Positioning In Internet of Things (IoT)

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Abstract **- In the Internet of Things (IoT) various devices are connected over the internet, and they communicate data with each other to make informed decisions. IoT has multiple applications across different sectors like agriculture, health care, supply-chain management, waste management, etc. The short-range IoT devices are linked through Wi-Fi and Bluetooth technologies, wide-area IoT devices are connected to the internet utilizing cellular connections or Low-Power Wide-Area Networks (LPWAN) such as LoRa, NB-IoT, or LTE-M. Numerous use cases in the Internet of Things (IoT) will benefit or require location information, making positioning a vital dimension of the IoT. This literature review focuses on various IoT positioning domains, how the positioning is achieved in LoRa, LTE-M, and NB-IoT, their design challenges, and an overview of their enhanced positioning.**

Keywords – Internet of Things (IoT), LoRa, LTE -M, NB-IoT, OTDOA

I. INTRODUCTION

The IoT is a vision of a future world where everything that can benefit from a connection will be connected. Each IoT application has its challenges, such as dealing with massive networks, low and ultra-low latency requirements, continuous monitoring of particular node locations, etc. Hence, for a specific application, choosing a connectivity solution depends upon how well its features solve the particular needs of that application. It is expected that a substantial part of IoT applications will need Location Based Services (LBS), which makes positioning an essential component of the IoT. Example IoT use cases needing positioning services include logistics tracking, wearables, animal husbandry, and fishery. The broadly used global navigation satellite system (GNSS) positioning method is not fit for massive IoT due to affordability concerns regarding power and cost to maintain GNSS chips. Besides, the IoT devices may be located in intense coverage challenging places that GNSS does not cover. Therefore, positioning based on terrestrial cellular networks is a promising alternative.

Cellular technologies are being built or advanced to play a vital role in the IoT world, particularly machine-type communication (7MTC) [1]. Two major MTC can be described by lower demands on data rates than mobile broadband, but with higher requirements on, for example, low-cost device layout, better coverage, and the capability to run for years on batteries without charging or replacing the batteries [2]. MTC technologies are the Long-Term Evolution (LTE) MTC (LTE-M) and Narrowband IoT (NB-IoT). With a least system bandwidth of 1.4 MHz, LTE-M is based on LTE and incorporates additional improvements to support IoT services better [3]. NB-IoT is a recent radio access technology that uses a system bandwidth of 180 kHz to provide more flexible deployment options [4]. LPWAN is designed to allow wide-area connectivity for low power at a low bit rate. These features meet the requirements of Internet of Things (IoT) applications, such as sensor nodes that work with batteries. The common LPWAN technologies include LoRa/LoRaWAN, Sigfox, and NB-IoT. Long-Range (LoRa) modulation is centered on Chirp Spread Spectrum (CSS) signals. It has become famous for wide-area Internet of Things (IoT) applications due to its operation in unlicensed spectrum (typically 868 MHz in Europe and 915 MHz in North America), its energy efficiency, and low cost [5].

The structure of this paper is as follows: In Section II, we provide an overview of various IoT positioning domains. In Section III, we introduce Long Range (LoRa) modulation, Long-Term Evolution (LTE) MTC (LTE-M), Narrowband IoT (NB-IoT). Section IV explains how the positioning is achieved in LoRa, LTE-M, and NB-IoT. In Section V, we provide the design challenges. Section VI gives an overview of how the positioning is enhanced, and Section VII provides the conclusions of this study.

II. OVERVIEW OF VARIOUS IOT POSITIONING DOMAINS

A set of measurements from known reference points are usually translated into a coordinate pair by a positioning system. In IoT terminology, these reference points are known as Access Nodes (AN), whereas they are known as anchors in localization terminology. They act as a means for the device of interest to be in a global or local reference frame. Suppose anchors make the positioning-related measurements; in that case, the positioning is considered network-centric, whereas the positioning in which the IoT end nodes or tags make positioning-related measures is called device-centric [6].

There are three main domains for an IoT positioning system in the scope of our study:

- Time-based.
- Space-based.
- Power or signal strength based.

Many other domains like light and sounds were not included in the scope of our study but are essential information sources for future IoT positioning systems. The following subsections will summarize the main challenges in these positioning domains and their system-wide impacts [6].

I. Time-Domain:

By estimating the time-of-appearance (TOA) or the time-difference-of-appearance (TDOA) from three or more fixed access nodes and converting those timing estimates into distances, the positioning estimation based on timing information is established. These time measurements need synchronized clocks, either at the receiver or the transmitter side, leading to a significant burden on device cost. Time-Domain doesn't play well for IoT applications, driven by the need to have low-cost devices [6].

II. Space-Domain:

The ranges are estimated in the space domain by measuring the angle of arrival (AoA) for the signal of interest by a sectorized antenna. The major constraint for achieving angle measurements in AoA relies only on the antenna design, which makes it particularly interesting for the IoT. However, its major drawback is that the error increases as the distance to the transmitter increases. This means that a slight deviation in the angle results in a significant error for the devices at the service edge [6].

III. Power or signal strength-based:

Most of the time, the device and battery consumption cost are not derived while deriving signal strength measurements from protocol operations. In the Power domain, several challenges like backscattered power (BP) because of shadowing caused by the surrounding environment, Received Signal Strength (RSS) fast fluctuations must be addressed by the positioning solutions. To model RSS measurements, we should understand accurately how the signal power changes in its surrounding environments.

An IoT positioning system can extract this information directly from the communication's signal, with no additional cost for the device. The battery cost will depend on the count of positioning location requests demanded per second in terms. Acquiring the RSS-based positioning will have no impact on the battery life if the requirement is to have an opportunistic location based on the sporadic communication of the device. Battery life is impacted only when the device or the infrastructure periodically listens for a specific pilot signal to get the RSS-based positioning. The limitation of RSS-based approaches is that some current IoT standards support only a coarse RSS measurement, adversely impacting positioning accuracy as the noise variance increases [6].

III. LORA, LTE-M & NB-IOT TECHNOLOGIES

A. *LoRa Technology*

This technical section on LoRa is based mainly on "A technical overview of LoRa ® and LoRaWAN ™" [7]. LPWAN is designed to allow wide-area connectivity for low power at a low bit rate.

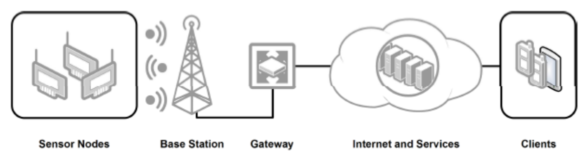

Figure 1. The communication protocol and system architecture of LoRaWAN

Figure 1 characterizes the specific parts and architecture of an LPWAN network. The sensor nodes, an edge node or an end node, collect one or more measured values and then send the data to the base station. The base station transmits the data through the backhaul gateway to some Internet cloud service. The end-user or clients can use the collected data from cloud services.

LoRa modulation is centered on spread spectrum techniques, a modification of the chirp spread spectrum (CSS) with incorporated forward error correction (FEC). It runs in the lower Industrial, Scientific, and Medical (ISM) bandwidths (USA: 915MHz, EU: 433MHz, and 868MHz). The LoRa modulation can be used by various diverse protocol architectures such as Star, Mesh, and 6lowPAN. Furthermore, the LoRa Alliance has standardized the MAC protocol called LoRaWAN. LoRaWAN (Figure 2) describes the communication protocol and system architecture for the network while the LoRa physical layer aids the long-range communication link. The edge nodes of the LoRaWAN network can transfer data to multiple base stations.

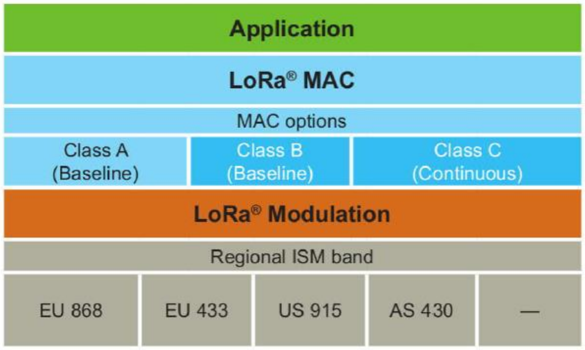

Figure 2. The communication protocol and system architecture of LoRaWAN

LoRaWAN defines three classes of devices. These device classes can negotiate network downlink communication latency versus the battery lifetime. These classes are shown in Fig. 2, and depending on the application needs, A, B, or C classes can be chosen. Battery-powered devices in “Class A” are intended for low-powered devices such as sensors. The B Class is focused on battery-powered devices, such as actuators and sensors. The C Class is used by bi-directional end devices with maximal receive slots. LoRaWAN network protocol security is based on IEEE 802.15.4 and is also extended by using two session keys: a network session key and an application session key. Each LoRaWAN edge node device also has its own 128-bit AES key, known as the AppKey.[7]

B. LTE-M Technology

LTE technology was built for Machine-to-Machine communication, and LTE-M is a branch. Affordable and efficient connectivity for the Internet of Things (IoT) applications is offered by Low Power Wide Area Networks (LPWANs). For the LTE-MTC low power wide area (LPWA) technology standard published by 3GPP in the Release 13 specification, LTE-M is the simplified industry term. Batteries in the LTE-M devices can last ten times or further between its Power Saving Mode (PSM) and Discontinuous Reception (DRX). IoT devices can transmit and receive large quantities of data without draining the battery by using LTE-M [8].

C. NB-IoT Technology

NarrowBand-Internet of Things (NB-IoT) is a low power wide area (LPWA) standard technology developed by 3GPP for cellular devices and services. NB-IoT focuses specifically on low cost, spectrum efficiency, indoor coverage, long battery life of more than ten years, and high connection density. NB-IoT serves better for IoT applications that require more frequent communications. The underlying technology of NB-IoT is simpler than today’s GSM/GPRS, and as demand increases, its cost decreases. NB-IoT can coexist with 2G, 3G, and 4G mobile networks and is supported by major mobile equipment and chipset manufacturers [8].

IV. POSITIONING

A. LoRa

This section explains LoRa signal-based positioning using Time of Arrival (ToA) and Time Distance of Arrival (TDoA). ToA can be calculated when a signal is transferred by an end-device and collected at multiple gateways to estimate the distances from the equivalent gateways by multiplying the speed of light to the time.

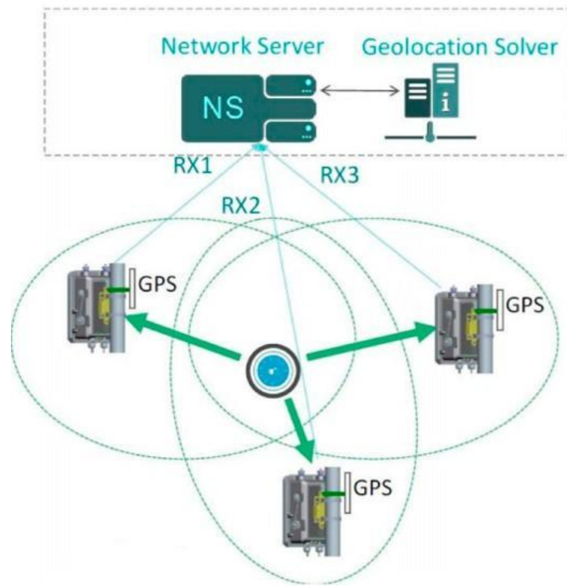

Figure 4: Semtech Corporation’s TDoA-based geolocation architecture.

The location of an end device can be calculated by the trilateration approach with the distances. The TDoA-based positioning method needs time synchronization only between gateways and not between a gateway and an end device. Hyperbolas are created by the set of locations for which the difference in distance from gateways is constant. The location of an end device can be obtained by calculating its intersection point.

Figure 4 demonstrates the TDoA-based positioning method. A LoRa end-device, shown by the blue circle in the figure, sends out an uplink packet to LoRa gateways. Each gateway records the packet onset time using a GPS time-synchronized gateway processor. The Geolocation Solver in the network computes the differences between these arrival times. The location of the end device is then determined by determining the point where hyperbolas overlap [9].

B. LTE-M and NB-IoT:

This section presents the OTDOA architecture preliminaries, and the protocols developed by 3GPP.

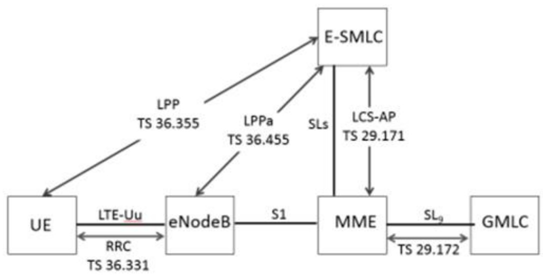

Figure 5: LTE positioning architecture

In OTDOA, to form the reference signal time difference (RSTD) measurements, which are the time difference of arrival (TDOA), UE subtracts the Time of Arrival (TOA) of a reference cell from the Time of Arrival (TOA) of positioning reference signals (PRS) coming from the multiple cells. Each TDOA constrains the desired UE's position to a hyperbola geometrically. The desired UR position is where hyperbolas intersect if the TOA measurements are noise and interference-free. Figure-5 illustrates the architecture that supports LTE Positioning [8].

Signal Flow under the LTE-supported positioning architecture is as follows.

1. An external LBS client communicates with a GMLC node first. The Mobility Management Entity (MME) receives a location service request or initiates a location service from the Gateway Mobile Location Centre (GMLC) or UE.
2. A positioning request to the Evolved Serving Mobile Location Centre (E-SMLC) by the MME.
3. The E-SMLC processes the request to communicate with the UE and requests for RSTD measurements.
4. The E-SMLC calculates the UE's position and sends the result back to the MME on receiving RSTD measurements from the UE.
5. The result may be further forwarded to the UE or GMLC by the MME as appropriate.
6. The LTE Positioning Protocol (LPP) is used for signaling between UE and the E-SMLC.
7. Also, there are interactions between the Evolved Node B (eNB) and E-SMLC via the LPP A (LPPa) protocol, and to some extent supported by the interactions between the eNB and UE via Radio Resource Control (RRC) protocol.
8. The procedures of LPP positioning will have the following steps.

- Capability transfer: An OTDOA-RequestCapabilities message to the UE by the E-SMLC, and the UE responds with a ProvideCapabilities message to the ESMLC.
- Assistance data transfer: A ProvdieAssistanceData message is sent to the UE by the E-SMLC with the suggested reference specific PRS configuration and neighbor cell list. UE knows when the PRS signals are transmitted using the assistance data and accordingly measures Time of Arrival based on the PRS signals.
- Location information transfer: A RequestLocationInformation message to the UE by the E-SMLC and the UE responds with a ProvideLocationInformation message with UE's RSTD measurement results [8].

V. DESIGN CHALLENGES:

Below are the challenges of LoRa networking.

A. *Energy Consumption:*

LoRa networks are anticipated to work for a more extended period of 5-10 years with minimum maintenance. Hence, power consumption becomes a main challenge for LoRa networking. The End-device operations can be classified into (1) micro-controller operations and (2) wireless transmissions. Charm [10] shows that wireless transmission extracts more power than micro-controller operations. LoRa technology uses two methods to decrease energy consumption, (1) consuming instantaneous bandwidth for transmitting a chirp signal and (2) not employing heavy MAC protocols for scheduling. Despite these techniques, end-devices consume more power than expected due to some unavoidable circumstances like retransmissions caused by channel impairments [11]. The solution to this challenge is that numerous techniques are employed to enhance battery lifetime of the end-devices. Some works propose techniques (1) to harvest ambient energy from the environment; (2) to use backscatter signals for transmission, and (3) to detect and decode weak signals and increase data rate to reduce power consumption [11].

B. *Security:*

There are many security attacks like eavesdropping, selective forwarding, and node impersonation [12] which try to get the key used for encryption. If this key is compromised, the complete system can be broken. Currently, LoRa technology employs a symmetric key cryptographic method with AES-128-bit encryption. Current LoRa technology generates the key and never renews it. Hence, Key generation and Key update process is a main concern [11]. As a solution, Naoui et al. [13]

discusses the options of applying proxy-based key exchange systems to improve the security. An attack by which the bits of ciphertext is altered, called Bit flipping attack is countered in [14] using circular shift and swap techniques.

Below are the challenges of LTE-M and NB-IoT networking.

A. *Limited Device Capability*:

The LTE-M and NB-IoT UEs have limited capabilities. The normal LTE UE can receive a 20 MHz wide signal, whereas the maximum channel bandwidth of low complexity bandwidth reduced LTE-M and NB-IoT UEs is 1.4 MHz and 180 kHz, respectively, and the more advanced LTE-M UE in Release 14 can receive a 5 MHz wide signal. The signal bandwidth limits the ranging resolution. It is challenging to provide adequate positioning support for the low complexity bandwidth-reduced devices [8].

B. *Coverage extension:*

NB-IoT is intended to enhance the coverage by 20 dB compared to standard GSM coverage, and LTE-M is intended to enhance the range by 15 dB compared to regular LTE coverage. LTE-M UEs may be in extreme coverage challenging locations, and for such devices, the signal-to-noise ratios are low, usually below -10 dB. It is a crucial design challenge to improve OTDOA positioning support for the extreme coverage challenging locations [8].

VI. ENHANCED POSITIONING

A. *Enhanced Positioning in LoRa*

The toughest challenge for Lora indoor positioning is the ranging error caused by multipath in the indoor environment. In the early days, the Kalman filter positioning algorithm was used primarily to solve the problem of achieving efficient state estimation for linear Gaussian systems [15]. Moreover, to deal with nonlinear distortions and unwanted errors, a particle filter (PF) is applied as a nonparametric filter to location, which is a recursive implementation of Monte Carlo-based statistical processing [16] and performs well in stability, accuracy, and localization efficiency. Shan Yang, XiuJun Bai, Qiang Liu, Xingli Gan [17] introduce a Lora indoor positioning system, which overcomes the problem of long-distance, low power consumption, and low cost. Then, a Lora-aided particle filter localization method is designed to solve the problem of indoor positioning. Later, numerous experiments were carried out with actual Lora RTT measurement data to evaluate the performance of the proposed approach; the cumulative distribution function (CDF) criteria have been used to measure the quality of the estimated location compared to the ground truth location. The results indicated that the indoor positioning accuracy is enhanced obviously with the help of the piecewise fitting correction technique. Simultaneously, the Lora indoor positioning system can achieve a positioning accuracy of 1m under the condition of the line of sight (LOS).

B. *Enhanced Positioning in LTE-M*

Since Release 9, In OTDOA, LTE PRS is a well-established signal for TOA measurement. The design of PRS signals is the main topic to enhance OTDOA support of LTE-M.

i. PRS SEQUENCE AND MAPPING TO RESOURCE ELEMENTS

The PRS sequence of LTE is a pseudo-random Quadrature Phase Shift Keying (QPSK) sequence as defined in [18], and LTE-M uses the same PRS sequence. This PRS sequence changes as the changes occur in slot index, physical cell identity, and an OFDM symbol index. Generation of a PRS sequence can be done by giving the above initialization parameters. Then the elements from the PRS sequence are mapped to resource elements determined by physical cell identity. Every resource block in LTE has 12 subcarriers, and if the PRS uses an OFDM symbol, only two of the 12 subcarriers will be used by PRS. Six orthogonal PRS mappings can be made by shifting the frequency mapping. By generating and mapping sequences repeatedly, PRS sequences are generated, which change with time, and each sequence is mapped to corresponding resource elements. Out of the OFDM symbols in a subframe, the first three will be used by LTE L1/L2 signals, and LTE Cell-specific Reference Signal (CRS) uses other frames which PRS does not use. The LTE PRS resource blocks can be 6,15,25,50,75, or 100, and these LTE PRS signals are mapped with the carrier's resource blocks. The low bandwidth LTE-M UE can receive only a 6-PRB wide signal, and frequency hopping can compensate for the loss because of reduced bandwidths. Every cell will configure 2 or 4 distinct places in the range of wideband LTE carrier, where the first location is fixed at the middle and PRS transmission cycles through these 2 or 4 frequency bands where each frequency hopping band will have 6 PRBS.

ii. PRS SUBFRAME CONFIGURATION

Periodically, with a period TPRS of 160,320,640 or 1280 subframes, the positioning occasions occur with 1,2,4 or 6 consecutive subframes where LTE PRS signals are transmitted.

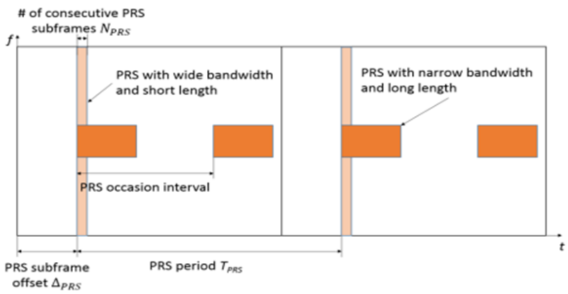

Figure 6: Positioning reference signals subframe configuration

The PRS transmission schedule is illustrated in Figure 6. The existing LTE PRS limits the performance of positioning of wideband LTE UEs that can receive a wider PRS. So to ensure good performance, multiple PRS transmissions are configured in a cell where every transmission and configuration is customized to a distinct type of device. Then LTE UE can receive the shorter wideband PRS transmission, and LTE-M can receive longer PRS transmission, which reduces PRS resource overhead. Since the LTE-M addresses are used in challenging environments, it is essential to instigate denser PRS transmissions, which can be achieved by raising the number of consecutive subframes per position occasion or lowering the periodicity of positioning occasion. The number of subframes per position occasion has been extended to {1, 2, 4, 6, 10, 20, 40, 80, 160} subframes to support denser PRS transmission schedule, and there can be 10,20,40 or 80 subframes in a PRS period positioning occasion interval. In figure-3, we can see two 2 PRS transmissions with the same subframe offset and period are scheduled, where one PRS transmission is configured for LTE UE with wide bandwidth and short PRS length, and another PRS transmission is configured for LTE-M UE with narrow bandwidth and long PRS length. The schedules of two PRS transmissions may overlap in frequency and time, facilitating the PRS signals sharing between LTE UE and LTE-M UE [8].

iii. PRS MUTING

In LTE OTDOA, PRS in the strong cell will be muted to enable better detectability of weak cell PRS, which shares the same frequency shift with strong cell PRS, and this is called PRS muting. A bit string of 2, 4, 8, or 16 bits specifies LTE PRS muting pattern, and all the PRS subframes in a PRS positioning occasion are either ON or OFF based on this bit string. The PRS muting will help reduce interference but increase the time-to-fix of positioning. LTE PRS muting mechanism is heavily used in LTE-M OTDOA. To ease the coordination of muting PRS signals of different UE types, the maximum bit string length of LTE-M PRS signals will be 1024 bits, resulting in extensive LPP assistance data overhead. To overcome this, each muting bit is applied to every PRS positioning occasion in a legacy PRS period where the bit string length does not change [8].

C. Enhanced Positioning in NB-IoT

The PRS signals design is the main topic to enhance OTDOA support for NB-IoT. PRS in NB-IoT is referred to as NPRS (Narrowband Positioning Reference Signal).

i. NPRS Subframe Configuration

NPRS Frequency hopping is not present in NB-IoT carriers, and each of them can have different parameters. NPRS can be configured by the network using Part A or Part B, or both.

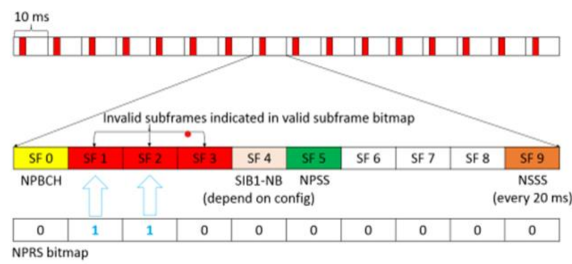

Figure 7: Narrowband positioning reference signals subframe configuration with Part A

Part A: It uses a bitmap of length, either 10 or 40 bits in NPRS Positioning occasion, to indicate NPRS subframes, and the value of each bit indicates the NPRS presence in the corresponding subframe. To allow networks to reserve some subframes, the valid subframe bitmap configuration was introduced in version 13. In NB-IoT UEs, the invalid set of subframes are not used for transmission. The NPRS bitmap length is considered as the NPRS positioning occasions period, and every NPRS period can be regarded as a positioning occasion, while the NPRS bitmap indicates the subframes used for NPRS. By this, we can infer that the NPRS subframes need not be consecutive in a positioning occasion. Figure 7 illustrates a Narrowband positioning reference signals subframe configuration with Part A, where the valid subframe configuration bitmap is 10 bits long with 1,2 and 3 subframes marked as invalid subframes. The bitmap of NPRS is also 10 bits long and indicates that subframes 1 and 2 contain NPRS signals that are invalid.

Part B: Like LTE PRS, this configuration mechanism specifies the NPRS subframe offset, periodicity, and number of consecutive NPRS subframes in a positioning occasion. The NPRS occasion periodicity is chosen from the subframes set {160, 320, 640, 1280}, where the NPRS subframe offset size is limited to lower the LPP assistance data transfer overhead. The NPRS subframe offset is a*TPRS, where a ∈ {0, 1/8, 2/8, 3/8, 4/8, 5/8, 6/8, 7/8} for a given periodicity TPRS of positioning occasions and number of consecutive NPRS subframes is selected from the {10, 20, 40, 80, 160, 320, 640, 1280} subframes set thereby making the successive NPRS transmission much longer in a positioning occasion. To address the coverage for deployments in challenging environments and compensate for the reduced bandwidth of NPRS, we need this long NPRS transmission [8].

ii. NPRS Sequence and Mapping to Resource Elements

NPRS resource element mapping depends on the configuration of NPRS subframes where the NB-IoT carrier is deployed inside an LTE carrier.

- NPRS signals are mapped to all NPRS subframe OFDM symbols except the first 3 OFDM symbols and other OFDM symbols used by CRS if the NPRS subframes are configured with part-A or both part-A and part-B.
- NPRS signals are mapped to all NPRS subframe OFDM symbols just like configurations involving part-A, except with the last two OFDM symbols in each slot are not mapped if the NPRS subframes are configured with Part-B only.

NPRS sequence also uses LTE PRS sequence, i.e., a pseudorandom QPSK sequence. LTE PRS sequence is long with two elements mapped on one resource block, can be used in an LTE carrier with a maximum bandwidth of 100 resource blocks. As the NB-IoT carrier system bandwidth is only 180 kHz, one resource block with a length-2 sequence is sufficient for NPRS. The central two elements of the LTE PRS sequence are used as NPRS sequences in standalone or guard band deployment. In a wideband LTE carrier, In band NB-IoT carriers can be placed in different positions [8].

iii. NPRS Muting

NPRS muting enables the efficient detectability of the PRS from the weak entity, which shares the same frequency shift with strong cell PRS. A bit string of 2,4, 8, or 16 bits is used to specify NPRS muting. On every NB-IoT carrier, one muting pattern associated with Part-A (if configured) is signalled, and one muting pattern associated with Part-B (if configured) is signalled. A bit in the muting pattern of part-A indicates whether the NPRS signals in 10 consecutive subframes are muted or not. In contrast, Part-B indicates whether the NPRS signals in a positioning occasion are muted or not. A subframe configured with Part-A and Part-B contains NPRS if the configuration of both parts suggests that the subframe includes NPRS, and it is muted if either Part-A or Part-B mutes it [8].

VII. Conclusion

Positioning is crucial for many IoT applications. In this literature review, we provided an overview of how positioning can be enhanced for LoRa, LTE-M and NB-IoT. The enhanced positioning support will further improve the market impact of these IoT technologies. We expect research in enhancing the positioning will gain much more attention soon since the implementation of IoT systems involves the networking of LoRa and an end-to-end system development up to the application layer, involving LoRa as one of the significant networking elements in the IoT ecosystem. Also, massive LTE-M and NB-IoT devices are expected to have a long life cycle that may go beyond network evolution toward 5G. It will be advantageous that future 5G positioning would be designed to have some collaborations with the LTE-M and/or NB-IoT positioning.

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