GTI IoT Wireless Solution White Paper

IoT Wireless Solution

WHITE PAPER

Global TD-LTE Initiative

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Contents

Executive summary

The Internet of Things(IoT) and its potential impact on the mobile industry is creating a slew of industry predictions and companies seeking to capitalise on what in now generally referred to as the 4th industrial revolution. 3GPP IoT technologies eMTC and NB-IoT are becoming the global dominant technologies that are set to enable the huge market growth discussed over the past few years.

eMTC and NB-IoT have multiple advantages, which like wide area ubiquitous coverage, fast upgrade of existing network, low-power consumption guaranteeing 10 year battery life, high coupling, low cost terminal, plug and play, high reliability and high carrier-class network security, unified business platform management. Initial network investment may be quite substantial and superimposed costs are very little. NB-IoT perfectly matches LPWA market requirements, enabling operators to enter this new field.

The early interest in IoT has developed into industry initiatives in area like connected and autonomous vehicles, connected or smart homes, smart cities and smart energy, linked to the expansion of the ecosystem. 2017 is a year for IoT technology to develop vigorously, which will fundamentally change the way people and things interact in the future. The largest segments for IoT are consumer electronics, automotive and healthcare.

Terminology and Abbreviation

Term	Description
MTC	Machine-Type Communications
MPDCCH	MTC Physical Downlink Control Channel
NPBCH	Narrowband Physical Broadcast Channel
NPDCCH	Narrowband Physical Downlink Control Channel
NPDSCH	Narrowband Physical Downlink Shared Channel
NPRACH	Narrowband Physical Random Access Channel
NPUSCH	Narrowband Physical Uplink Shared Channel
NPSS	Narrowband Primary Synchronization Signal
NSSS	Narrowband Secondary Synchronization Signal
LPP	Location and Positioning Protocol
RAI	Release Assistance Information
OTDOA	Observed Time Difference of Arrival
SC-PTM	Single Cell-Point to Multi-point
TBS	transport block sizes
HARQ	Hybrid Automatic Repeat request
SC-MTCH	Single Cell-Multi Transport Channel
LPWAN	Low-Power Wide-Area Network
LoRa	Long Range
RPMA	Random Phase Multiple Access
IoT	Internet of Things
NB-IoT	Narrowband-Internet of Things
MCL	Maximum Coupling Loss
RB	Resource block
SIB	System Information Block
SEM	Spectrum Emission Mask
EVM	Error Vector Magnitude
RF	Radio Frequency
UL	Up link
DL	Down Link
OFDMA	Orthogonal Frequency Division Multiplexing
SC-FDMA	Single-carrier Frequency-Division Multiple Access
RRU	Radio Remote Unit
SDR	Software-defined radio

Term	Description
eMTC	enhanced machine type communication
BS	Base Station
EPC	Evolved Packet Core
A-GNSS	Assisted-Global Navigation Satellite System
AGPS	Assisted Global Position System
E-CID	Enhanced Cell-ID
eMTC	enhanced Machine Type Communication
E-SMLC	Evolved Serving Mobile Location Center
GDOP	Geometric Dilution of Precision
GIS	Geographic Information System
GMLC	Gateway Mobile Location Center
GNSS	Global Navigation Satellite System
GPS	Global Position System
LCS	LoCation Services
LPP	LTE Positioning Protocol
LPPa	LTE Positioning Protocol Annex
LPWA	Low Power Wide Area
LwM2M	Lightweight Machine to Machine
M2M	Machine to Machine
MDT	Minimization of Drive Tests
MO-LR	Mobile Originated Location Request
MR	Measurement Report
MT-LR	Mobile Terminated Location Request
NI-LR	Network Induced Location Request
NPRS	Narrowband Positioning Reference Signal
NRSRP	Narrowband Referenced Signal Received Power
NRSRQ	Narrowband Reference Signal Received Quality
OTDOA	Observed Time Difference of Arrival
PNLBS	Positioning, Navigation and Location Based Services
PRACH	Physical Random Access Channel
PRS	Positioning Reference Signal
RFPM	Radio Frequency Pattern Matching
RSRP	Referenced Signal Received Power

1. Introduction

IoT technology has become the most popular technology at present, and it will have a profound impact on the future.There are predicted to be between 30 and 50 billion IoT end-points by 2020 driving a total IoT market of up to $8.9 trillion1, which will fundamentally change the way people and things interact. The largest segments for IoT are consumer electronics, automotive and healthcare. This digitalisation of industry will see sectors such as energy, industrial, agriculture and construction adopt the latest mobile technologies.

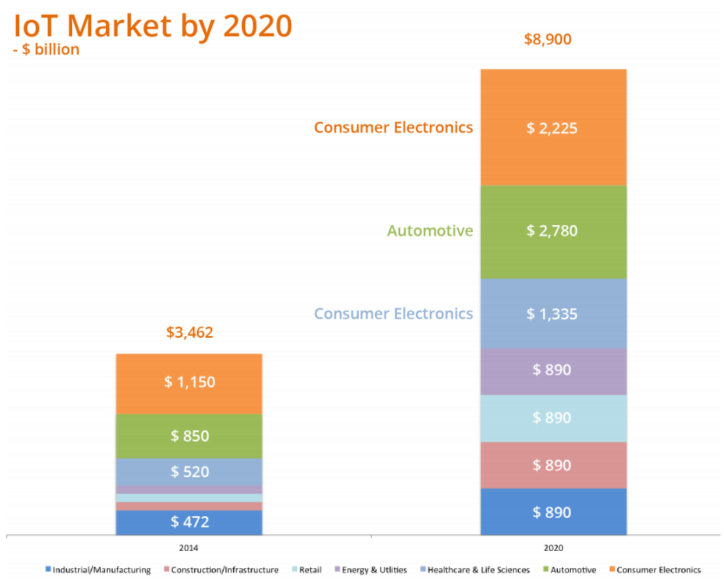


Figure 1 IoT Market By 2020

eMTC and NB-IoT are the most mainstream technologies of IoT. With the gradual opening of the market, the Internet of things will become the new blue ocean of operators, helping operators to create new growth points of revenue.

This white paper covers:

- Introduction of eMTC technology and future evolvement
- Introduction of NB-IoT technology and future evolvement
- LPWA Wireless Solution Analysis
- IoT Network Architectures and Solutions, concluding Deployment Strategy, Network Planning and Optimization and IoT Small Cells.

2. IoT Standardization and Function

2.1. Cellular IoT Standardization and Function

2.1.1. eMTC

2.1.1.1. eMTC Standardization Background

The provision of Machine-Type Communications (MTC) via cellular networks is proving to be a significant opportunity for new revenue generation for mobile operators [1]. The Rel-12 work item "Low cost & enhanced coverage MTC UE for LTE" specified a low complexity LTE device for MTC with Bill of Material cost approaching that of an EGPRS modem using a combination of complexity reduction techniques. However, results from the study item documented in TR 36.888 [2] indicated that further complexity reduction of LTE devices for MTC can be achieved if additional complexity reduction techniques are supported.

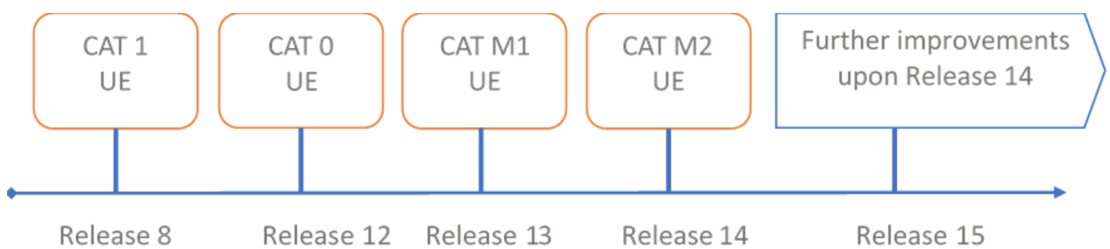


Figure 2 Evolution of MTC for LTE in 3GPP

In addition, the study report TR 36.888 concluded that a coverage improvement target of 15-20 dB for both FDD and TDD in comparison to normal LTE footprint could be achieved to support the use cases where MTC devices are deployed in challenging locations, e.g. deep inside buildings, and to compensate for gain loss caused by complexity reduction techniques. The Rel-12 work item "Low cost & enhanced coverage MTC UE for LTE" also made significant progress towards specifying solutions for enhanced coverage but due to time limitations this was removed from the Rel-12 scope. Instead, RAN#63 endorsed a way forward (RP-140512) to continue MTC Coverage enhancements in Rel-13.

Continuing the normative work started in Release 12 to specify key physical layer and RF enablers to enhance LTE's suitability for the promising IoT market, the key focus for Release 13 is to define a new low complexity UE category type that supports reduced bandwidth, reduced transmit power, reduced support for downlink transmission modes, ultra-long battery life via power consumption reduction techniques and extended coverage operation.

The objective of Release 14 is to make further enhancement of eMTC, which has been carried out into aspects as: Positioning, Multicast, Mobility enhancement, Higher data rates and VoLTE enhancement. A new category of eMTC terminal has been introduced, dubbed as Cat.M2, which can support larger maximum TBS and wider bandwidth.

Release 15 will build some improvements upon enhancements from Release 14, such as: latency, power consumption, spectral efficiency and load control.

2.1.1.2. Principles of eMTC

2.1.1.2.1. Comparison of eMTC&LTE

The physical layer of eMTC is designed based on LTE physical layer. The two tables below show the comparisons of eMTC physical channels and LTE physical channels in uplink and in downlink respectively.

In downlink, CRS\PSS\SSS is shared by LTE and eMTC. eMTC does not use PCFICH and PHICH. PBCH is also shared by eMTC and LTE, but more repetition is made for eMTC. eMTC does not use PDCCH or EPDCCH.MPDCCH is the downlink control channels of eMTC. MPDCCH is designed based on EPDCCH but repetition allowed. eMTC also use PDSCH to transfer downlink traffic, paging and SI. But eMTC PDSCH can use repetition and is scheduled via MPDCCH across different subframe.

Table 1 Comparison of eMTC and LTE in downlink physical channels

	eMTC	LTE
PSS\SSS	Primary Synchronization Signal/Supplementary Synchronization Signal has no change with LTE.	
CRS	Cell Reference Signal has no change with LTE.	
PCFICH	There is no PCFICH for eMTC.	
PHICH	There is no PHICH for eMTC.	
PBCH	• 40ms in period, transmission on subframe 0#, and repetition on subframe 0# and 9# • Compatible with legacy LTE PBCH	• Subframe 0# of 10ms radio frame, 40ms period • Seventy-two sub-carriers occupied in the middle of the bandwidth.
PDCCH	• MPDCCH: based on R11 EPDCCH • Supports transmission repetition	• PDCCH R8 • EPDCCH R11
PDSCH	• Supports transmission repetition • Mode A: QPSK/16QAM • Mode B: QPSK • TM1/TM2/TM6/TM9 • Scheduled across the subframe	• QPSK/16QAM/64QAM • TM1/TM2/TM3… • Scheduled in the subframe

In uplink, eMTC also use PUSCH to transfer uplink traffic. But eMTC PUSCH can use repetition and is scheduled via MPDCCH. PUCCH is used for eMTC ACK/NACK, SR and CQI via format 1/1a/2/2a. eMTC PRACH's format selection is same with LTE RPACH's. But eMTC PRACH resource can be divided at most 4 Coverage Enhancement Levels.

Table 2 Comparison of eMTC and LTE in uplink physical channels

	eMTC	LTE
PUSCH	• Mode A: QPSK,16QAM • Mode B: QPSK • Transmission repetition supported (1~32 for mode A,1~2048 for Mode B) • Frequency hopping	• QPSK, 16QAM and 64QAM • Frequency hopping Type1 • Frequency hopping Type2
PUCCH	• Mode A supports PUCCH 1&2. • Mode B doesn't support PUCCH 2. • Transmission repetition supported	• PUCCH 1/1a/1b • PUCCH 2/2a/2b • PUCCH 3…
PRACH	• 6 PRB, Format 0,1,2,3 • Time slots are configured according to PRACH configuration index • At most four groups of PRACH parameters according to different CE levels. • Supports transmission repetition. • Supports periodic configuration.	• 6 PRB, Format 0,1,2,3 • Time slots are configured according to PRACH configuration index
SRS	• Periodic and non-periodic SRS are supported by Mode A. • SRS is not supported by Mode B. • Follows Rel 12 SRS configuration.	• Periodic and non-periodic SRS are supported. • Last symbol of the subframe
DMRS	• Almost the same as LTE • Little difference in Cyclic Shift of PUSCH DMRS	• DMRS for PUCCH • DMRS for PUSCH

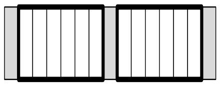
2.1.1.2.2. Narrowband configuration

For the purpose of merge into the existing LTE system network, a unique way of resource allocation had been invented.

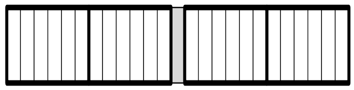
Defining 6PRB as a resource unit, named as "narrowband" [3], configured as the resource pool allocated for eMTC terminals. And the PRBs not be used by eMTC terminals could be used by legacy LTE terminals.

For certain bandwidth, certain narrowband configuration has been predefined, as below:

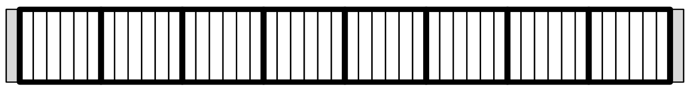
3MHz/15PRB：



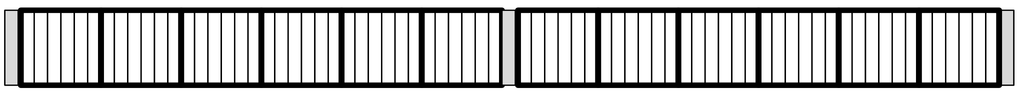
5MHz/25PRB：



10MHz/50PRB：



15MHz/75PRB：



20MHz/100PRB：

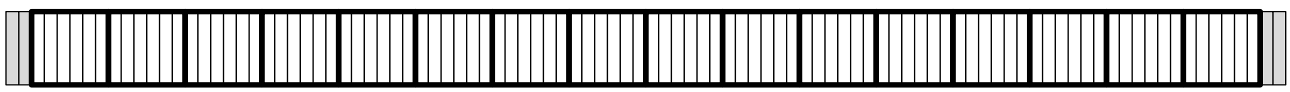


Figure 3 Narrow Band Configuration in Different System Bandwidth

2.1.1.2.3. PBCH

To reach the coverage enhancement of eMTC, repetition is applied for PBCH. In a 40ms PBCH period, slot 1# in subframe 0, slot 18# and slot 19# in subframe 10 of each radio frame is to transmit the same encoding of MIB. These repetitions are only identified by eMTC terminals.

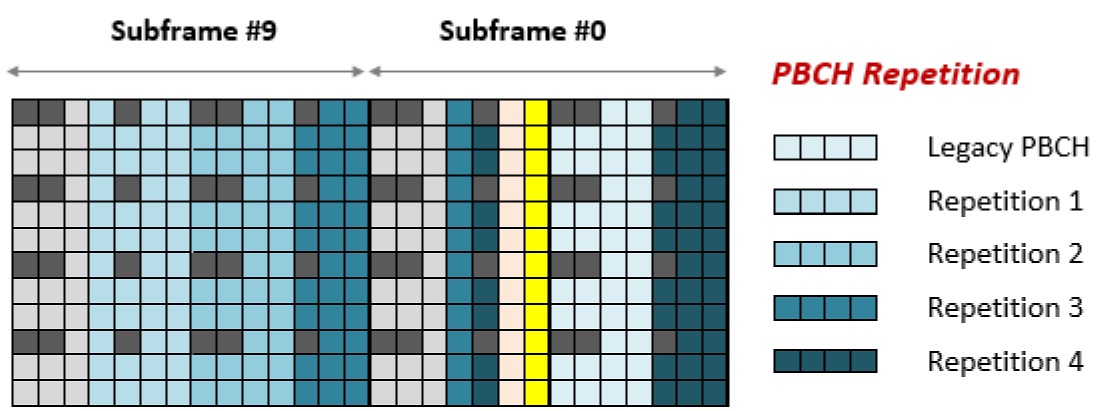


Figure 4 PBCH Repetition for eMTC

2.1.1.2.4. MPDCCH

Because eMTC terminal do no has the ability to access PDCCH, MPDCCH was developed for eMTC terminal.

MPDCCH is an expand of EPDCCH, which can share with PDSCH of RPB resource , that means MPDCCH could be allocate into narrowband. Thus eMTC terminal could find control message within narrowband.

2.1.1.2.5. Coverage Enhancement

There were scenarios for eMTC terminals to be deployed under stringent pathloss circumstances. Therefore coverage enhancement with respect to legacy LTE system network will be necessary in some scenarios.

The direct approach to enhance coverage ability of eMTC terminal is repetition, also with frequency hopping and inter-sub-frame channel estimation as subsidy.

Table 3 Repetition and Hopping of eMTC Physical Channels

	Repetition	**Frequency hopping**	**Inter-sub-frame channel estimation**
PBCH	8	n	N
SIB1	16	y	N
PRACH	128	y	N
MPDCCH	256	y	Y
PDSCH	2048	y	Y
PUSCH	2048	y	Y
PUCCH	32	y	Always support, no need to configuration

Based on the times of repetition, mode A and mode B has been defined to configure the working mode of eMTC terminal.

Furthermore, mode A can be divided into CEL0 and CEL1, with the maximum repetition time of 32 in the case of PUSCH and PDSCH.

Same way goes to mode B, CEL2 and CEL3, with the maximum repetition time of 2048 in the case of PUSCH and PDSCH.

2.1.1.2.6. MIB

MIB is carried on PBCH. As describe on chapter 5.1.1.2.3, for eMTC terminals, more slots are used to transmission the repetition of MIB. If a LTE cell has the capability to access eMTC terminals, the scheduling information of SIB1-BR should be included in MIB. So the eMTC terminals know whether the cell has the eMTC capability. If no scheduling information of SIB1-BR, eMTC terminals should not camp on the cell and search another cell.

2.1.1.2.7. SI-BR

For the purpose of mapping eMTC terminals into narrowband, certain set of system information elements were defined [4], which were transparent to legacy LTE terminals, but significant to eMTC terminals.

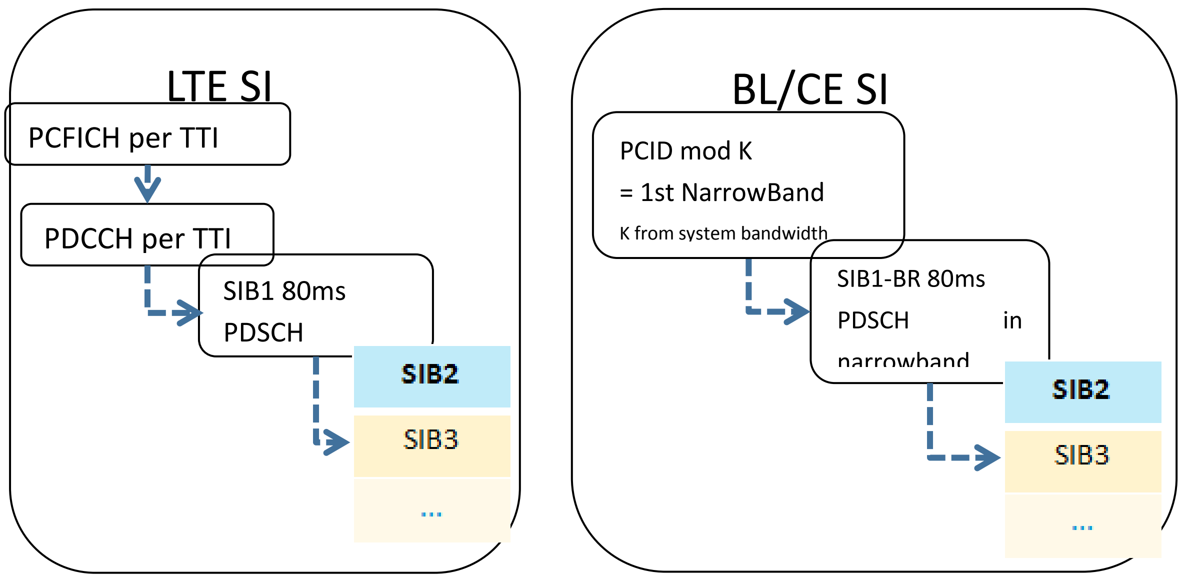


Figure 5 Scheduling of LTE SI and eMTC SI Respectively

Legacy LTE terminal need to get from CFI to find out how and where the the PDCCHs were mapped into the sub-frames. According to the information in PDCCH, SIB1 could be targeted, SIB2 and other SIBs will follow.

Enhanced-MTC terminal mapped into narrowband could not receive PDCCH, but could locate the first position of narrowband by calculate “k” and PCID. “k” can be made out from system bandwidth which can be achieved from MIB in PBCH. PCID can be achieved from PSS/SSS.

Thus eMTC terminal could locate SIB1-BR, then with the information in SIB2 to initiate random access process.

2.1.1.2.8. Comparison of eMTC TDD & FDD

eMTC FDD has two Duplex mode, Full-Duplex and Half-Duplex. HD is similar to TDD， so the comparison in this chapter is based upon e-MTC FDD HD and e-MTC TDD.

2.1.1.2.8.1. Special sub-frame

Special sub-frame is a unique feature of eMTC TDD, in which UpPTS can be allocated for SRS, DwPTS for traffic channels.

2.1.1.2.8.2. Frequency deployment

eMTC FDD usually share carrier with LTE FDD.

eMTC TDD usually share carrier with LTE TDD.

2.1.1.2.8.3. Multi-antenna scheme

eMTC FDD usually co-exist with LTE FDD, and share antenna with LTE FDD, mainly 2 or 4 antennas.

eMTC TDD usually co-exist with LTE TDD, and share antenna with LTE TDD, mainly 8 antennas in China Mobile network.

2.1.1.2.8.4. Scheduling and peak rate

Because eMTC FDD doesn’t equipped with HARQ-ACK bundling, and facilitated with fewer HARQ processes than eMTC TDD, so the peak rate of eMTC FDD is lower than eMTC TDD.

A roughly estimated scheduling peak rate listed as below.

Table 4 Peak Rate of A Single eMTC Terminal

		PDSCH rate	**PUSCH rate**
FDD	Half duplex MODE A	300 kbps	375 kbps
	MODE B	187.2 kbps	234 kbps
TDD（2, 7）	MODE A	800kpbs	200kbps
	MODE B	187.2kpbs	187.2kbps

2.1.1.3. Future Evolvement of Emtc

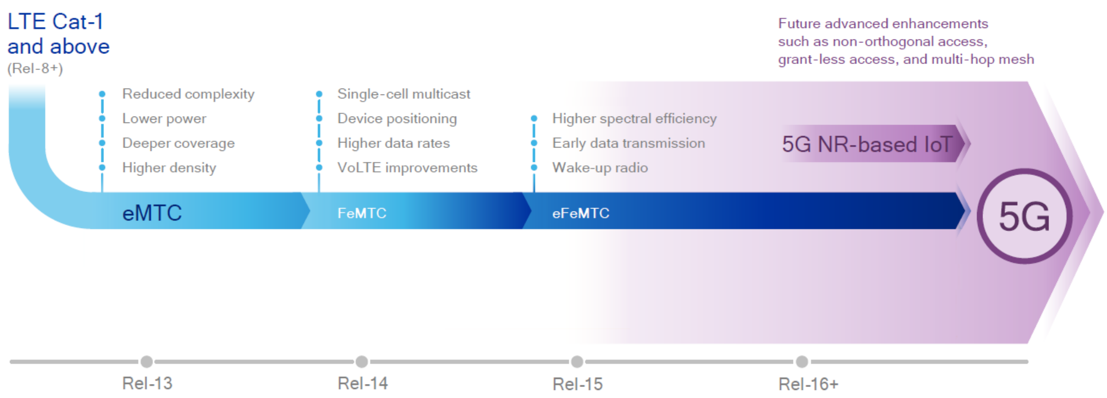


Figure 6 eMTC 3GPP functionality evaluation

In 3GPP releases 14 and 15 further enhancements are currently being developed to improve battery life, message latency, and other aspects of performance, which will make it possible to meet the requirements with more system configurations.

Release 14 introduces Release Assistance Information (RAI) which allows the device to request it be released from the connected state after it has completed all its communications. This reduces the time the device spends in the connected state and thereby reduces power consumption. In addition to this battery-life improvement, Release 14 features also include increased data throughput, a new 5-MHz category-M2 device, multicast support, positioning enhancements, voice optimizations, and improved mobility support. For a full description of the LTE-M features introduced in Release 14, see the work item summary in [5].

Release 15 enhancements for LTE-M are ongoing and expected to be completed by June 2018 [6]. Key objectives for this release include improving latency, spectral efficiency, and power consumption. To improve latency, potential enhancements include reducing system acquisition time (e.g. by improving cell search or system information acquisition performance) and supporting early data transmission (i.e. data transmission already during the random access procedure). The spectral efficiency, and hence the system capacity, is improved in the downlink by the introduction of higher-order modulation (64QAM) and in the uplink by the introduction of finer-granularity (sub-PRB) resource allocation. To reduce power consumption, potential enhancements include introducing the already mentioned early data transmission and sub-PRB resource allocation as well as wake-up signals, new synchronization signals, improved HARQ feedback, and relaxed measurements for cell reselection.

Supporting the features introduced in Releases 14 and 15 is optional for both the device and the network. All UEs and networks are fully backward compatible with Release 13, meaning that the new features can be introduced gradually.

2.1.2. **NB-IoT**

2.1.2.1. NB-IoT Standardization Background

To meet the requirement of low cost, low power consumption, coverage enhancement and large capacity requirement of IoT, NB-IoT WI (RP-151621) was approved in RAN #69 meeting. NB-IoT WI was related to RAN1 /RAN2 /RAN3 /RAN4 WGs in 3GPP. Rel-13 NB-IoT RAN1, RAN2, RAN3 and RAN4 core part related specifications were frozen in June of 2016. RAN4 performance and BS conformance test part were completed in November of 2016. The complete NB-IoT specs were published in February of 2017.

2.1.2.2. Principles of NB-IoT

2.1.2.2.1. NB-IoT deployment modes

Similar to LTE system, OFDMA is used in downlink of NB-IoT system while SC-FDMA is applied in uplink of NB-IoT system. Three operation modes: in-band, guard-band and standalone operation modes are used for different deployment scenarios, as below. In downlink, only 15 kHz subcarrier spacing is supported in NB-IoT.

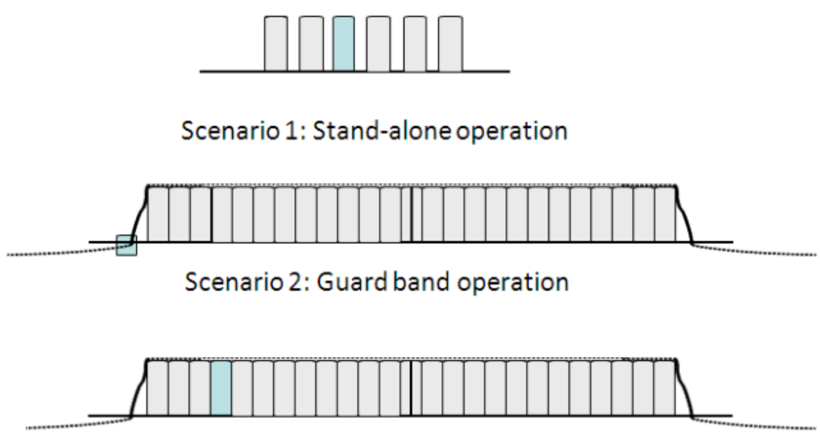


Figure 7 operation mode

2.1.2.2.2. NB-IoT downlink

2.1.2.2.2.1. Downlink slot structure and resource elements

Definition of downlink slot structure, downlink resource element, downlink resource grid in legacy LTE system are reused for NB-IoT. For NB-IoT, each downlink slot only includes 12 sub-carriers. The downlink resource structure for in-band operation mode is shown in Figure 8. Similar structure is used for standalone and guard-band operation modes, the only difference is there has no LTE CRS and PDCCH region for standalone and guard-band operation modes.

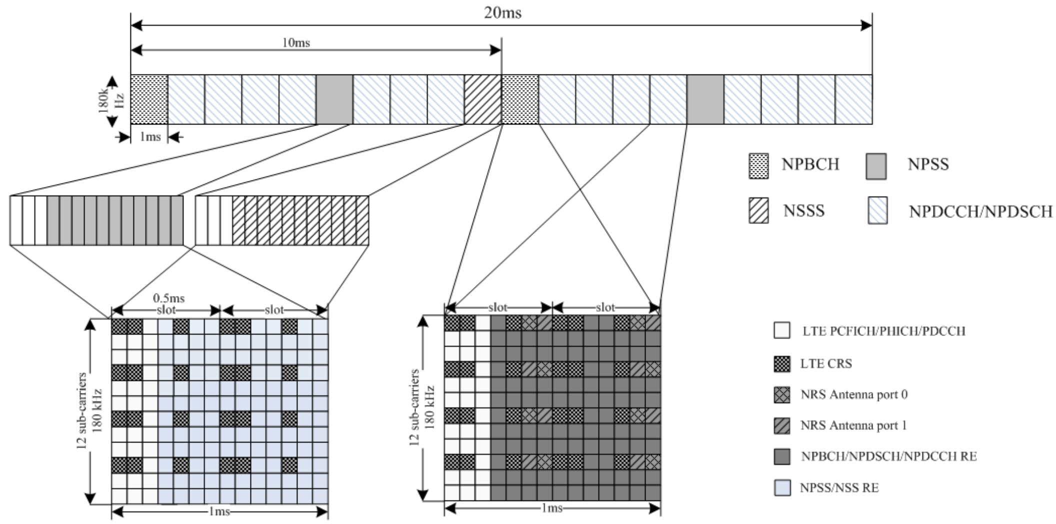


Figure 8 NB-IoT downlink slot structure

2.1.2.2.2.2. NPSS and NSSS

The time and frequency location of NPSS/NSSS is shown in Figure 9, where NPSS occupies 11 sub-carriers while NSS occupies 12 subcarrier in frequency domain. NPSS is transmitted every 10ms while NSSS is transmitted every 20ms. The NPSS sequence length is 11 which is composed of ZC sequence and cover code sequence. NSSS sequence length is 131 which is composed of ZC sequence and Hadamard sequence.

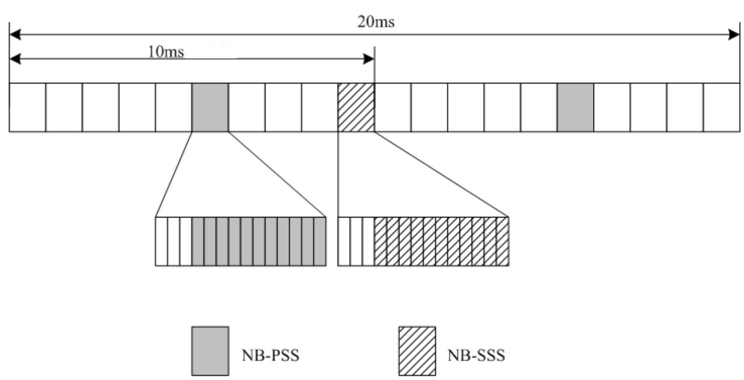


Figure 9 NPSS and NSSS

2.1.2.2.2.3. NPBCH

NPBCH structure is shown in Figure 10. NPBCH is transmitted in subframe #0 of every radio frame with the transmission period of 640ms. In subframe #0, NPBCH is transmitted in all other OFDM symbols except for the first three OFDM symbols.

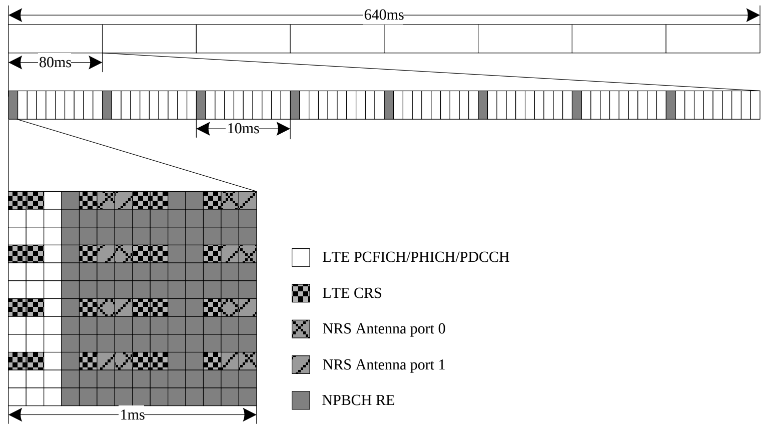


Figure 10 NPBCH structure

2.1.2.2.2.4. SIB

The scheduling of SIB1 in NB-IoT is similar to that of eMTC. The system bandwidth of SIB1-NB is one PRB. The period and number of SIB-NB repetition are shown in Figure 11.

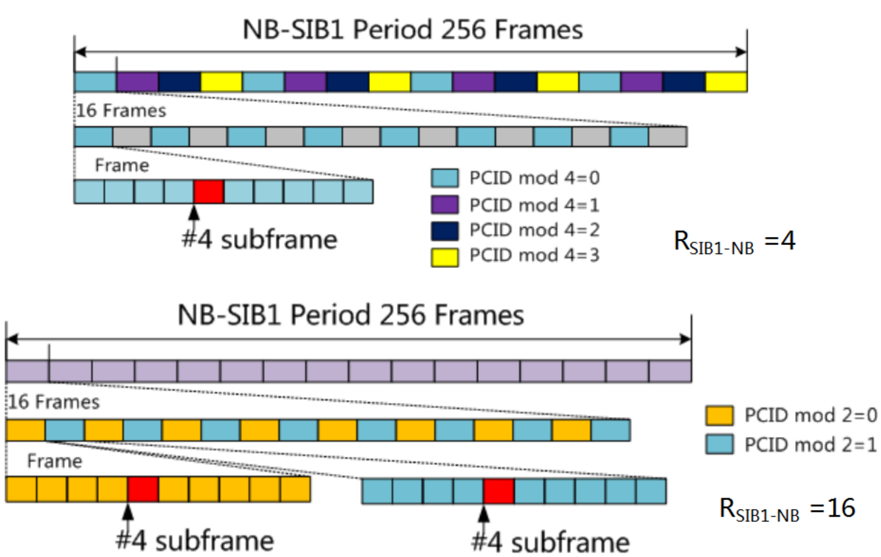


Figure 11 SIB1 structure

2.1.2.2.2.5. NPDCCH

The control channel element of NPDCCH (NCCE) is half PRB pair. Specifically, Two NCCEs are defined in one PRB pair. NCCE #0 is composed of subcarriers with index #0-5 and NCCE #1 is composed of subcarriers with index #6-1 as shown in Figure 12.

The starting symbol for NPDCCH is the first OFDM symbol in guard-band and standalone operation modes. For in-band operation mode, the starting symbol for NPDCCH transmission is indicated in SIB1-NB.

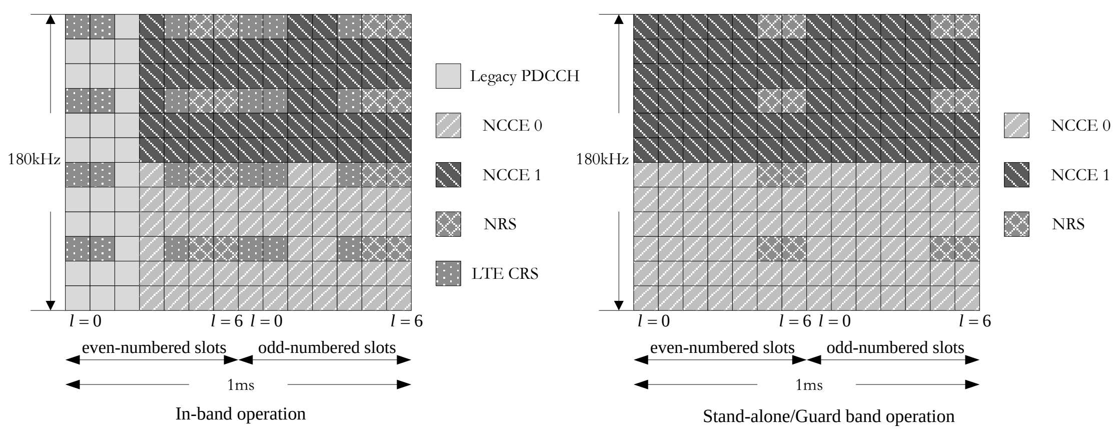


Figure 12 NB-CCE structure

2.1.2.2.2.6. NRS and downlink transmission mode

Downlink reference signal in NB-IoT (NRS) is similar to CRS in LTE. NRS also supports single port and two ports. The NRS pattern is shown in Figure 13. Single port and two-port SFBC diversity transmission are supported in NB-IoT.

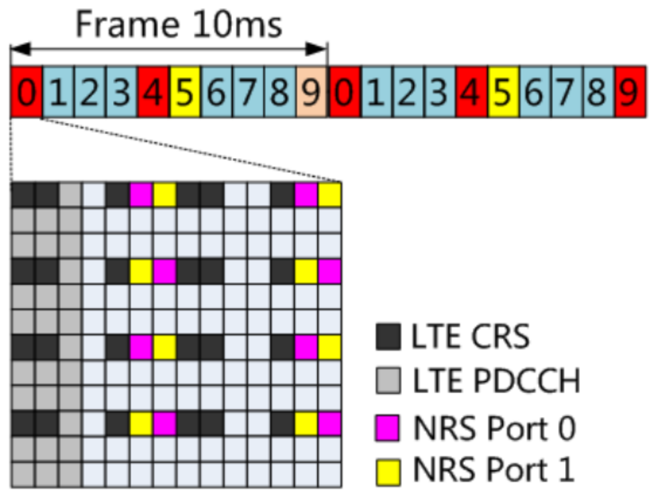


Figure 13 NRS pattern

2.1.2.2.3. NB-IoT uplink

2.1.2.2.3.1. Uplink slot and resource element

For 15 kHz subcarrier spacing, the NB-IoT uplink slot structure is same as legacy LTE. The radio frame length in uplink is 10ms which includes 20 slots with length of 0.5ms.

Besides resource grid and resource element, definition of resource unit (RU) is introduced in NB-IoT uplink. Uplink data scheduling and HARQ-ACK transmission are based on the unit of RU.

The criterion of RU definition is to guarantee the number of valid resource element in a RU is same for RU with different number of sub-carriers. Meanwhile, the time domain length is power of 2 which can reduce the resource fragmentation for scheduling with different RUs. When subcarrier spacing is 3.75 kHz, only single tone transmission is supported. In this case, the RU only occupy one subcarrier in frequency domain and the time domain length is 32ms. The RUs defined in Rel-13 NB-IoT are shown in Figure 14.

- 12 subcarriers by 1ms
- 6 subcarriers by 2ms
- 3 subcarriers by 4ms
- 1 subcarriers by 8ms for 15kHz subcarrier spacing and 1 subcarrier by 32ms for 3.75 kHz subcarrier spacing

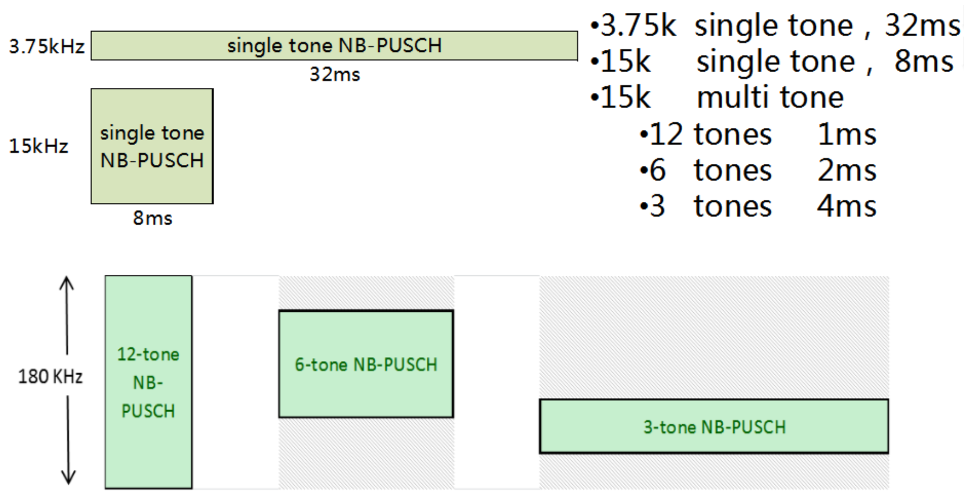


Figure 14 RU Structure

2.1.2.2.3.2. NPRACH

Preamble is transmitted by single tone with 3.75 kHz subcarrier spacing. NPRACH frequency hopping is supported by default. NPRACH Preamble is composed of 4 symbol groups, where each symbol group is composed of a CP and 5 OFDM symbols. As shown in Figure 15, the CP and symbols in each symbol group occupy the same subcarrier. Two-level frequency hopping gap is configured for the frequency hopping of 4 symbol groups. i.e., For hopping between 1st/2nd symbol group and 3rd/4th symbol group, the frequency hopping gap is equal to FH1= 3.75 kHz. For hopping between 2nd/3rd symbol group, the frequency hopping gap is equal to FH2 = 22.5 kHz.

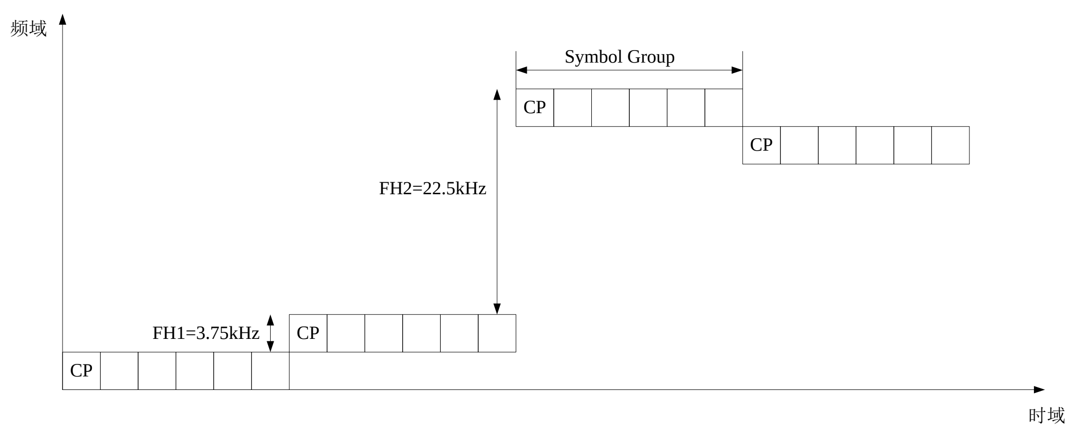


Figure 15 NPRACH 4 symbol groups structure

2.1.2.2.4. Comparison of FDD and TDD

TDD NB-IoT reuses the definition of subcarrier spacing, resource unit, and physical channel structure in FDD NB-IoT. TDD NB-IoT reuses the definition of TDD configuration and special subframe configuration in TDD LTE. In TDD NB-IoT, only TDD configuration 1, 2, 3, 4, 5 are supported. For 3.75 kHz subcarrier spacing, only TDD configuration 1 and 4 can be supported.

The major difference for TDD NB-IoT and FDD NB-IoT is the time domain location of NPBCH, SIB-NB and NPSS/NSSS. In TDD NB-IoT, SIB1-NB and other SIBs can be transmitted on non-anchor carrier.

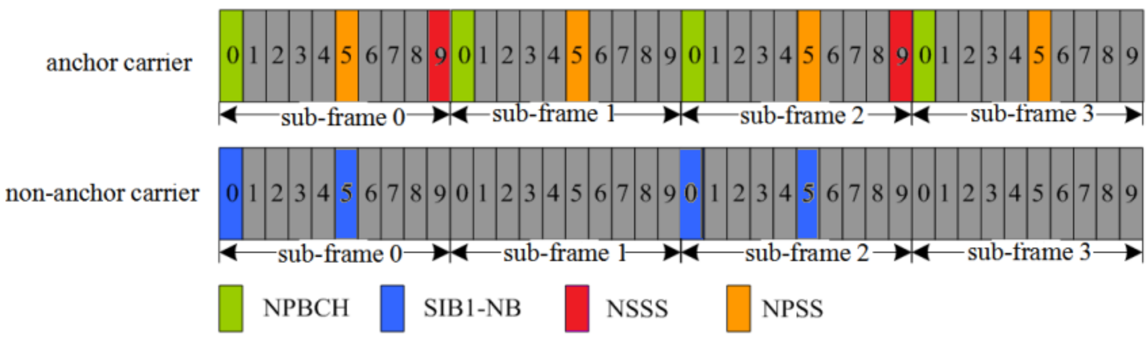


Figure 16 NPBCH, SIB-NB and NPSS/NSSS

Besides, 5 NPRACH formats are introduced in TDD NB-IoT as shown in Table 4 and Figure 17, 18

Table 5 TDD NPRACH format

Format	Description	G	P	N	CP length	Nominal cell size
0	Two symbol groups followed by a guard time fit into 1 UL subframe	2	4	1	4778 Ts (~155.5us)	~23.3km
1	Two symbol groups followed by a guard time fit into 2 UL subframes	2	4	2	8192 Ts (~266.7us)	~40.0km
2	Two symbol groups followed by a guard time fit into 3 UL subframes	2	4	4	8192 Ts (~266.7us)	~40.0km
0-a	Three symbol groups followed by a guard time fit into 1 UL subframe	3	6	1	1536 Ts (~49.95us)	~7.5km
1-a	Three symbol groups followed by a guard time fit into 2 UL subframes	3	6	2	3072 Ts (~99.9us)	~15.0km

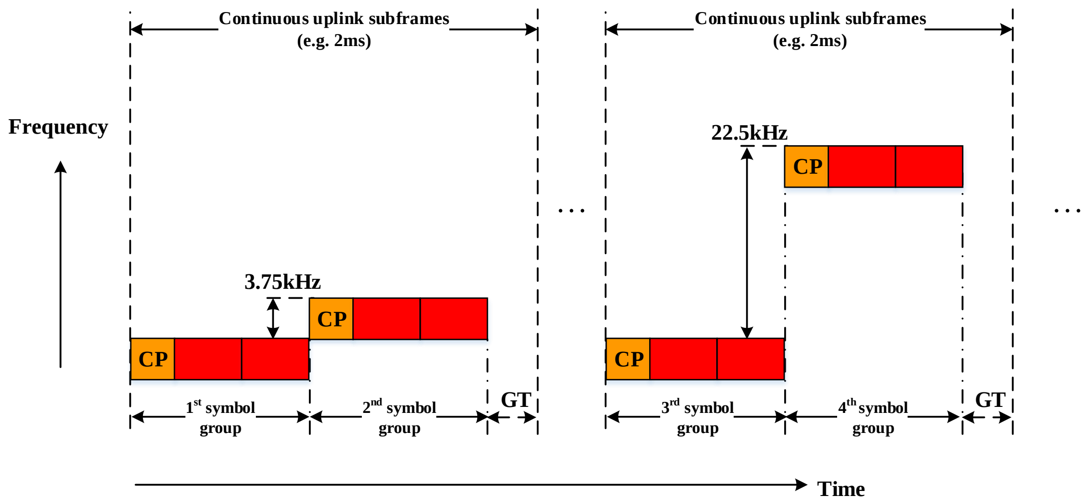


Figure 17 TDD NPRACH format 0, 1 and 2

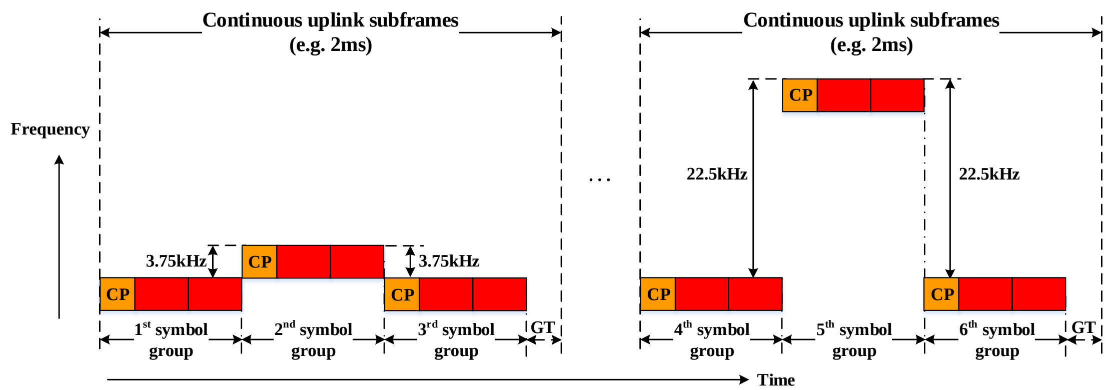


Figure 18 TDD NPRACH format 0-a and 1-a

2.1.2.3. Future Evolvement of NB-IoT

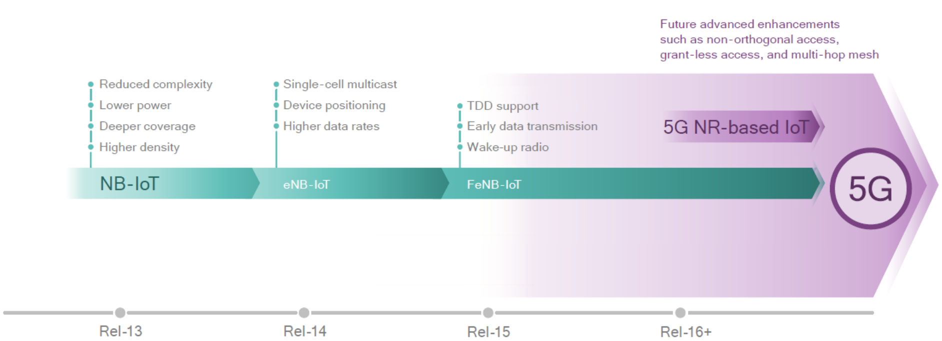


Figure 19 NB-IoT 3GPP functionality evaluation

Similar status with CAT-M1, in 3GPP release 14 and 15, further enhancements are being developed to improve positioning, mobility, latency and battery life.

Release 14 improves positioning. LPP (Location and Positioning Protocol) signalling is introduced as the positioning protocol for NB-IoT. The UE indicates its capability to perform OTDOA-, A-GNSS-, E-CID, terrestrial beacon service-, sensor-, WLAN-, and Bluetooth-based positioning. Of these, OTDOA and E-CID are specified in 3GPP. The UE indicates in the capability signalling when it requires idle mode to perform the measurements. Multicast also is introduced based on SC-PTM, with simplifications to suit the low complexity of an NB-IoT UE. Similar with LTE, SIB20-NB configures the transmission of the single SC-MCCH per cell which in turn configures up to 64 SC-MTCHs. The transmissions can be on anchor or non-anchor NB-IoT carriers. The modification and repetition periods of SC-MCCH are extended to account for the repetitions used for coverage extension on NPDCCH and NPDSCH. To enhance mobility, for the Control Plane CIoT EPS optimizations, RRC Connection Re-establishment and S1 eNB CP Relocation Indication procedures are introduced, to allow maintaining the S1 connection and retransmissions of the NAS PDUs by MME and UE NAS in case of radio rink failure. To reduce the time and UE power required to transfer larger messages in more favourable coverage, the range of transport block sizes (TBS) the NB-IoT UE can support is increased to 2536 bits on both DL and UL. This establishes a Category NB2 UE. The Cat NB2 UE may optionally have 2 HARQ processes for UL and DL. Furthermore, lower power UE class is introduced with a maximum transmit power of 14dBm. For a full description of the NB-IoT features introduced in Release 14, see the work item summary in [7].

Release 15 further enhancements for NB-IoT are ongoing. Key objectives for this release mainly include further latency and power consumption reduction, Narrowband measurement accuracy improvements, TDD support, small cell support etc. [8].

2.1.3. Cellular IoT Positioning Function

2.1.3.1. Positioning Extending IoT Scenarios

Most information in daily life includes space positions. Position information is closely related to people's daily life. With the development of technologies, location services gradually develop. The location service is a result of the integration and mutual infiltration of computer technology, mobile communications technology, and geographical location technology. Its core is that a user can obtain the geographical information service based on the location information at any time at any place. The biggest feature is to meet the positioning requirements of people, things, time, and places in the wireless world. In the era of connectivity of everything, more and more things need to be located, and IoT positioning emerges.

The basic version of NB-IoT and eMTC, as two important communications technologies of IoT, has been completed in 3GPP Release 13. 3GPP Release 14 further provides specific solutions for the following key requirements of IoT: positioning, terminal software upgrade, group control, peak rate, small-sized terminals with lower costs, and mobility enhancement. Positioning is one of the most important key requirements and the standard had been completed in the 3GPP plenary meeting held in June 2017.

LPWA will dominate fast growing tracking connections. According to the prediction of Machina, the number of tracking connections based on LPWA will reach 140 million in 2024, 14% of M2M connections [9].

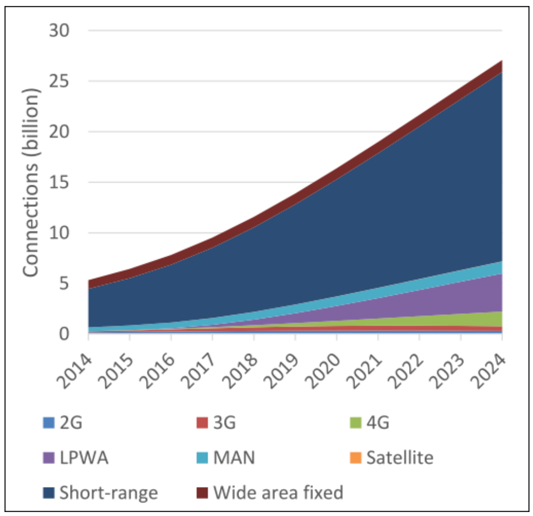


Figure 20 Global M2M connections 2014-2024 by technology[23]

IoT applications, such as Internet of Vehicles (IoV) and kid tracking, generally require positioning functions and require terminals to work at low power consumption and have low costs. Service fees occupy a large part of the value chain of tracking applications, which has great potential.

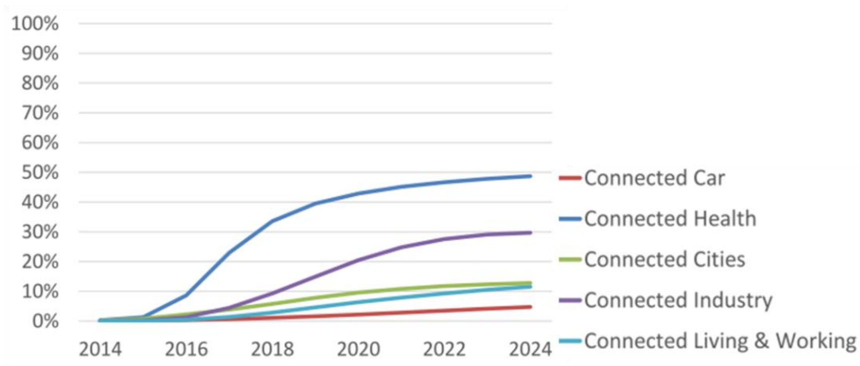


Figure 21 LPWA share of M2M connections by sector 2014-24[23]

IoT positioning is widely used in various IoT applications, such as vehicle positioning in fleet management, GIS-based geological hazard monitoring (detection of ground surface displacement and landslide), environment monitoring (reporting sensor locations), bicycle sharing (tracking bicycle locations), asset management (tracking asset locations), kid or pet tracking, and logistics tracking.

Figure 22 Applications of IoT positioning

2.1.3.1.1. Smart Agriculture

Precision agriculture is about managing variations in the field to increase crop yield, raise productivity and reduce consumption of agricultural inputs. While solutions such as auto guidance and machine monitoring and control via on-board displays today are mainstream technologies in the agricultural industry, telematics and Variable Rate Technology (VRT) are still in the early days of adoption. Smart farming solutions rely on public GNSS for accurate positioning of machines and other assets.

Smart agriculture refers to the application of information and communication technology in articulation production system. The introduce of GPS technology in the mid-1990s marked the advent of precision agriculture as it allows for precise positioning of agricultural machines driving in the field. By integrating positioning in agricultural machinery, farmers are able to measure and address field variability to increase yield and reduce the consumption for fertilisers and crop protections chemicals. Telematics solutions emerged in the early 2000s, aimed at monitoring vehicle fleets and optimising logistics processes at the farm.

Agriculture machinery connected to farm management information system needs to have a GNSS receiver and a wireless communication unit. The unit can be of a wide range of form factors and may be connected to various devices, peripherals and data interfaces inside the vehicle.

In agricultural production, GNSS receivers are used in a range of precision agriculture tasks and logistical applications. High accuracy satellite positioning helps growers to monitor site-specific crop yield, reduce overlaps. Plant more accurate rows of crops as well as apply fertilizers and pesticides in the right location. Although requirement vary between tasks, precision farming operations require positioning accuracy below 1 meter [10].

A subset of the tasks are performed in precision farming require very high accuracy down to centimetre level. Such operations include for example precision planning, drip irrigation installation and navigation, between tight rows.

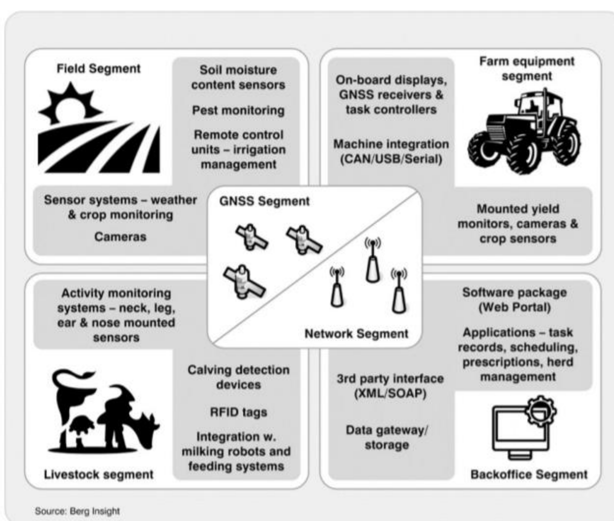


Figure 23 Smart farming infrastructure overview[10]

2.1.3.1.2. Bicycle-Sharing

Government institutions and organizations around the world is investing into more efficient urban transit facilities to provide sustainable emission-free transportation systems. Smart vehicles and car-free urban mobility is one of the domains where IoT is envisioned to be ubiquitous. Cellular IoT technologies allow conventional personal vehicles, such as bicycles, to be turned into globally connected systems that offer a wide range of benefits for users and riders, as well as for urban mobility in general.

A set of research works and products were proposed for other bicycle applications. These aim to enhance riding experience, improve safety levels and address the needs that riders encounter every day, such as cycling routes navigation, fitness feedback, and theft protection. Shared bicycles the topic of connected vehicles and bikes has attracted attention from both research groups and industry.

In 2017, bicycle-sharing showed explosive growth in China, and now Chinese bicycle-sharing firms are expanding business outside China. Mobike one of the leading bike sharing firms – uses cellular devices and GPS chip sets to keep track of its fleet, allowing users to identify the location of bikes using GPS. They can also use the system to lock or unlock the bikes remotely.

On another hand the booming industry also brings problems like bikes scattered across sidewalks and irresponsible bike riding. With more and more bikes were put on the road, bike parking become another serious issue for city governors. To address the problems, the central government released a guideline on Aug 3 urging city governments to set up parking zones for the bikes and strict punishment for misbehaviour on bikes. The Chinese national guideline calls for strict penalties for improperly parked shared bicycles, companies are turning to positioning technology for solutions [11]. In Sept, 2017, Beijing authorities have stipulated specific standards for shared bike technology, services and parking. According to rules issued by the local government, shared bikes should be installed with satellite positioning devices. Smart terminals should be installed to collect information about the location, use time, and lock status of bikes. Electronic maps should be provided on user APP to show parking lots and areas where parking and riding are prohibited [12].

In Singapore, in a bid to halt the indiscriminate parking that has led to complaints, bike-sharing firms are required to use technology that determines if their two-wheelers are left in designated zones which will require a high-accuracy location of the bikes and satellite positioning is for no doubt a better solution to address the accuracy of positioning accuracy. The Land Transport Authority (LTA) of Singapore is also studying the use of infrastructure to enhance the accuracy of the geofencing, as well as the possibility of common standards for its usage.

2.1.3.1.3. Asset Trackers

The internet of things is a crowded market challenged by proprietary and standardized connectivity, as well as long-term interoperability of devices being connected to global networks. But, LTE-based connectivity has emerged as the go-to for carrier-grade applications in need of reliable and robust network access, high-end security and efficient use of network and spectral resources all in a cost-effective package.

In terms of applications, asset tracking has emerged as high-value applications with a clear path to return on investment [8]. With the extensive coverage of the cellular network, GNSS based trackers use the extensive cellular networks to report the asset location to the data platform for tracking and data analysis.

Global asset tracking in oil and gas, and transportation, are expected to overpower cellular-based network technologies and strengthen IoT use cases according to research from Frost & Sullivan [7]. It is one of four key industry trends around Industrial IoT platforms identified in Frost & Sullivan report.

2.1.3.1.4. Drones

Some concepts for drone usage involve the airframe operating Beyond Visual Line of Sight (BVLOS). In order for these to be viable it is vital that the user knows the location of the drone with a very high level of integrity. This requirement is further intensified by the nature of drones making them difficult for ground based surveillance technologies to detect and locate (they are too small for conventional primary radar, and do not have power to operate typical secondary radar transponders). The positioning solution for drones therefore naturally involves GNSS. For the purposes of aviation, the integrity of this position must be extremely high. For example, drones flying into restricted airspace pose a safety risk; high integrity geofencing (which can be achieved through EGNOS) provides a solution. For the purposes of the end user application which the drone is supporting, the positioning solution may also have high accuracy requirements. In this context the push for MC/MF and SBAS are obvious technical enablers, providing greater redundancy and resilience [24].

2.1.3.1.5. Construction equipment

Construction equipment (CE) telematics refers to telematics hardware and associated software solutions deployed for remote monitoring and management of fleets of machinery and equipment used in the construction sector. The concept of telematics is a portmanteau of telecommunications – long-distance communications – and informatics – the science of information that is being addressed as mobile IoT with the booming of cellular IoT solution. Today, most construction equipment manufacturers have introduced some type of telematics offerings for its customers, Such solutions enable construction equipment manufacturers to offer value-added telematics-based services to its customers to boost both productivity and security at construction sites, while at the same also enabling the OEMs to collect valuable information about its machines which can be used internally for early detection of faults and to guide future development efforts. The construction equipment telematics solution relies on public GNSS system for accurate positioning of the machines [14].

2.1.3.1.6. Fleet management industry

Motor vehicle fleet management is one of the most mature application areas for cellular M2M communication around the world. The industry started with satellite based systems GNSS system for road transportation in the 1980s and subsequently expanded into the broader market of light commercial vehicles. A great number of players have emerged in local markets, of which some have later expanded regionally and internationally, often with the support from larger industrial groups and financial investors. In the past years, there has been an accelerating trend of consolidation on a regional and global basis.

2.1.3.2. Positioning Technologies for IoT

Internet of Things (IoT) connects sensing devices to the Internet for the purpose of exchanging information. Location information is one of the most crucial pieces of information required to achieve intelligent and context-aware IoT systems. Recently, positioning and localization functions have been realized in a large amount of IoT systems.

The aim of positioning technology for IoT is being looked forward to an accurate, low-cost, low-power, reliable, and scalable solution for cutting-edge applications. To achieve this goal, several challenges should be addressed, such as improving positioning accuracy, reducing the power cost, handling to track millions of devices as well as transmitting and processing big data.

Positioning solutions for mobile IoT can be classified as satellite enabled, mobile network enabled and assisted.

2.1.3.2.1. Satellite Positioning

Internet of Things (IoT) connects sensing devices to the Internet for the purpose of exchanging information. Location information is one of the most crucial pieces of information required to achieve intelligent and context-aware IoT systems. Recently, positioning and localization functions have been realized in a large amount of IoT systems.

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Global Navigation Satellite Systems (GNSS), including Beidou, play a key role in the Internet of Things. Information on positioning, velocity and timing is driving growth in a wide array of context-aware applications, from drones and driverless cars, to asset tracking.

There are four global navigation satellite system in operation or development. These include GPS operated by US military, GLONASS operated by the Russia military, Galileo developed by the European Union as a civil project and BDS/Compass deployed by China.

As one of the first methods to track and catalogue digital data of the physical world, GPS had an essential influence on internet of things technologies. IoT can collect and quantify large amounts of data for everything from personal health to vehicles. The global positioning system (GPS) was founded by the United States department of defence in 197 to track objects on earth in real time. It uses 24 active satellites known as the global navigation satellite system and three backup satellites in case an active satellite fails. All on a 12-hour orbit of earth. Non-military users are allowed to use its standard positioning system without fees or restrictions. GPS is invaluable to an IoT system since it quantifies and records location, speed, time and direction [15]. GPS uses satellites to track the position of any object with a GPS tracking chip, including vehicles, people, and pets. It works regardless of weather conditions and provides real-time and historical data. Tracking the verticality of objects is possible, but nowhere near as accurate as horizontal tracking.

GPS, originally, was developed to satisfy the U.S. military operational need for a precise navigation system and has been used only for U.S. military purposes until 1980s. But later realizing its potential civil uses, it has been opened to all users free of charge starting from 1980.

Development of GLONASS began in the Soviet Union in 1976 and the “constellation” was completed in 1995. With the advent of GLONASS system, the term GNSS was begun to be used.

BeiDou Navigation Satellite System (BDS) is a Chinese satellite navigation system it consists of two separate satellite constellations – a limited test system that has been operating since 2000, and a full-scale global navigation system that is currently under construction. BDS began to offer navigation services, mainly for customers in China and neighboring regions, since 2000. And the second generation of BDS consisting of 35 satellites began to offer service in the Asia-Pacific region in December 2012. The positioning of accuracy is about 10 – 20 meters with CEP 68%.

The first Galileo test satellite, the GIOVE-A, was launched in 2005, while the first satellite to be part of the operational system was launched on 21 October 2011. As of December 2017, 22 of the planned 30 active satellites are in orbit. Galileo is intended to provide horizontal and vertical position measurements within 1-metre precision.

Today, GPS is used for virtually all civil applications worldwide. All four systems are designed to provide global coverage separately or in conjunction. The availability of multiple satellite navigation systems has many benefits for end users. More satellites will be visible from more locations at any given time to ensure accurate positions. The quality of service increases as more independent system become available.

GNSS has advantages such as high precision, low cost, ease of use. In a broad geodetic sense, satellite positioning concerns the application of a satellite, or satellites and a variety of techniques and technologies to the determination of an instruments position in an appropriate coordinate system. For some applications, kilometre-level satellite position accuracy is acceptable; however, it is generally the case that geodetic and geophysical applications have accuracy requirements at the centimetre level [16].

Table 6 give an overview and prediction of GNSS based devices for smart agriculture. And the **错误!未找到引用源。**5 shows GPS enabled IoT devices will greatly increase in wearables and industrial IoT segments.

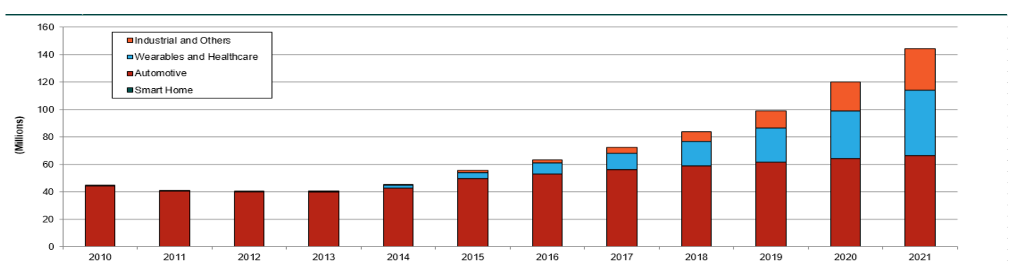

Figure 24 GPS-enabled IoT shipment [13]

Table 6 Shipments and installed base of GNSS devices for ag (world 2016 – 2021) [10]

Thousand units	2016	2017	2018	2019	2020	2021
Device shipments						
Europe	55	60	70	80	90	105
North America	175	190	205	230	260	295
Latin America	15	30	35	50	75	100
Asia Pacific	105	125	150	180	205	240
Middle East & Africa	25	35	55	75	100	135
Total	*375*	*445*	*515*	*615*	*735*	*875*
Installed base						
Europe	265	300	340	380	460	500
North America	745	865	980	1,105	1,180	1,340
Latin America	40	80	120	195	235	315
Asia Pacific	395	470	550	710	865	1,020
Middle East & Africa	80	120	160	200	315	435
Total	*1,525*	*1,835*	*2,155*	*2,585*	*3,055*	*3,605*
GNSS Penetration[1]	11 %	13 %	16 %	19 %	23 %	32 %

[1]Proportion of all high-powered tractors equipped with GNSS

Different approaches have been proposed over the years to address the high-power consumption of GPS modems. One approach is to adapt and reduce the utilization of GPS modem exploiting historical user habits and data coming from other sensors through machine learning schemes [17].

The internet of things is steadily becoming the engine of growth for mobile network operators. However, none of this growth is possible without location awareness provided by global navigation satellite system. IoT monitors objects and hardware to give real-time information and data about a device's operation, while GNSS provides the physical coordinates of the hardware or object. With these systems working in tandem, they form the foundation of smarter cities, innovative products such as self-driving cars and health-related wearable technologies and a vast, interconnected ecosystem that allows for smart devices to interact with sophisticated locating capabilities to achieve goals previously thought impossible.

Global navigation satellite system (GNSS) enables real-time and accurate product tracking, telematics, timing and other global position enabled machine-to-machine communication. As the IoT market continues to expand, the expectation and demand placed on these satellite systems will expand at the same time.

European Union is hoping that the satellite navigation system is a step towards satisfying evolving IoT need and enabling manufacturers and developers to create new devices and applications that leverage stronger GNSS signals. And China BDS launched the 3rd generation development and deployment plan in 2015. The current third generation of BeiDou claims to reach millimetre-level accuracy (with post-processing).

For these reasons, IoT solutions should employ GNSS chipsets that have the leading-edge technology to take advantage of today's sophisticated satellite systems.

2.1.3.2.2. Mobile Network Enabled Positioning

Mobile IoT technologies (Cat M and Cat NB) are key features enabled by 3GPP. 3GPP also defined and enhanced positioning solutions for such mobile IoT devices, which can be divided into two types: network-based positioning and terminal-based positioning.

The positioning technologies based on UE and non-3GPP standards have been introduced and described in many other documents. This document describes the satellite and network-based positioning technologies on the IoT network.

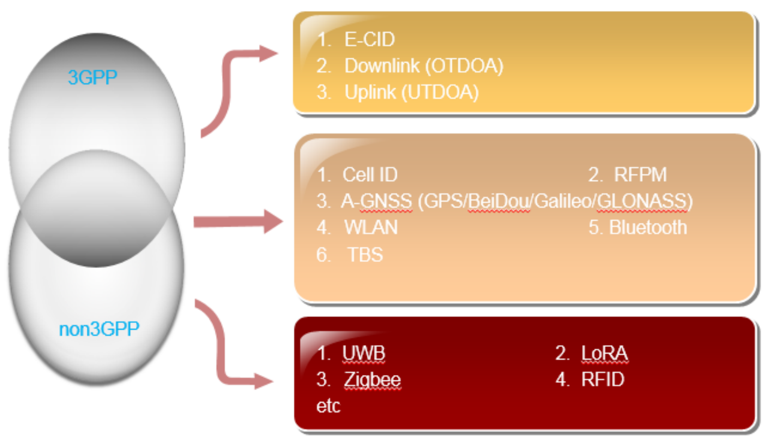

Figure 25 IoT positioning solution classification

2.1.3.2.2.1. Cell ID

Cell ID-based positioning locates a UE based on the serving cell ID. The positioning accuracy depends on the cell radius, and UEs may be located with a deviation of several hundred meters or even several kilometres. The larger the radius of the cell coverage, the lower the positioning accuracy. However, in urban areas, especially hot spots deployed with micro cells in city central areas, the cell radius may be only 150 meters or even smaller.

Compared with other positioning solutions with higher accuracy, the biggest advantage of cell ID-based positioning is that it directly provides location-based services for UEs without upgrading existing terminals and networks supporting IoT. The location information of UEs can be obtained in the access or online state. The positioning process involves only the eNodeB and MME and does not require the UE to perform any location related measurement. Therefore, the response time required for positioning is short, reaching second level.

In cell ID-based positioning, only the information of the cell serving the UE is available such as ECGI and TAI. It can be deployed in two modes:

- Deployment without E-SMLC. When the GMLC/SCEF receives an external positioning request, the MME reports the information about the cell where the UE is located to the GMLC over the SLg interface.
- Deployment with E-SMLC. The E-SMLC calculates the latitude and longitude of the cell where the UE is located. The positioning procedure is the same as that for E-CID-based positioning.

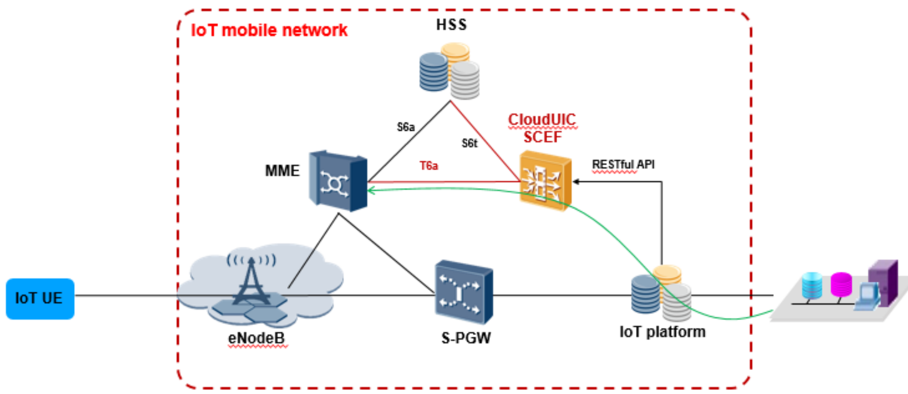

Figure 26 Networking for the deployment without E-SMLC

2.1.3.2.2.2. E-CID-based Positioning

E-CID-based positioning is an enhancement of the cell ID-based positioning method. The cell ID-based positioning method can only determine whether a UE is located within this area. With T_{ADV} and RSRP (NPRSP for NB-IoT) and RSRQ (NPRSQ for NB-IoT) of neighboring cells, however, the E-CID-based positioning method can determine the exact location of the UE in this area.

The T_{adv} is the round-trip delay between eNodeB's antennas and a UE to be positioned, and can be used to estimate the distance (S) between the UE and the antennas using the following formula: $S = \frac{T_{adv}}{2} \times C$

In this formula, C represents the speed of light.

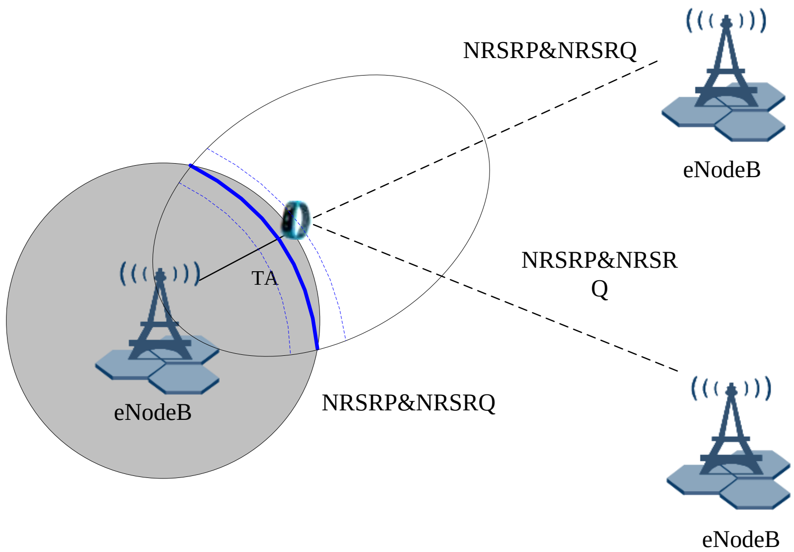

Figure 27 Principles of E-CID-based positioning

The difference between E-CID-based positioning in eMTC scenarios and that in NB-IoT scenarios lies in the eNodeB measurement items, as described in Table 1.

Table 7 Major differences between NB-IoT E-CID-based positioning and eMTC E-CID-based positioning

Item	NB-IoT E-CID-based Positioning	eMTC E-CID-based Positioning
UE mode for measurement	RRC_IDLE mode	RRC_CONNECTED mode
UE measurement items	Including the cell ID, TADV, narrowband reference signal received power (NRSRP), and narrowband reference signal received quality (NRSRQ)	Including the cell ID, TADV, RSRP, and RSRQ
eNodeB measurement items	Cell ID and type 2 TADV	Cell ID, type 1 TADV, type 2 TADV, RSRP, and RSRQ
E-SMLC location calculation	The E-SMLC uses TADV, NRSRP, and NRSRQ to determine UE locations.	The E-SMLC uses TADV, RSRP, and RSRQ to determine UE locations.

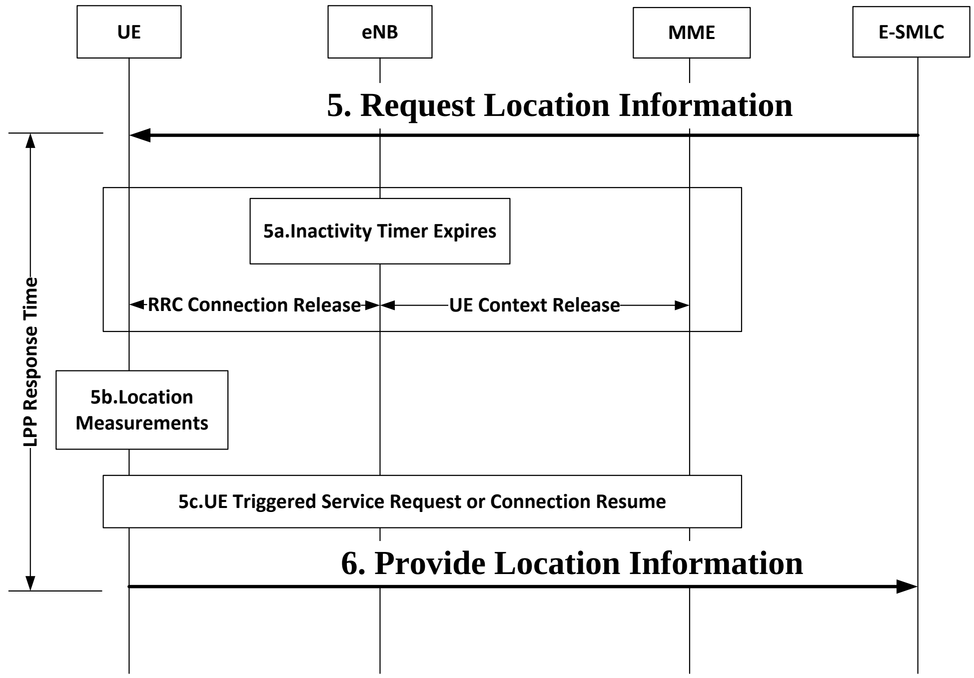

Figure 28 Measurement of NB-IoT UEs in RRC_IDLE state for E-CID-based positioning

NB-IoT UEs do not support measurement reporting to the eNodeB. Therefore, it is difficult to perform positioning-related measurements in connected mode. Certain NB-IoT UEs can perform neighboring cell measurement only in RRC_IDLE state[18]Compared with the common downlink E-CID-based positioning procedure, downlink E-CID-based positioning of an NB-IoT UE includes the following additional steps:

- In step 5a, the UE continues with the on-going service after receiving a Request Location Information message, and then waits for resource release at the network side after the service is completed.
- In step 5b, the UE performs neighboring cell measurement after entering the RRC_IDLE state, including the measurement of NRSRP, and NRSRQ.
- In step 5c, the UE triggers a service request for network re-access or resumes RRC connection reestablishment, and then sends a Provide Location Information message containing the measurement results to the E-SMLC.

The reporting range of RSRP for IoT UE is defined from -140dBm to -44dBm with 1 dB resolution.

The mapping of measured quantity is defined in Table. The range in the signalling may be larger than the guaranteed accuracy range.

Table 8 RSRP measurement report mapping

Reported Value	Measured Quantity Value	Unit
RSRP_00	RSRP < -140	dBm
RSRP_01	-140 ≤ RSRP < -139	dBm
RSRP_02	-139 ≤ RSRP < -138	dBm
…	…	…
RSRP_95	-46 ≤ RSRP < -45	dBm
RSRP_96	-45 ≤ RSRP < -44	dBm
RSRP_97	-44 ≤ RSRP	dBm

The reporting range of NRSRP for NB-IoT is defined from -156dBm to -44dBm with 1 dB resolution.

The mapping of measured quantity is defined in Table. The range in the signalling may be larger than the guaranteed accuracy range [19].

Table 9 NRSRP measurement report mapping

Reported Value	Measured Quantity Value	Unit
NRSRP_00	**NRSRP < -156**	**dBm**
NRSRP_01	**-156 ≤ NRSRP < -155**	**dBm**
NRSRP_02	**-155 ≤ NRSRP < -154**	**dBm**
…	**…**	**…**
NRSRP_111	**-46 ≤ NRSRP < -45**	**dBm**
NRSRP_112	**-45 ≤ NRSRP < -44**	**dBm**
NRSRP_113	**-44 ≤ NRSRP**	**dBm**

2.1.3.2.2.3. OTDOA-based Positioning

OTDOA-based positioning locates a UE based on the measured difference in arrival times between signals transmitted from multiple eNodeBs. As it does not use absolute time, it can ensure high positioning precision and accuracy.

As shown in Figure X, two hyperbola branches are derived when both the following differences are constant:

- Distance from the UE to eNodeB 0 and to eNodeB 1 (d1 – d0)
- Distance from the UE to eNodeB 1 and to eNodeB 2 (d2 – d1)

The UE location is determined based on the intersection of the two hyperbola branches and additional information, such as the geographic locations of the eNodeBs. The more eNodeBs involved in positioning, the more precise and accurate the positioning results are.

The basic formulas are as follows:

$$d_{01} = d_0 - d_1 = \sqrt{(x-x_0)^2 + (y-y_0)^2} - \sqrt{(x-x_1)^2 + (y-y_1)^2} = c \times (t_0 - t_1) + c \times \Delta t_{01}$$
$$d_{02} = d_0 - d_2 = \sqrt{(x-x_0)^2 + (y-y_0)^2} - \sqrt{(x-x_2)^2 + (y-y_2)^2} = c \times (t_0 - t_2) + c \times \Delta t_{02}$$

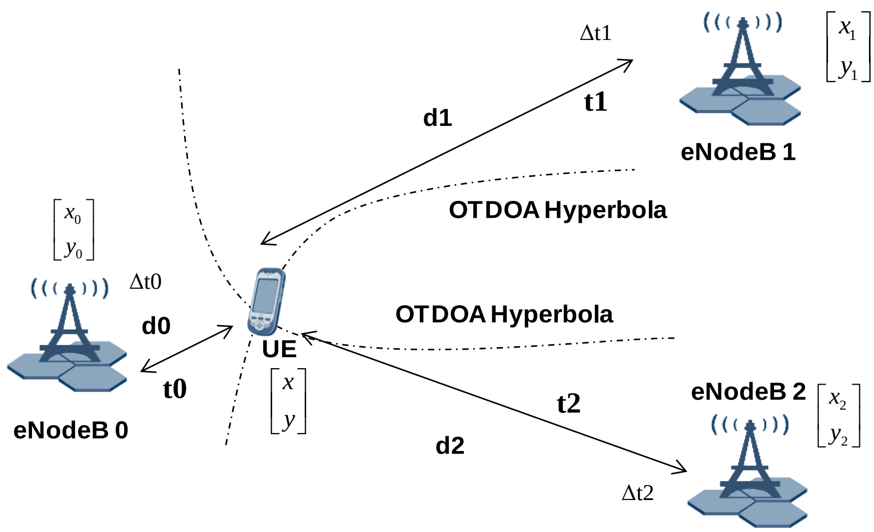

Figure 29 Principles of OTDOA-based positioning

The UE listens to multiple eNodeBs, measures the time it takes for PRSs to travel from the eNodeBs to the UE, and then calculates the OTDOA between the neighboring cells and the reference cell.

Based on the Relative Time Difference (RTD) information sent by the E-SMLC for frame timing specific to signal transmission in each of multiple cells, the UE obtains the actual Time Difference of Arrival (TDOA) between the neighboring cells and reference cell. The following formula expresses the relationship between TDOA, OTDOA and RTD:

TDOA = OTDOA – RTD

The UE then reports the TDOA to the E-SMLC. The E-SMLC uses a combination of the TDOA and the geographic location of the eNodeB to calculate the geographic location of the UE.

Editor's note: The neighboring cells of the cell where the UE to be located resides are measured to assist the positioning. During positioning, a cell where the UE to be located most likely resides is identified and known as the reference cell for measurement. Commonly, this is the serving cell of the UE.

The principles of NB-IoT OTDOA-based positioning are similar to those of eMTC OTDOA-based positioning. Table 10 lists the differences.

Table 10 Differences between NB-IoT OTDOA-based positioning and eMTC OTDOA-based positioning

Item	NB-IoT OTDOA-based Positioning	eMTC OTDOA-based Positioning
UE positioning measurement	Completed when UEs are in the RRC_IDLE state.	Completed when UEs are in the RRC_CONNECTED state.
UE OTDOA capability field	ue-assisted-NB-r14	ue-assisted
Method that the eNodeB generates PRS signals	NB-IoT cells transmit NPRS signals, and signals are generated based on NPRS IDs.	eMTC cells transmit PRS signals, and signals are generated based on PRS IDs.
Support of inter-frequency RSTD for OTDOA	Not supported	Supported

The relative timing difference between the neighboring cell j and the reference cell i specifies the relative timing difference between this neighboring cell and the RSTD reference cell [20].

The reporting range of RSTD is defined from $-15391T_s$ to $15391T_s$ with $1T_s$ resolution for absolute value of RSTD less or equal to $4096T_s$ and 5Ts for absolute value of RSTD greater than $4096T_s$.

The mapping of measured quantity is defined in Table 11[19].

Table 11 RSTD report mapping

Reported Value	Measured Quantity Value	Unit
RSTD_0000	-15391 > RSTD	Ts
RSTD_0001	-15391 ≤ RSTD < -15386	Ts
…	…	…
RSTD_2258	-4106 ≤ RSTD < -4101	Ts
RSTD_2259	-4101 ≤ RSTD < -4096	Ts
RSTD_2260	-4096 ≤ RSTD < -4095	Ts
RSTD_2261	-4095 ≤ RSTD < -4094	Ts
…	…	…
RSTD_6353	-3 ≤ RSTD < -2	T_s
RSTD_6354	-2 ≤ RSTD < -1	T_s
RSTD_6355	-1 ≤ RSTD ≤ 0	T_s

Reported Value	Measured Quantity Value	Unit
RSTD_6356	0 < RSTD ≤ 1	T_s
RSTD_6357	1 < RSTD ≤ 2	T_s
RSTD_6358	2 < RSTD ≤ 3	T_s
…	…	…
RSTD_10450	4094 < RSTD ≤ 4095	T_s
RSTD_10451	4095 < RSTD ≤ 4096	T_s
RSTD_10452	4096 < RSTD ≤ 4101	T_s
RSTD_10453	4101 < RSTD ≤ 4106	T_s
…	…	…
RSTD_12709	15381 < RSTD ≤ 15386	T_s
RSTD_12710	15386 < RSTD ≤ 15391	T_s
RSTD_12711	15391 < RSTD	T_s

2.1.3.2.2.4. A-GNSS-based Positioning

A-GNSS-based positioning is network-assisted. In A-GNSS-based positioning, the network provides positioning assistance information for a UE. This information helps the UE search for satellite signals, thereby shortening the GNSS positioning time.

The following uses A-GPS as an example to describe the positioning principles.

GPS is a global navigation satellite system developed by the U.S. Department of Defense. It is capable of precisely locating objects on Earth by providing a sufficient number of satellites within the line of sight of the object. In an E-UTRAN, the basic principles of A-GPS-based positioning are the same as the principles of common GPS pseudorange-based positioning.

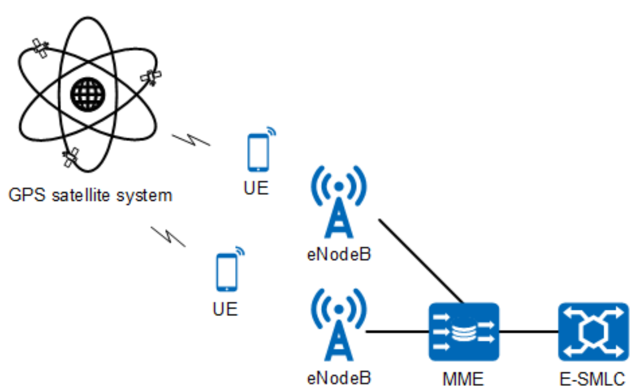

Figure 30 Principles of the A-GPS-based positioning

The primary difference between A-GPS-based positioning and common GPS pseudorange-based positioning is that in A-GPS-based positioning the E-SMLC collects the GPS satellite information and delivers the GPS assistance data to the target UE. The assistance data can be the reference location, reference time, or ionosphere model and helps the UE receive GPS satellite signals more efficiently. For the UE, the time taken to measure the pseudoranges is shortened, power consumption is reduced, and the receive sensitivity is increased.

If there are fewer than four satellites with line of sight to the UE, the information obtained for A-GPS-based positioning is insufficient to determine the location of the UE. In this case, other measurements in the E-SMLC can also be used to help calculate the location of the UE.

Table 11 lists assistance data for both UE-assisted and UE-based modes that may be sent from the E-SMLC to the UE [21].

Table 12 Information that may be transferred from the E-SMLC to UE

Assistance Data
Reference Time
Reference Location
Ionospheric Models
Earth Orientation Parameters
GNSS-GNSS Time Offsets
Differential GNSS Corrections
Ephemeris and Clock Models
Real-Time Integrity
Data Bit Assistance
Acquisition Assistance
Almanac
UTC Models

The information that may be signalled from UE to the E-SMLC is listed in table 13.

Table 13 Information that may be transferred from UE to the E-SMLC

Information	UE-assisted	UE-based
Latitude/Longitude/Altitude, together with uncertainty shape	No	Yes
Velocity, together with uncertainty shape	No	Yes
Reference Time, possibly together with GNSS-E-UTRAN time association and uncertainty	Yes	Yes
Indication of used positioning methods in the fix	No	Yes

Code phase measurements	Yes	No
Doppler measurements	Yes	No
Carrier phase measurements	Yes	No
Measurement quality parameters for each measurement	Yes	No
Additional, non-GNSS related measurement information	Yes	No

For IoT terminals, due to the limitation of the air interface rate, GNSS auxiliary data must be properly designed and transmission delay and satellite searching duration must be considered.

2.1.3.2.3. Radio Frequency Pattern Match

Radio Frequency Pattern Matching (RFPM) sometimes is referred to as RF fingerprinting, is a general class of positioning techniques by which a set of RF measurements, made either by the UE or the eNodeB, is compared against a reference set of values in order to estimate the UE location, where the reference set of values may be based on predicted and/or collected measurements. Typical types of RF measurements include Referenced Signal Received Power (RSRP) and UE Rx-Tx measurement [22].

Data in the fingerprint database comes from the GPS MR (wireless measurement data with high-precision location information, which can be obtained from the UMTS A-GPS MR, LTE MDT, or drive tests). The location server constructs the fingerprint map from the combination of the measurement information contained in the GPS MR and the geographical location, by using the grid and signature combination algorithms.

If the location server cannot directly obtain fingerprint database of the IoT network, it constructs the database by converting the fingerprint data of a UMTS or LTE network. The UMTS or LTE cells must meet all the following conditions:

- The UMTS or LTE cell and IoT cell must work in the same frequency band.
- The UMTS or LTE cell and IoT cell must share the same antenna.
- In the positioning area, it is recommended that the number of UMTS or LTE cells be consistent with the number of IoT cells.

A cell signature feature indicates a set of cells that can be measured at a certain location. The coverage capabilities of different RATs are different. Therefore, cell measurement information needs to be normalized, so as to ensure that information in database can be matched in the match phase.

The principle of fingerprint positioning is similar to fingerprint search. Assume that user A is running services at point P1. User A can measure the optimal cell at point P1, neighboring cells, and other information about the neighboring cells, such as level strength and delay. In this way, based on these measurement results, a comprehensive fingerprint feature value can be created for P1.

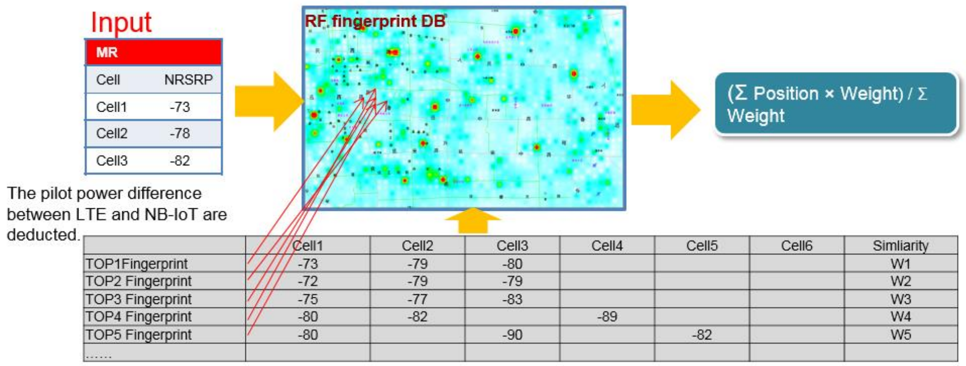

Figure 31 Principle of fingerprint positioning

The precision of fingerprint positioning depends on the size of the GPS sample library. The larger the number of samples in a grid, the more precise the fingerprint positioning. In addition, as the inter-site distance increases, the positioning precision of the fingerprint positioning deteriorates slowly.

2.1.3.3. Conclusion

Wireless positioning performance is affected by the following major factors:

- Positioning measurement accuracy
- Geometric Dilution of Precision (GDOP)
- Locating algorithm

Positioning measurement precision is the foremost factor that affects the positioning accuracy. The positioning measurement accuracy depends on the measurement algorithm capability of the related measurement NEs (such as UE and eNodeB) and the radio environment where these NEs are located.

Positioning performance fluctuates greatly with radio environment, which is the most uncontrollable factor. For example, satellite locating is difficult in indoor or high-rise areas, and positioning error increases under cloudy weather. E-CID- and OTDOA-based positioning is affected by the radio environment and networking. The positioning accuracy is in direct proportion to the number of neighboring cells in unobstructed areas. Radio waves experience a large number of refractions and reflections in areas with obstacles, which cause the positioning accuracy to deteriorate.

GDOP is a geographical geometric precision factor in positioning calculation. It is determined by a relative position between a UE and a GNSS satellite (A-GNSS method) or a relative position between a UE and a base station (OTDOA- or E-CID-based method). The more the reference points involved in the positioning and the closer the UE is to the center of the reference points, the better the positioning performance.

Positioning algorithms are implemented in location servers. Positioning performance varies greatly depending on positioning algorithms.

Different positioning technologies provide different QoS. Therefore, user can select positioning technologies based on QoS requirements of services.

For example, the A-GNSS and GNSS positioning technologies can be used for shared bicycles, which require high-precision positioning. In addition, network-based positioning can be used as a supplement in indoor and densely-populated urban areas.

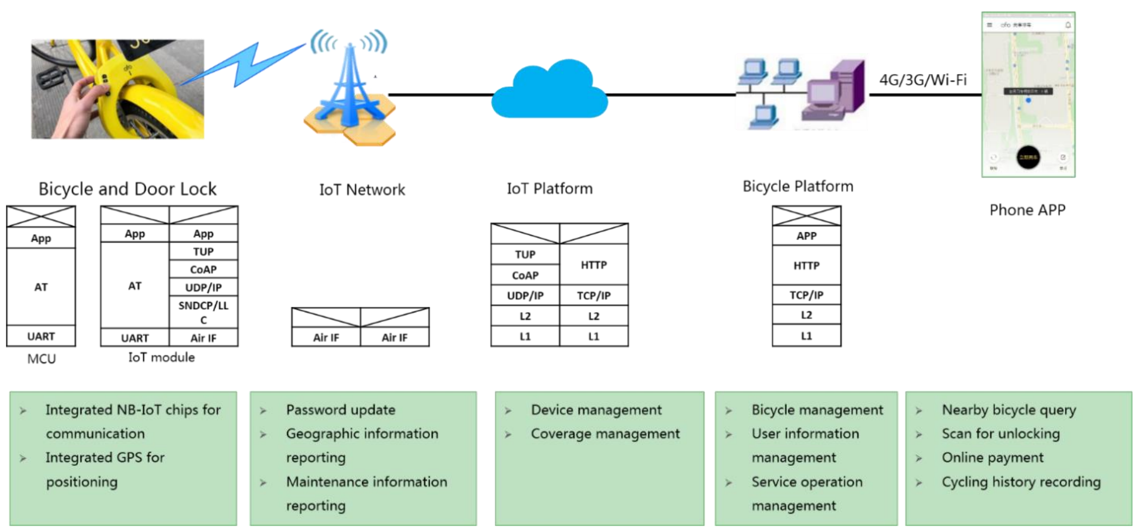

Figure 32 NB-IoT-based E2E smart bicycle solution

The cell ID-based positioning method can be used in logistics tracking, which has low positioning precision requirements. Techniques such as ultra-wideband (UWB), Bluetooth, and deep coverage of IoT can be used as supplements in indoor warehouse logistics management to achieve wireless positioning data backhaul and meter-level positioning. These techniques significantly reduce deployment costs.

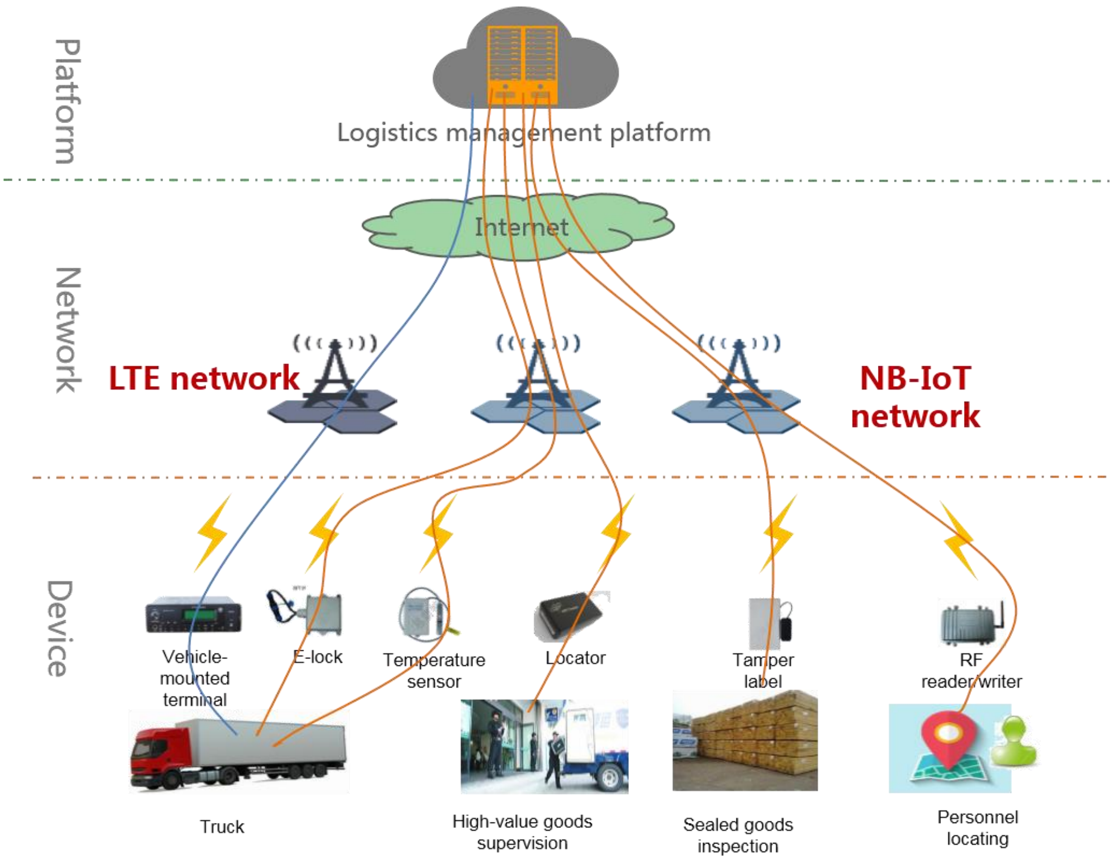

Figure 33 Smart E2E logistics solution

E-CID with fingerprint positioning can be used in animal husbandry tracking to achieve grid GIS area management.

Figure 34 GIS-based grid

2.2. None Cellular IoT Technology

A Low-Power Wide-Area Network (LPWAN) is a type of wireless telecommunication wide area network designed to allow long range communications at a low bit rate among things (connected objects), such as sensors operated on a battery. The low power, low bit rate and intended use distinguish this type of network from a wireless WAN that is designed to connect users or businesses, and carry more data, using more power. The LPWAN data rate ranges from 0.1kbit/s to 50kbit/s per channel.

A LPWAN may be used to create a private wireless sensor network, but may also be a service or infrastructure offered by a third party, allowing the owners of sensors to deploy them in the field without investing in gateway technology.

There are a number of competing standards and vendors in the LPWAN space, the most prominent of which include LoRa, Sigfox(UNB),etc. Following table is the key specification comparison.

Table 14 Key LPWA Technology Specification Comparison

	LoRa	Sigfox /UNB
Modulation	SS Chirp	UL BPSK/DL GFSK
Bandwidth	7.8 ~ 500KHz, Typical 125KHz	100Hz
Peak Rate	5.4 Kbps @125KHz	100 bps
Link Budget	154 dB	151 dB
Power Consumption	Typical: TX: 20dBm/125mA @3V RX: 14.7 mA Sleep: 1.8uA	Typical: TX: 49 mA RX: 10 mA Sleep: 100nA
Security	Support, AES	Not Support
Mobility	Support	Not Supported

2.2.1. LoRa

LoRa is a patented (EP2763321 from 2013 and US7791415 from 2008) technology developed by Cycleo (Grenoble, France) and acquired by Semtech in 2012. LoRa uses license-free sub-gigahertz radio frequency bands like 169 MHz, 433 MHz, 868 MHz (Europe) and 915 MHz (North America) and offers a very compelling mix of long range, low power consumption and secure data transmission.

LoRaWAN is a media access control layer protocol for managing communication between LPWAN gateways and end-node devices, maintained by the LoRa Alliance. Version 1.0 of the LoRaWAN specification was released in June 2015.

LoRaWAN defines the communication protocol and system architecture for the network while the LoRa physical layer enables the long-range communication link. LoRaWAN is also responsible managing the communication frequencies, data rate, and power for all devices. Devices in the network are asynchronous and transmit when they have data available to send. Data transmitted by an end-node device is received by multiple gateways, which forward the data packets to a centralized network server. The network server filters duplicate packets, performs security checks, and manages the network. Data is then forwarded to application servers. The technology shows high reliability for the moderate load, however it has some performance issues related to sending acknowledgements.

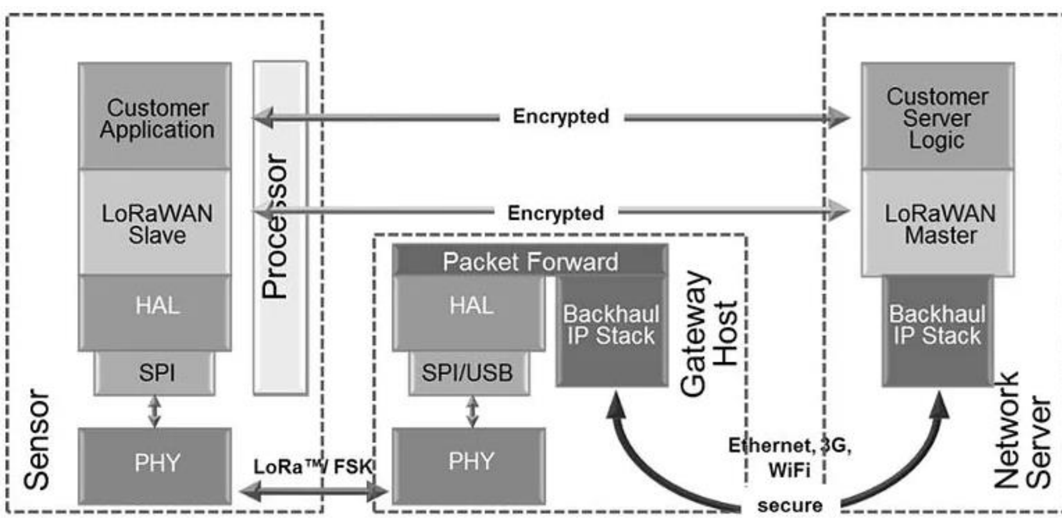

Figure 35 LoRaWAN Protocol Architecture

2.2.2. **Ultra Narrow Band (Sigfox)**

SigFox is a narrowband (or ultra-narrowband) technology. It uses a standard radio transmission method called binary phase-shift keying (BPSK), and it takes very narrow chunks of spectrum and changes the phase of the carrier radio wave to encode the data. This allows the receiver to only listen in a tiny slice of spectrum which mitigates the effect of noise. It requires an inexpensive endpoint radio and a more sophisticated base station to manage the network.

SigFox has tailored a lightweight protocol to handle small messages. Less data to send means less energy consumption, hence longer battery life. An uplink message has up to 12-bytes payload and takes an average 2s over the air to reach the base stations which monitors the spectrum looking for UNB signals to demodulate. For a 12-byte data payload, a Sigfox frame will use 26 bytes in total. The payload allowance in downlink messages is 8 bytes.

2.2.3. **RPMA**

Formerly On-Ramp Wireless, Ingenu is a US-based company which developed Random Phase Multiple Access (RPMA), a LPWA network technology specifically for IoT, using the 2.4GHz unlicensed band, available globally.

It is low rate, two way, low power technology, providing wide coverage and able to provide firmware upgrades. It is positioned between SIGFOX and the 3GPP standard in terms of price-performance.

This band is widely used by Bluetooth and Wi-Fi, but there is 80MHz of spectrum, and RPMA has been developed to deal with packet loss and make good use of available spectrum.

Ingenu provides the silicon and base stations and is rolling out a US public network (with nationwide coverage expected in late 2017). It has developed partnerships with a number of companies, notably in the energy sector.

It has also partnered with Meterlinq, which is building a public network across Italy, largely targeted at utilities and industrial applications.

2.2.4. **Cellular-Based LPWA**

Infrastructure vendors, cellular service providers and standards bodies worldwide have coordinated to develop several LTE- and GSM-based LPWA specifications. LTE-Cat-M1, NB-IoT, and EC-GSM-IoT are the three most relevant to the LPWA market.

Cellular-based solutions have the advantage of relying upon private, typically carrier-owned spectrum rather than unlicensed bands. Additionally, carriers can implement the new standards with a software only deployment—which makes it cost-effective and attractive to carriers. The new standards will make cellular connectivity more cost-effective and attractive to utilities for large numbers of endpoints.

That said, utilities are not all amenable to relying upon public carriers for grid management applications. However, as the standards deploy worldwide, the low prices along with widespread coverage may pique their interest. In some cases, a cellular-based solution may be deployed alongside a proprietary solution, such as LoRa, for backup.

3. IoT Network Deployment Strategy and Planning

3.1. IoT Network Deployment Strategy

3.1.1. Macro Cells

3.1.1.1. Overview

The deployment strategy of the Internet of things is the first step in the development strategy of the operator of the Internet of things, which directly determines the wireless network construction of the Internet of things.

There are many aspects that need to be considered in the deployment of Internet of things:

Technology selection: NB-IoT or eMTC

Frequency band selection: low or high band

Frequency point selection: same frequency or different frequency

Deployment mode selection: stand-alone, guard-band and in-band

Deployment scale selection: 1:N relative to the original network

3.1.1.2. Technology Selection

The comparison of NB-IoT and eMTC technology is shown in the following table.

Table 15 Comparison of NB-IoT and eMTC Technology

	Coverage	User peak rate	Capacity	Delay	Mobility	Terminal life	Cost
NB-IoT	MCL 164dB	Uplink:60kbps Downlink:25kbps	50k@200KHz	10s	<60km/h	10 years	<$5/module
eMTC	MCL 155dB	full duplex:1Mbps Half duplex:375kbps	100k@5MHz	<700ms	<350km/h	10 years	<$10/module

NB-IoT has the characteristics of wide coverage, multi connection, low power consumption and low cost. It is suitable for low speed or static internet of things devices, such as intelligent meter reading, intelligent parking, intelligent agriculture, smart city (manhole cover, street lamp).

eMTC has the characteristics of good mobility, high transmission rate and small delay. It is suitable for mobile applications such as logistics monitoring, smart wearable, Internet of vehicles, etc.

Two technologies (NB-IoT and eMTC) for IoT can be selected according to operators own network status and business development plan. There are three choices: priority NB deployment, priority eMTC deployment, NB-IoT + eMTC deployment.

Table 16 Development Selection of NB-IoT and eMTC

Current network	Development planning of IoT	Deployment recommendations
2G/3G network, no LTE	Low rate packet service	priority NB deployment
FDD LTE	Low rate packet service	priority NB deployment
FDD LTE	Medium and high speed mobile applications	priority eMTC deployment
FDD LTE	Low rate packet service+ Medium and high speed mobile applications	NB-IoT+eMTC deployment

3.1.1.3. Frequency Band Selection

NB-IoT supports only FDD in the 3GPP R13/R14 phase, and the TDD band is introduced in the R15 phase. eMTC supports all the frequency segments of FDD and TDD.

NB-IoT is designed to operate in the E-UTRA operating bands 1, 2, 3, 4, 5, 8, 11, 12, 13, 14, 17, 18, 19, 20, 21, 25, 26, 28, 31, 66, 70, 71, 72, 74.

The coverage of different frequency bands is shown as shown in the following table.

(Stand-alone, NBTx power 43dBm, NRS power 32.2dBm, Outdoor RSRP requirement -112dBm).

Table 17 The coverage of different frequency bands

	700M	800M	850M	900M	1800M	2100M
Dense Urban	0.77	0.70	0.67	0.64	0.40	0.35
Urban	1.48	1.34	1.28	1.23	0.76	0.66
Suburban	3.06	2.77	2.64	2.53	1.78	1.54
Rural	10.07	9.10	8.70	8.33	5.84	5.02

The coverage of the low frequency segment is obviously better than that of the high frequency section. From the comparison of the link budget, it is known that (the following table), the coverage distance of 700MHz is 2 times that of 1800M. In the case of the same coverage distance, the difference between the path loss of 900M and 1.8G is about 6-10dB, and the difference between 1.8G and 2.1G is 1-3dB.

The difference in penetration ability of different frequency bands is also larger, and the penetration ability of low frequency is obviously better than that of high frequency. For example, the difference in penetration loss of 800M and 2.1G is about 2dB (the direct direction of the antenna main lobe).

In view of the NB-IoT spectrum selection of the specific operators, it is necessary to consider the factors such as the spectrum resources of the industry chain, the operator's spectrum, the demand of network performance, and the interference.

NB-IoT recommends that low frequency segments be preferred, such as 700M/800M/850M/900M.

EMTC recommends that priority be given to co deployment with LTE FDD, with a priority selection of low frequency segments.

3.1.1.4. Frequency Point Selection

The deployment of NB-IoT networks can choose the same frequency (1*1) or different frequency network (3*1).

For Stand-alone deployment, According to the simulation and experimental results that in the co-site network environment (such as 1:1), different frequency network compared to the same frequency network average SINR upgrade 5-7dB. In the non-co-site network environment (such as 1:4), different frequency network compared to the same frequency network average SINR upgrade 4-6dB.

Due to the current NB-IoT terminal resistance of same frequency interference is relatively weak, in sufficient frequency resources and disturbed environment, choose different frequency network, so as to enhance the signal quality of the whole network, so as to enhance the transmission efficiency.

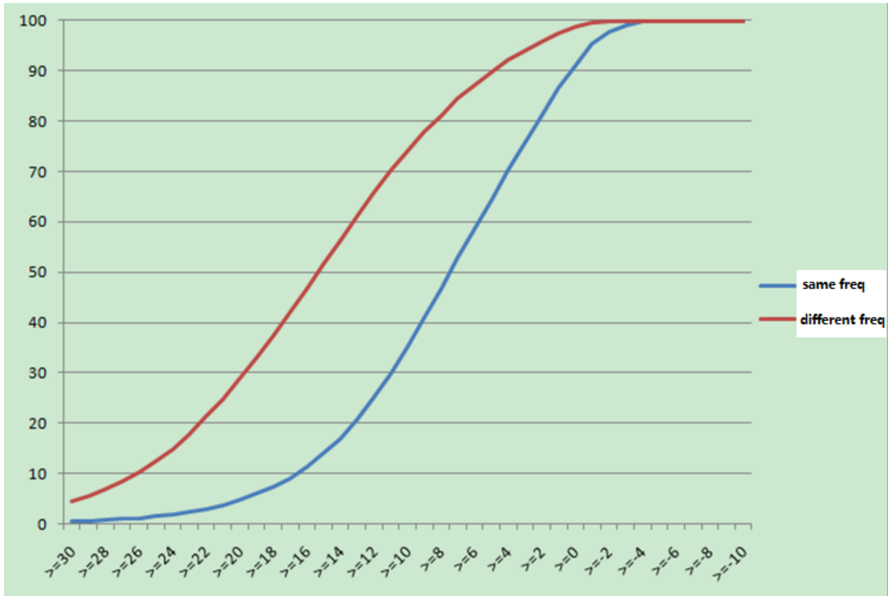

Figure 36 Comparison of same frequency(1*1) and different frequency(3*1)

3.1.1.5. Deployment Mode Selection

Three spectrum deployment scenarios for eMTC is in-band with LTE FDD.

Three spectrum deployment scenarios for NB-IoT in 3GPP:stand-alone, guard-band and in-band.

Stand-alone deployment mainly utilizes the free spectrum of the current network or the new spectrum resources to deploy the NB-IoT. Guard-band deployment utilizes the protection band spectrum deployment of the current network LTE network to maximize the spectral resource utilization. In-band deployment is the use of the current network LTE network frequency of existing RB (Resource block) to deploy the NB-IoT.

When building NB-IoT networks, operators must choose at least one of the three modes of stand-alone, guard-band and in-band. The different ways of deploying them are specifically recommended as follows:

Table 18 Deployment Mode Selection

Stand-alone	**free spectrum or GSM/UMTS/CDMA spectrum refarming, high coverage requirements**
In-band	LTE spectrum above 3MHz, the evolution of the expansion of demand.
Guard-band	LTE spectrum above 5MHz, guard-band deployment without legal risk

3.1.1.5.1. Stand-alone

There are two ways to stand-alone deployment mode: free spectrum and GSM/UMTS/CDMA spectrum refarming

3.1.1.5.2. Guard-band

Guard-band frequency point position required by the 3GPP protocol is shown in the following table [10] [18] .

Table 19 Frequency point position for Guard-band

LTE system bandwidth	5 MHz	10 MHz	15 MHz	20 MHz
Edge frequency of LTE transmission (kHz)	±2257.5	±4507.5	±6757.5	±9007.5
NB-IoT carrier center frequency closest to 100kHz channel raster (kHz)	±2392.5	± 4597.5/4702.5 /4807.5/4897.5	± 6892.5/6997.5/7102.5/7207.5/7297.5/7402.5	± 9097.5/9202.5/9307.5/9397.5/9502.5/9607.5/9697.5/9802.5/9907.5
Edge-to-edge separation of LTE and NB-IoT (kHz)	45	0/105/210/300	45/150/255/360/450/555	0/105/210/300/405/510/600/705/810

3.1.1.5.3. In-band

For In-band deployment scenario, the NB-IoT downlink RB position is required to meet the 3GPP TS36.101 protocol constraints, and the NB-IoT uplink RB location is recommended to be deployed on the edge RB [10] [18].

NB-IoT and LTE (no eMTC) In-band deployment scenario:

Table 20 Downlink PRB Position for In-band Deployment (no eMTC)

LTE FDD Cell Bandwidth	The Position of NB-IoT Downlink RB Deployment (based on 3GPP defined)
3MHz	2,12
5MHz	2，7，17，22
10MHz	4，9，14，19，30，35，40，45
15MHz	2，7，12，17，22，27，32，42，47，52，57，62，67，72

LTE FDD Cell Bandwidth	The Position of NB-IoT Downlink RB Deployment (based on 3GPP defined)
20MHz	4，9，14，19，24，29，34，39，44，55，60，65，70，75，80，85，90，95

NB-IoT, LTE and eMTC In-band deployment scenario:

Table 21 Downlink PRB Position for In-band Deployment (with eMTC)

LTE FDD Cell Bandwidth	The Position of NB-IoT Downlink RB Deployment	Center 6RB	eMTC SIB1	The Position of NB-IoT Downlink RB Deployment
3MHz	2,12	4~9	1~12	Unable to deploy NB-IoT
5MHz	2，7，17，22	9~14	0~5,18~23	7，17
10MHz	4，9，14，19，30，35，40，45	22~27	1~18,31~48	19，30
15MHz	2，7，12，17，22，27，32，42，47，52，57，62，67，72	34~39	1~30,43~74	32，42
20MHz	4，9，14，19，24，29，34，39，44，55，60，65，70，75，80，85，90，95	47~52	2~43,56~99	44，55

3.1.1.6. Deployment Scale Selection

The network deployment of eMTC is co-site network with LTE 1:1.

The deployment rhythm of NB-IoT is determined according to the business needs of the operator's Internet of things and the network construction plan.

Table 22 Deployment Scale Selection of NB-IoT

Deployment Scale	Application scene and analysis
1:N	Suitable for the Internet of things early, coverage requirement is low, the business less, from the cost of priority 1:N network, such as 1:4
1:1	Suitable for the development of the Internet of things, high coverage requirements and high capacity

3.1.1.6.1. Spectrum resources

For stand-alone mode, NB-IoT and GSM/UMTS/LTE/CDMA frequency deployment requirements is shown in the following table [13].

Table 23 Frequency deployment requirements for stand-alone mode

	Co-site (1:1)	**Non Co-site (e.g.1:4)**
Interference protective between NB-IoT edge and GSM	100KHz	300KHz and above
Interference protective between NB-IoT edge and UMTS	0KHz (Centre frequency interval 2.6MHz)	0KHz(Centre frequency interval 2.6MHz)
Interference protective between NB-IoT edge and LTE	0KHz	0KHz: bandwidth higher than 5MHz 100KHz guard-band: bandwidth below 5MHz
Interference protective between NB-IoT edge and CDMA	135KHz	285KHz and above

For Guard-band mode, NB-IoT and LTE frequency deployment requirements is shown in the following table.

Table 24 Frequency deployment requirements for guard-band mode

	Co-site (1:1)	**Non Co-site(e.g.1:4)**
RF requirements(SEM or EVM)	>100KHz	>100KHz
Coexistence interference requirements: Edge-to-edge separation of LTE	>100KHz	>200KHz

For In-band mode, NB-IoT and LTE frequency deployment requirements is shown in the following table.

Table 25 Frequency deployment requirements for In-band mode

Guard RB for NB-IoT and LTE	**Co-site(1:1)**	**Non Co-site(e.g.1:4)**
RF requirements(SEM or EVM)	0 RB	0 RB
Coexistence interference requirements	0 RB	1RB

3.1.1.6.2. Antenna solutions

With the original NB-IoT network antenna solutions: independent antenna or common antenna.

NB-IoT independent antenna network cannot rely on the original network antenna, can be optimized independently. Independent antenna solutions can be obtained with respect to antenna network coverage gain greater.

In the antenna conditions to meet the requirements and cost constraint, recommended choice of independent antenna.

The simulation results show that: Independent antenna (optimal angle and direction angle) compared with common antenna coverage gain and edge rate, as shown in the following table.

Table 26 Antenna solutions for NB-IoT

	1:1		**1:2**		**1:4**	
Antenna solutions	Independent antenna	Common antenna	Independent antenna	Common antenna	Independent antenna	Common antenna
Coverage gain relative to the original network	22dB	20dB	19dB	15dB	17dB	10dB

3.1.1.7. Deployment Multi-carrier

NB-IoT wireless network capacity upgrade and expansion, the most direct means is to increase the number of stations and increase the number of carriers. If the existing network is LN 1:N network, it is recommended to increase the number of stations to 1:1 network and then consider the multi-carrier. If the existing network is already the scale of LN 1:1 networking, it is recommended that the above multi-carrier should be considered first.

3GPP R13/R14 protocol supports stand-alone + stand-alone, in-band + in-band, guard-band + guard-band, and guan guard-band + in-band. R15 enhancement supports stand-alone + guard-band, stand-alone + in-band.

In view of the different networking modes of the existing network, the deployment of different carriers should be carried out.

Table 27 Deployment of Multi-carrier mode

NB-IoT existing network	R13/R14	R15
Stand-alone	Stand-alone + Stand-alone	Priority: stand-alone + stand-alone Followed: stand-alone +

NB-IoT existing network	R13/R14	R15
		guard-band Finally: stand-alone + in-band
Guard-band	Priority: guard-band + guard-band Followed: guard-band + in-band	
In-band	Priority: in-band + in-band	

3.1.2. **IoT Small Cells**

3.1.2.1. Scenarios

Editor's note: describe Small Cell specific IoT scenarios. It is need to describe the benefit of using Small Cell in the scenario.

3.1.2.1.1. Areas within Deep Coverage

Areas within deep coverage such as Underground parking garage are where signals from macro cell can hardly reach, so that phones or other communicating modules in these areas can receive only a little signal or even no signals. This is because Macro Cell's eNBs are implemented above the ground, and their signal cannot penetrate through walls without attenuation, even will cause so much loss that no signal can be found by the communication modules.

So in this scenario, to improve the quality of signal, we can implement NB-IoT Qsites according to the layout in these areas within deep coverage, using wired or wireless backhaul to transmit data to EPC Core network. These NB-IoT Qsites as complementary to the Macro Cell eNB serve these specific areas as small cells to make up signal bad or unreachable problems caused by path loss and attenuation, and then to make real full coverage come true.

Moreover, from the point of view of the flexibility of deployment and no need of wired arrangement, small cell stations using wireless backhaul will be much better than that with wired backhual.

3.1.2.1.2. Logistics Tracking

Install a NB-IoTQsite on a truck to track or trace the logistics location, states and other aspects interested. And then these base stations transfer the collected data to EPC core network using wireless backhaul technology.

Using NB-IoTQsites on the trucks can adjust accessing frequency flexibly according to the location where the truck are running, as well as trace logistics.

Meanwhile, the NB-IoTQsite can use only one signaling tunnel to transmit messages from different goods or objects on the truck to the core network by converging instead of using as many signaling tunnels to core network as the amount of the goods or objects which are traced, to reduce Macro Cell signaling expense.

In this scenario, wireless backhaul must be supported, due to the travelling NB-IoTQsites.

3.1.2.1.3. Deployment if needed with low cost

There are some scenarios such as greenfield factory and mine in a mountain district which both have the characteristics with low density of population but concentration in a specific field.

Considering these characteristics, it is a good choice to deploy NB-IoTQsites to cover these specific areas to provide communication capability. Comparing to the deployment of macro cell BS in these scenarios, it will benefit from using NB-IoTQsites with lower cost and much better targeted coverage to provide communication services.

In these scenario, deploy NB-IoTQsites to cover these specific fields and provide communication services using wired or wireless backhaul to the core network.

3.1.2.2. Function Requirements

Editor's note: describe Small Cell specific function requirements.

3.1.2.2.1. NB-IoT Small Cell Function Requirements

1. NB-IoT small cell shall support wireless backhaul, especially for the NB-IoTQsite travelling scenario.
2. NB-IoT small cell shall be able to support converging function.

3.1.2.3. Performance Requirements

Editor's note: describe Small Cell specific performance requirements.

3.1.2.3.1. NB-IoT Small Cell Performance Requirements

1. NB-IoT standalone
2. The capacity shall be no less than 2000 users per cell per day.
3. Output power is no less than 21dBm.

3.2. IoT Network Planning and Optimization

3.2.1. Overview

The NB-IoT planning and optimization process is almost the same as LTE. In the detail. There are some differences between them. The below table shows the similarities and differences between NB-IoT and LTE.

Table 28 Similarities and differences between NB-IoT and LTE

Type	FDD LTE	NB-IoT
Service type	Data Service &VoLTE Service people-to-people communication	thing-to-thing communication (Wireless meter reading, industrial & agricultural device status monitoring, and logistics monitoring)
Service features	High speed, low delay, insensitive to power consumption	Low speed, high delay, and small power consumption
Channel bandwidth	1.4MHz、3MHz、5 MHz、10MHz、15MHz、20MHz	200 kHz
Modulation mode	DL: OFDMA UL: SC-FDMA	DL: OFDMA UL: SC-FDMA
Coverage	NO repetition, max. MCL = 140 dB	Repetition coverage gain, max. MCL = 164 dB
Capacity	Business model: UL & DL data services Volte voice services Estimation of single-cell capacity bearing capability based on the average single-user bandwidth in data services and voice services	Business model: Mobile Autonomous Reporting (MAR) exception reports Mobile Autonomous Reporting (MAR) periodic reports Network Command Software update/reconfiguration model
Penetration loss	Usually, the penetration loss of two walls is taken into account.	As most terminals are in indoor in-depth coverage areas, the penetration loss of more than two walls should be taken into account.

3.2.2. Network Planning

3.2.2.1. Coverage Planning

The target of coverage planning is to get the cell coverage radius based on the link budget calculation.

The link budget mainly includes four parts:

- Analyzing the coverage requirement
- Calculating the maximum allowed path loss for UL and DL
- Calculating the cell coverage radius
- Calculating the site quantity

Analyzing the coverage requirement

Based on the analysis of the existing IoT services which are used in the GPRS network, the throughput of these services is as the following table:

Table 29 Throughout of IoT Services

Server Type	Service Process	Uplink Throughput(bps)	Downlink Throughput (bps)
Smart meter	Uploading of the meter data	128	0
	Account charging, adjustment of prepaid fees, and query of signal strength	512	512
POS machines	Around 10 services, such as consumption, preauthorization, and subscription	965	1163
	Credit point granting for signing in, consumption booking	290	0
Water Quality Monitoring	Data reporting from water monitor terminals	285	160

There are three MCL coverage levels defined in 3GPP protocol: MCL144, MCL154 and MCL164. Compared with GPRS network, the NB-IoT network has 20dB gain in coverage based on the repetition function.

The UE maximum throughput for uplink and down link in three MCL levels is as follows:

Table 30 The throughput in three MCL

MCL Level	DL Throughput (SA mode)	UL Throughput (3.75KHz/15KHz)
MCL144dB	20~25kbps	4~5kbps /15~16kbps
MCL154dB	10~15kbps	2~3kbps
MCL164dB	2~3kbps	0.2~0.4kbps

Services such as smart meter and POS service need high throughput, so standalone mode with MCL154dB is recommended. Other services need lower throughput requirement, so NB-IoT UEs can be deployed in the coverage of MCL164dB.

Finally, in order to meet coverage requirements of most IoT services, the MCL154dB for the cell edge coverage target is recommended.

Calculating the maximum path-loss for UL and DL

The maximum path loss = Transmitter power - Receiver sensitivity + Gains (antenna gain, etc.) - Losses (feeder loss, penetration loss, shadow margin, interference margin etc.)

MCL = Transmitter power - Receiver sensitivity

So, the maximum path loss = MCL + Gains (antenna gain, etc.) - Losses (feeder loss, penetration loss, shadow margin, interference margin etc.)

Based on the formula, the UL max path loss and down link max path loss can be calculated. Choose the minimum value as the final path loss.

Calculating the cell coverage radius

Based on the building height and distribution, four types of clutter classification are defined: Dense urban, Urban, Suburban and Rural.

Table 31 Four clutter classifications

Clutter Classification	Area Description
Dense Urban	Central business districts, dense shopping centers, dense residential areas; dense high buildings; No obvious boundary, nor regular street alignment. Average building height above 40m, and density higher than 35%.
Mean Urban	Industrial parks, shopping centers, residential areas; Clear boundary and regular street alignment. Average building height less than 40m, and density between 8% and 35%.
Suburban	The edge of cities, the center of villages and towns; Most areas with obvious big streets, typically 30*30m buildings, scattered houses, and stretches of vegetation; Building height less than 20m, and density between 3% and 8%.
Rural	Farms, open land, the edge of villages and towns; large open areas, scattered small building; Building height less than 20m, and density less than 3%.

In different clutter classification, some parameters are different. For example, the propagation model and penetration loss are different.

The Okumura-Hata and Cost231-Hata propagation models are always used in the link budget to calculate the cell coverage radius.

Okumura-Hata is applied to 150M~1.5G, whose formula is as the following formula

$$L = 69.55 + 26.16 * \lg(f) - 13.82 * \lg(h_b) - a(h_m) + (44.9 - 6.55 * \lg(h_b)) * \lg(d)^{\gamma} + C_{terrain}$$

The definition of parameters in the formula:

Table 32 Description of parameters

Parameters	Unit	Description
L	dB	The maximum path loss
f	MHz	The frequency band
$\mathbf{h_b}$	meter	eNB antenna Height
$\mathbf{h_m}$	meter	UE antenna height
d	km	Distance from the base station to the mobile station (cell coverage radius)

a(hm) is the correct factor of h_m. The formula is as follows:

$$a(h_m) = \begin{cases} (1.1\lg f - 0.7)h_m - (1.56\lg f - 0.8) & \textbf{medium-small city} \\ \begin{cases} 8.29(\lg 1.54h_m)^2 - 1.1 & 150 < f < 200MHz \\ 3.2(\lg 11.75h_m)^2 - 4.97 & 400 < f < 1500MHz \end{cases} & \textbf{Large city} \end{cases}$$

γ is the correct factor of distance. The formula is as follows:

$$\gamma = \begin{cases} 1 & d \leq 20\ \mathrm{km} \\ 1 + (0.14 + 1.87 \times 10^{-4} f + 1.07 \times 10^{-3} h_b)(\lg \frac{d}{20})^{0.8} & d > 20\ \mathrm{km} \end{cases}$$

$C_{terrain}$ is the correct factor of clutter. In different clutter classification, the values are different. The formula is as follows:

$$
C_{terrian} = \begin{cases} 3 & \textbf{Dense Urban} \\ 0 & \textbf{Urban} \\ -2[\lg(\frac{f}{28})]^2 - 5.4 & \textbf{Suburban} \\ -4.78(\log f)^2 + 18.33\log f - 40.94 & \textbf{Rural} \\ -\left(\lg\frac{f}{28}\right)^2 - 2.39(\log f)^2 + 9.17\log f - 23.17 & \textbf{Open} \end{cases}
$$

Cost231-Hata is applied to 1.5G-2.1G, the formula of which is as follows.

$$
L = 46.3 + 33.9 * \lg(f) - 13.82 * \lg(h_b) - a(h_m) + (44.9 - 6.55 * \lg(h_b)) * (\lg(d))^{\gamma} + C_{terrian}
$$

The parameters are the same as Okumura-Hata model.

Based on the propagation model formula and max allowed path loss, the cell coverage radius can be calculated.

Calculating the site quantity

In order to get the site quantity for coverage planning, firstly the site coverage area can be calculated based on the cell coverage radius.

For three-sectors sites, $D = 1.5 * R$ and $S = 1.95 * R^2$.

R is the cell coverage radius. D is distance of site between site. S is the coverage area of each site.

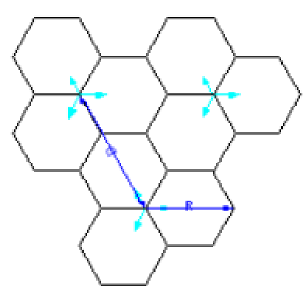

Figure 37 cell radius and area of cell coverage

Secondly drawing the clutter classification based on the digital map and calculate the polygon area.

The site quantity for coverage planning equals the area of clutter classification divided by the site coverage area.

3.2.2.2. Capacity Planning

The target of capacity planning is firstly to analyze the maximum UEs supported by each site based on the traffic model. Secondly to calculate the site quantity for capacity requirement.

Mainly the capacity include three parts:

- Analyzing the capacity requirement (traffic model)
- Calculating the cell capacity (maximum UEs supported)
- Calculate the site quantity

Analyzing the capacity requirement

In 3GPP TR45.820, four typical IoT services type are defined:

- Mobile Autonomous Reporting (MAR) exception reports
- Mobile Autonomous Reporting (MAR) periodic reports
- Network Command
- Software update/reconfiguration model

There will be a large number of capacity requirements for the two services types: Mobile Autonomous Reporting (MAR) periodic reports and Network Command services will.

In 3GPP TR 45820, MAR periodic UL reporting traffic model is provided.

Table 33 Traffic models from TR 45.820

Percentage	Trafficinter-arrival	Traffics/day/UE	Weighted
40%	1day	1	0.4
40%	2hours	12	4.8
15%	1hour	24	3.6
5%	30min	48	2.4
		Average traffics/day/UE	11.2

Calculating the cell capacity (maximum UEs can be supported)

The cell capacity will be calculated based on some assumptions.

Assumption1: The MCL coverage level distribution

Table 34 MCL coverage proportion

MCL（dB）	144	154	164
Proportion	88.42%	9.01%	2.57%

Assumption2: 200byte for each UL services

Based on the TBS=1000, then 200byte package (1600 bit) will be put in two TBS.

The signaling process for 200byte UL services is as follows:

Msg1（RPACH）

2. Msg2（PDCCH-PDSCH）

3. Msg3（PUSCH)

4. Msg4（PDCCH-PDSCH-ACK）

5. Msg5（PDCCH-PUSCH）

6. UL 200byte data1 transmission（PDCCH-PUSCH）

7. UL 200byte data2 transmission（PDCCH-PUSCH）

8. UL RLC ACK（PDCCH-PDSCH）

9. RRC Release（PDCCH-PDSCH-ACK）

The UL resource overhead includes RPACH message, Msg3/Msg5 UL signaling message and 3 times ACK/NACK message.

The down resource overhead includes 7 times PDCCH message and Msg2/Msg4/RRC release message.

Based on the assumptions above, the NB-IoT cell in standalone mode can support about 50 thousand UEs.

Calculating the site quantity

For three-sector site, the site capacity equals 3 * cell capacity.

The site quantity for capacity planning equals the capacity of clutter classification divided by the site capacity.

3.2.2.3. Frequency Planning

The frequency planning of NB-IoT is a little complex than LTE. The inter frequency of NB-IoT should be calculated.

For NB-IoT inter frequency calculation, there are some conditions:

- The channel raster is an integer multiple of 100 kHz, and in standalone mode the inter frequency is the same as channel raster.
- The DL carrier center frequency of NB-IoT will not be an integer multiple of 100 kHz in guard-band or in-band operation mode. The frequency offset between NB-IoT center frequency and channel raster should be no more than 7.5 KHz.
- The frequency offset between NB-IoT center frequency and channel raster should be ± 2.5KHz and 7.5KHz.
- In guard-band mode, the edge-to-edge frequency separation of LTE DL band and NB-IoT DL band is an integer multiple of 15 kHz

The available center frequency for guard-band and in-band mode is in the chapter 6.1.4.

3.2.3. **Network Optimization**

3.2.3.1. RF Optimization

At the current stage, the mainly network optimization is the RF optimization. For example the down-tilt optimization to control the overlapping area.

When NB-IoT and LTE use the dual mode RRU, it is better to optimize the LTE network structure first. Because, firstly, the qualities of the LTE and the NB-IoT are similar based on the dual mode. Secondly, the LTE drive test tools are more useful than NB-IoT tools.

In the commercial network, the NB-IoT RSRP and SINR pre and post LTE RF optimizations is as follows:

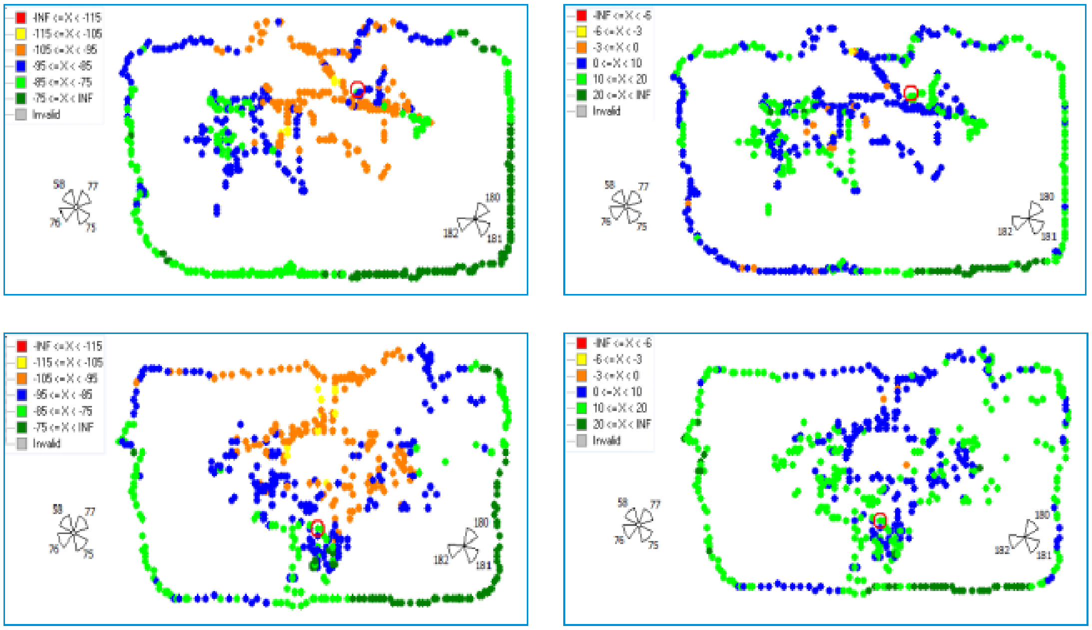

Figure 38 NB-IoT RSRP and SINR pre and post LTE RF optimizations

The average NRSRP is improved from -82.56 to -79.52dBm. And the NRS SINR is improved from 3.14dB to 7.63dB.

Table 35 NB-IoT RSRP and SINR pre and post LTE RF optimizations

	Network	Average RSRP	Average SINR
Pre-Optimization	NB(RS=29.2)	-82.56	3.14
	LTE(RS=18.2)	-89.86	9.23
Post-Optimization	NB(RS=29.2)	-79.52	7.63
	LTE(RS=18.2)	-88.38	12.25

3.2.3.2. Radio Parameters Optimization

The radio parameter optimization is related with the performance algorithm. After the UEs increase in the commercial network, the algorithm improved will be considered.

4. Conclusion

With the rapid development of Internet and mobile Internet, the Internet of things is coming into an outbreak period. As a result, the demand for massive and diversified connection has also promoted the emergence of a new intelligent ecosystem composed of cellular technology and networking. LTE technology based networking technology is new, application of IoT brings many advantages, including wide coverage, predictable deepening of network service quality, high reliability, stable end to end security support and global standards for seamless interoperability, will bring more opportunities for networking.

NB-IoT and eMTC due to the different application scenarios, the operators will choose two collaborative, jointly expand the industrial chain, continue to boost consumption upgrade, B terminal manufacturers to provide more not the application scene of technical limitations, let the C end users to enhance the experience, stimulate the rigid demand of users, and lay the foundation for the integration of 5G and the development of the industry, which will be the future integration of NB-IoT and eMTC in the development of the road.

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