NB-IoT-U: The Next Generation Dedicated IoT Network for Enterprise Customers

MULTEFIRE®

I. Overview of NB-IoT-U

1. Motivation to Enable Cellular NB-IoT in License-Exempt Spectrum, and the Relation to 3GPP NB-IoT

NB-IoT is a LPWA (Low Power Wide Area) communications technology which was originally designed in 3GPP in Release 13 for wireless network operators, and has been continuously enhanced in 3GPP Releases 14, 15, and 16. NB-IoT is now evolving as one of the key technologies for 5G next generation wireless system. By the end of 2018, there were around 60 commercial NB-IoT networks launched in nearly 40 countries according to industry sources (e.g., GSMA, GSA, analysts), and market adoption is progressing at an accelerating rate.

Meanwhile, some enterprise customers in the verticals require an LPWA solution that can be deployed in license-exempt spectrum (rather than the licensed spectrum used by 3GPP NB-IoT deployments). For license-exempt deployments, a solution that shares the cellular IoT eco-system will not only satisfy the requirements from enterprise customers for a dedicated IoT network, but will also benefit from expanded chipset volume, and hence lower cost since the same chipset can be used for both licensed and license-exempt variants of NB-IoT. A further benefit is that inter-RAT cell selection between licensed and license-exempt variants could be supported.

Technically, many of the advanced wireless techniques in 3GPP cellular system offer better performance for IoT connections and can also be adapted to license-exempt spectrum. This addresses the concerns in the market on the performance issues of existing proprietary LPWA systems, such as quality of service and cell capacity. The cellular techniques include advanced modulation schemes, high performance FEC (Forward Error Correction), adaptive modulation and coding, transmit diversity, Hybrid ARQ, etc. Most of the existing LPWA systems are either fully or partially proprietary and have tended to adopt relatively simple technical approaches which inevitably compromise performance. For example, as the number of IoT connections increases, these compromises will have a large impact on network performance and reliability.

MulteFire is in a unique position to enable cellular NB-IoT in license-exempt spectrum by adapting the established and proven 3GPP NB-IoT technology. The resulting technology is referred to as NB-IoT-U and is the next generation LPWA technology, long desired by the market.

2. Spectrum and Coexistence with Other Systems

NB-IoT-U is designed for wide area coverage and can operate in the low frequency bands below 1 GHz since such frequencies have favorable radio propagation characteristics. Although NB-IoT-U is not limited to sub-1 GHz frequencies, it has been particularly optimized for the 902-928 MHz band governed by FCC regulations, and for bands within the 865-870 MHz band governed by EU regulations. For example, NB-IoT-U performs frequency hopping for data transmissions under the FCC regime, while it is duty cycle limited under the EU SRD regime. Both mechanisms reduce the probability of collisions with the transmissions from other systems in the shared spectrum without having to resort to LBT (Listen-before-Talk), which can be unreliable in the case that two devices are far apart yet are both within range of the same base station. In future evolution of the standard, NB-IoT-U could also be adapted to the worldwide 2.4 GHz ISM band, for applications in which coverage is not the primary requirement.

a. The SRD Bands in Europe

The bands of interest for NB-IoT-U in Europe are known as Short Range Device (SRD) bands at around 865 – 870 MHz [1]. Typical SRD applications include social alarms, analog audio, RFID and a number of other uncoordinated, low-power applications. Table 1 shows the relevant bands from the EU Decision 2017/1483 [2], i.e. there are five channels currently available for IoT connections in EU SRD bands, which fulfil the 200kHz bandwidth[1] and 500mW (e.r.p.) transmit power limitation property targeted by NB-IoT-U, one channel in band 54, and four channels in band 47b.

[1]Band 54 is actually 250 kHz in bandwidth but allows operation at narrower passband bandwidths.

Band	Frequency Range	Category of SRD	Transmit power limit/field strength limit/power density limit	Additional parameters (channelling and/or channel access and occupation rules	Other usage restrictions	Implementation deadline
47b	865-868 MHz	Non-specific short-range devices	500 mW e.r.p. Transmissions only permitted within the bands 865.6-865.8 MHz, 866.2-866.4 MHz, 866.8-870.0 MHz and 867.4-867.6 MHz. Adaptive Power Control (APC) required. Alternatively, other mitigation technique with at least an equivalent level of spectrum compatibility.	Techniques to access spectrum and mitigate interference that provide at least equivalent performance to the techniques described in harmonised standards adopted under Directive 2014/53/EU must be used. Bandwidth: ≤ 200 kHz. Duty cycle: ≤ 10% for network access points, Duty cycle: ≤ 2.5% otherwise.	This set of usage conditions is only available for data networks.	1 January 2018
54	869.4-869.65 MHz	Non-specific short-range devices	500 mW e.r.p.	Techniques to access spectrum and mitigate interference that provide at least equivalent performance to the techniques described in harmonised standards adopted under Directive 2014/53/EU must be used. Alternatively, a Duty cycle limit of 10 % may also be used.	Analogue video applications are excluded.	1 July 2014

Table 1. SRD bands Currently Available for NB-IoT-U Devices in Europe [2]

The downlink transmit duty cycle can be up to 10% for each channel if used by individual transmitters, but in band 47b this limit applies in total across the four subbands. Uplink duty cycle ranges from 2.5% to 10% depending on the frequency band. Multiple 200 kHz channels are sufficient for multi-cell networking while avoiding interference between adjacent cells. Band 54 has been available for 500 mW devices since 2014. For band 54, the harmonized standard EN 300 220-2 [3] is in place and can be applied. On band 47b there is a restriction in use to data networks, which means that the regulations require all devices to operate under the control of a network access point. ETSI is developing new harmonized standards that would be applicable for such networked devices.

Due to EU Decision 2018/1538[2], more SRD bands are foreseen to become available for IoT in EU, which further increases the attractiveness of these frequency bands for IoT connections.

b. The 902-928 MHz Band by FCC Regulations

In the United States, FCC rules [3] have provisions for the use of license-exempt devices (radiators) based on three types of operation: frequency hopping (FHSS), digitally modulated (DTS) and hybrid. All of these mechanisms can be used at the 902 – 928 MHz ISM band. Table 2 and 3 provide a summary of the FCC regulatory requirements at 902-928 MHz for a FHSS and a DTS system, respectively.

[2]COMMISSION IMPLEMENTING DECISION (EU) 2018/1538 of 11 October 2018 on the harmonization of radio spectrum for use by short-range devices within the 874-876 and 915-921 MHz frequency bands, could introduce up to six additional 200 kHz bands for data networks.

Number of Hopping Frequencies	Average Occupancy Per Channel	Maximum Tx Power
At least 50	400 ms/20 s	30 dBm (1 W)
At least 25	400 ms/10 s	24 dBm (250 mW)

Table 2. FCC regulations on frequency hopping systems at 902-928 MHz

For FHSS the maximum allowed 20 dB bandwidth of the hopping channel is 500 kHz, which is easily met by the NB-IoT-U waveform, and the system uses 64 channels for its hopping sequence. NB-IoT-U meets the pseudo randomness requirement of the hopping frequencies with a non-repeating hopping pattern extending across one hyper frame of 40.96 s. The hopping pattern is set by the base station for devices under its control and it ensures that each frequency is used equally on the average by each transmitter.

6 dB Bandwidth	Maximum Power Spectral Density	Maximum Tx Power
>500 kHz	8 dBm/3 kHz	30 dBm (1 W)[1]
[1]Antenna directional gain not exceeding 6 dBi		

Table 3. FCC Regulations on Digitally Modulated Systems at 902-928 MHz

In the downlink, NB-IoT-U adopts hybrid operation. FCC specifies rules for hybrid devices by combining certain FHSS and certain DTS requirements to allow devices to operate under the FHSS rules in some operating modes and the DTS rules at other times. Recent clarifications of the Hybrid mode of operation is contained in the FCC Measurement Guidance [4]. Under the hybrid operation, the NB-IoT-U downlink uses DTS on its anchor segment and FHSS on its data segment.

c. Coexistence with Other Systems

NB-IoT-U is designed to have very good coexistence properties for sharing license-exempt spectrum with other systems that may be operating nearby. NB-IoT-U achieves coverage extension by time-spreading in which multiple repetitions are applied in the time domain under the control of adaptive modulation and coding. This means that NB-IoT-U is inherently robust in license-exempt spectrum as the signal can still be recovered at the receiver if a subset of repetitions is corrupted by collisions with transmissions from another license-exempt system. Furthermore, when utilizing FHSS, NB-IoT-U is additionally a frequency-spread system since the transmissions are distributed across a wide bandwidth, which improves further the communication robustness.

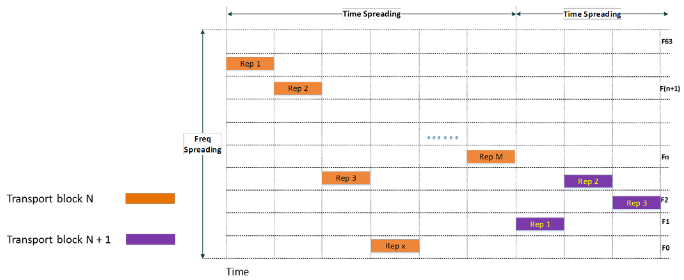

Figure 1. Illustration of Frequency Spreading and Time Spreading for NB-IoT-U

NB-IoT-U is designed such that the base station (referred to as eNB in 3GPP terminology) and device (referred to as UE in 3GPP terminology) receiver bandwidths can be limited to 180 kHz. In other words, the base stations and devices only need to receive a 180 kHz bandwidth at any point in time, with the center frequency of the 180 kHz potentially changing over time according to the frequency hopping pattern.

This means that the co-channel interference inherent in wideband systems can be considerably reduced through the selectivity of the narrowband receiver, as shown in Figure 2. This is also helpful in reducing receiver complexity and power consumption, since the ADC sampling rate can be also reduced.

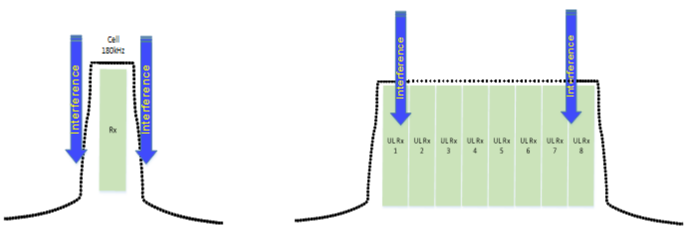

Figure 2. Interference rejection by a narrow band system

3. Summary of the Design and the Key Features

The frame structure for NB-IoT-U under FCC regime is illustrated in Figure 3. The anchor segment for the downlink mainly contains information required for a device to synchronize to the network and complies with the digital modulation regulations in FCC. The data segment for both downlink and uplink is designed to comply with the FHSS regulations.

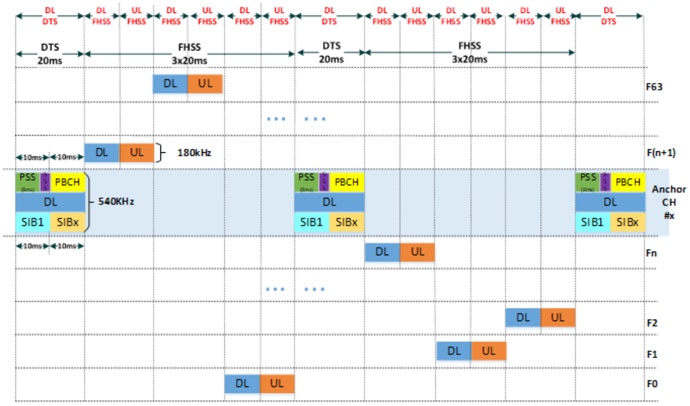

Figure 3. Frame structure for FCC regulations

In order to operate in SRD bands in the EU, the frame structure is modified such that the system utilizes a single 200 kHz channel (without FHSS) and with a 10% downlink transmit duty cycle constraint applied on the channel (which means that the frame structure is scaled in the time domain in order to achieve the required duty cycle). The synchronization signal has the same format for both FCC and EU frame structures, which means that a device can synchronize to either frame structure without a-priori knowledge.

Some key features of NB-IoT-U include:

- Extended coverage: depending on the allowed transmission power, the coverage defined in terms of maximum path loss (MPL) can be as large as 161dB (for FCC) and 154dB (for EU).
- Low power consumption for battery operated IoT devices: the system is optimized for battery operated IoT communications. For typical IoT traffic (a few hundreds of bytes every two hours), a device with 3 AAA batteries could operate for multiple years of communication life.
- Low cost device: the system is optimized to support a terminal chipset with very low complexity resulting in very low device cost. Furthermore, a common chipset design can support both 3GPP NB-IoT and NB-IoT-U, which provides further benefits of scale.
- Massive connectivity: Each base station is capable of supporting thousands of IoT devices following the typical traffic pattern specified in 3GPP TR45.820.
- Roaming between licensed and license-exempt networks: Since a common chipset design can support both 3GPP NB-IoT and license-exempt NB-IoT-U, without any significant cost overhead, it is feasible for devices to roam between licensed and license-exempt networks where this is beneficial to the IoT vertical.

4. Summary of the Design and the Key Features

a. Sharing the Ecosystem with 3GPP NB-IoT Through a Common Design

The underlying channel bandwidth (180kHz at receiver), modulation schemes (OFDM on downlink, SC-FDMA on uplink), coverage enhancement techniques and forward error correction schemes (convolution coding on downlink, turbo coding on uplink) are identical between 3GPP NB-IoT and NB-IoT-U. The key changes between 3GPP NB-IoT and NB-IoT-U relate to the lower physical layer, where the synchronization and broadcast channels (NPSS, NSSS and NPBCH) have been modified to satisfy the license-exempt regulations while achieving the target performance for NB-IoT-U. Other physical channels and physical layer procedures defined by 3GPP NB-IoT are retained with only minimal changes for NB-IoT-U. Similarly, the higher layer procedures are almost unchanged compared with 3GPP NB-IoT. This commonality between 3GPP NB-IoT and NB-IoT-U means that NB-IoT-U benefits from the advanced techniques developed within 3GPP for LTE and subsequently NB-IoT (which can be considered as an ultra-lightweight version of LTE in terms of the physical layer). It also means that it is straightforward for a common chipset design to support both standards.

The NB-IoT-U signals/channels are compared to 3GPP NB-IoT in Table 4.

Channels	3GPP NB-IoT	MulteFire NB-IoT-U
Primary Sync	NPSS (Narrow-band Primary Synchronization Signal)	MF-NPSS (part of NDRS)
Secondary Sync	NSSS (Narrow-band Secondary Synchronization Signal)	MF-NSSS (part of NDRS)
Broadcast	NPBCH (Narrow-band Physical Broadcast Channel)	MF-NPBCH (part of NDRS)
Random Access	NPRACH (Narrow-band Physical Random Access Channel)	Same as 3GPP NB-IoT
Uplink Control	NPUCCH (Narrow-band Physical Uplink Control Channel)	Same as 3GPP NB-IoT
Uplink Data	NPUSCH (Narrow-band Physical Uplink Shared Channel)	Same as 3GPP NB-IoT
Downlink Control	NPDCCH (Narrow-band Physical Downlink Control Channel)	Same as 3GPP NB-IoT
Downlink Data	NPDSCH (Narrow-band Physical Downlink Shared Channel)	Same

Table 4. Comparison of physical channels in 3GPP NB-IoT and NB-IoT-U

b. NB-IoT-U Shares the Ecosystem of 3GPP NB-IoT

The NB-IoT ecosystem mainly consists of chipset vendors, terminal module vendors, network equipment vendors, and application integrators. A comprehensive lists of ecosystem partners can be found in [5]. NB-IoT-U can share the full ecosystem of NB-IoT due to the considerable similarities between the technologies, whilst also supporting new entrants into the ecosystem who wish to focus on Enterprise applications in license-exempt spectrum.

Availability of the NB-IoT-U chipset is of the most critical importance for ecosystem development. There are already more than 14 3GPP NB-IoT chipset vendors in the marketplace, which include all the major semi-conductor vendors in the cellular market. As highlighted in the previous sections, NB-IoT-U can be implemented based on the same silicon as a 3GPP NB-IoT chipset, typically through software changes. Furthermore, a chipset supporting dual-mode operation of 3GPP NB-IoT and NB-IoT-U will enable more applications where support for roaming between licensed and license-exempt is beneficial, which will increase the total market size and further reduce the chipset cost for both NB-IoT and NB-IoT-U.

5. Applications Supported by NB-IoT-U

There is a huge number of IoT applications in the LPWA market, ranging from smart city applications to smart metering [6]. All such applications can be supported by NB-IoT-U.

a. Non-exhaustive List of Applications that Can be Supported by NB-IoT-U:

- Smart City: Smart Water Leakage Detection, Smart Flood Sensors, Smart Bus Schedule Signs, Smart Street Lighting, Smart Waste Management, Real-Time Acoustic Monitoring, Parking management
- Smart Home and Building: Smart Fire Evacuation, Smart Door Locks, Smart Home Management, Building security management
- Smart Industrial control and campus: Sensing at harsh industrial environment, Industrial temperature monitoring, Liquid pipeline monitoring, Tank monitoring
- Smart Supply Chain & Logistics: Cargo Tracking, Bike Share Location Tracking, Airport Asset Tracking, Stolen Vehicle Recovery, Shipping Container Tracking
- Smart Agriculture: Autonomous Irrigation, Cattle tracking and heath monitoring, Smart Soil Sensors, Precision farming
- Smart Environment: Natural Disaster Communication, Endangered Species Protection, Radiation Leak Detection, Air Pollution Monitoring, Drink water source monitoring
- Smart Metering: Real-Time Water Metering, Real-time electrical metering, Gas metering, Electrical transformer monitoring

b. What Benefits Can be Provided by Using NB-IoT-U for IoT Communications?

Many standardized IoT applications require multiple two-way interactions between an application server and the terminals, a typical example being electricity metering. If the throughput performance of an IoT system is not capable of supporting the native service, the whole application has to be tailored to cope with the limitations of the communications system which will result in a non-standard solution and also a significant cost for application re-engineering. Furthermore, it will be difficult and expensive to duplicate these customized solutions across multiple verticals and this will eventually damage the whole eco-system. As described in Section III, NB-IoT-U is a relatively high throughput LPWA system (much higher peak data rates than some other LPWA IoT technologies) which means that NB-IoT-U can be seamlessly integrated into such applications.

Furthermore, NB-IoT-U is a synchronized network where random access is only used for initial network access and then subsequent transmissions are scheduled by the base station. This is attractive for quality of service since reliable delivery can be ensured by the acknowledgement and retransmission system (HARQ). Furthermore, the shortest transmission delay can be as low as 40 ms where latency rather than coverage extension is the priority. In this scenario, NB-IoT-U is a good solution for delay sensitive applications such as industrial monitoring and control.

It is expected that the number of IoT connections will become very high, particularly in scenarios such as smart campus or smart port. This means that the communications technology must be robust to heavy loading of the network. Technologies that rely heavily on random access will suffer severe reliability degradation in this environment. In contrast, NB-IoT-U uses scheduled transmissions with HARQ to ensure reliability, which ensures better performance as cell loading increases.

As described in previous sections, NB-IoT-U re-uses the same underlying modulation, coding, transmit diversity, adaptive rate control, retransmission schemes, etc., as 3GPP NB-IoT, which in turn was derived from LTE. These advanced techniques mean that NB-IoT-U has a coverage advantage over other LPWA technologies. This coverage advantage directly reduces the number of base stations required to cover a certain geographical area and this converts to a cost reduction of the network deployment

II. How to Make NB-IoT Operational in License-Exempt Spectrum

1. Design of the Common Discovery Reference Signal

a. Principles to Maximize the Commonalities Between Different Regions

NB-IoT-U is designed to operate in license-exempt spectrum under different regulatory regimes, termed Operation modes. NB-IoT-U introduces a narrowband discovery reference signal (NDRS) which shares the initial access part across regions to enable a common initial access procedure for a device regardless of where it accesses the NB-IoT-U radio access network.

The common part of NDRS that is shared across regions is illustrated in Figure 4, and it has the following components:

- MulteFire narrowband primary and secondary synchronization signals (MF-NPSS/MF-NSSS)
- Master Information Block (MIB-NB-MF) via the MulteFire NPBCH (MF-NPBCH)

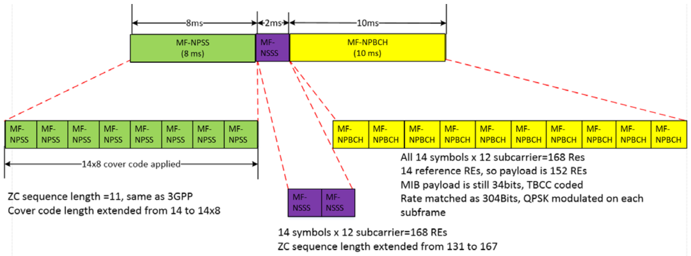

Figure 4. Common NDRS in NB-IoT-U

The Master Information Block (MIB) has a total length of 34 bits, which is identical to 3GPP NB-IoT. The content of the MIB block is very similar regardless of the region in which the UE operates, with the only bit level difference being the presence of the MSB of the system frame number for FCC deployments. The operation mode information indicates whether this field is present. Operation mode information also tells the NB-IoT-U UE how to interpret the field values in subframe assignment and System Information Block Type-1 (SIB1) scheduling information elements.

	Size	Notes
hyperSFN-LSB	2bits	
schedulingInfoSIB1	4 bits	
systemInfoValueTag	5 bits	
Ab-Enabled	1 bit	
Subframe assignment	3 bits	
Operation mode info	2 bits	Choice of 4 options
systemFrameNumber-MSB	If Operation Mode 1 (FCC), 4 Bits If Operation Mode 2 (EU), 0 Bits	
Spare	13 (FCC) or 17 (EU) bits	
Total	34 bits	

Table 5. The Contents of Master Information Block

Subframe assignment field in the MIB indicates the assignment of DL and UL subframes in one nframe. The ratio of UL to DL subframes is scalable to allow DL heavy or UL heavy traffic depending on scheduling needs.

The NB-IoT-U UE always operates on only one Physical Resource Block (PRB), and the common NDRS of one PRB width is unique across regions. Upon initial access, the UE will search for the discovery reference signal on specific frequency raster points defined in the specification. Successful synchronization on a given raster point directly indicates the operation mode in use by the network. Also, when the UE reads the MIB, it can verify the operation mode and consequently knows where to look for the system information (SI) messages and data channels.

b. MF-NPSS/MF-NSSS Design

The primary and secondary synchronization signals occupy the first half of the 20 ms NDRS duration. MF-NPSS is mapped onto eight consecutive subframes, followed by NSSS mapped onto two consecutive subframes. The sequence generation is based on a frequency-domain Zadoff-Chu sequence which is similar to 3GPP NB-IoT.

c. MF-NPBCH Design

The physical broadcast channel occupies the latter half of the 20 ms NDRS duration. One MF-NPBCH code word is distributed to eight blocks transmitted across a modification period of 640 ms for Frame Structure Type 3N1 and 10240 ms for Frame Structure Type 3N2. Each block is mapped onto one subframe and repeated in nine consecutive subframes on the same radio frame.

2. Time and Frequency Domain Strcuture

a. Operation Modes

NB-IoT-U supports two operation modes in Release 1.1:

- Hybrid mode (deployments under FCC rules in the USA), using Frame Structure Type 3N1
- Duty cycle mode (deployments under EU decisions in Europe), using Frame Structure Type 3N2

The FCC rules allow hybrid systems that employ a combination of frequency hopping and digital modulation techniques. In hybrid mode, the downlink transmissions from NB-IoT-U eNB are split into anchor segment and data segment as shown in Figure 3. The anchor segment uses digital modulation over a bandwidth of 540 kHz, constituting three Physical Resource Blocks. The data segment uses frequency hopping over 64 single-PRB channels.

Under European SRD regulations, a NB-IoT-U cell operates on a single-PRB channel under duty cycle regime where the active transmit time of a device is limited over an observation period of one hour

b. NDRS Placement

The NDRS is positioned in the first PRB of a three-PRB anchor segment in Frame Structure Type 3N1 (FCC). Upon successful synchronization and MIB acquisition, the UE will access other PRBs of the anchor segment. The anchor segment repeats every 80 ms. Figure 5 shows the position of the NDRS within the Frame Structure Type 3N1, with guard period for frequency channel change in grey color.

The NDRS is positioned at the beginning of a 1280 ms cycle in Frame Structure Type 3N2 (EU).

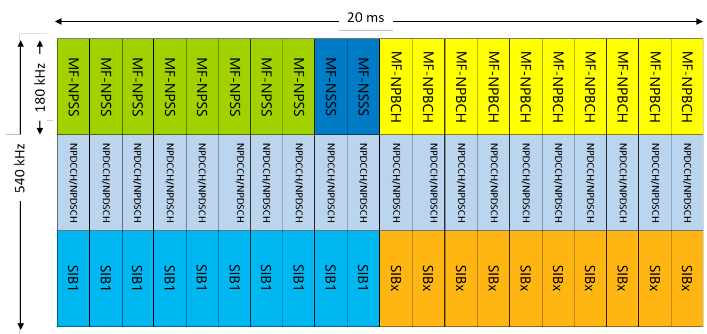

Figure 5. Anchor segment in Frame Structure Type 3N1

c. Frequency Hopping Operation on Data Channels (FCC)

As described above, under hybrid operation, the NDRS is transmitted in digital modulation mode over the anchor segment. The data channels follow FHSS regulations where a pseudo-random hopping pattern on 64x8 hops is applied to both downlink and uplink transmissions in a cell.

d. Duty Cycle Operation (EU)

The frequency bands occupied by NB-IoT-U in Europe are assigned to SRD. Typically, such devices operate on peer-to-peer basis and have low transmit powers. The regulations aim to improve coexistence of multiple, potentially very different systems through the use of duty cycle limitations. NB-IoT-U is designed to operate on bands which support at least 10% duty cycle in downlink and 2.5 % duty cycle in uplink.

These duty cycles are set with completely independent SRD transmitters in mind so that each device has sufficient capacity to communicate with its peers. NB-IoT-U is a scheduled system where all the UEs are under the control of the base station. This enhances the throughput of a 10% duty cycle link beyond what could practically be achieved with completely independent transmitter-receiver pairs.

e. UL/DL Configuration

NB-IoT-U transmissions are structured into radio frames of 10 ms duration. Radio frames are further combined into nframes, which are the fundamental building blocks in the NB-IoT-U physical channel structure. Depending on the operation mode and UL/DL configuration, a nframe constitutes 2, 4 or 8 radio frames.

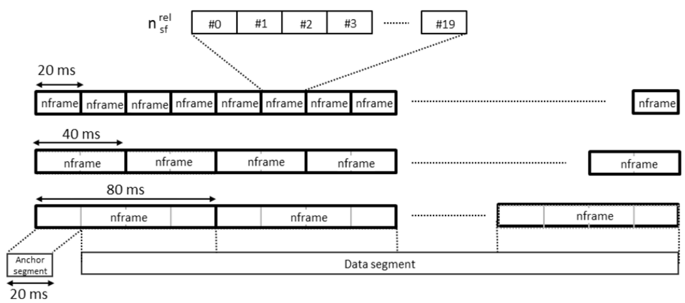

Figure 6. NB-IoT-U nframes within a frame structure

One nframe thus includes DL subframes followed by UL subframes. The proportion of DL subframes to UL subframes is indicated in MIB that the UE reads during initial access to a cell. Tables 6 and 7 depict the UL-DL configurations available for the two NB-IoT-U operation modes.

Uplink-downlink configuration	N_{nframe}^{frame}	Downlink-to-Uplink Switch-point periodicity	Relative subframe number (n_{sf}^{rel})																			
			0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
0	2	20 ms	D	D	D	D	D	S	U	U	U	U	U	U	U	U	U	U	U	U	U	U
1	2	20 ms	D	D	D	D	D	D	D	S	U	U	U	U	U	U	U	U	U	U	U	U
2	2	20 ms	D	D	D	D	D	D	D	D	D	S	U	U	U	U	U	U	U	U	U	U
3	2	20 ms	D	D	D	D	D	D	D	D	D	D	D	S	U	U	U	U	U	U	U	U
4	2	-	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U
5	2	10 ms	D	D	D	S	U	U	U	U	U	U	D	D	D	S	U	U	U	U	U	U
6	2	10 ms	D	D	S	U	U	U	U	U	U	U	D	D	S	U	U	U	U	U	U	U
7	2	10 ms	D	S	U	U	U	U	U	U	U	U	D	S	U	U	U	U	U	U	U	U

Table 6. Uplink-downlink configurations for nframes carrying only a data segment for frame structure type 3N1

Uplink-downlink configuration	N_{nframe}^{frame}	Downlink-to-Uplink Switch-point periodicity	Relative subframe number (n_{sf}^{rel})															
			0	1	2	3	4	5	6	7	8	9	10	11	12,…,15	16,…,19	20,21,…39	40,41,…79
0	8	80 ms	D	D	D	D	D	D	D	D	U	U	U	U	U	U	U	U
1	8	80 ms	D	D	D	D	D	D	D	D	D	D	D	D	D	U	U	U
2	4	40 ms	D	D	D	D	U	U	U	U	U	U	U	U	U	U	U	
3	4	40 ms	D	D	D	D	D	D	D	D	U	U	U	U	U	U	U	
4	2	20 ms	D	D	U	U	U	U	U	U	U	U	U	U	U	U		
5	2	20 ms	D	D	D	D	U	U	U	U	U	U	U	U	U	U		
6	2	20 ms	D	D	D	D	D	D	D	D	U	U	U	U	U	U		
7	2	10 ms	D	D	U	U	U	U	U	U	U	U	D	D	U	U		

Table 7. Uplink-downlink configurations for nframes carrying only a data segment for frame structure type 3N2

3. Transmission of SIB (System Information Blocks)

a. Overall Procedures

The common part of the NDRS allows a NB-IoT-U UE to read MF-NPBCH in a similar way regardless of the operating region. The MIB carried by MF-NPBCH provides detail on how the System Information Blocks (SIBs) are mapped onto physical channels in each operation mode. In hybrid operation with Frame Structure Type 3N1, the SIB1 and other SI messages are mapped onto the PRB at the opposite side of the 3-PRB anchor segment from the NDRS. In duty cycle operation with Frame Structure Type 3N2, the SIB1 is mapped evenly distributed across the NDRS cycle of 1280 ms. For both operation modes the SI messages are transmitted within periodically occurring time domain windows (referred to as SI-windows).

b. SIB1 and SIBx for FCC

For hybrid operation with Frame Structure Type 3N1 (FCC), the SIBs are mapped only to the anchor segments. Each anchor segment has one PRB reserved for SI messages. The SIB1 periodicity is 2560 ms which is the same as 3GPP NB-IoT. Each SIB1 codeword may be repeated 4, 8 or 16 times depending on the coverage requirement in the NB-IoT-U cell.

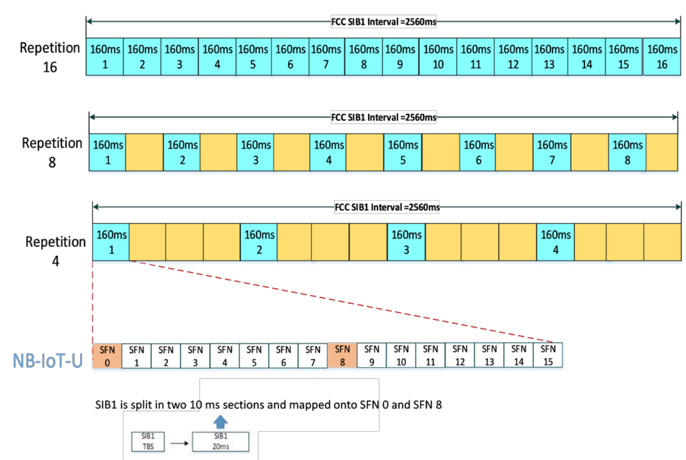

Figure 7. SIB1 mapping under hybrid operation mode with Frame Structure Type 3N1

c. SIB1 and SIBx for EU

For duty cycle operation with Frame Structure Type 3N2 (EU), the System Information Blocks are mapped to the data segment. Due to duty cycle limitations on DL throughput, the SIB1 periodicity is twice that of 3GPP NB-IoT, so 5120 ms. In the nframes where SIB1 is mapped, it occupies one half of the DL subframes whilst the other half is retained for NPDCCH/ NPDSCH to allow the eNB to send UE assignments at any nframe, Outside nframes used for SIB1, other SI messages may similarly occupy one half of DL subframes, The SI messages are transmitted within SI-windows and the mapping details are provided in SIB1.

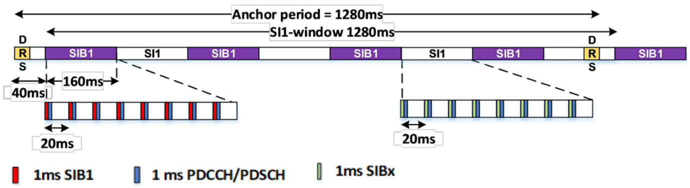

Figure 8. SIB1 mapping under duty cycle operation mode with Frame Structure Type 3N2

4. Physical Channels

The two uplink physical channels defined in NB-IoT-U are:

- Narrowband Physical Uplink Shared Channel (NPUSCH)
- Narrowband Physical Random Access Channel (NPRACH)

These physical channels are adopted from 3GPP NB-IoT and operate effectively in a very similar fashion with differences mainly in the physical layer mapping of these channels. NB-IoT-U UE may transmit either NPUSCH or NPRACH in the UL subframes of a nframe. In hybrid operation with Frame Structure Type 3N1, the UL physical channel is mapped onto frequency channels in accordance with the pseudo random hopping pattern that the eNB has configured for the cell. In duty cycle operation with Frame Structure Type 3N2, the UL physical channel is mapped onto UL sections of nframes and the UE must limit its use of UL resource to the duty cycle limitation based on an observation interval of one hour.

The three downlink physical channels defined in NB-IoT-U are:

- Narrowband Physical Downlink Shared Channel (NPDSCH)
- Narrowband Physical Downlink Control Channel (NPDCCH)
- MulteFire Narrowband Physical Broadcast Channel (MF-NPBCH)

NPDSCH and NPDCCH are adopted from 3GPP NB-IoT and operate effectively in a very similar fashion with differences mainly in the physical layer mapping of these channels. In hybrid operation with Frame Structure Type 3N1, the NB-IoT-U eNB may transmit NPDCCH or NPDSCH in either the center PRB of the anchor segment or in accordance to the pseudo random hopping pattern in the DL sections of nframes in the data segment. In duty cycle operation with Frame Structure Type 3N2, the MulteFire NB-IoT eNB maps the NPDSCH or NPDSCH to DL sections of nframes and the eNB must limit its use of DL resource to the duty cycle limitation based on an observation interval of one hour.

MF-NPBCH is introduced as a new physical channel to support the transmission of MIB in the NB-IoT-U cell.

5. Higher Layer

As shown in Figure 9, NB-IoT-U employs the same protocol structure and core network as 3GPP NB-IoT. The major changes occurred at the low physical layer as indicated in red color. The higher layers are based very closely on 3GPP NB-IoT as indicated by green color, with only minor changes arising from the changes on the lower physical layer.

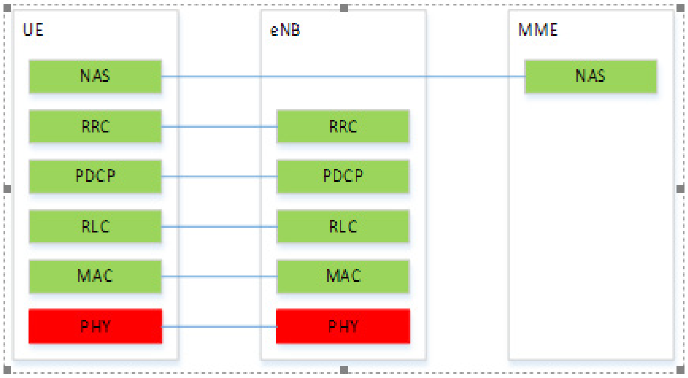

Figure 9. NB-IoT-U Protocol Structure, green indicates a same design with 3GPP NB-IoT

III. Performance of NB-IoT-U

1. Coverage, Indicative Data Rate, and Measurable Data Rate

Many of the existing LPWA systems make claims about coverage performance without stating associated data rates at the extreme coverage. Furthermore, the channel models used in their evaluations are not stated and are likely to be benign (AWGN, hence with no fading), yet it is known from 3GPP studies that the channel model (fading profile, Doppler, etc.) has an important impact on coverage and data rate for LPWA deployments.

It should be noted that coverage performance can be traded against transmission time or equivalently data rate, as more transmission time means additional energy spent on the information bits but with a consequent reduction in data rate. Claiming a large coverage in terms of maximum dB link loss, without stating the associated data rate is almost meaningless for real deployments as the services that can be supported at this coverage may be very limited. In this paper, the data rate at the claimed coverage level is evaluated in a consistent way so that it is possible to determine the trade-off for real deployments and applications.

Furthermore, there are two different ways to evaluate the data rate, and the adopted method must be clear in any evaluation:

- Indicative Data Rate: equals to the payload Transport Block Size (TBS) (bits)/frame length (ms), which does not consider the overhead of DL/UL ratio and the grant and ACK overhead.
- Measurable Data Rate: equals to the payload TBS (bits)/total transmission time (ms), where the total transmission time includes the overhead of DL/UL ratio as well as the grant and the ACK overhead.

In real deployments, the channel between base station and device will be subject to fading due to multipath reflections from surrounding objects, given that the cell size can be large. Furthermore, even for static IoT devices, there will be non-zero Doppler on the channel fading model due to movements in the reflectors. If the IoT device is moving, then the Doppler can be much larger. It is sometimes seen that other LPWA technologies are evaluated with an AWGN channel which means that there is no multipath fading. An AWGN channel model will give the best simulated performance but is misleading because it ignores multipath fading and Doppler that will occur in any real deployments.

To avoid misleading results, NB-IoT-U performance is evaluated with a clear and stated set of modelling assumptions in the following sections, with the aim being to reflect performance in a realistic deployment.

2. Common Assumptions

The common assumptions for NB-IoT-U performance evaluation are summarized in Table

Parameters	Values or Criteria
Channel Model	TU1Hz (fading model from 3GPP, using 1Hz Doppler)
eNB Power	FCC: max 30dBm at antenna port as allowed by regulation - Anchor: 25.2dBm, which is 8dBm/3kHz in 180kHz; - Data: 25.2dBm, which assumes 4.8dB loss due to PAPR. EU: 29.215dBm (EIRP)
eNB Tx/Rx Antenna	2Tx/2Rx
eNB Antenna Gain	15dBi/6dBi
eNB Noise Figure (dB)	3
UE Power	23dBm at antenna port
UE Tx/Rx, Antenna Gain	1Tx/1Rx/0dBi (device has single antenna for low cost)
UE Noise Figure (dB)	5
UE Power on Freq. Error	20ppm (typical value for a low cost XTAL reference)
UE Re-sync Freq. Error	5ppm
UE Residual Freq. Error	±50 Hz with 90% confidence level
UE Residual Time. Error	±64Ts, 90% , Ts=1/30.72MHz

Table 8. Common assumptions for NB-IoT-U performance evaluation

3. Performance of Common Control Channels: MF-NPSS, MF-NSSS, MF-NPBCH, SIB1, and SIBx

The performance of common control channels for the FCC and EU designs, which include MF-NPSS, MF-NSSS, MF-NPBCH, SIB1, and SIBx are summarized in Table 9 and Table 10. The coverage is expressed as Maximum Path Loss (MPL) in dB which is the difference between transmitted power (EIRP) in dBm and the reference sensitivity in dBm.

Channels	Signal Configurations	SINR (dB)	RefSens (dBm)	MPL (dB)
MF-NPSS	5 combinations, detection time = 5x80ms= 400ms, 90% confidence.	-13.4	-129.8	161.0
MF-NSSS	1 shot detection immediately after MF-NPSS, 90% confidence.	-13.4	-129.8	161.0
MF-NPBCH	TBS=34bits, CRC=16bits, coded in 10ms. Repeated 8 times in 640ms, 8 combinations	-14.5	-130.9	162.1
SIB1	TBS=680bits in 20ms, reps= 16 times in 2560ms	-12.8	-129.2	160.4
SIBx	TBS=680bits in 20ms, reps=18 times in 2880ms	-13.4	-129.8	161.0

Table 9. Performance of Common Control Channels in FCC

Channels	Signal Configurations	SINR (dB)	RefSens (dBm)	MPL (dB)
MF-NPSS	2 shots, detection time = 5x1280ms= 2560ms, 90% confidence	-8.5	-124.9	154.0
MF-NSSS	1 shot detection immediately after MF-NPSS, 90% confidence.	-8.5	-124.9	154.0
MF-NPBCH	TBS=34bits, CRC=16bits, coded in 10ms. Repeated 8 times in 10240ms, combinations of two occurrences	-8.5	-124.9	154.0
SIB1	TBS=680bits, Period = 5120ms	-8.0	-124.4	153.5
SIBx	TBS=680bits, Period = 6080ms	-8.5	-124.9	154.0

Table 10. Performance of Common Control Channels in EU

4. Performance of Data Channels

NB-IoT-U supports multiple downlink/uplink configurations so that diversified services can be supported with flexibility and optimized efficiency. The coverage in different downlink/uplink configurations can be the same but the data rate available for downlink versus uplink may be different. The downlink/uplink ratio assumptions are noted in each table below in the form of xD+yU, which means x ms downlink transmission followed by y ms uplink transmission.

Table 11 and Table 12 show the downlink and uplink data channel performance for FCC, respectively. The data channel performance for EU is summarized in Table 13.

Channels	Signal Configurations	SINR (dB)	RefSens (dBm)	MPL (dB)	Indicative Data Rate (kbps)	Measurable Data Rate (kbps)
NPDCCH	TBS=23bits in 1ms, CRC=16bits, reps =84 (128), air time=183ms[3]	-13.4 (-15.3)	-129.7 (-131.7)	161.0 (163.0)	N/A	N/A
NPDCCH	TBS=23bits in 1ms, CRC=16bit, reps=32, air time=46ms	-9.3	-125.7	157.0	N/A	N/A
NPDSCH	TBS=680bits in 4ms, reps=128, air time=732ms	-13.4	-129.8	161.0	1.3	0.72
NPDSCH	TBS=680bits in 4ms, reps=32, air time=183ms	-7.6	-124.0	155.2	5.3	-
NPDSCH (Max Data Rate)	TBS=1032bits in 4ms, reps=1 air time=4ms	14.0	-102.4	133.7	258	63.4 (1 HARQ)[4]

Table 11. Performance of Downlink Channels (FCC: 12D+8U)

Channels	BW (kHz)	Signal Configurations	SINR (dB)	RefSens (dBm) Antenna = 6dBi	MPL (dB) (23dBm)	Indicative Data Rate (kbps)	Measurable Data Rate (kbps)
NPUSCH Format 1 (Single HARQ) (Min)	15	TBS=808bits, RU=8, 8ms*RU*4 (reps=4) = 256ms, Air Time =256/(24/80) = 853ms	-3.5	-138.7	161.7	808bits/256ms=3.16	0.77kbps
	3.75	TBS=808bits, RU=8, 32ms*RU*2(reps=2) = 512ms, Air Time = 512/(24/80)= 1706ms	0.5	-140.8	163.8	808bits/512ms=1.58	0.43kbps
NPUSCH Format 1 Assume full UL allocation (Max)	15	TBS=1000bits, RU=6, 8ms*RU*1(reps=1) = 48ms, air time = 48/(24/80)=160ms	12.0	-123.2	146.2	1000bits/48ms=20.8	6.3kbps
	3.75	TBS=504bits, RU=3, 32ms*RU*1(rep=1) = 96 ms, air time = 96*24/80= 320ms	13.2	-128	151.0	504bits/96ms =5.25	1.58kbps
	180	TBS=2024bits, RU=8 1ms*RU*1(rep=1)= 8ms	16.4	-108	131.0	2044bits/8ms =253.0	75.9kbps
NPUSCH (Max Coverage)	3.75	TBS=56bits, RU=3 32ms*RU*128(reps=128)= 12288ms	-5.5	-146.7	169.8	56bits/12288 ms=4.6bps	-
NPUCCH	15	TBS=bits*16=16bit; 2ms*2 (reps=2) = 4ms	-4.0	-139.2	162.2	-	-
		TBS=1bits*16=16bit; 2ms*1(rep=1) = 2ms	-2.0	-146.2 (15dBi)	169.2	-	-
	3.75	TBS=1bits*16=16bit; 2ms*1(rep=1)=2ms	0	-141.3	164.3		
		TBS=1bits*16=16bit; 2ms*1(rep=1) = 2ms	0	-150.3	173.3	-	-
NPRACH	3.75	5.6ms, reps = 4 air time = 4 x20ms+20ms=100ms	2.5	-138.8	161.8	-	-
		5.6ms, reps =2 air time = 2x20ms=40ms	9.0	-141.3 (15dBi)	164.3	-	-
		max reps=128; air time = floor(128/3)x80+2*20=3400ms	-8.0	-149.3	172.3	-	

Table 12. Performance of Uplink Channels (FCC: 12D+8U)

Channels	BW (kHz)	Signal Configurations	SINR (dB)	RefSens (dBm)	MPL (dB)	Measurable Data Rate (kbps) (with TDD DL/UL ratio considered)
NPDSCH	180kHz	TBS=680bits, N_sf=4 (N_sf is the number of DL Subframe), reps=32 or 64, air time = 3034ms[5] (32 repetitions) air time = 6068ms (64 repetitions)	-8 (32) -11 (64)	-124.4 (32) -127.4 (64)	153.5 (32) 156.5 (64)	0.11kbps
NPDSCH	180kHz	TBS=1032bits, N_sf=4, rep=1, air time = 80ms	14	-102.4	131.5	12.5kbps
NPDCCH	180kHz	TBS=23bits+16bits, N_sf=1, reps=32, air time = 32/2*40 = 640ms	-9.6	-126.0	155.1	-
NPUSCH Format 1	15kHz (6dBi)	TBS=1000bits, RU=6, 8ms*RU*4(reps=4)= 192ms, air time = Floor (192/36)*40 +4DL+ (192Mod 36) =221ms	1.5	-133.7	156.0	4.5kbps
	15kHz (15dBi)	TBS=1000bits, RU=6, 8ms*RU*1(rep=1)= 48ms, air time: 40ms+4ms+12ms=56ms	10.5	-133.7	156.0	17.9kbps
	180kHz (6dBi)	TBS=2024bits, RU=8 1ms*RU*1(rep=1) = 8ms	16.4	-108	131.0	218.2kbps
NPUSCH Format 2	15kHz (6dBi)	TBS=16bits; 2ms*1(rep=1)=2ms	-2	-137.2	160.2	-
	15kHz (15dBi)	TBS=16bits; 2ms*1(rep=1)=2ms	-2	-146.2	169.2	-
NPRACH	3.75 kHz (6dBi)	5.6ms * 2(reps = 2); air time =12ms	6.5	-134.8	157.8	-
	3.75 kHz (15dBi)	5.6ms * 1 (rep = 1) ; air time = 6ms	18	-132.3	155.3	-

Table 13. Performance of EU Design (4D+36U)

5. Power Consumption

The power saving mechanisms for NB-IoT-U are identical to 3GPP NB-IoT. For example, NB-IoT-U includes power saving mode (PSM) which is suitable for devices initiated traffic (since the device does not need to be paged by the network in the absence of any uplink traffic), whereas eDRX allows the device to remain for long periods in a low power "idle" state where it can be paged by the network with a well-defined maximum latency according to the configured eDRX periodicity.

The power consumption of an NB-IoT-U UE is estimated based on the traffic model shown in Table 14, the signaling procedures illustrated in Figure 10, and the power consumption assumptions for a typical UE implementation shown in Table 13 (which are already achieved for commercial NB-IoT UEs).

The analysis indicates that a NB-IoT-U UE can operate for many years based on a 5 Watt-hour battery, assuming the typical IoT traffic model.
It is interesting to note that the battery life can be substantially improved depending on the receiving antenna gain at eNB, for example:

- For eNB receiving antenna gain of 6dBi, the UE battery life at MPL = 161dB can be 10 years
- For eNB receiving antenna gain of 15dBi, the UE battery life at MPL = 161dB can be 15 years

[3]There are 56ms DL and 24ms UL in 80ms in case of 12D+8U configuration. Transmission of 128 reps requires 128/56*80ms by average which is roughly 183ms.

[4]A single HARQ process is supported in MF1.1 NB-IoT-U. In future evolution of NB-IoT-U, the addition of a second HARQ process (following 3GPP NB-IoT Rel-14) will be considered which can provide a peak data rate of around 104 kbps.

[5]Total NPDSCH is 4x32ms. Total downlink resources in 1280ms is 128ms considering 10% duty cycle. The resources available for NPDSCH, SIB1/SIBx are 128ms-20ms (Anchor) in 1280ms. Assuming that SIB1/SIBx and NPDSCH/NPDCCH occupy 50% of total resources, the resources available for NPDSCH is 54ms in 1280ms. This converts to 4*32ms/54*1280=3034ms.

If the UE is located in good coverage, such as MPL=141dB, the battery life can be as long as 32 years (in practice, the limiting factor will be self-discharge of the battery in this case).

Battery Capacity	Traffic Type
5Wh	200 bytes, every 2 hours
	200 bytes, every 1 day

Table 14. Traffic model for power consumption evaluation

The full interactions between UE and eNB for power consumption evaluation are illustrated below:

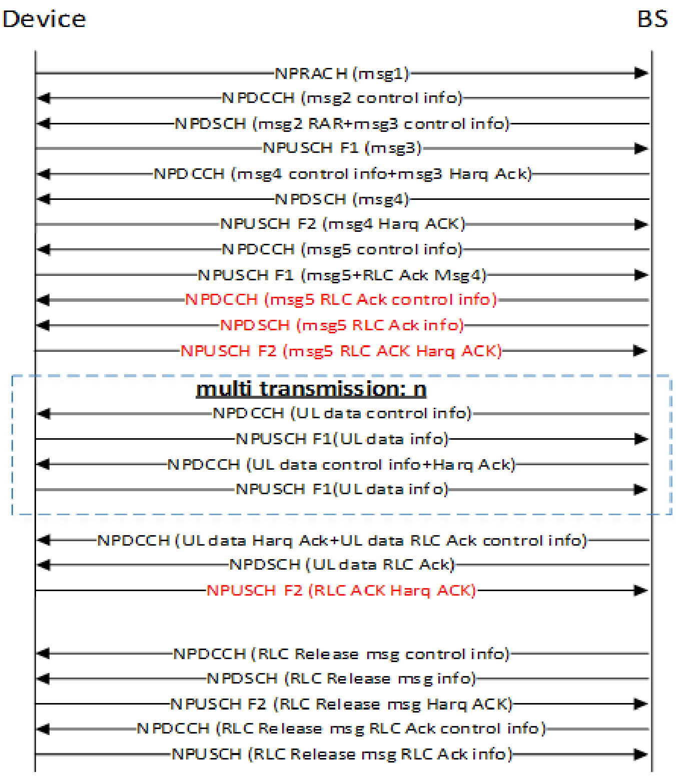

Figure 10. Messages reflecting the interactions between UE and eNB

Operation Mode		Conditions	NB-IoT-U	Unit
Deep Sleep		All peripherals (including DMA and Flash) and system clock is active	15	uW
Idle		Transmit and receiving models are inactive. Processes are active for signaling processing.	3	mW
Active Mode	Receive Mode	All processors and Receiver (ADC, LNA, etc.) active	80	mW
	Transmit Mode	All processors and Transmitter (DAC, PA etc.) active; RFOP=23dBm	535	mW

Table 15. Typical UE power consumption (for reference only)

It is important to note that the power consumption values in the above table are in units of Watts. This means the numbers are independent of battery voltage. It is common to see other LPWA technologies state power consumption in Amps, but this is potentially misleading without also stating the assumed battery voltage (e.g. 3.3V).

6. Capacity

In order to evaluate the network capacity, an IoT traffic model must be assumed. A realistic traffic model, derived from a real application, is defined in IEC62056-DLMS/COSEM which is used for electrical metering, as shown in Table 16. It can be seen that uplink traffic load is 4 times higher than downlink traffic in standard electrical metering services.

Assuming that there is one metering transaction every 4 hours, the total number of transactions that can be completed in 4 hours by one eNB can be evaluated at difference coverage levels. As the downlink and uplink traffic load as well as radio resources are different, the total number of transactions can be estimated for both downlink and uplink.

	Message	Downlink (Bytes)	Uplink (Bytes)
1	AARQ AARE	64	51
2	Reading load profile Data 1	40	245
3	Reading load profile Data 2	15	245
4	Reading load profile Data 3	15	245
5	Reading load profile Data 4	15	245
6	Reading Item Data 3	15	176
7	Reading Item Data 4	21	17
8	Reading Item Data 5	21	14
9	Reading Item Data 6	21	30
10	Reading Item Data 7	21	17
11	Reading Item Data 8	21	17
12	RLRQ & RLRE	10	31
	Total (Bytes)	279	1333

Table 16. IEC62056-DLMS/COSEM for Electrical Metering

The methodology to calculate the capacity is to divide the total radio resources by the radio resources required by each meter to complete one transaction. The calculation is done for Downlink and Uplink separately, including all overheads for radio resource grant and ACK, as well as the higher layer message header.

The maximum number of supported meters under FCC and EU rules are shown in Table 17 and Table 18, respectively. For the purpose of this analysis, the simplifying assumption is made that all the meters are at the stated coverage level, and this provides some useful bounds on capacity. In a real deployment, the meters are distributed across a continuous range of coverage levels, from Near to Far, and a rough distribution could be 10% at Far, 30% at Middle, and 60% at Near. It should be noted that in this context "Far" is likely to correspond to meters that are in particularly difficult locations from a radio propagation perspective, which is why the percentage is quite low.

Coverage	Downlink	Uplink
161dB (Far)	1544	15000
141dB (Near)	86897	34468

Table 17. Number of transactions that can be supported in 4 hours: FCC

Coverage	Downlink	Uplink
154dB (Far)	260	111040
144dB (Near)	4130	207170

Table 18. Number of transactions that can be supported in 4 hours: EU

In both cases, the uplink is capacity is significantly higher than downlink, and the bottleneck in the system is downlink. This is as expected since the downlink power is restricted by regulations, and also the downlink under the EU rules is restricted by the 10% duty cycle requirement. Nonetheless, in both cases, the NB-IoT-U system could support electricity metering service assuming reasonable network planning.

It should be noted that the IEC62056-DLMS/COSEM traffic model requires significantly higher capacity per UE than the MAR model as defined in 3GPP TR 45.820. When the MAR traffic model is used, the NB-IoT-U system is able to support the London urban house hold density as defined in 3GPP TR 45.820, which is more than 50000 for each cell.

Autonomous Reporting (MAR)	
Application payload size distribution	Pareto distribution with shape parameter alpha = 2.5 and minimum application payload size = 20 bytes with a cut off of 200 bytes i.e. payloads higher than 200 bytes are assumed to be 200 bytes.
Periodic inter-arrival time	Split of inter-arrival time periodicity for MAR periodic is: 1 day (40%), 2 hours (40%), 1 hour (15%), and 30 minutes (5%)

Table 19. MAR defined in 3GPP TR 45.820

7. Latency

A key latency requirement for 3GPP NB-IoT is to complete an emergency report of 20 payload bytes within 10 seconds at worst case coverage (highest supported MPL). NB-IoT-U should also be capable of supporting this same emergency report service.

Furthermore, the time to finish an IEC62056-DLMS/COSEM transaction was evaluated based on the FCC frame structure. The whole transaction is evaluated message by message with PDCCH grant, HARQ feedback considered. The detailed procedures are omitted in this paper. The analysis showed that the total latency is 18.8 seconds at the worst case coverage of 161dB MPL.

For applications in which latency rather than coverage is the priority, NB-IoT-U can have much smaller transmission latency. As shown in the Figure 11, the minimum latency to transmit a downlink package at good coverage can be smaller than 50ms when using always-connected mode and the data rate can reach 63.4kbps even using just one HARQ process as shown in Table 6. This is sufficient to support many industrial interfaces.

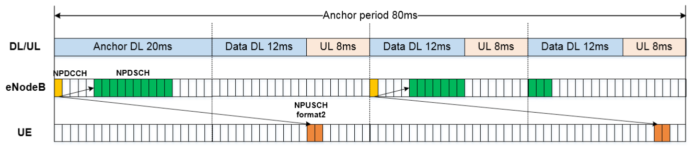

Figure 11. NB-IoT-U user plane latency in FCC always-connected mode

IV. Conclusions

In summary, NB-IoT-U is designed to share the mature ecosystem of the 3GPP NB-IoT system with very limited re-engineering efforts. Existing NB-IoT chipsets will be able to support NB-IoT-U with only limited changes, typically only software changes. This means that NB-IoT-U will benefit from the commercially available, low cost NB-IoT chipsets from multiple vendors. Furthermore, it allows roaming between licensed and license-exempt networks with no significant UE cost overhead, which will be beneficial for some application verticals.

NB-IoT-U has very good coexistence properties with other license-exempt systems that can also occupy the shared spectrum. NB-IoT-U is a time-spread system in which coverage extension is realized by means of repetitions in the time domain. Therefore, it is inherently robust because the signal can still be correctly received and decoded even if collisions with transmissions from other systems corrupt a subset of the repetitions. In addition, when frequency hopping is used it is also a frequency-spread system which means the whole transmission is distributed across a wide bandwidth which further improves the communication robustness.

The eNB and UE receiving bandwidth for NB-IoT-U are both limited to 180 kHz. This means that the co-channel interference inherent in wideband systems can be substantially reduced through the selectivity of narrow band receiver. In addition, the UE is simplified because the required sampling rates for the receiver ADC and digital processing can be reduced.

NB-IoT-U can be seamlessly integrated into many applications requiring relatively high throughput (in comparison with other LPWA technologies), which avoids having to re-define and re-engineer the application system. This allows a standard solution based on NB-IoT-U to be duplicated across multiple targeted verticals which is important for a fast-growing eco-system and market size. NB-IoT-U is also a good solution in delay sensitive applications such as industrial monitoring and control due to its low transmission latency in good coverage conditions.

NB-IoT-U can offer scalable network capacity as each individual cell offers additional capacity. Because of the coverage advantages offered by NB-IoT-U due to its use of advanced techniques derived from LTE, the number of eNBs required to cover a given geographical area is significantly smaller than other proprietary LPWA systems. This results in a lower cost of network deployment. Therefore, when capacity demanding applications are considered (or the network must be future-proofed for an expected increase in capacity), NB-IoT-U has clear advantages in terms of system performance and deployment cost.

In conclusion, NB-IoT-U is the next generation license-exempt LPWA technology long-desired by the market.

References

[1] ERC Recommendation 70-03 relating to the use of Short Range Devices (SRD), 13 October 2017.

[2] Commission implementing decision (EU) 2017/1483 of August 8th, 2017, amending Decision 2006/771/EC on harmonisation of the radio spectrum for use by short-range devices and repealing Decision 2006/804/EC.

[3] ETSI EN 300 220-2 V3.2.1, Short Range Devices (SRD) operating in the frequency range 25 MHz to 1 000 MHz; Part 2: Harmonised Standard covering the essential requirements of article 3.2 of Directive 2014/53/EU for non specific radio equipment, June 2018

[4] FCC Title 47, Chapter I, Subchapter A, Part 15, Section 247: Operation within the bands 902-928 MHz, 2400-2483.5 MHz, and 5725-5850 MHz.

[5] 558074 D01 15.247 MeasGuidance v05, GUIDANCE FOR COMPLIANCE MEASUREMENTS ON DIGITAL TRANSMISSION SYSTEM, August 24, 2018

[6] GSMA, NB-IoT Ecosystem Partner list, https://www.gsma.com/iot/huawei-nb-iot-ecosystem-partner-list/

Glossary of Terms

3GPP – Third Generation Partnership Project
AARE – A-Associate Response
AARQ – A-Associate Request
ADC – Analog-to-Digital Converter
AWGN – Average White Gaussian Noise
COSEM – COmpanion Specification for Energy Metering
DAC – Digital-to-Analog Converter
DL - Downlink
DLMS – Device Language Message Specification
DMA – Direct Memory Access
DRS – Discovery Reference Signal
DRX – Discontinuous Reception
DTS – Digital Transmission System
EIRP – Equivalent Isotopically Radiated Power
eNB – evolved Node B
EU – European Union
FCC – Federal Communications Commission
FHSS – Frequency Hopping Spread Spectrum
GSA - Global mobile Suppliers Association
GSMA – The GSM Association
HARQ – Hybrid Automatic Repeat reQuest
IoT – Internet of Things
ISM – Industrial, Scientific and Medical radio
LBT – Listen-Before-Talk
LNA – Low Noise Amplifier
LPWA – Low Power Wide Area
MAR – Mobile Autonomous Reporting
MF-NPBCH – MulteFire Narrowband Physical Broadcast CHannel
MF-NPSS – MulteFire Narrowband Primary Synchronization Channel
MF-NSSS – MulteFire Narrowband Secondary Synchronization Channel
MIB – Master Information Block
MPL – Maximum Path Loss
MSB – Most Significant Bit
NB-IoT – Narrowband Internet of Things
NB-IoT-U – Narrowband Internet of Things Unlicensed
NPDCCH – Narrowband Physical Dedicated Control CHannel
NPDSCH – Narrowband Physical Dedicated Shared CHannel
NPRACH – Narrowband Physical Random Access CHannel
NPUSCH – Narrowband Physical Uplink Shared CHannel
OFDM – Orthogonal Frequency Division Multiplexing

PA – Power Amplifier
PRB – Physical Resource Block
RAT – Radio Access Technology
RFID – Radio Frequency IDentification
RLRE – A-Release Response
RLRQ – A-Release Request
SC-FDMA – Single Carrier Frequency Division Multiple Access
SIB1 – System Information Block Type 1
SIBx – System Information Block Type x
SRD – Short Range Device
TBS – Transport Block Size
UL – Uplink

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