an enhanced in BLER. For the NRep=16, the BLER=0% as well as in case of using Rep=32 that means when repetition is used with cooperative relay, the ratio of Block error will decrease. The Rate of enhanced BLER could be reach to 100% when compared with using repetition only.

4.4.2 Instantaneous Data Rate

For NB-IoT data rate performance, the Data rate (DR) metric will show the average number of bits per unit time unit (bits/second). As shown in the figure (4-5) (4-6) and table (4-3), if number of repetition decrease, the data rate will increase but that is a discount on the performance of BLER which shows a significant increase. To solve this problem repetition with a cooperative relay has been introduced which will contribute to be a trade-off between data rate, throughput and BLER.

Table (4-3): Data rate for Repetition without and with a Cooperative Relay.

Repetitions	**DR Case (kbps)**	**SNR (dB)**			
		-20	**-15**	**-10**	**-5**
1	**Without Cooperative Relay**	**45**	**45**	**45**	**72**
1	**With Cooperative Relay**	**72**	**120**	**120**	**180**

16	Without Cooperative Relay	2.8125	2.8125	2.8125	4.5000
16	With Cooperative Relay	4.5000	7.5000	7.5000	11.2500
32	Without Cooperative Relay	1.4063	1.4063	1.4063	2.2500
32	With Cooperative Relay	2.2500	3.7500	3.7500	5.6250

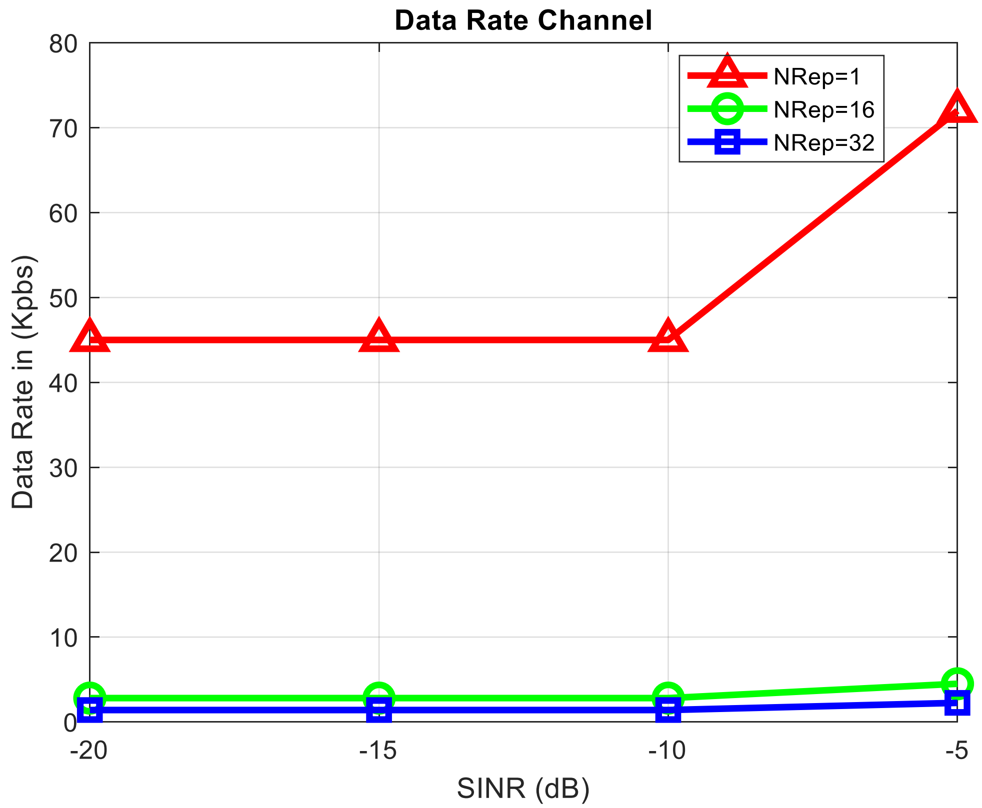


Figure (4-5): Data Rate for Repetition without Cooperative Relay.

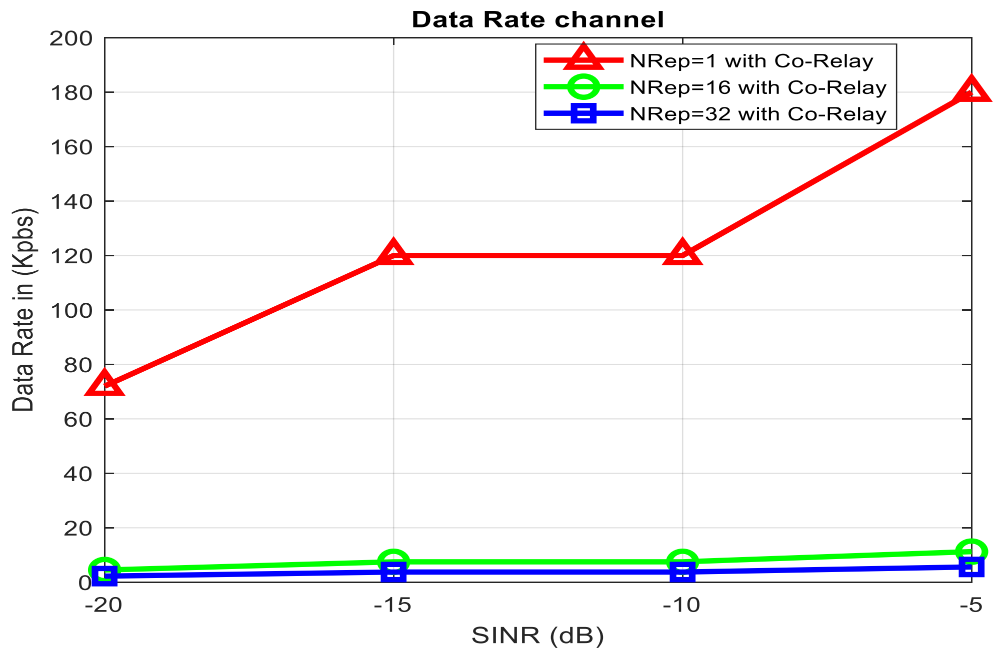


Figure (4-6): Data Rate for Repetition with Cooperative Relay.

In case of using repetition with cooperative relay, BLER shown an acceptable improvement, leads to efficient throughput and keep to reduce the number of repetitions. When using repetition with cooperative relay, the data rate is increased by= 60% when compared with using repetition only. Note that data rate for SINR range (from -20 dB to -10 dB) has same values of data rate due to condition of AMC-CQI thresholds.

4.4.3 Accumulated Throughput

System throughput is defined as the total number of bits correctly received by all users. The performance results of NB-IoT system throughput due to repetition effect with and without using cooperative relay are shown as follows, Table (4-4): Throughput for Repetition without and with a Cooperative Relay

Repetitions	TH Case (kbps)	SNR (dB)			
		-20	-15	-10	-5
1	Without Cooperative Relay	0	0	0	0
1	With Cooperative Relay	57.6	177.6000	297.6000	477.6000
16	Without Cooperative Relay	0	0.5625	3.3750	7.8750
16	With Cooperative Relay	4.5000	12.0000	19.5000	30.7500
32	Without Cooperative Relay	0	0.5625	1.9688	4.2188
32	With Cooperative Relay	2.2500	6.0000	9.7500	15.3750

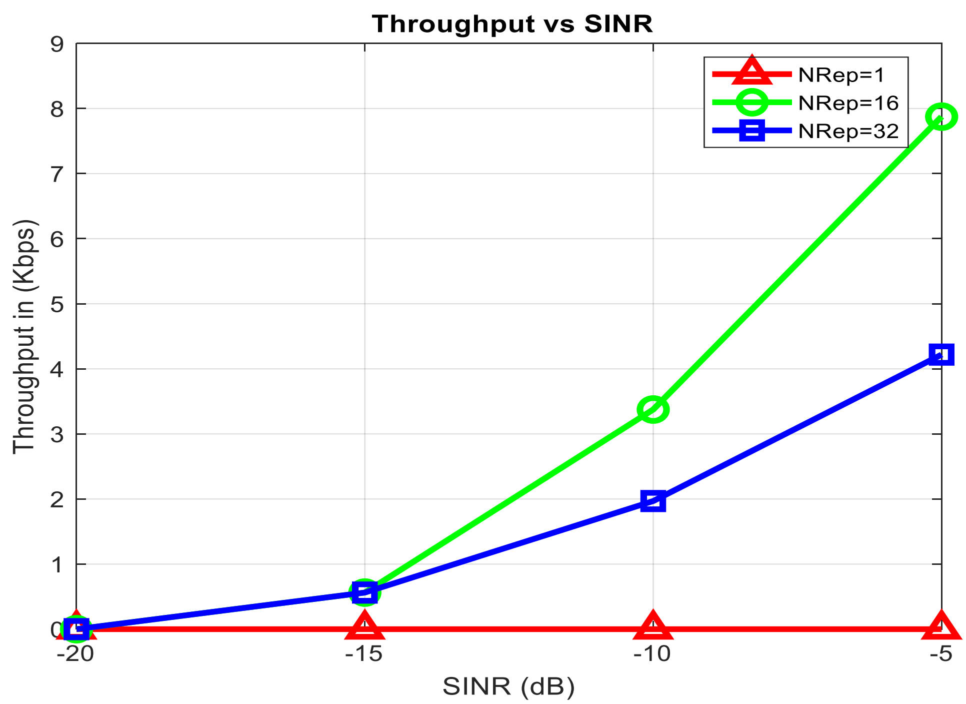


Figure (4-7): Throughput for Repetition without Cooperative Relay.

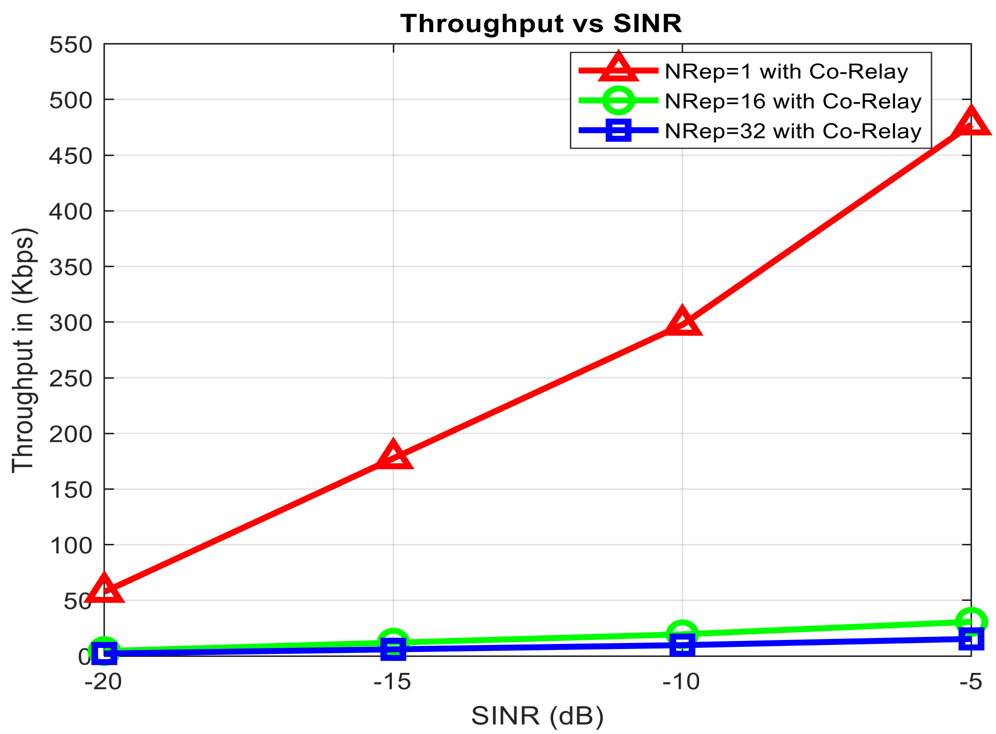


Figure (4-8): Throughput for Repetition with Cooperative Relay.

As shown in the figure (4-7) (4-8) and table (4-4), in case of using repetition only, the throughput when NRep=1 is zero which means there is no corrected received bits due to this reason increase the number of repetition is required Also, number of repetition has a threshold value i.e., if the number of repetition is increase/decrease than this value it obtained degrades in the system throughput. Moreover, NRep=16 has the best system throughput. When we use repetition with a cooperative relay, no need to increase the number of repetitions. The best throughput result is NRep=1. The repetition with a cooperative relay enhanced system throughput by rate ≅ 74% when compared with using repetition only.

4.4.4 Spectral Efficiency

Spectral Efficiency, refers to the information rate that can be transmitted over a given bandwidth in a given system (bit/s/Hz). Form figure (4-9) (4-10) and table (4-5), show that in case of using repetition only, spectral efficiency directly proportional with system throughput, there is a threshold value to achieve high spectral efficiency.

Table (4-5): Spectral Efficiency for Repetition without and with a Cooperative Relay.

Repetitions	SE Case (b/s/Hz)	SNR (dB)			
		-20	-15	-10	-5
1	Without Cooperative Relay	0	0	0	0
1	With Cooperative Relay	0.3200	0.6667	0.6667	1.0000
16	Without Cooperative Relay	0	0.0031	0.0156	0.0250
16	With Cooperative Relay	0.0250	0.0417	0.0417	0.0625
32	Without Cooperative Relay	0	0.0031	0.0078	0.0125
32	With Cooperative Relay	0.0125	0.0208	0.0208	0.0313

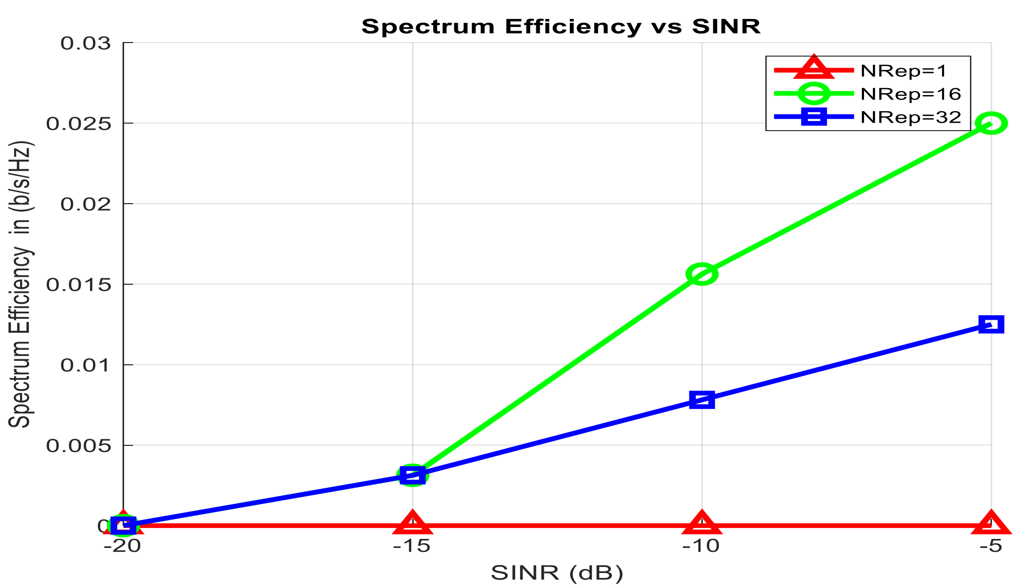


Figure (4-9): Spectral Efficiency for Repetition without Cooperative Relay.

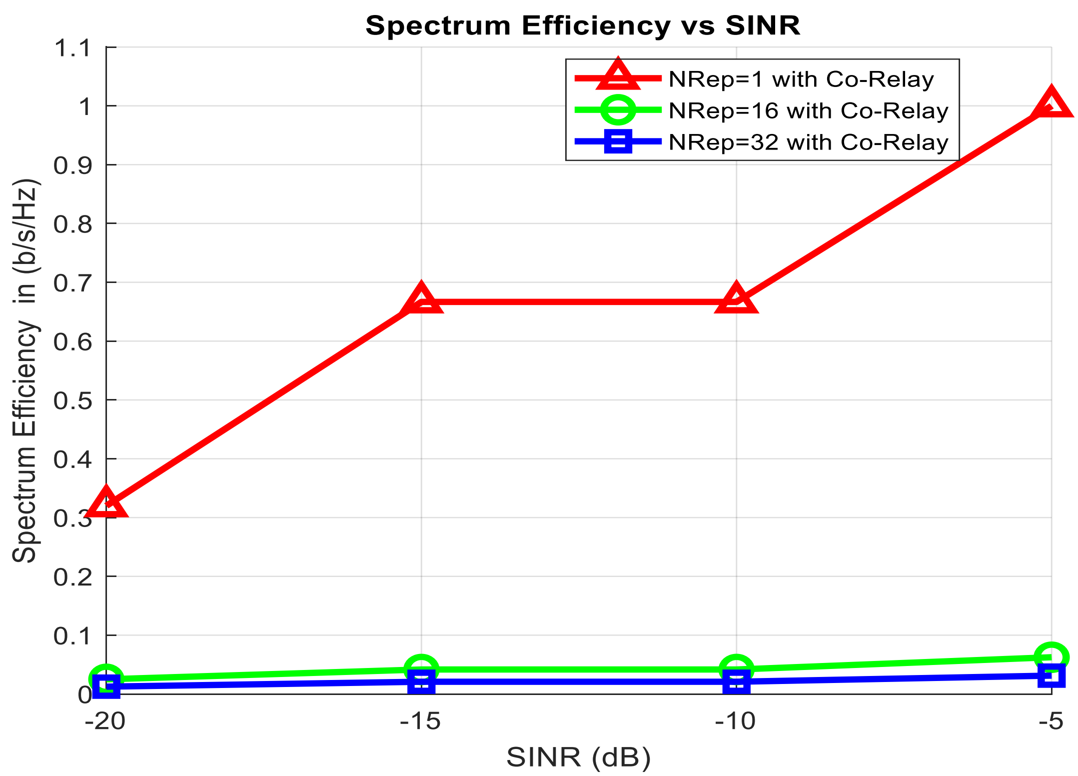


Figure (4-10): Spectral efficiency for Repetition with Cooperative Relay.

The best value of spectral efficiency in NRep=16. Whereas when using repetition with a cooperative relay the best value of spectral efficiency in NRep=1 that means in case of using repetition with cooperative relay no need to increase number of repetitions to get better spectral efficiency. Repetition with cooperative relay enhanced the performance of the least repetition and no need to increase the repetition to optimal value. The rate of enhanced spectral efficiency≅60 %.

4.4.5 Delay Transmission

System delay gives the average of the total queuing delay of all packets in the buffers at the NB-IoT eNBs. As illustrated in the figure (4-11) (4-12) and table (4-6), the delay transmission is directly proportional with data rate as well as when number of repetitions increase the delay transmission will remain to increase.

Table (4-6): Delay Transmission for Repetition without and with a Cooperative Relay.

Repetitions	DT Case (sec)	SNR (dB)			
		-20	-15	-10	-5
1	Without Cooperative Relay	0.0222	0.0222	0.0222	0.0139
1	With Cooperative Relay	0.0139	0.0083	0.0083	0.0056
16	Without Cooperative Relay	0.3556	0.3556	0.3556	0.2222
16	With Cooperative Relay	0.2222	0.1333	0.1333	0.0889
32	Without Cooperative Relay	0.7111	0.7111	0.7111	0.4444
32	With Cooperative Relay	0.4444	0.2667	0.2667	0.1778

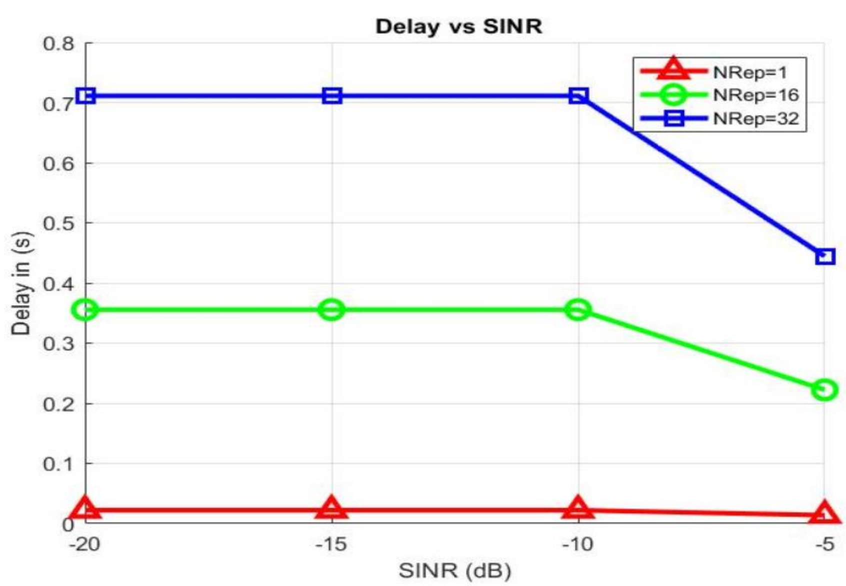


Figure (4-11): Delay Transmission for Repetition without Cooperative Relay.

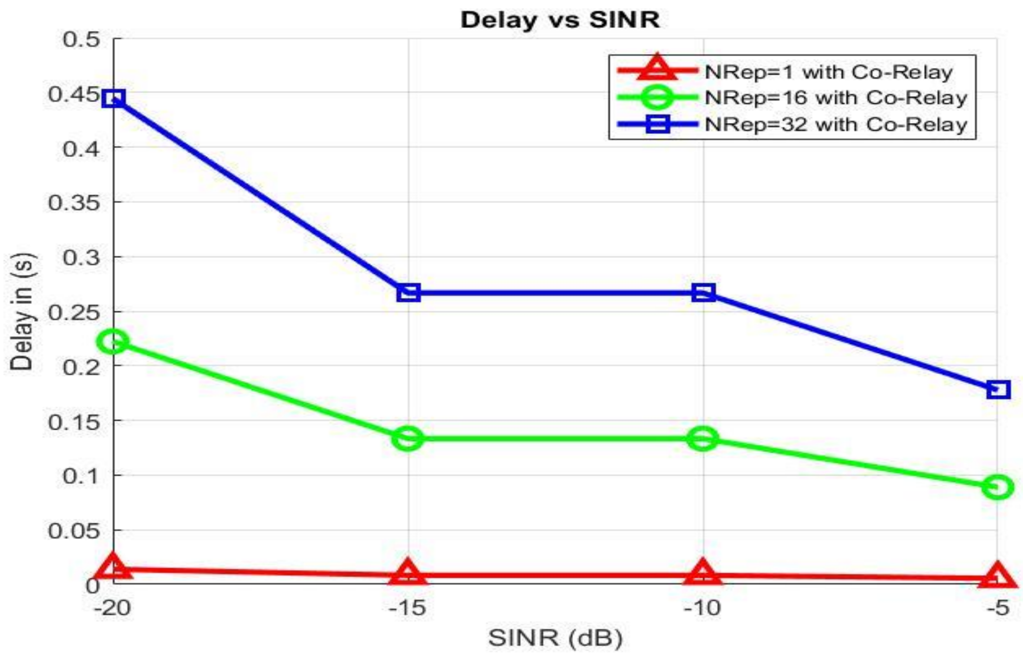


Figure (4-11): Delay Transmission for Repetition with Cooperative Relay.

Delay transmission has same values, when SINR range from -20 to -10 dB due to delay transmission=data/ (data rate). In case of using repetition with a cooperative relay, observe that NRep=1 has the best result in case of using repetition with/without a cooperative relay. Moreover, rate of enhancement for delay transmission in case of using repetition with cooperative-relay ≅ 60% when comparing with using repetition only.

4.4 Final Report

In case of using repetition only, observed that increasing number of repetition will enhance the BLER but degrades the data rate. Also, observed that there is an optimal value for number of repetition to achieve better system throughput. However, when number of repetition increase from this value, it leads to degrade the network performance. Spectral efficiency is directly proportional with system throughput. Number of repetition is directly proportional with delay transmission and data rate. The method of using repetition with a cooperative relay, no need to increase number of repetition for achieving better results i.e., in case of using a repetition with cooperative relay, the least number of repetition has a better performance. If user 2 is very close to user 1, there is no improved in the NB-IoT network.

4.5 Summary

We conclude that in case of using repetition only, number of repetition has an optimal value to obtain the best network performance. When number of repetition increased than this value, it will give a degrades result in throughput, network performance and QoS for the channel. While in case of implement repetition with a cooperative relay, no need to increase the number of repetition to obtain a better performance. Furthermore, propagation channel would be enhanced when using repetition with a cooperative relay and it provides better performance than using repetition only.

Chapter Five

Conclusions and Recommendations

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Conclusions and Recommendations

5.1 Conclusions

This thesis concentrates on repetition with a cooperative relay scheme to enhanced system performance for NPUSCH. The evaluation metrics that took are BLER, data rate, system throughput, spectral efficiency and delay transmission. This analysis used to show the enhanced in physical layer for NB-IoT uplink network when using repetition with a cooperative relay. Comparison between using repetition only and repetition with a cooperative relay was made as well as considering the number of repetition utilized are 1, 16 and 32. The simulation results obtained shows that in case of using repetition only, there is an optimal value for number of repetitions to get the best system performance but if the value increased form the optimal value, it will lead to degrade system throughput, spectral efficiency and quality of service for the channel. Whilst in case of using repetition with a cooperative relay, using the least number of repetition will achieve enhancement in system performance of overall NB-IoT uplink network (NPUSCH). Moreover, using repetition with a cooperative relay award better system performance. Enhancement rate in BLER=100%, data rate increased by 60 %, throughput increased by 74 %, spectral efficiency enhanced by 60 % and delay transmission by 61 % from using repetition only.

5.2 Recommendations

Based on the insights we have gained in this thesis on enhanced physical layer in NB-IoT, we identified a number of issues that need to be addressed in future research.

1. There are many comprehensive algorithms that could be implemented in the future works such as multi-player scenario (that a several NB-IoT end devices need to access dynamically the network) and vehicles could act as relay nodes of the NB-IoT UEs.
2. Extend the performance evaluation to other metrics of interest such as probability of message losses and energy efficiency, while taking into consideration communication models, power control mechanisms, delay transmission, packet scheduling and number of repetition.
3. Study the scenario for a large NB-IoT cellular network and calculate the performance of IoT devices with eNBs by using NS-3 simulation.
4. Investigate utilization of repetition with a cooperative relay in NPDSCH to enhance overall NB-IoT network such as enhanced coverage area, throughput, spectral efficiency and delay transmission.

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Appendices

Appendix A: Repetition without Cooperative Relay

Steps to calculate and plot BLER, data rate, throughput, spectral efficiency, delay transmission for repetition only as follows:

1. Identify number of simulated transport block, rnge of SNR values in dB, number of repetition that used and parameters required for NPUSCH generation.
2. Calculate the RVseq according to RV offset.
3. Generate if statement for type of NPUSCH format to identify information length.
4. Initialize channel model configuration structure including channel seed, number recive antennas, delay profile, Doppler frequency, multi-antenna correlation, oscillators that used in fading model, type Rayleigh fading model, normalize delay profile power and normalize for transmit antennas.
5. Find number of time slots in a resource unit.
6. Find the slot grid and number of slots per frame
7. Perform NB-IoT NPUSCH link level simulation.
8. Initialize BLER, throughput result, UE , channel, fading channel configuration, number of transport block with errors, NPDSCH encoder state, NPDSCH decoder state, transport block, full grid and DM-RS state for each repetition.
9. Calculate the frame number and slot number within the rame.
10. Generate the slot grid.
11. Determine the coded transport block size.
12. Calculate noise gain.
13. Normalize noise power.
14. Create AWGN.

15. Generate the received time domain waveform.
16. Generate timing synchronization, extract the appropriate subframe of the received waveform, and perform OFDM demodulation.
17. Find NPUSCH indice.
18. Find NPUSCH resource elements from the received slot
19. Calculate the block error rate.
20. Calculate the maximum and simulated throughput.
21. Plot Block Error Rate vs SNR results.
22. Calculate data rate, throughput, spectral efficiency and delay transmission.
23. Plot data rate, throughput, spectral efficiency and delay transmission vs. SNR.

Appedix B: Repetition with Cooperative Relay

Steps to calculate BLER, data rate, throughput, spectral efficiency, delay transmission for repetition with cooperative relay as follows:

1. Identify number of simulated transport block, rnge of SNR values in dB, number of repetition that used and parameters required for NPUSCH generation.
2. Identify power transmit in dBm, gain for basestation and IoT, distance between two IoTs and frequency.
3. Generate random noise and interference.
4. calculate received power and pass loss.
5. Calculate the RVseq according to RV offset.
6. Generate if statement for type of NPUSCH format to identify information length.
7. Initialize channel model configuration structure including channel seed, number recive antennas, delay profile, Doppler frequency, multi-antenna correlation, oscillators used in fading model, type Rayleigh fading model, normalize delay profile power and normalize for transmit antennas.
8. Find number of time slots in a resource unit.
9. Find the slot grid and number of slots per frame
10. Perform NB-IoT NPUSCH link level simulation.
11. Initialize BLER and throughput result.
12. Initialize UE , channel, fading channel configuration, number of transport block with errors, NPDSCH encoder state, NPDSCH decoder state, transport block, full grid and DM-RS state for each repetition.
13. For each repetition calculate SINR cooperative and sort the result.
14. Claulate the frame number and slot number within the rame.

15. Generate the slot grid.
16. Determine the coded transport block size.
17. Calculate noise gain.
18. Normalize noise power.
19. Create AWGN.
20. Generate the received time domain waveform.
21. Generate timing synchronization, extract the appropriate subframe of the received waveform, and perform OFDM demodulation.
22. Find NPUSCH indice.
23. Find NPUSCH resource elements from the received slot
24. Calculate the block error rate.
25. Calculate the maximum and simulated throughput.
26. Plot Block Error Rate vs SNR results.
27. Calculate data rate, throughput, spectral efficiency and delay transmission.
28. Plot data rate, throughput, spectral efficiency and delay transmission vs. SNR.