COMPUTER & ELECTRONIC
ENGINEERING

NB-IoT and eMTC in NTN

Applications (1)

- NB-IoT/eMTC satellite access is designed to deliver IoT and machine-type communication (MTC) services for sectors like agriculture, transport, logistics, and security. When 5G services for satellite were first studied in 3GPP Release-15, an initial classification for massive MTC (mMTC) was defined in TR 38.811. It includes two main categories
- 1. **Wide-Area IoT**.
These involve large groups of fixed or mobile sensors/actuators spread across a broad region. Devices send data to, or receive commands from, a central server. Potential use cases include:
  - Automotive and transportation: High-density vehicle platooning, HD map updates, traffic optimization, vehicle software updates, diagnostics, usage-based insurance, safety status reports (e.g., airbag deployment), targeted advertising, context-aware information, and remote vehicle access (e.g., unlocking doors).
  - Energy: Monitoring critical infrastructure, such as long-distance oil and gas pipelines.
  - Transportation & logistics: Fleet management, asset tracking, and remote road alerts.
  - Smart agriculture: Livestock monitoring and farming applications.

Applications (2)

- 2. **Local-Area IoT**

  A cluster of sensors shares local data, communicates internally, and sends information to a central controller. This controller can also operate actuators to perform local tasks. These systems are typically used in:

  - Smart grid subsystems (e.g., advanced metering)
  - Moving platforms such as shipping containers, trucks, or trains

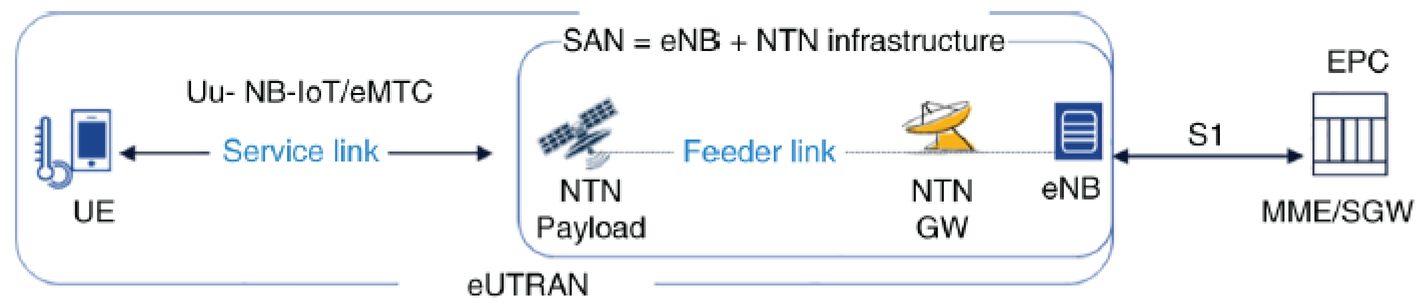
Bandwidths

- N255
- Is a 3GPP band introduced for 5G NTN (Non-Terrestrial Networks), e.g. direct-to-device satellite communications.
- Frequencies
  Uplink (UL): 1626.5 MHz – 1660.5 MHz
  Downlink (DL): 1525 MHz – 1559 MHz
  FDD (Frequency Division Duplex)
  Duplex spacing: –101.5 MHz
- Channel Bandwidths Supports
  channel bandwidths of 5, 10, 15, 20 MHz.
- Defined in 3GPP Release 17.
- Use Cases - Good for remote areas, IoT devices, or where terrestrial coverage is poor

Bandwidths

- N256
- Is a 3GPP band introduced for 5G NTN (Non-Terrestrial Networks), e.g. direct-to-device satellite communications.
- Frequencies
  Uplink (UL): 1980 MHz – 2010 MHz
  Downlink (DL): 2170 MHz - 2200 MHz
  FDD (Frequency Division Duplex)
- Channel Bandwidths Supports
  channel bandwidths of 30 MHz.

Architecture



UE maximum output power in NTN

EUTRA band	Class 3 (dBm)	Tolerance (dB)	Class 5 (dBm)	Tolerance (dB)
256	23	±2	20	±2
255	23	±2	20	±2

[1] 3GPP TR 36.763 V17.0.0: "Study on Narrow-Band Internet of Things (NB-IoT)/enhanced Machine Type Communication (eMTC) support for Non-Terrestrial Networks (NTN) (Release 17)", June 2021.

Architecture

NB-IoT/eMTC reference scenarios from TR 36.763

Scenario	Orbit	Altitude (km)	Payload type	Coverage
A	GEO	35 786	Transparent	Earth-fixed beams
B	LEO	600, 1200		Earth-fixed beams
C	LEO	600, 1200		Earth-moving beams
D	MEO	10 000		Earth-moving beams

Set-1 of satellite parameters for NB-IoT/eMTC

Parameter	**GEO, 35 786 km**	**LEO, 1200 km**	**LEO, 600 km**
Satellite antenna pattern	Clause 6.4.1 in TR 38.811		
Central beam edge elevation	2.3°	26.3°	27.0°
Central beam center elevation	12.5°	30°	30°
Half Power Beam Width (HPBW)	0.4011°	4.4127°	
Equivalent satellite antenna aperture	22 m	2 m	
EIRP density	59 dBW/MHz	40 dBW/MHz	34 dBW/MHz
Maximum TX/RX gain	51 dBi	30 dBi	
G/T	16.7 dB/K	−12.8 dB/K	
Beam diameter at nadir	250 km	90 km	50 km

Set-2 of satellite parameters for NB-IoT/eMTC

Parameter	GEO, 35 786 km	LEO, 1200 km	LEO, 600 km
Satellite antenna pattern	Clause 6.4.1 in TR 38.811		
Central beam edge elevation	11.0°	22.2°	23.8°
Central beam center elevation	20°	30°	30°
Half Power Beam Width (HPBW)	0.7353°	8.8320°	
Equivalent satellite antenna aperture	12 m	1m	
EIRP density	53.5 dBW/MHz	34 dBW/MHz	28 dBW/MHz
Maximum TX/RX gain	45.5 dBi	24 dBi	
G/T	14 dB/K	−4.9 dB/K	
Beam diameter at nadir	450 km	190 km	90 km

Set-3 of satellite parameters for NB-IoT/eMTC

Parameter	GEO, 35 786 km	LEO, 1200 km	LEO, 600 km
Central beam edge elevation	12.5°	30°	
Central beam center elevation	20.9°	46.05°	43.78°
Half Power Beam Width (HPBW)	0.7353°	22.1°	
Equivalent satellite antenna aperture	12 m	0.m	
EIRP density	59.8 dBW/MHz	33.7 dBW/MHz	28.3 dBW/MHz
Maximum TX/RX gain	45.7 dBi	16.2 dBi	
G/T	16.7 dB/K	−12.8 dB/K	
Beam diameter at nadir	459 km	470 km	234 km

Set-4/5 of satellite parameters for NB-IoT/eMTC

Parameter	LEO, 600 km
Central beam edge elevation	30°
Central beam center elevation	90°
Half Power Beam Width (HPBW)	104.7°
Equivalent satellite antenna aperture	0.097 m
EIRP density	21.45 dBW/MHz
Maximum TX/RX gain	11 dBi
G/T	−18.6 dB/K
Beam diameter at nadir	1700 km

Parameter	MEO, 10 000 km
Central beam edge elevation	81.6°
Central beam center elevation	90°
Half Power Beam Width (HPBW)	6.5°
Equivalent satellite antenna aperture	1.5 m
EIRP density	45.4 dBW/MHz
Maximum TX/RX gain	28.1 dBi
G/T	3.8 dB/K
Beam diameter at nadir	1140 km

Bandwidth

- Operating bands

E-UTRA operating band	Uplink (UL) operating band BS receive UE transmit	Downlink (DL) operating band BS transmit UE receive	Duplex mode
	F_{UL_low}–F_{UL_high}	F_{DL_low}–F_{DL_high}	
256	1980 MHz–2010 MHz	2170 MHz–2200 MHz	FDD
255	1626.5 MHz–1660.5 MHz	1525 MHz–1559 MHz	FDD

For category NB1 and NB2		For category M1	
Channel bandwidth $BW_{Channel}$ (kHz)	200	Channel bandwidth $BW_{Channel}$ (MHz)	1.4
Transmission bandwidth configuration N_{RB}	1	Transmission bandwidth configuration NRB	6
Transmission bandwidth configuration $N_{tone\ 15kHz}$	12		
Transmission bandwidth configuration $N_{tone\ 3.75kHz}$	48		

Timing and frequency compensation

- The network provides the information needed to access an NTN cell in SIB31. This includes satellite ephemeris data and common Timing Advance (TA) parameters. Before connecting to an NTN cell, an IoT device must obtain its GNSS position and receive the satellite ephemeris and common TA information.
- For uplink synchronization, IoT NTN follows the same approach as NR NTN. Before performing random access (RA), the IoT device must have valid GNSS position, satellite ephemeris, and common TA. Using this information, it must pre-compensate for Timing Advance and Doppler shift based on the satellite's position and its own location.
- Once in RRC connected mode, the UE must continually update its Timing Advance and frequency pre-compensation but does **not** need to redo GNSS acquisition. The UE stops transmitting if its ephemeris, common TA, or GNSS data become outdated, based on defined timers.
- In connected mode:
  - If satellite ephemeris or common TA becomes outdated, the UE re-acquires the broadcast information.
  - If the GNSS position becomes outdated, the UE transitions to idle mode.

Timing Advance

- Timing Advance formula for NTN can be transposed to IoT-NTN with Ts used instead of Tc.
- The timing advance is given by:

$$T_{TA} = \left(N_{TA} + N_{TA,offset} + N_{TA,adj}^{common} + N_{TA,adj}^{UE}\right) T_s$$

where T_s is given by $T_s = (15000 \cdot 2048)^{-1}$ ms

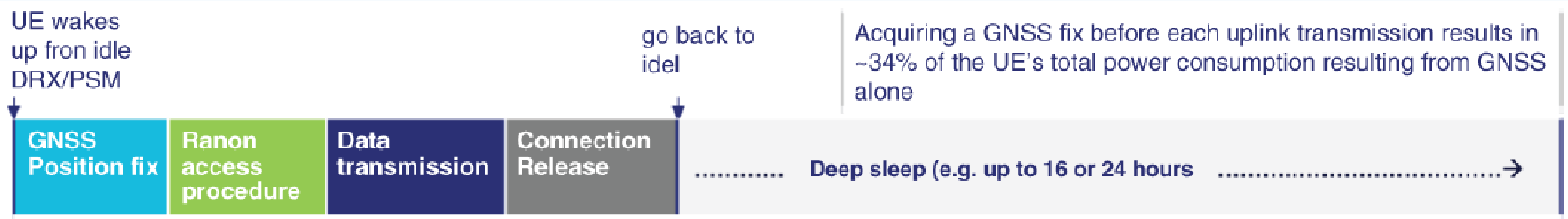
- $N_{TA,adj}^{UE}$ is UE self-estimated TA to pre-compensate for the service link delay. It is computed by the UE based on UE position and serving satellite-ephemeris-related higher-layers parameters if configured, otherwise $N_{TA,adj}^{UE}$ =0.

Power efficiency

- UE power efficiency is a key consideration in IoT NTN design. Because uplink time and frequency synchronization depends on GNSS, the power impact of obtaining a GNSS position fix becomes a critical issue. In Release-17 studies on NB-IoT/eMTC support for NTN, battery-life evaluations were performed assuming a GNSS position fix for every uplink transmission. These studies examined both GNSS power consumption (for integrated GNSS–IoT modules and for separate modules) and the effect of GNSS Time To First Fix (TTFF) on UE power usage, following the battery-life methodology in TR 45.820.

- The studies showed that GNSS acquisition time is about 30 seconds for a cold start (where the terminal has no prior satellite information), and only a few seconds for a warm start (where rough position, timing, and almanac data are already available), and up to 2 seconds in hot start (the terminal has accurate position, timing, and almanac data to start from).

Energy efficiency



- For short and sporadic connections, acquiring a GNSS fix before each uplink transmission accounts for about 34% of the UE’s total power consumption. This means that moving IoT devices—such as tracking devices that frequently send short bursts of data—may experience significant power drain due to repeated GNSS position fixes. In contrast, fixed IoT devices (e.g., smart meters or water meters) can save power by using a much less frequent GNSS fix, such as once per week or once per month, depending on their requirements. .

Energy efficiency

- For long connections using connected-mode DRX with a ~10-second DRX cycle (Figure 8.6), [1] reports that obtaining a GNSS fix before each uplink transmission consumes around 45% of the UE's total available energy when no additional power-saving enhancements are used. To address this, 3GPP Release-17 introduced a mechanism for GNSS position-fix validity for sporadic short transmissions in RRC CONNECTED mode.
- In this mode, an idle UE wakes from DRX/PSM, accesses the network, performs brief uplink/downlink communication, and then returns to idle. Before accessing the network, the UE acquires a GNSS fix once, and does not need to reacquire it for every packet transmission. If the GNSS fix becomes outdated, the UE in RRC_CONNECTED must return to idle mode and reacquire a valid fix.

Energy efficiency

- The UE autonomously determines how long its GNSS fix remains valid, known as gnss-validityDuration, and reports this to the network via RRC signaling. Examples include:
  - s10 → 10 seconds
  - s20 → 20 seconds
  - min5 → 5 minutes
  - min10 → 10 minutes
- The UE reports the GNSS-ValidityDuration in the following RRC messages:
  - RRCConnectionSetupComplete-NB (after completing connection establishment)
  - RRCConnectionReconfiguration
  - CompleteRRCConnectionReestablishmentComplete-NB
  - RRCConnectionResumeComplete-NB
- These messages confirm the successful completion of connection reconfiguration, reestablishment, and resumption, respectively.

Towards 6G – a work plan hypothesis

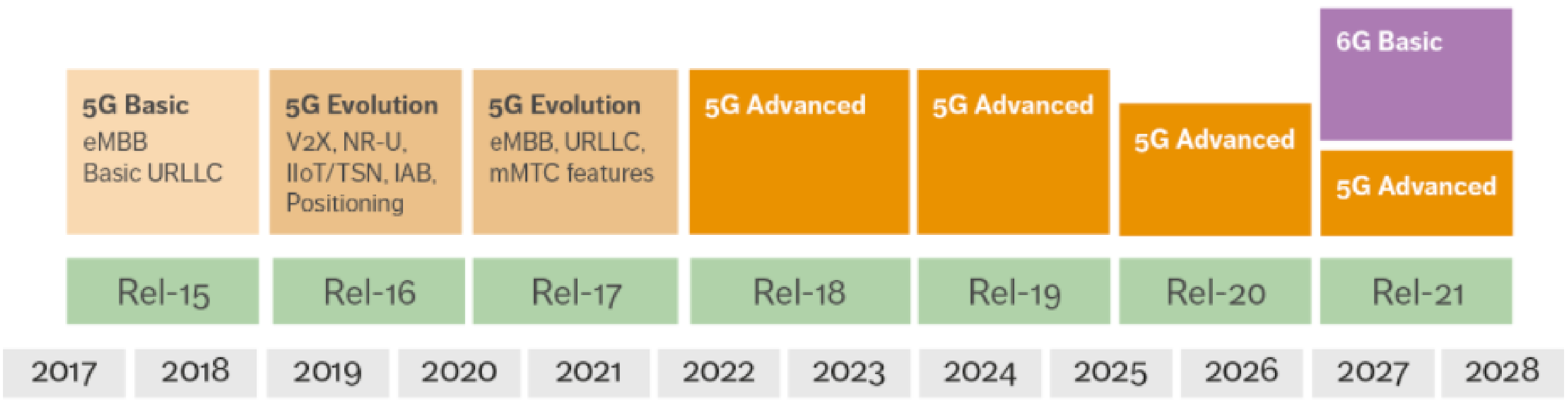


Figure 1 - 3GPP's 5G evolution tentative time plan