TAMPEREEN TEKNILLINEN YLIOPISTO
TAMPERE UNIVERSITY OF TECHNOLOGY

SOHEL RANA

POSITIONING IN IOT TECHNOLOGY

Master of Science Thesis

Examiner: Assoc. Prof. Elena-Simona Lohan
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ABSTRACT

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Nowadays IoT (Internet of Things) technology is designed with massive deployment, wide coverage, low battery powered in the Radio Access Network. The application field of IoT technologies is diverging in all the parts of human life and industrial market. Recently, the new feature accurate positioning is making these IoT technologies more different and demandable from each other. IoT technologies can be classified in different basis like coverage area and band with specifications. Among several invented IoT technologies, LoRa (Long Range Wide Area Network) and NB-IoT (Narrow Band- IoT) are the most promising technologies based on some features called positioning, bandwidth specifications, modulation technique and wide coverage area. The performance evaluation of these IoT technologies will be make one-step forward to specify the better next generation IoT technology.

LoRa modulation technique is based on the Chirp Spread Spectrum (CSS) and NB-IoT uses the OFDMA (Orthogonal Frequency Division Multiple Access) modulation technique. However, LoRa is based on ToA (Time of Arrival) positioning technique and NB-IoT is designed based on OTDOA (Orthogonal Time Difference Arrival). After studying the detailed theoretical background of LoRa and NB-IoT, a simulation is implemented to observe the performance of LoRa and NB-IoT in terms of positioning accuracy. The matlab simulation tools is used to implement the simulation because of its flexibility to implement. From this implementation, several results are achieved to observe the positioning accuracy level.

After observing the simulation results called RMSE positioning error versus noise variance and RMSE positioning error versus number of transmitters, a couple of comparisons have done to evaluate the performance. It is found that the NB-IoT positioning accuracy is better than the LoRa technologies positioning level. However, some new parameters are also chosen for future work to enlarge this comparison with other IoT technologies and to achieve more accurate results to specify the required features of next generation IoT technologies.

PREFACE

This research helps me to gather knowledge of IoT technologies and there application in positioning. It is very hard to finish a thesisime. However, I enjoyed the simulation and writing parts of this thesis.

It was always a great feelings to complete my study with some of my great friends those are always motivating me.

Tampere, 7.9.2017

Sohel Rana

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LIST OF SYMBOLS AND ABBREVIATIONS

3GPP	Third Generation Partnership Project
4G	Fourth Generation
A-GNSS	Assisted Global Navigation Satellite System
AOA	Angle of Arrival
CP	Cycle Prefix
DTOA	Difference Time of Arrival
OTDOA	Orthogonal Time Difference of Arrival
E-Cell ID	Enhanced Cell ID
FCC	Federal Communication Commission
GDOP	Geometrical Dilution of Precision
GNSS	Global Navigation Satellite System
LoRa	Long Range
NB-IoT	Narrow Band-IoT
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access
RMSE	Root Mean Square Error
RSRP	Reference Signal Received Power
RSRQ	Reference Signal Received Quality
RSS	Received Signal Strength
RSSI	Received Signal Strength Indicator
RSTD	Reference Signal Time Difference
RTT	Round Trip Time
RX	Receiver
SC-FDMA	Single Carrier Frequency Division Multiple Access
ToA	Time of Arrival

φ	Phase shift
α	Angle of arrival
c	Speed of light
d	Distance
d_0	Reference distance
d_{ar}	Antenna array elements inter-distance
d_{ar1}	Projection of d_{ar} onto E
Δt	Time-offset
f_c	Carrier frequency
t	Received signal time
t_0	Transmit signal time
t_1	Received signal time at reference node one
t_2	Received signal time at reference node two

1. INTRODUCTION

In the year 2017 the emergence of IoT is enlarged, where everything from cars to the kitchen is to be connected to the internet in order to provide services for the users. The field of IoT is divers and broadly covers industrial applications involving M2M communications, where more emphasis is to connect a large number of nodes and also to track objects. Nowadays the positioning in IoT is a crucial fact.

There are so many IoT standards are released to perform positioning, low chip-cost and support for tens of thousands of nodes in a single cell. The IoT technologies can be classified as Fixed & Short Range (RFID, Bluetooth, Zigbee and WiFi) and Long Range technologies (Non 3GPP Standards (LPWAN): LORA, SIGFOX, Weightless and also 3GPP Standards: LTE-M, EC-GSM and NB-IoT). One of them is LoRa (Long Range) [1] Wide Area Network where ToA (Time of Arrival) [4] positioning principle is being used to perform the positioning of the user. In LoRa, the modulation schema is based on Chirp Spread Spectrum with 125 kHz bandwidth and the coverage of 15km [2]. However the limitation of the technique is the coverage area is very small and positioning accuracy level of the ToA (Time of Arrival) principle.

After that, NB-IoT [3] is released for better modulation technique and wider coverage area to achieve higher level of positioning accuracy. NB-IoT is based on OFDMA with SCS modulation technique and Orthogonal Time Difference of Arrival (OTDOA) [4] principle is used to perform positioning with the coverage of 35km.

1.1 Motivation

Nowadays, the usability of IoT devices is increasing in different fields of daily life. The IoT applications are covering smart building, management service, object tracking, fire alarms for commercial & housing property and realtime health service. To implement a better and higher performed IoT application, it is required to analyze the performance of existing IoT technologies with different parameters. The positioning is the most crucial parameter to characterize the performance of a IoT technology.

1.2 Objective

This thesis is focused on the performance evaluation of LTE based IoT technologies (LoRa and NB-IoT) in terms of the positioning accuracy level. In addition, a detailed description about the modulation techniques used in these technologies is being done in this research. The main aim is to study about the existing positioning algorithm used IoT technologies and implement a simulation for LoRa and NB-IoT. After observing the simulation results, it can be possible to characterize the performance of LoRa and NB-IoT in terms of positioning accuracy level, coverage area and modulation technique. This performance comparison will achieve to choose a better positioning technique, modulation technique and coverage area for the next generation IoT devices.

1.3 Thesis Outline

In chapter 2, the overview of IoT and its definition is described with some basic requirements and design criteria of IoT devices. After that in chapter 3, the classification of IoT technologies is described and in chapter 4, the positioning algorithms are illustrated those are used in different IoT technologies. However, the chapter 5 is totally focused on the overview of LoRa and NB-IoT technologies. The chapter 6 is described the simulation implementations and simulation results.

This thesis is concluded in chapter 7. The final results are summerized and the future plan of the research is mentioned.

2. IOT (INTERNET OF THINGS) OVERVIEW AND DEFINITIONS

The Internet of Things IoT is the internetworking of several devices, Mobiles, buildings, vehicles and other items embedded with actuators, electronics, sensors, software and network connectivity to collect and exchange data. In several literatures, the number of connected things are predicted to reach 50 billion in future. In 2011, the quantity of Internet-equipped devices overtook the human population. However, in 2013, these devices were 9 billion whereas the number of connected devices except tablets, PCs and phones, will be 15 billion in 2020 among them 13.0 billion will use short range technology, such as Bluetooth, Zigbee or Wi-Fi and 2.0 billion will be based on cellular connection [5]. Moreover, according to the report [5], it is predicted that if the cellular technology could fulfill the IoT requirements then 5.5 billion of the 13 billion would be replaced by cellular technology. In fact, because of the cellular based IoT technology, 5.7 billion of connections would be added to reach the number at 20 billion by 2020. With the increase of these numbers, the IoT world provides a promising market and an uncounted of business opportunities to the mobile operators.

However, the IoT devices are also be able to use PAN (Personal Area Network), LAN (Local Area Network), WAN (Wide Area Network) or cellular network. Moreover, the IoT devices restrictive requirements (powered by battery, high autonomy and low cost) have concerned the use of wireless technologies like NFC, RFID, Zigbee or Bluetooth. However, the attachment of cellular technology in the IoT world could be a curtail fact to increase the number of connected things, which will also make the cellular technology as a significant networking part of the IoT. That is why, GSM, UMTS or LTE, any kind of cellular network would be chosen as a part of IoT networking. However, CDMA2000 or GPRS technologies have already been chosen to support wide-area connections, because of being low cost and higher coverage capability. LTE has the flexible architecture and greater potential to deal with the IoT ecosystems. Moreover, the cost-effective spectrum arrangement in LTE system is the key to provide cost-efficient and global networking.

2.1 The Internet of Things Communication Systems and Requirements

The requirements and patterns of M2M (machine-to-machine) communication in IoT technology are separate to those of H2H (human-to-human) communication in the traditional LTE networks. According to [6], the 3GPP have generalized with the following requirements that are based on M2M communications.

- **Device Identifier:** The number of identifier for the networking devices is predicted to be two orders of magnitude bigger than the number for H2H communications. It is therefore essential to establish a protocol to a network where each device and subscriber will be identified uniquely.
- **Addressing:** The most common pattern of data communication in the IoT is expected to be many-to-one like as many sensors are periodically transmitting data to a central server. Generally, the huge number of devices attached with a particular server. To support all the devices two scenarios can be considered: the server may support IPv6 addressing to assign all the devices with IPv6 addresses by the network or the server may be reachable by IPv4 address. Moreover, the addressing can be assigned as a public or private but it is preferable to assign a private IPv4, because of the scarcity of public IPv4 addresses.
- **Charging Data:** It looks wasteful to generate detailed charging records of each device, because of being connected large number of devices in the network and their pattern of communications. The 3GPP suggests the network to collect charging data and it can inform the use of resources.
- **Security:** Compared to the traditional H2H communications, the devices in the IoT network face security challenges in many applications. As an example, it is common to left unattended after installing the devices, in order to making them optimal targets. Moreover, in different case, the devices may be targeted to perform a denial of service attack on them. The 3GPP requires that optimizations which will not degrade the security in M2M communications with respect to the H2H communications. There also should have secure connections between the devices and the servers in the network.
- **Low mobility:** In most cases, the IoT devices remain stationary at their lifetime. For example, pump, power meters remain in the same place once installed. Mobility management and update location procedures are irrelevant for the precious network resources. The most required performance of these devices is to be able to change the frequencies by the network operator.
- **Triggering:** In different use cases, devices in the IoT transmit data only when requested by a server. To optimize these use case and protect the wastage of resources, a device triggering mechanism is required in the network. It means that when the device is lost to the network or cannot be able to connect, the network can request a special device to repair the connection for data transmission.

- **Small data transmission:** Sometimes IoT devices need only to transmit small amount of data around 1KB. The network have to support the small data transmission with the optimal procedure.
- **Time controlled communications:** In some applications, there are a time interval to transmit or receive data. In that case, regular procedure will be a wasteful when performed outside of the time intervals. Thus, the network operator can reject or charge differently for such kind of communication taking place outside of the time interval and make an alarming system about the time intervals in accordance with the local criteria.
- **Monitoring:** the network should monitor the status of the device, such as loss of communication, change of location and usage of the devices based on their Universal Subscriber Identity Module.
- **Grouping:** IoT devices are frequently connected in groups. The requirement to deploy the network is to manage the groups of devices with broadcasting messages among the groups.
- There should be a way for the network operator to reduce the frequency of mobility management procedures in the step of initiating the device for transmissions.

2.2 LTE for IoT

Among all the LTE (Long Term Evolution) specifications, the first one is Release 8, which was introduced in 2008, and then in December 2009, the commercial network operation had started. After that the next six years, about 145 countries are commercially lunched more than 440 LTE networks. However, the number of LTE subscriptions reached one billion at the end of 2015 [7].

To improve efficiency, user and system performance, LTE specifications have been consistently updated from release 9 to 14 with some new features and enhancements. [8]

2.2.1 Low cost LTE devices

To provide initial support for lower cost devices in LTE, 3GPP has formed by adding the additional category 0 in Release 12. The 3GPP TS 36.306 is named to specify the capability of a category 0 UE (User Equipment) [9]. The crucial factors about the cost reduction in category 0 are mostly related to the data rate reduction, which is done by limiting the maximum transport block size (TBS) per subframe. As an example, the maximum DL-SCH (Downlink Shared Channel) TBS has been introduced to 1000 bits compared to the former 10296 bits in category 1 devices.

As an optional, a half-duplex type B operation can be used in Category 0 devices. This new feature allows them to increase the guard period by removing the DL sub frame before and after the UL sub frames like as TS 36.211 [10].

More specification enhancements are also predicted in 3GPP release 13 in the context of proposal from TS 36.888 [11]. Several aspects are being analyzed to reduce the device cost with the broad coverage. Specially, up to 75% cost is expected to be reduced compared to the category 1 in terms of the bandwidth and data rates.

2.2.2 Long battery life time

The common demandable case for IoT that the devices can be deployed once and then remain for their lifetime without changing the battery. However, these devices are always powered by the batteries those are not rechargeable. According a Nokia white paper [8], it is estimated that these devices can be able to operate for at least 10 years with the power of two long life AA batteries.

A power saving mode (PSM) was introduced in Release 12 that can extend the battery life dramatically for the devices to send data from time to time. In the PSM supported devices, the duration of an active timer is set up during the Tracking Area Update (TAU) procedure. The timer starts, when the device switches to the idle mode. While the timer is started, the device remains in the idle mode and checking for paging during Discontinuous Reception (DRX). The devices enter PSM and are stopping any checking for paging, because of the timer expires. According to [12], it is noted that there is a trade-off between battery life extension and reachability of the devices using longer sleep cycle. As an example, in the establishment of the DRX cycle to 2 minutes, a device lifespan powered with two AA batteries will reach 111 months by transmitting 100 bytes daily without addition modifications.

2.2.3 Coverage Enhancement

Several techniques are being introduced in TS 36.888 [13] to improve the coverage to 20db. A set of techniques is introduced like code spreading, TTI (Transmission Time Interval) bundling, repetition, HARQ (Hybrid Automatic Repeat Request) retransmission, low modulation order, RLC (Radio Link Control) segmentation, new decoding techniques and low rate coding, which can be used to prolong the transmission time. Moreover, power boosting is also a mechanism by which the signal transmission will be more powerful from the base station or Evolve Node B (eNB) to the MTC UE. However, power spectral density (PSD) boosting is another technique which allows the power to be adjusted in a reduced bandwidth at the UE or the eNB. To fulfill the coverage improvement requirement, new signals or channels can be designed and implemented [14].

Some existing coverage improvement solutions like external antennas, directional antennas can be deployed for the normal LTE UE. Finally, D2D (device-to-device) LTE Direct communications can spread the coverage. In Release 12, D2D was introduced to the traditional subscribers and the public because of enabling reliability of one-to-many communications between all the devices those are in and out of coverage. After that, an extended version of D2D was introduced in Release 13 with some new communication mechanisms and discoveries like multi-carrier system and wide coverage. Moreover, D2D communications extended features reshaped it to consider multi-hop communication system in Release 14 in order to apply in V2V (vehicle-to-vehicle) communications [14].

2.2.4 Triggering Function

According to [14], the triggering mechanism was first attached to the device in Release 11 in order to increase the reachability using the external unique identifier. These identifiers assist the providers to get access terminals by SMS without allocating the IP. By receiving the SMS the UE identifies the application and then takes a proper action on the application [14].

2.2.5 Security Management

IoT devices are always being attacked due to its limited memory and processing capacity. Sometimes these devices are affected by the denial of service attack in order to the huge number of device deployment in a network. According to [15], 2G systems are considered as insecure due to several unexpected acts are being discovered in that IoT systems. Moreover, it is also considered that additional encryption layer should be used in this Cellular IoT system to make the system secure from being attacked [15].

2.2.6 Positioning

The new indoor positioning requirements was introduced by the FCC. However, the main platform about the positioning mechanisms were introduced in Release 9 with horizontal accuracy. After that, a vertical positioning measurement was introduced in Release 13 as an example Bluetooth nodes and WiFi reporting. However, in Release 14, a new enhancement was added for positioning mechanism using a reference signal called PRSs (positioning reference signals).

2.3 Requirements for Future LTE standards

From the above discussions about the evolutions of LTE over the Release 9 to 14 are introducing some challenges for the next LTE standards like 5G Mobile Communication System. According to [8], the main requirements for 5G radio access are like better Positioning mechanism, Massive multiple antenna systems, Enhanced multimedia broadcasting. In this literature, it is also mentioned that the use cases of radio access will be classified in three categories for 2020 and next which are included in the 5G requirements. The three requirements are Massive Machine-type Communication (mMTC), Enhanced Mobile Broadband (eMBB), Ultra-reliable and low-latency communication (URLLC).

Finally, it can say that a bunch of improvements over mMTC use cases were introduced in Release 13 by reducing the power to 20dbm and the device bandwidth to 1.4 MHz with lower device cost. Moreover, another LTE specification called NB-IoT (narrowband IoT) was standardized in Release 13 with some challenges like device complexity, power consumption, coverage and positioning accuracy level. However, Today 4G LTE standards are competing the mobile industry for better performance in mobile broadband coverage to more than billions of subscribers. In March 2017, the Release 14 was started to finalize the require challenges. Hence, the evolution of LTE through Release 9 to 14 will make one-step forward to address 5G requirements and use cases.

3. BANDWIDTH SPECIFICATIONS OF IOT TECHNOLOGIES

Nowadays, Analysis of bandwidth specifications for IoT technologies is the curtail part to generalize the next generation IoT technologies with high system capacity, width coverage and long battery lifetime. Licensed and Unlicensed are the main types of frequency bands used for the Wireless Radio Access Technologies. Although the other access systems like wired has more reliability and security, the IoT applications are based on wireless technologies with mobility, high quality and cost efficiency.

Around four types of wireless networks can be classified based their access coverage such as WPAN (wireless personal area network), WLAN (wireless local area network), WWAN (wireless wide area network) and NFC (near field communication). Among these network technologies, the unlicensed band is being used by NFC such as RFID [20], WLAN such as (WiFi [16] and ZigBee [17]) and WPAN such as Bluetooth [18, 19] those are applied in short-range local wireless applications like as indoor (House or Building) positioning. Since the WLAN is using unlicensed (free) band, it is popular in industrial applications and smart house applications. However, the licensed band is being assigned for WWAN to provide a wide coverage, mobility and network, which is mainly used in cellular networks (3GPP LTE). That is why WWAN is the best choice to the network operators of telecommunication companies. Several IoT applications like traffic safety and control are fully cellular based technology. On the other hand, some applications like smart cities, remote sensing and indoor positioning which are classified by low battery power, wide coverage and support for massive scale are fully based on low-Power wireless WAN (LPWAN) technologies. Nowadays, this LPWAN technology is dominating the IoT markets where around 70 percent of products are covered by this technology. Most of the LPWAN technologies are now designed for Ultra Narrow Band (UNB) by names of LoRa, SIGFOX and Weightless led. Moreover, the LPWAN technologies unlicensed spectrum is widely available compared to the short cellular licensed spectrum.

3.1 Unlicensed Spectrum for LPWAN

LoRa and SIGFOX are the main leading LPWAN technologies that are using unlicensed band due to its cost efficiency property. However, some drawbacks have to be compromised to use this band because of the lack of quality and uncontrollable interference.

3.1.1 (UNB) Ultra-Narrow Band Technology

According to [21], the wide-area wireless technology called ultra-narrow band was introduced by SIGFOX in 2009 in order to cover global networks and connectivity with a great deployment of low powered IoT devices. This UNB can be classified in three categories such as 100 Hz UNB communication channels including 160 db coupling loss, UP triggering transmissions following client-server mechanism and then the receptions like cooperative such as the transmitted signal can be simultaneously received by multiple UNB base stations which is more possibility to be successes in receptions. The centralized scheduling is not applied in this technology because of the client server mechanism. This client server mechanism has a great advantage about power consuming by saving the periodic weak up for data transmission and receive. Thus, it can operate in a maximum battery lifetime. The device only wakes up in uplink data service by selecting a random channel over 200 Hz total bandwidth (ultra narrow-band) for uplink data transmission with very low data throughput like as 100 bps. This device uses DBPSK modulation technique for uplink signal transmission and GFSK modulation technique for downlink connectivity. However, the coverage of this technology is 50km in rural areas and 10km in urban areas. Nowadays around 60 countries are now planning to deploy cellular IoT connectivity globally based on this technology within the next 5 years.

3.1.2 (LoRa) Long Range

Semtech first introduced LoRa wide area IoT technology in 2015 [22]. LoRa Wide-area network is based on the chirp spread spectrum (CSS) modulation where as FSK (Frequency Shifting Keying) is a common modulation technique in other IoT technologies like SIGFOX because of its low power characteristics. The chirp spread spectrum modulation will ensure addition property like wide communication range with the low power transmission. The spectral bandwidth of the modulated signal is depends on the the chip rate of the chirps which is equal to 125, 250 or 500 KHz of bandwidth. LoRa technology uses the bandwidth separately for individual devices to get maximum battery life and network coverage where as SIGFOX uses a fixed bandwidth. Moreover, this technology is using star topology where a central server is dedicated to connect all the end devices. According to [18], It is also find that LoRa technologies are using the network-originated transmission mechanisms to save battery charge when the end-devces wake up and respond to receive the transmitted data. The wide coverage of the technology is 15km.

Nowadays, another LPWAN technology called Weightless is dominating the IoT technology market. Weightless Special Interest Group (SIG) introduced the Weightless-N technology first. This technology uses the 200 Hz ultra-narrow band over the sub-GHz ISM band, which is comparatively similar to SIGFOX. Moreover, the latest technology Weightless-P is also developed by Weightless SIG, which uses 12.5 kHz narrowband channels with FHSS (frequency hopping spread spectrum). This technology uses the Offset-QPSK/GMSK modulation technique for better power saving mechanisms [22].

3.2 Licensed Spectrum for LPWAN

From the above discussions we can see that most of the LPWAN technologies are deployed based on the unlicensed spectrum. The licensed spectrum is more costly and limited in LTE cellular network compared to the unlicensed bandwidth. However, there is no guarantee of availability to get service in unlicensed spectrum. In comparison between the LPWAN and the LTE UE technology, it is observed that the LTE cellular network is mainly based on human-type communication and LPWAN is implemented with low rate MTC and low powered battery. Moreover, LPWAN technology is deployed in indoor applications that may introduce some additional coupling loss of around 20dB compared to the former LTE cellular with the maximum coupling loss of 140dB Some additional parameters such as rechargeable batteries, costly, high capacity and high hardware complexity are also observed in order to explain the LTE UE deployment with respect to the high mobility, high data rates and performance [23].

3.2.1 LTE-M

Cellular MTC is introduced by 3GPP in the early stage of 2009 in order to analyze the advance requirement of the LTE cellular network. However, in Release 12, some new features like peak rate reduction, narrow band specification (1.08MHz) and hardware specification are included to introduce the enhanced MTC (eMTC or former LTE-M) with low cost and power consumption, while the transmission modulation structure is remained similar to the former LTE design where OFDMA (orthogonal frequency division multiple-access) was used for downlink and SC-FDMA (single-carrier frequency division multiple-access) was used for uplink data transmission. The LTE-M uses 1.08 MHz bandwidth over the channel in order to cover the minimum transmission bandwidth to be 180 kHz. In LTE-M, the coverage is extended to the 15dB in order to the 155dB maximum coupling loss by deploying the MTC devices potentially. The accurate coverage of LTE-M is 100km [23].

3.2.2 (NB-IoT) Narrow Band IoT

It is believed that the LTE-M is not able to support low-power massive IoT as a solution of 5G technology. This is because of its extended coverage bandwidth of 180 kHz that is considered wasteful as spectrum efficiency and its system bandwidth 1.08MHz that is also considered to affect the deployment of narrow band like as GSM bands in the LTE-M. To solve the massive IoT specification challenges, 3GPP started working on the new standardization called NB-IoT in order to assign a new air-interface that will support low power massive IoT [24, 25].

NB-IoT is a new radio access technology that is build based on the existing LTE technologies. According to [26], NB-IoT technology is designed with some features such as higher indoor covearage of 20dB, ultra-low complex it devices deployed, supporting massive low-throughput IoT devices within a network cell, higher power efficiency with 5Wh battery capacity. At the physical layer, NB-IoT operates on 180 kHz bandwidth for both downlink and uplink data transmission. It has 12 subcarriers with spacing 15 kHz for every 180 kHz channel. NB-IoT frequency band can be operate in three forms such as in-band, guard-Band and standalone of LTE carriers. The downlink data transmission modulation structure of NB-IoT is designed with the OFDMA (orthogonal frequency division multiple-access) modulation technique and 15 kHz subcarrier spacing. On the other hand, the uplink NB-IoT uses the SC-FDMA (single-carrier frequency division multiple-access) modulation technique with subcarrier spacing at 3.75 kHz. The maximum coupling loss of NB-IoT is extended to the 20dB over the 140dB of LTE footprint. It has a good coverage area around 35km. Moreover, NB-IoT uses OTDOA (Orthogonal Time Difference of Arrivals) algorithm for its accurate positioning support. Table 1 summarizes the key functionalities of the LPWAN unlicensed band and licensed band technologies.

Table 3.1: The key functions of the LPWAN technologies

Technology	**Unlicensed Band**		**Licensed Band**	
	LoRa	SIGFOX	LTE-M	NB-IoT
Frequency Band	Sub-GHz ISM	Sub-GHz ISM	Licensed	Licensed
Transmission Bandwidth	125 kHz	200 Hz (ultra-narrow band)	180 kHz	180 kHz & 3.75 kHz
Modulation Technique	Chirp spread spectrum, GFSK	D-BPSK, GFSK	BPSK, QPSK, 16QAM, 64QAM	OFDMA with SCS
Medium access control (MAC)	Unslotted ALOHA	Unslotted ALOHA	SC-FDMA	SC-FDMA
Data rate	0.3-38.4 kb/s	100 b/s	Up to 1000 kb/s	Up to 100 kb/s
Standardization	LoRaWAN	No	LTE (Release 12)	LTE (Release 13)
Positioning supported (Yes/no)	Yes	Unknown	Partially support	Partially support
Coverage	15km	50km rural 10km urban	100km	35km

Among all of the above key functionalities, the positioning mechanisms and supports is the more challenging issues nowadays in LPWAN technologies. Different technologies are implemented based on different positioning algorithms such as RSRP (Reference Signal Received Power), RSSI (Received Signal Strangth Indicator), RSRQ (Reference Signal Received Quality), OTDOA (Orthogonal Time Difference of Arrival), AOA (Angle of Arrival), DTOA (Difference Time of Arrival) and TOA (Time of Arrival) in order to achieve better positioning accuracy. Recently, more studies have been taken into account the comparisons in between the several positioning algorithms based on their properties such as complexity, memory space, execution time consume and implementation complexity in order to suggest the more accurate positioning mechanism in 5G LTE technologies implementation.

4. POSITIONING IN IOT TECHNOLOGIES

Positioning is the mechanism to obtain the geographical position of an object or a device like as mobile, tablet computer, laptop computer, navigator, tracking equipment, a PDA (personal digital assistant). In this mechanism, the coordinates of a device or object are being obtained first and then these are delivered to the requested end. The customer services that use location information to offer better service is called location-based services (LBSs). The networks like self-learning and optimized is the example of location based service. Moreover, the weather forecast, navigation, object tracking and application to find the nearest bus stop are also the great examples of LBSs.

Positioning in the LTE radio access network is a challenging issue to the user application, verity of choice and their mobility to access the network. The typical definition of positioning QoS is determined in terms of accuracy level, execution time and implementation complexity. The next challenges of positioning is considered as more reliable and accurate level of positioning, user adaptable positioning service, frequent analysis of the positioning results to make comparison in rural, urban, indoor and outdoor. The LTE positioning mechanisms are classified based on their positioning signal structure and parameters such as RSS-based LTE positioning and Non RSS-based LTE positioning [31]. Different LTE standards have been developed based on different positioning algorithms because of their specific positioning mechanisms such as LoRa uses TOA (Time of Arrival) and NB-IoT uses OTDOA (Orthogonal Time Difference of Arrival).

4.1 Positioning algorithm of Non RSS-based LTE technologies

In this section, different kinds of positioning signal parameters and algorithms will be discussed those are implemented in non RSS-based LTE technologies such as OTDOA, E-CID and assisted GNSS. These mechanisms are being characterized by observing the positioning signal parameters such as TOA, AOA and DTOA.

4.1.1 LTE Positioning Signal Parameters

TOA (Time of Arrival)

The Time of Arrival is the traveling time of a signal in between two communication nodes. The LTE signals propagation distance can be calculated by the equation:

$$d = c(t - t_0)$$

Where c is the speed of light since the signals propagate as a light, t_0 is the time to transmit the signal and t is the time to receive the signal. According to the circular triangulation fundamental [27], it is observed that the location or coordinate of a targeted unknown node within two nodes can be defined by a circle. Thus, if there are three nodes with three circles, it can be possible to determine the location of target node based on the intersection point of three circles.

The time synchronization in between Base Station and User End is crucial to be accurate enough for the correct positioning measurement. In example, if there is a few microseconds time offset, then a long distance error might be happened in the signal propagation and the error is approximately 300m per microsecond. The practical expression for the estimation of distance is known as,

$$d = c(t - t_0 + \Delta t)$$

Where, Δt is the time-offset estimation [31].

However, the statistical cross correlation calculation is the classical way to measure the TOA estimation. The process is to find the maximum point of the cross correlation between the reference signal and the actual received signal. The oversampling factor is also correlated to the measurement. There are several literatures like [28] have been published based on oversampling and the application of TOA-based estimator. It is also observed that the accuracy level of TOA-based estimation is comparatively better in LOS (Line of Site) propagation rather than the NLOS (Non Line of Site) propagation [29].

DTOA (Difference Time of Arrival)

The DTOA (Difference Time of Arrival) parameter is calculated by the TOA difference between the target device and two different network ends. Here the distance difference can be calculated as,

$$d_{21} = c(t_2 - t_0) - (t_1 - t_0)$$

Where, t_0 is the transmit time, t_2 and t_1 are recived signal time [31]. Moreover, it is possible to solve the synchronization problem between the transmitted signal and the received signal with the requirements of transmitting time alignment among the reference modes. The most crucial problem clock synchronization can also be resolved by containing the limitations of propagation channel [30].

AOA (Angle of Arrival)

The AOA (Angle of Arrival) is define as the angle of incidence for an uplink (UE to Base Station) radio wave propagation. This parameter can be obtained by the base station that is equipped with the special adaptive antenna. The antenna array elements are being designed by placing them in equal space known as d_{ar} (separation distance) which is equal to the half wavelength. If we consider a simple model, then there would be a receiver with two antenna and a single propagation path channel. Because of this single path, the transmitted signal of unknown device can receive to the antenna by the direct path or the line of sites propagated at different time and phase shift. According to [31], there is a geometrical schema to define the angle of arrival (α) with the calculation of carriers phase shift which can be expressed as a equation like,

$$\alpha = \cos^{-1}\left(\frac{d_{ar1}}{d_{ar}}\right) = \cos^{-1}\left(\frac{\varphi c}{2\pi f_c \, d_{ar}}\right)$$

Where d_{ar1} can define as the projection of d_{ar} on to the distance between transmitter and receiver, c is the speed of light, f_c is the carrier frequency and φ is the phase shift. There is also an estimated condition that the distance between transmitter and receiver is much smaller than the d_{ar}. In this paper, the performance of AOA based localization is also being observed with a block diagram model and the great result.

4.1.2 LTE Positioning Mechanisms

A-GNSS (Assisted Global Navigation Satellite System)

The LTE positioning method A-GNSS is applied in 4G cellular network with a great improvement of the acquisition time of satellites. Actually, this method is structured with a GNSS-LTE capable target device, minimum four satellites and network coverage. However, the constellation of the number of satellites depends on the GNSS system like GLONASS and GPS. Normally, around 30 satellites require covering the whole earth.

The satellite, which can be detected by its transmitted signal, is known as active or visible satellite. However, it is very difficult to detect the GNSS signal in the indoor communication compare to the outdoor environment. In contrast, urban and rural area environments are more convenient to deploy the GNSS receiver and to detect the GNSS signals with the minimum deployment of four satellites.

The fundamental GNSS positioning system has great performance in terms of accuracy level based on the specific environment. However, the performance goes down in hostile environments. Moreover, sometimes it takes several minutes to process the satellite signals, which makes more difficult to get accuracy in several location-based services.

In this method, the targeted GNSS receiver performs the satellite signal tracking, signal acquisition and decoding of the received signals in order to get its own location. The main purpose of the combination of cellular network and GNSS system is just to reduce the processing time at the receiver end to measure the location correctly and in a short time.

OTDOA (Orthogonal Time Difference of Arrival)

The OTDOA positioning method observes the reference signal time difference (RSTD) from different BS in order to make a good measurement. The positioning principle of OTDOA is similar to the TDOA. The exact location of a LTE based target device can calculated by the intersection of three or more hyperbolas arranged with the hyperbolic iterative algorithm. The intersection point can be assigned with the Cartesian coordinates x and y as the OTDOA calculation. There may be some kind of errors in the calculations as the error in TOA is mainly caused by the multipath propagation. However, the error can be influenced by the bandwidth of the signal that may vary significantly depending on the deployment of the channel bandwidth. It is known that the larger bandwidth causes the smaller error in the multipath propagation. It is also observed that the error to 20MHz channel bandwidth deployment is much smaller than the error to the 1.4 MHz channel bandwidth [31].

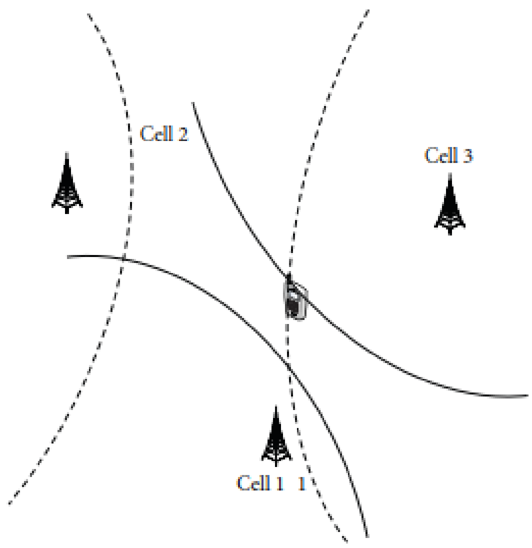

Figure 4-1 OTDOA positioning mechanism.

The cause of the positioning error is geometrical arrangement of BSs. This error is mainly depends of the arrangement of the number of BSs, location of BSs and location of BSs related to the target device. Geometrical Dilution of Precision (GDOP) is a parameter to calculate the gain of the error caused geometrical factors.

The main limitation of OTDOA is the clock time used at BSs which are mainly arranged for communication. These clocks have not been able to address the OTDOA positioning. A better solution can be considered as to use atomic clock at BS in order to calculate the OTDOA positioning.

E-Cell ID

The E-Cell ID principle is formed with the combination of RTT (Round Trip Time), TOA (Time of Arrival) and the basic Cell ID method, which depend on the cell identification. The basic cell ID method is designed based on the BSs locations to get UE location estimation. The cell size and the positioning accuracy depend on the cellular network and its deployment.

The RTT is calculated as the time difference between the MS and the BS. It can be expressed as T_{ms}-T_{bs} where T_{bs} is the time in between the transmission and reception of signal by the BS and T_{ms} is the time in between the transmission and reception of signal by the MS. However, we can calculate the distance between the BS and MS using the calculation like, d=(RTT/2)*c, where c is the speed of light. Thus, it can be possible to find the estimated location of MS with the help of forming the circle of radius d and the center point is BS location [31].

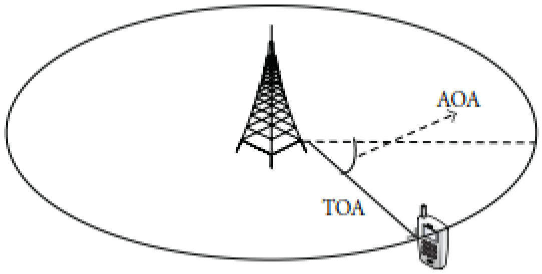

Figure 4-2 E-Cell ID positioning mechanism.

It considers that the accuracy level of E-Cell ID can be improved by adding another positioning parameter called AOA (Angle of Arrival). Thus, it is possible to get the direction of signal transmission from BS to MS and then the estimated positioning will be more accurate than the previous description.

From the above discussions, it is observed that the OTDOA is better than the other positioning algorithms because of its usability in different IoT applications like NB-IoT, simple implementation and calculation and fastest processing time. However, the IoT standard LoRa is designed based on the TOA positioning technique, which is called the basic algorithm of positioning with a great performance in tracking the targeted device.

5. OVERVIEW OF LORA AND NB-IOT TECHNOLOGY

In this section, IoT technologies called LoRa and NB-it will be discussed in more details. As it is mentioned in previous sections 3.1 and 3.2, LoRa and NB-IoT are the most challenging and market demandable technologies in the present world. It is also predicted that the next generation IoT technologies will be developed based on the basic principle of LoRa and NB-IoT technologies.

5.1 LoRa (Long Range) Wide Area Network Overview

Lore is a LPWAN (Low Power Wide Area Network) technology, which is established by the LoRa Alliance. Semtech built the LoRa modulation schema. In this technology, an additional layer was attached to handle the end device and BS traffic loads. The main purpose of this development is to enable wide area IoT technology based sensor network.

The LoRa technology developer LoRa Alliance is an organization, which includes around 200 companies that covers the whole LoRaWAN technologies. This organization is formed with sponsors, institutional members, adopters and contributors. In 2012, Cycleo a French startup company initially developed The LoRa standard, which was acquired by Semtech. After that Semtech is joined with Microchip, IBM and Cisco to form a new network standard using the LoRa Modulation.

5.1.1 LoRa Modulation Technique

The LoRa IoT technology uses the Chirp Spread Spectrum (CSS) modulation technique to transmit and receive the signal in between the MS and BS. This modulation schema creates wide band linear frequency modulated chirps. The chirp rate is equal to the spectral bandwidth like 125 kHz, 250 kHz or 500 kHz.

Chirp Spread Spectrum

In 1940, the chirp spread spectrum (CSS) was first developed in the form of radar communication. Day by day, this modulation technique used in number of military and secure communications applications. It is also observed that this technique applied in huge number of data communication technologies in the past twenty years because of its low power transmission requirements in multipath propagation, fading, in-band jamming and Doppler interferers.

Chirp modulation is a digital modulation that is formed with a chirp signal. A chirp signal is sinusoidal signal whose frequency changes over time like increasing or decreasing. The linear chirp modulation equation can be express as,

$$s(t) = A\cos(2\pi(f_c t + 0.5kt^2) + \varphi_c) \text{ for } 0 \leq t \leq \tau$$

Where, f_c is the starting frequency (Hz)

k is the chirp rate (Hz/s)

φ_c is the starting phase

B is the chirp bandwidth

However, B can be calculated as,

$$B = k\tau$$

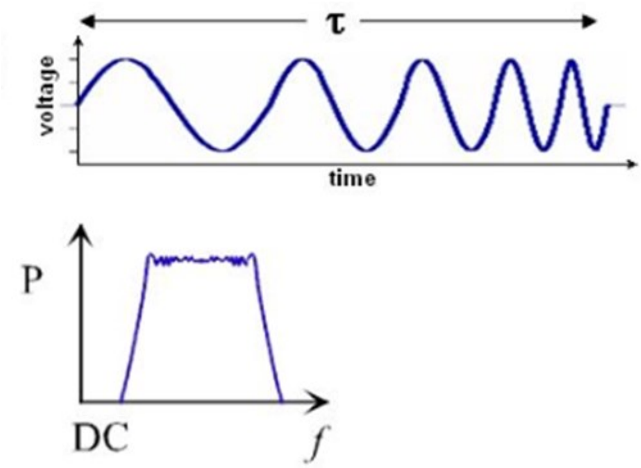

Figure 5-1 A sample Chirp signal and its Power Spectral Density.

The chirp signal can be classified as Up Chirp signal and Down Chirp signal. In the Up Chirp signal generation, the frequency rises from low to high in between the bandwidth for a pulse time interval as shown in figure-5.2.

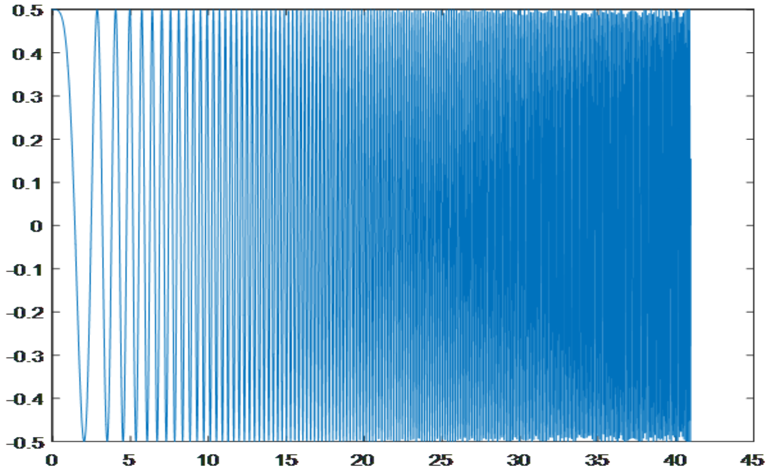

Figure 5-2 Linear Up Chirp Signal

However, the frequency decreases from high to low in between for a pulse time interval for the Down Chirp signal formation, which is also shown in figure-5.3.

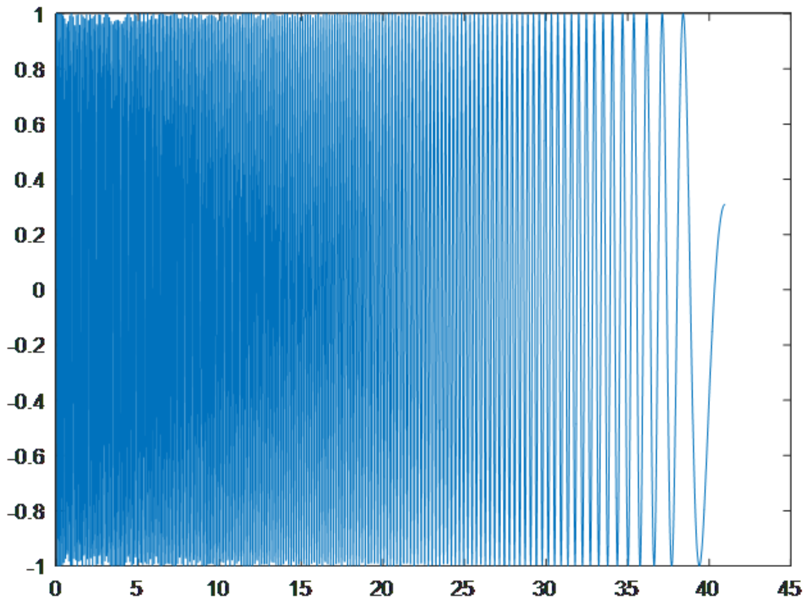

Figure 5-3 Linear Down Chirp Signal

5.1.2 LoRa Spread Spectrum Technique

The spreading of the LoRa modulation Spectrum is achieved by generating a continuous frequency varying chirp signal. It has a great advantage in receiver design complexity by making an equality in timing and frequency offsets between transmitter and receiver. The spectral bandwidth the signal is equal to the chirp frequency band.

According to [32], the relation between symbol rate, required data bit rate and chip rate for this modulation can be express as,

$$R_b = SF * \frac{1}{\frac{2^{SF}}{BW}} \; bits/sec$$

Where, R_b= the modulation bit rate, SF = Spreading factor (7 to 12) and BW = modulation bandwidth (Hz).

The bit rate of LoRa can vary between 0.3 and 22 kpbl depending on the spreading factor and the spreading factor can be chosen from the values 7 to 12.

The symbol period, T_s can be express as,

$$T_s = \frac{2^{SF}}{BW} \; secs$$

Thus, the symbol rate, R_s can be calculated as,

$$R_s = \frac{1}{T_S} = \frac{BW}{2^{SF}} \; Symbols/sec$$

From the above calculations, the chip rate, R_c can be defined as,

$$R_C = R_S * 2^{SF} = BW \; chips/sec$$

5.1.3 LoRa License-free Carrier

The Lora modulation uses a license-free carrier frequency band that can vary in different areas in the world. Nowadays the frequency band 433-870 MHz is being allocated for Europe, US and China. The frequency band that used in LoRaWAN, all of them are ISM bands. The frequency band 863-870 MHz is commonly used in Europe.

5.2 NB-IoT (Narrowband-IoT) Technology Overview

NB-IoT is a new Radio Access Networking system which is designed with the existing LTE technologies and principles. This technology is designed with some desirable performance like as,

- Low cost and ultra-low complexity devices to support the network.
- Enable to support massive number of IoT low throughput devices within a cell.
- Improve the indoor coverage of 20 dB.

- Improving the battery power of ten years.

NB-IoT occupies small bandwidth 180 kHz compare to the LTE bandwidths of 1.4-20 MHz. It is designed with the 12 subcarriers to make up the 180 kHz channel with 15 kHz spacing. It is also observed that NB-IoT can also be operated with 48 subcarrier with 3.75 kHz subcarrier spacing in 180 kHz channel.

5.2.1 Downlink Transmission

The downlink transmission of NB-IoT is designed with the OFDMA (Orthogonal Frequency Division Multiple-access) modulation technique with 15 kHz subcarrier spacing. The time duration of Slot, Subframe and frame are 0.5ms, 1 ms and 10 ms respectively. The slot format is designed in terms of cyclic prefix (CP) duration. The NB-IoT carrier uses twelve 15 kHz subcarrier in one LTE PRB (Physical Resource Block) to form 180 kHz in total.

5.2.2 Uplink Transmission

The NB-IoT Uplink transmission is based on SC-FDMA (single-carrier frequency division multiple-access) modulation technique which is operating with the same 15 kHz subcarrier spacing, 1ms subframe, 0.5 ms slot. This technology can operate in both 15 kHz and 3.75 kHz. Operating with the 15 kHz provides the best coexistence performance with LTE for the uplink transmission. However, the 3.75 kHz uses 2 ms slot durations. The NB-IoT carrier uses the 180 kHz total bandwidth for uplink transmission that is similar to its downlink bandwidth.

5.2.3 Deployment of NB-IoT

The NB-IoT can be deployed in three scenarios with the agreement of 3GPP technologies. The three deployments are Guard Band, In Band and Stand Alone.

It is also observed in [33] that the stand-alone carrier is using when the availability of the spectrum is exceeding the total bandwidth like 180 kHz or 200 kHz. However, the guard band carrier deployment uses the bandwidth reservation in the guard band of the LTE network and the in-band carrier deployment use the same LTE carrier resource block of the existing LTE network. A small scenario of the deployment options of NB-IoT with a 200 kHz LTE carrier is illustrated in figure-5.4.

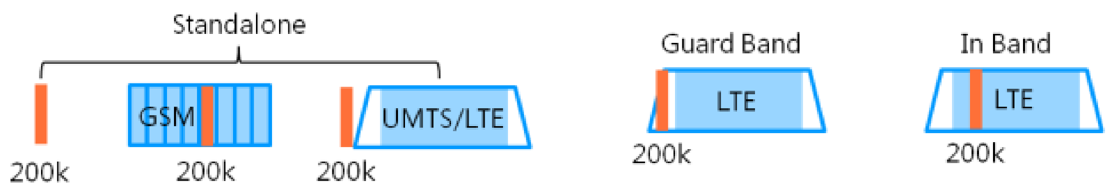

Figure 5-4 The deployment Scenario of NB-IoT.

5.2.4 Coverage of NB-IoT Technology

According to literature [34 35], the NB-IoT achieves 20 dB maximum coupling lose which is higher than the LTE Rel-12. The coverage can be enhanced depends on the data rate related to the number of repetitions and also by introducing single subcarrier in NPUSCH (Narrow Physical Uplink Shared Channel) transmission.

It is also observed in the literature [36] that the NPUSCH with 15 kHz provides a data rate of 20 bps in configuring with the lowest modulation, highest repetition factor and lowest coding mechanism. The data rate is increased by 35 bps by operating the NPDSCH (Narrowband Physical Downlink shared Channel) with the repetition factor 512. Thus the total supported coupling loses goes to 170 dB with this configuration, whereas around 142 dB coupling lose is supported by the LTE Rel-12 network.

5.2.5 NB-IoT Operating Capacity

A massive number of IoT devices are supported by NB-IoT which uses only one PRB in both uplink and downlink. The introduction of sub-PRB in uplink UE scheduled bandwidth including single subcarrier NPUSCH causes the massive capacity of this technology. According to [37], one PRB of NB-IoT supports around 52500 UEs per cell. Moreover, NB-IoT can operate multicarrier operations, which also makes this capacity massive to support the IoT devices.

After a long and detail overview of the IoT technologies LoRa and NB-IoT, it can be possible to make a simulation platform and calculation to observe and compare the performance of these two IoT technologies in terms of Positioning accuracy, Capacity, Battery lifetime, Multicarrier operation, better Modulation technique, Coupling loss and Bit rate.

6. SIMULATION-BASED STUDIES

In previous sections, A detailed knowledge of IoT technologies has been done and this knowledge inspires to go forward to build up the simulation for all the IoT technologies and observe their performance with comparisons in order to make a prediction of the next generation IoT technologies inventions.

In this research, LoRa and NB-IoT Technology are chosen because of their big market value, popular usability in different applications and. A huge simulation has been built up in this research to observe their Positioning Accuracy and better Modulation Technique.

6.1 Simulation

The simulation part has been divided into two parts such as LoRa simulation and NB-IoT simulation. A practical Radio Access Network field is designed to perform the simulation and observation, which has shown in figure 6.1.

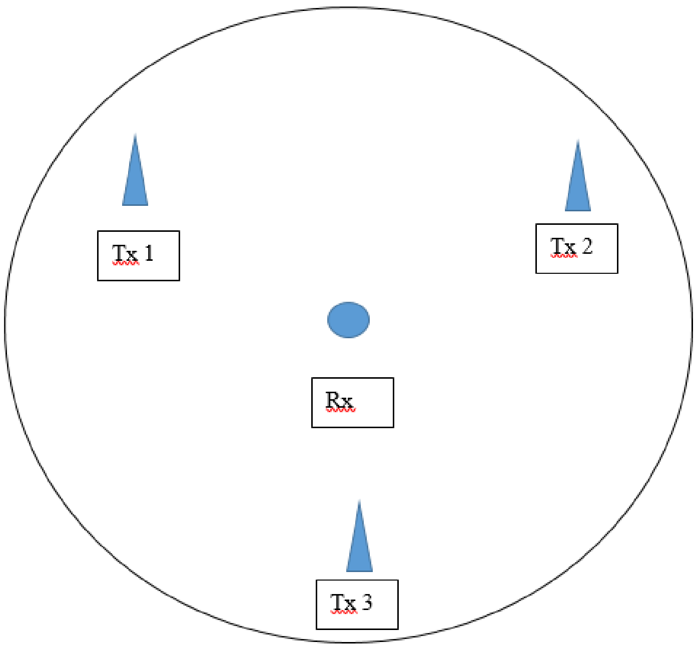

Figure 6-1 A Scenario of Radio Access Network Field.

In this network, the transmitter and receivers position can be changed randomly in every round of propagation and observation. Here, three transmitter are being used to find the receivers coordinates which is the minimum requirements of positioning. We also increased the number of transmitters in order to get the comparisons of better positioning accuracy.

To set up the simulation, a couple of steps have been taken which is given below:

- First, a number of simulation parameters have been set up for establishing the simulation platform and characterize them.
- Second, the transmitted signals are generated according to their modulation technique in order to observe the transmit time and distance measurement.

Third, from the transmit time and distance measurement, positioning algorithm is applied to calculated the receiver coordinated and its accuracy level of positioning.

6.1.1 LoRa Simulation Platform Set Up

In this simulation, different simulation parameters are initialized to pattern the platform. The LoRa simulation parameters are calculated by using equations which is mentioned in the section 5.1.1. The LoRa simulation parameters are given in table 2.

Table 6.1: LoRa Simulation Parameters

Parameters	**Values**
Bandwidth	125 kHz
SF (Spreading Factor)	7
Modulation Technique	CSS (Chirp Spread Spectrum)
Network area	0.2 km radius
Number of transmitters	3-10

LoRa Transmitted Signal Generation

The LoRa technology uses the chirp modulation technique to generate the transmitted signal which is described in section 5.1.1. The generated transmitted signal with spectrogram is shown in figure 6.2 and 6.3.

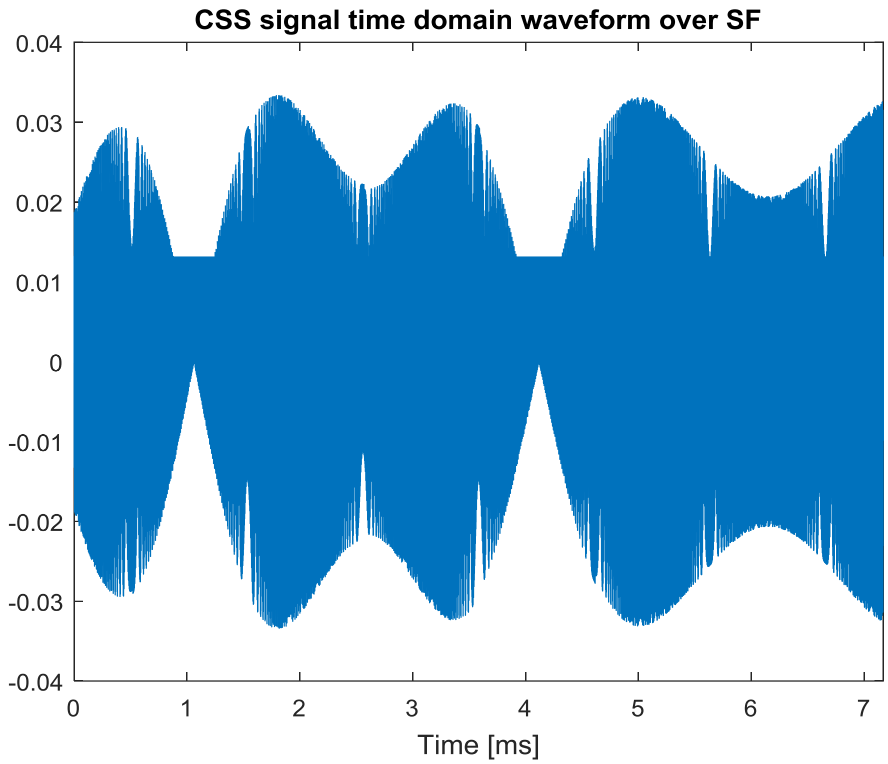

Figure 6-2 The LoRa Transmitted Signal in Time Domain.

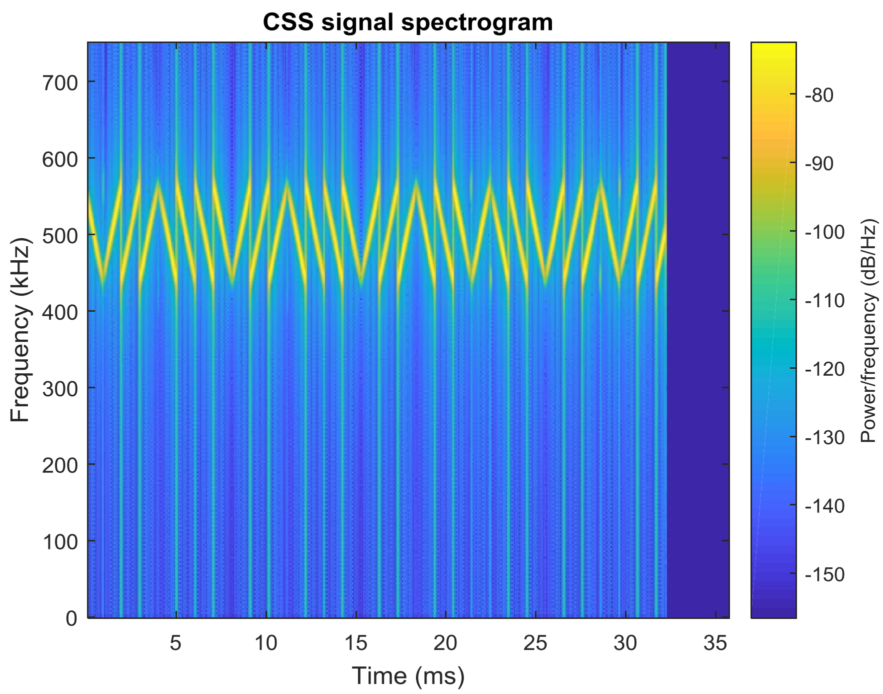

Figure 6-3 The Spectrogram of the Lora Transmitted Signal

The figure 6.3 is showing the formation of the transmitted signal with the chirp samples and there frequency formations. As it is described in section 5.1.1.1 that there are two kinds of chirp signals such as Up Chirp and Down Chirp. The Up Chirp and Down Chirp signal generation is shown in figure 6.4 to 6.7.

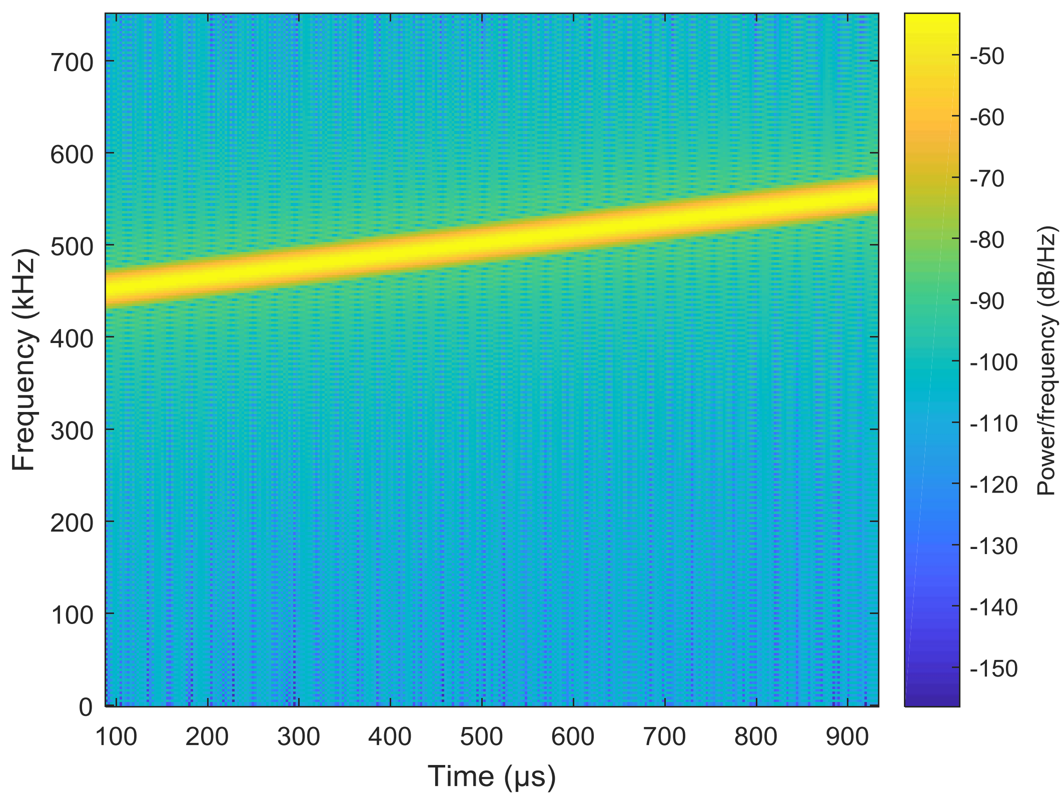

Figure 6-4 The Spectrogram of Up Chirp Signal Sample.

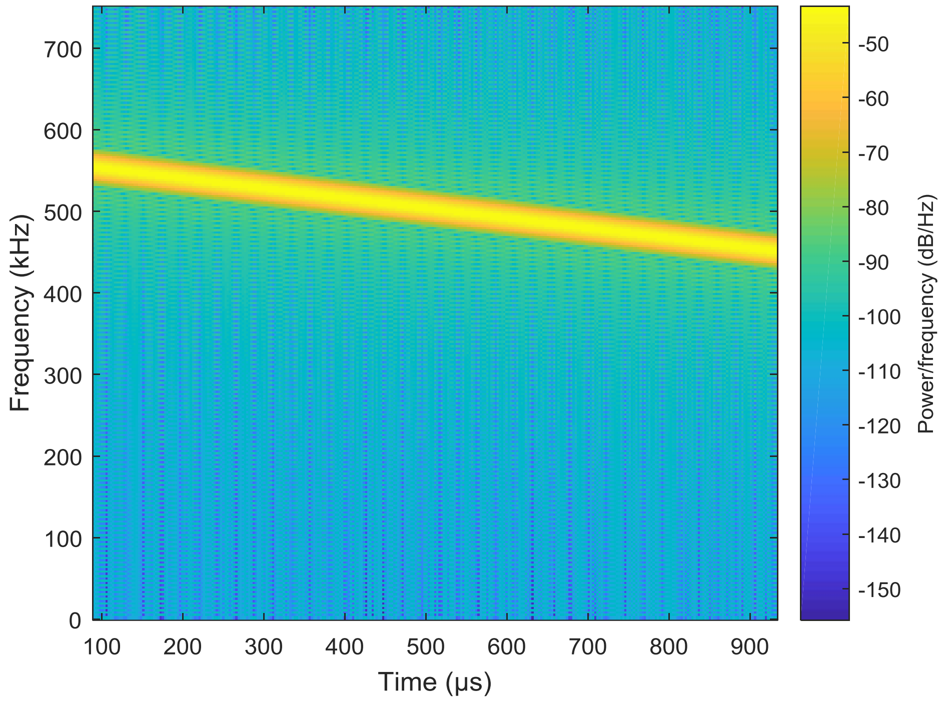

Figure 6-5 The Spectrogram of Down Chirp Sample.

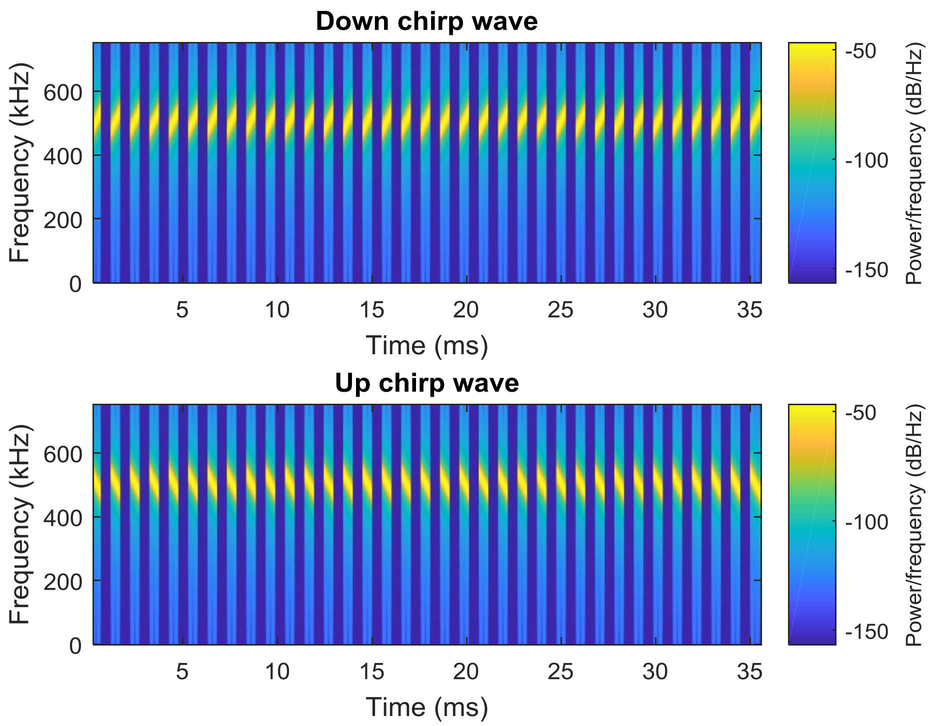

Figure 6-6 The Spectrogram of Up Chirp and Down Chirp Samples Series.

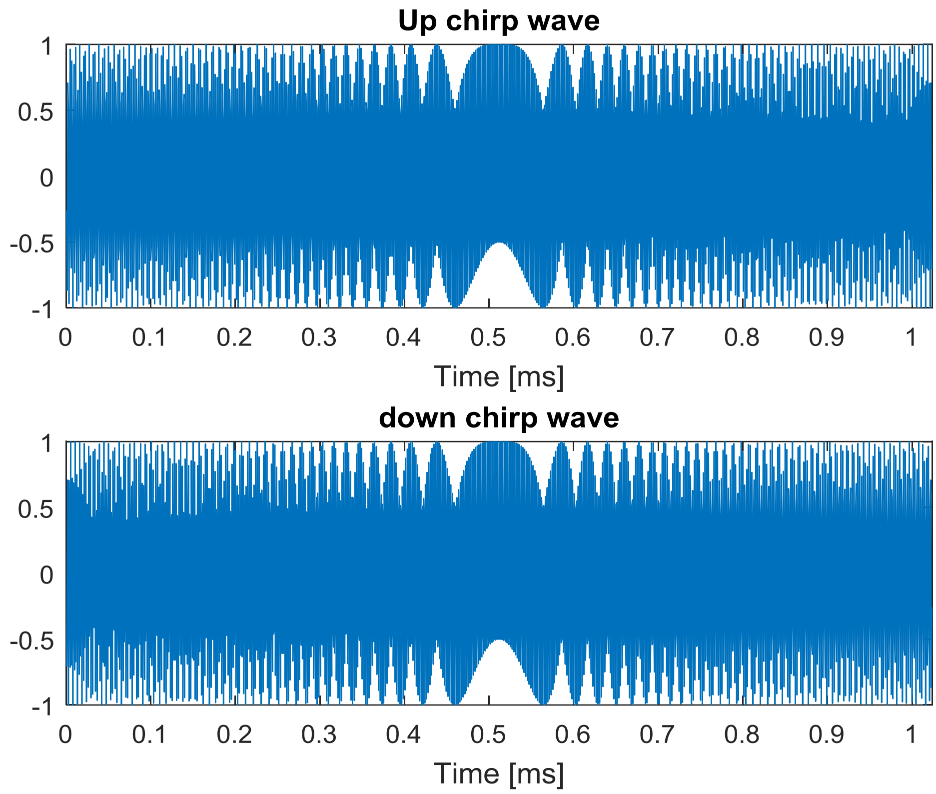

Figure 6-7 The Time Domain Plot of Up Chirp and Down Chirp Samples Series

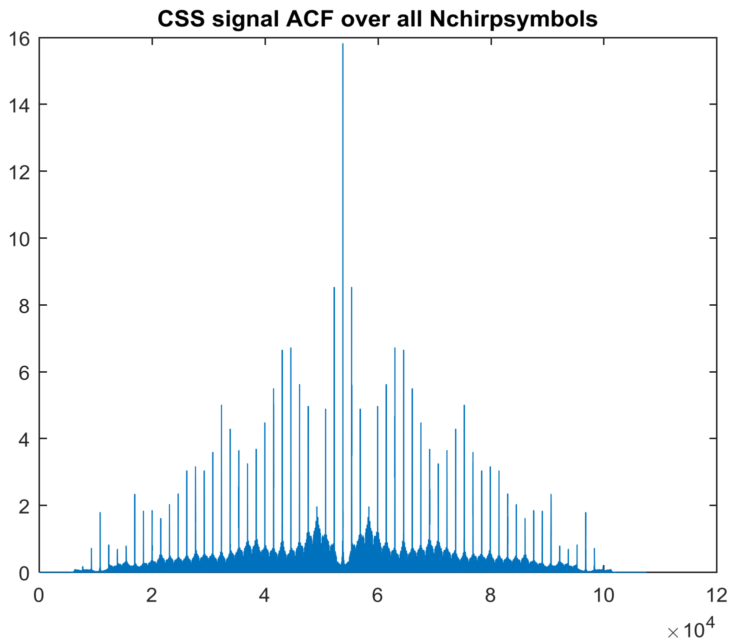

Figure 6-8 Correlation between the Transmitted Signal and Received Signal.

In the figure 6.8, the correlation between the transmitted signal and received signal is shown by which we can get the peak value to calculate the positioning coordinates of the receiver and also the positioning error by applying the positioning principle TOA (Time of Arrival).

6.1.2 NB-IoT Simulation Platform Set Up

The NB-IoT simulation is totally different than the LoRa simulation platform. The simulation parameters of NB-IoT is given in table 3.

Table 6.2: The Simulation Parameter of NB-IoT

Parameters	**Values**
Bandwidth	3 MHz
Channel Bandwidth	180 kHz
Modulation Technique	OFDMA (Orthogonal Frequency Division Multiple Access).
Network area	0.2 km radius
Subcarrier Spacing	15 kHz
Number of Transmitter	3-10

NB-IoT Transmitted Signal Generation

The modulation technique of NB-IoT is based on OFDMA (Orthogonal Frequency Division Multiple Access) to generate the transmitted signal. The figure 6.9 shows the series of symbols of the transmitted signal.

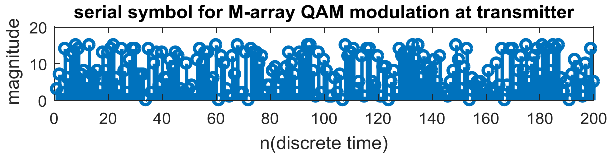

Figure 6-9 The series of the Symbols of transmitted Signal.

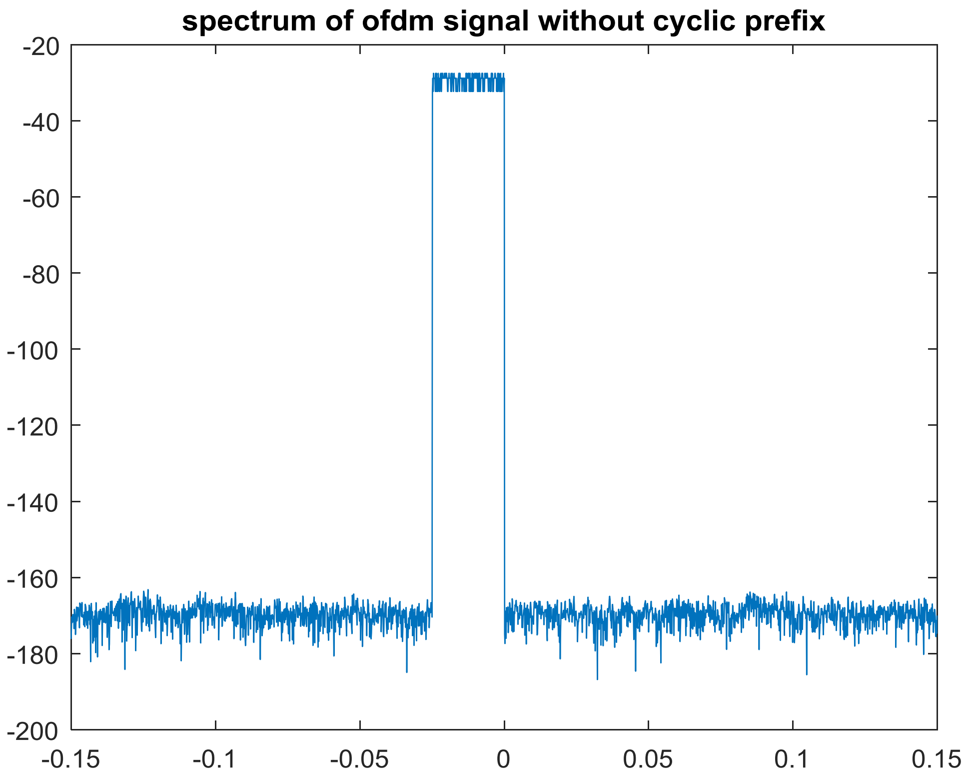

Figure 6-10 The Frequency Spectrum of the OFDMA modulated Signal without Cyclic Prefix.

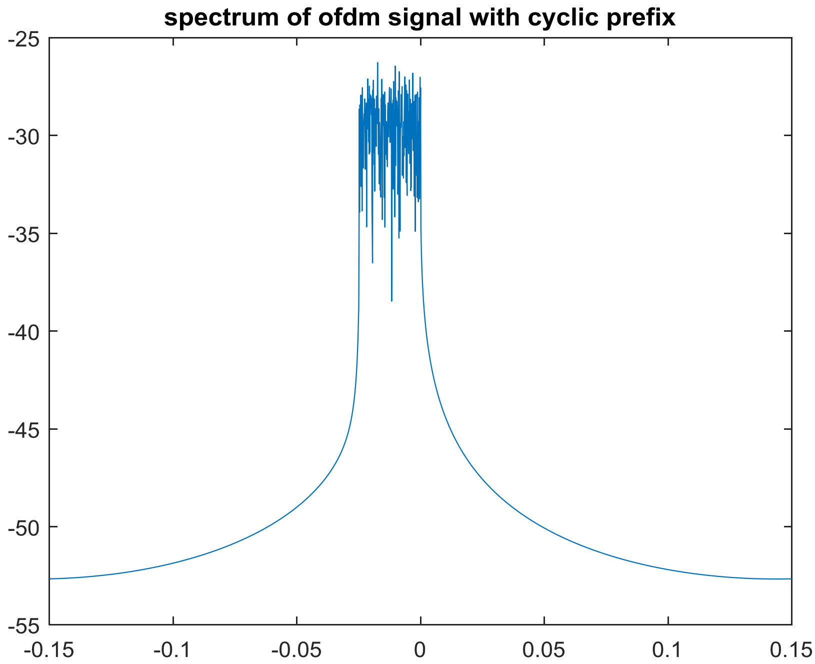

Figure 6-11 The Frequency Spectrum of the OFDMA modulated Signal with Cyclic Prefix.

The figures 6.10 and 6.11 are describing the frequency domain plot of the OFDMA modulated signal with related to the cyclic prefix (CP).

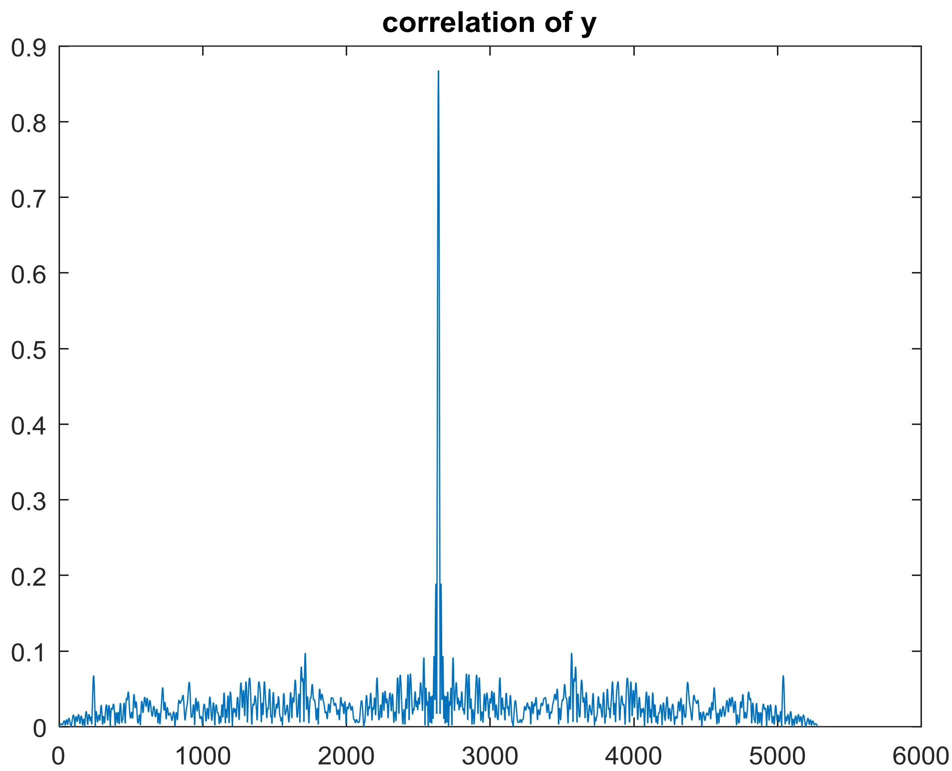

Figure 6-12 The correlation between the OFDMA modulated transmitted signal and received signal.

The figure 6.12 illustrates the measurement of the correlation of transmitted signal and received signal.

6.2 Results and Observations

6.2.1 LoRa Simulation Results

After a long simulation set up, a number of results are observed in terms of RMSE positioning error versus Noise Variance and RMSE positioning error versus number of transmitters in order to characterize the performance evaluation of the LoRa technologies.

The Figure 6.13 illustrates the changes of RMSE positioning error with respect to the noise variance levels. In this figure, It is also observed that the RMSE positioning error was constant until the noise variance reached to the value of 0.1 and the error value is around 68. However, the error level is fluctuating from the noise variance of 0.1.

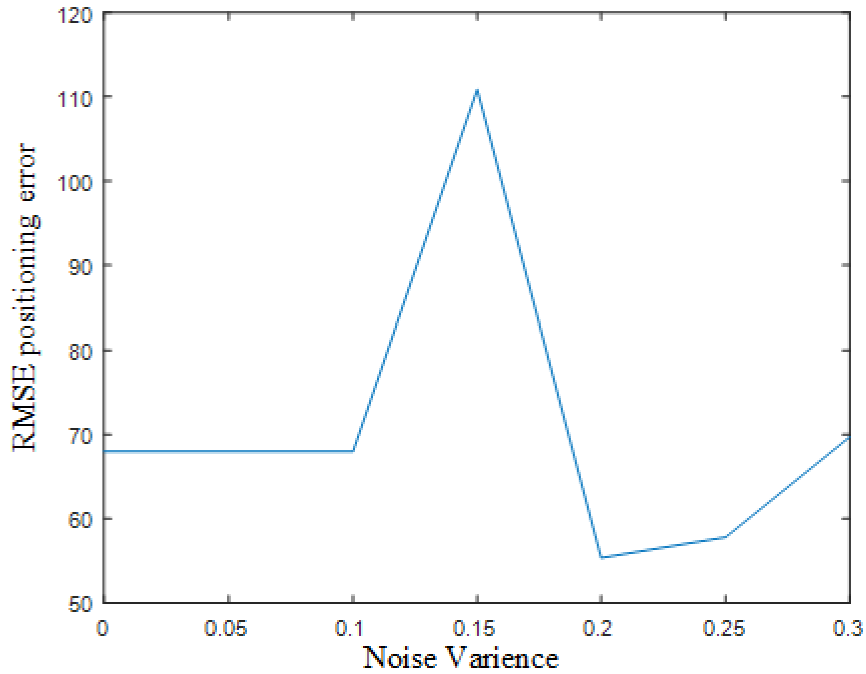

Figure 6-13 The plot of RMSE Positioning Error versus Noise Variance for LoRa.

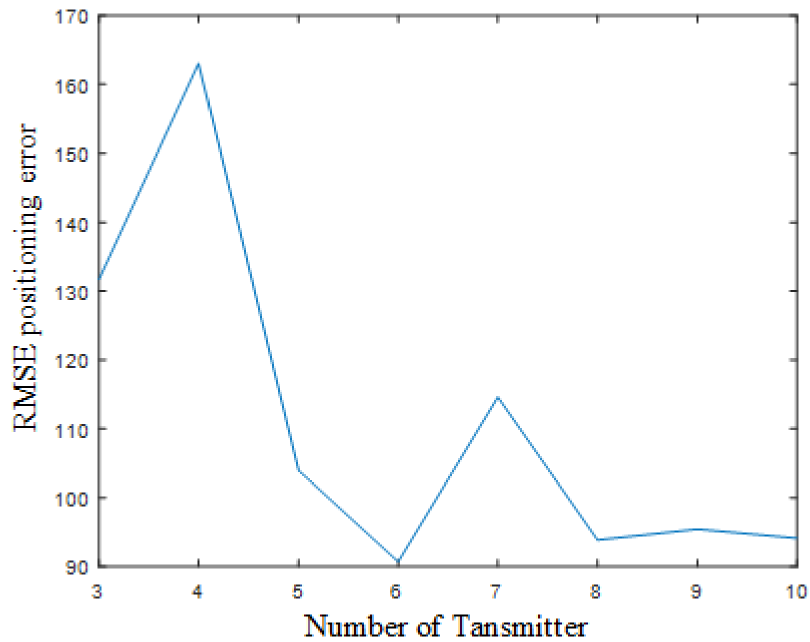

Figure 6-14 The plot of RMSE Positioning Error versus Number of Transmitters for LoRa.

The Figure 6.14 illustrates the changes of RMSE positioning error with respect to the number of transmitters used to calculate the coordinate of the targeted device. In this figure, It is also observed that the RMSE positioning error was more than 130 in the initial stage with respect to the three number transmitters was used for positioning. However, the error level goes down to the zero when the used number of transmitters was six. After that, the error level remains comparatively saturated up to the ten numbers of transmitters were being used and the final error value was around 94.

6.2.2 NB-IoT Simulation Results

From the second simulation part, the same parameters of LoRa simulation results are being observed to make a good comparison about performance evaluation in between the two IoT technologies called LoRa and NB-IoT.

The Figure 6.15 illustrates the changes of RMSE positioning error with respect to the noise variance levels. In this figure, It is also observed that the RMSE positioning error was around 20 in the initial state where as the value was around 68 for LoRa IoT technology. However, the error level is fluctuating from the noise variance of 0.1 which is around similar to the LoRa simulation results.

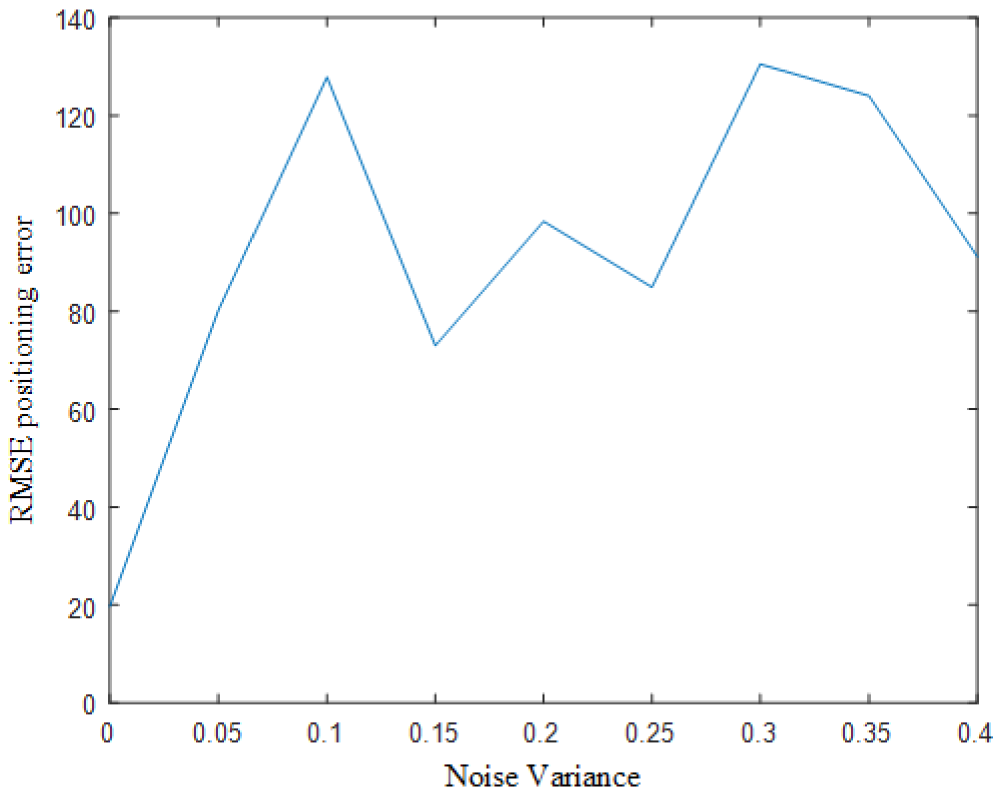

Figure 6-15 The plot of RMSE Positioning Error versus Noise Variance for NB-IoT.

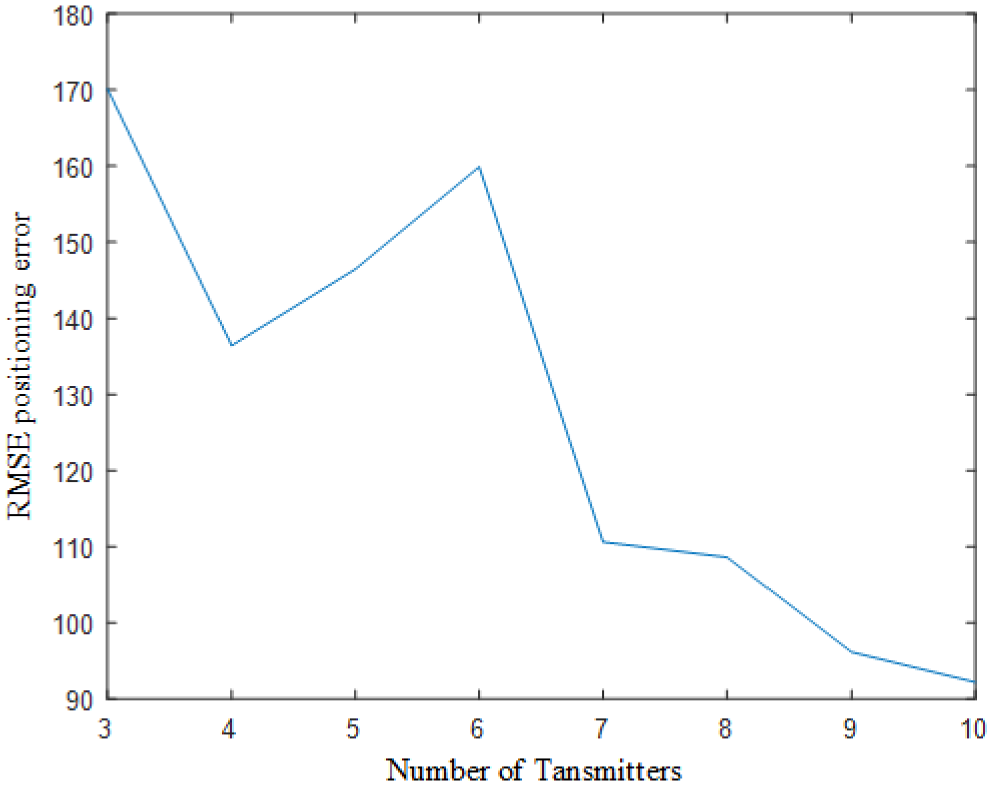

Figure 6-16 The plot of RMSE Positioning Error versus Number of Transmitters for NB-IoT.

In the figure 6.16, it is explaind that the changes of RMSE positioning error with respect to the number of transmitters used to calculate the coordinate of the targeted device. The positioning error level was high in the initial stage. However, this level was sharply down to around 92 for the ten number of transmitters being used to calculate the positioning error.

After making some possible comparisons of the simulations results, it can observe that the NB-IoT has better modulation technique and positioning mechanisms to achieve a higher level of positioning accuracy compare to the LoRa modulation technique, positioning mechanisms and simulation results.

7. CONCLUSION AND FUTURE WORK

By the use of theoretical background of LoRa and NB-IoT technologies, it was possible to achieve the huge knowledge about the usability of IoT devices in industrial market and M2M communications. Moreover, this theoretical study provides the most promising modulation technique details called chirp spread spectrum (CSS) and OFDMA (Orthogonal Frequency Division Multiple Access) which helps to implement the big simulation platform in order to observe some results and the performance comparisons between LoRa and NB-IoT.

After implementing the simulation, around two parameters are being observed in order to characterize the positioning level and performance evaluation of these IoT technologies called LoRa and NB-IoT. First, the noise variance versus positioning error result describes how the error level is changing according to the change of noise level. Second, the positioning error versus number of transmitters result illustrates how the positioning error has changed with respect to the number of transmitters used in the signal propagation.

A number of decisions have been taken about the positioning accuracy level and performance evaluation of LoRa and NB-IoT technologies by making a great comparison of the simulation results. From the comparison, it is find that the NB-IoT has a massive capacity to support huge number of IoT devices because of its frequency arrangement and modern modulation technique compare to the LoRa based IoT technologies. It is also found that the positioning accuracy level of NB-IoT is higher than the LoRa based IoT technologies because of the better positioning algorithm used in NB-IoT technologies.

In future, it can be possible to generate the simulation for other IoT technologies in order to make a huge comparison with some additional parameters like as the positioning error versus the operating distance, which will provide a clear knowledge of the better positioning technique to be chosen for the implementation of the next generation IoT technologies.

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