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**System Reference document (SRdoc);
Short Range Devices (SRD);
Technical characteristics for Ultra Narrow Band (UNB)
SRDs operating in the UHF spectrum below 1 GHz**

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Foreword

This Technical Report (TR) has been produced by ETSI Technical Committee Electromagnetic compatibility and Radio spectrum Matters (ERM).

The present document includes necessary information to support the co-operation under the MoU between ETSI and the Electronic Communications Committee (ECC) of the European Conference of Postal and Telecommunications.

Modal verbs terminology

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Executive summary

Ultra-Narrowband (UNB) systems already perform a valuable role in the Internet of Things. They are an effective technology for star-topology Low Power Wide Area (LPWA) sensor/control networks for a wide range of applications in domains which include smart cities, utilities, infrastructure networks, environment monitoring, transport and healthcare.

UNB is an umbrella term for a range of systems already in use, in development or planned, which are characterized by a very narrow signal bandwidth allowing receivers with very effective noise and interference filtering, which can therefore achieve wide geographical coverage. Thanks to state-of-the-art processing in UNB receivers, high link budget is achieved with relatively low power at the transmitters. Therefore, UNB is a powerful approach to implementing LPWA networks that are, by nature, very heavily asymmetric. Thanks to the high link budget, 100 000 end-points scattered over an area can be served by a base-station acting as concentrator with a typical deployment density of one BS per 10 square kilometres.

More precisely, when used for LPWA networks, UNB base-stations are deployed outdoors at a typical density of up to 0,1 BS/km^2 and a transmit power of up to 500 mW e.r.p., in a bandwidth of around 1 kHz in the 869,40 MHz - 869,65 MHz band (band h1.6). End-points transmit at a power of up to 25 mW e.r.p. in a bandwidth of typically 250 Hz in the 868,0 MHz - 868,6 MHz band (h1.4). UNB systems are ideal where the infrequent communication of small packets of data at very low cost and where (in some cases) a battery life of many years is needed.

ECC Report 200 [i.10] and Report 207 [i.11] describe relevant sharing studies already carried out, others are ongoing by ECC PT SE24 and reported in Draft ECC Report WI42-2 [i.27] and Draft ECC Report 246 [i.28]. However these studies do not specifically model UNB systems, and further sharing studies are proposed in the present document.

UNB systems will continue to grow their support for a wide range of applications. They can help minimize the environmental footprint of cities, improve environment monitoring and management, bring benefits in personal health and help drive wider benefits through integration with "big data" systems.

Independent forecasts of demand for LPWA networks show the number of global connections (or end-points) rising to over 3 bn by 2023, in a market which is seen as incremental to that addressed by traditional cellular-based M2M technologies. Global accumulated connectivity revenues from LPWA services are expected to reach $34 bn by 2023.

The present document quantifies the rapidly growing market for the applications enabled by LPWA systems such as UNB and identifies the importance of ensuring that UNB systems can have access to suitable spectrum under appropriate access/mitigation requirements. The technical characteristics of UNB systems are presented as a basis for the consideration of regulatory measures which could be taken to enable UNB systems to continue to meet this growing need.

Potential contributions to a solution include (in the uplink) the use of the 915 MHz - 921 MHz band (especially with the chance of first-level harmonisation with countries under FCC regulation) as well as the 865 MHz - 868 MHz band. More flexibility in the measurement of DC in the 915 MHz - 921 MHz band would also enable certain new applications.

Potential steps for the downlink include the use of the 915 MHz - 921 MHz band (with the chance of FCC harmonisation) and use of the 865 MHz - 868 MHz bands. Deployed systems demonstrate that a minimum downlink duty cycle of at least 10 % is required, and a downlink transmit power (especially with multi carrier) of 2 W e.r.p. (with specific mitigation techniques) would reduce the geographical density of base-stations required.

1 Scope

The present document applies to the potential future usage of Ultra Narrowband (UNB) systems within the 865 MHz to 868 MHz and 915 MHz to 921 MHz bands. In particular:

- It gives an market overview of Low Power Wide Area Networks in general and UNB systems in particular.
- It describes technical characteristics of UNB systems.
- It explains the requested regulation changes to allow the efficient use of UNB system for future market demands.

2 References

2.1 Normative references

Normative references are not applicable in the present document.

2.2 Informative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the referenced document (including any amendments) applies.

Referenced documents which are not found to be publicly available in the expected location might be found at https://docbox.etsi.org/Reference/.

NOTE: While any hyperlinks included in this clause were valid at the time of publication, ETSI cannot guarantee their long term validity.

The following referenced documents are necessary for the application of the present document.

[i.1] TALQ: "TALQ Specification Overview".

NOTE: Available at http://www.talq-consortium.org.

[i.2] Analysys Mason: "Low-powered wireless solutions have the potential to increase the M2M market by over 3 billion connections".

NOTE: Available at https://docplayer.net/746686-Low-powered-wireless-solutions-have-the-potential-to-increase-the-m2m-market-by-over-3-billion-connections.html.

[i.3] Energy Saving Trust: "A Guide to Telematics".

NOTE: Available at https://energysavingtrust.org.uk/sites/default/files/Telematics.pdf.

[i.4] Department of Transport (UK) FBP1042: "Telematics for Efficient Road Freight Operations".

NOTE: Available at http://webarchive.nationalarchives.gov.uk/20110615041210/http://www.freightbestpractice.org.uk/categories/3505_551_publications.aspx?filter=69,Guide.

[i.5] IPPR: "Implementing Pay-As-You-Drive Vehicle Insurance".

NOTE: Available at http://www.ippr.org/files/uploadedFiles/events/ToddLitman.pdf?noredirect=1.

[i.6] National Bureau of Economic Research: "Measuring Positive Externalities from Unobservable Victim Precaution: An Empirical Analysis of Lojack".

NOTE: Available at http://www.nber.org/papers/w5928.

[i.7] ERC Report 25: "The European table of frequency allocations and applications in the frequency range 8.3 kHz to 3000 GHz (ECA table)", May 2015.

[i.8] ERC Recommendation 70-03 (Tromsø 1997 and subsequent amendments): "Relating to the use of short range devices (SRD)", Recommendation adopted by the Frequency Management, Regulatory Affairs and Spectrum Engineering Working Groups, Version of 21 October 2016.

[i.9] ETSI EN 300 220-1 (V2.4.1) (2012-05): "Electromagnetic compatibility and Radio spectrum Matters (ERM); Short Range Devices (SRD); Radio equipment to be used in the 25 MHz to 1 000 MHz frequency range with power levels ranging up to 500 mW; Part 1: Technical characteristics and test methods".

[i.10] ECC Report 200: "Co-existence studies for proposed SRD and RFID applications in the frequency band 870-876 MHz and 915-921 MHz", September 2013.

[i.11] ECC Report 207: "Adjacent band co-existence of SRDs in the band 863-870 MHz in light of the LTE usage below 862 MHz", January 2014.

[i.12] Study for European Commission DG Communications Networks, Content & Technology: "DG Communications Networks, Content & Technology: Definition of a Research and Innovation Policy Leveraging Cloud Computing and IoT Combination", 2013.

[i.13] ETSI EN 301 502 (V11.1.1) (2014-07): "Global System for Mobile communications (GSM); Harmonized EN for Base Station Equipment covering the essential requirements of article 3.2 of the R&TTE Directive".

[i.14] ETSI EN 301 511 (V9.0.2) (2003-03): "Global System for Mobile communications (GSM); Harmonized EN for mobile stations in the GSM 900 and GSM 1800 bands covering essential requirements under article 3.2 of the R&TTE directive (1999/5/EC)".

[i.15] ETSI EN 300 609-4 (V9.2.1) (2010-10): "Global System for Mobile communications (GSM); Part 4: Harmonized EN for GSM Repeaters covering the essential requirements of article 3.2 of the R&TTE Directive".

[i.16] ETSI EN 301 908-1 (V5.2.1) (2011-05): "IMT cellular networks; Harmonized EN covering the essential requirements of article 3.2 of the R&TTE Directive; Part 1: Introduction and common requirements".

[i.17] ETSI EN 301 166-1 (V1.3.2) (2009-11): "Electromagnetic compatibility and Radio spectrum Matters (ERM); Land Mobile Service; Radio equipment for analogue and/or digital communication (speech and/or data) and operating on narrow band channels and having an antenna connector; Part 1: Technical characteristics and methods of measurement".

[i.18] ETSI EN 301 449 (V1.1.1) (2006-07): "Electromagnetic compatibility and Radio spectrum Matters (ERM); Harmonized EN for CDMA spread spectrum base stations operating in the 450 MHz cellular band (CDMA 450) and 410, 450 and 870 MHz PAMR bands (CDMA-PAMR) covering essential requirements of article 3.2 of the R&TTE Directive".

[i.19] ETSI EN 301 526 (V1.1.1) (2006-07): "Electromagnetic compatibility and Radio spectrum Matters (ERM); Harmonized EN for CDMA spread spectrum mobile stations operating in the 450 MHz cellular band (CDMA 450) and 410, 450 and 870 MHz PAMR bands (CDMA-PAMR) covering essential requirements of article 3.2 of the R&TTE Directive".

[i.20] ETSI EN 302 426 (V1.1.1) (2006-09): "Electromagnetic compatibility and Radio spectrum Matters (ERM); Harmonized EN for CDMA spread spectrum Repeaters operating in the 450 MHz cellular band (CDMA450) and the 410 MHz, 450 MHz and 870 MHz PAMR bands (CDMA-PAMR) covering essential requirements of article 3.2 of the R&TTE Directive".

[i.21] ETSI EN 302 561 (V1.3.2) (2014-10): "Electromagnetic compatibility and Radio spectrum Matters (ERM); Land Mobile Service; Radio equipment using constant or non-constant envelope modulation operating in a channel bandwidth of 25 kHz, 50 kHz, 100 kHz or 150 kHz; Harmonized EN covering the essential requirements of article 3.2 of the R&TTE Directive".

[i.22] ETSI EN 300 422-1 (V1.3.2) (2008-03): "Electromagnetic compatibility and Radio spectrum Matters (ERM); Wireless microphones in the 25 MHz to 3 GHz frequency range; Part 1: Technical characteristics and methods of measurement".

[i.23] ETSI EN 302 208-1 (V1.4.1) (2011-11): "Electromagnetic compatibility and Radio spectrum Matters (ERM); Radio Frequency Identification Equipment operating in the band 865 MHz to 868 MHz with power levels up to 2 W; Part 1: Technical requirements and methods of measurement".

[i.24] ETSI EN 301 357-1 (V1.4.1) (2008-11): "Electromagnetic compatibility and Radio spectrum Matters (ERM); Cordless audio devices in the range 25 MHz to 2 000 MHz; Part 1: Technical characteristics and test methods".

[i.25] ETSI EN 303 204-1 (V1.1.1) (2014-10): "Electromagnetic compatibility and Radio spectrum Matters (ERM); Network Based Short Range Devices (SRD); Radio equipment to be used in the 870 MHz to 876 MHz frequency range with power levels ranging up to 500 mW; Part 1:Technical characteristics and test methods".

[i.26] ECC Report 37: "Compatibility of planned SRD applications with currently existing radio communications applications in the frequency band 863-870 MHz".

[i.27] Draft ECC Report WI42-2: "Short Range Devices in the frequency range 862-870 MHz".

[i.28] Draft ECC Report 246 - companion to ECC Report 200: "Wideband and Higher DC Short Range Devices in 870-875.8 MHz and 915.2-920.8 MHz".

[i.29] ITU Radio Regulations (RR), Edition 2012.

[i.30] ECC/DEC/(02)05: "Designation and availability of frequency bands for railway purposes in the 876-880 MHz and 921-925 MHz bands".

[i.31] ECC/REC/(05)08: "Frequency planning and frequency coordination for the GSM 900, GSM 1800, E-GSM and GSM-R Land Mobile Systems".

[i.32] ERC/DEC(97)02: "Extended frequency bands to be used for the GSM Digital Pan-European Communications System".

[i.33] ECC/DEC/(06)13: "Designation of the bands 880-915 MHz, 925-960 MHz, 1710-1785 MHz and 1805-1880 MHz for terrestrial UMTS, LTE and WiMAX® systems".

[i.34] ECC/REC/(08)02: "Frequency planning and frequency coordination for the GSM 900, GSM 1800, E-GSM and GSM-R Land Mobile Systems".

[i.35] ECC/DEC/(08)08: "Harmonised use of GSM systems in the 900 MHz and 1800 MHz bands, UMTS systems in the 2 GHz band and LTE systems in the 1800 MHz and 2.6 GHz bands on board vessels".

[i.36] ECC/DEC/(04)06: "Availability of frequency bands for the introduction of Wide Band Digital Land Mobile PMR/PAMR in the 400 MHz and 800/900 MHz bands".

[i.37] ERC/DEC(94)01: "Frequency bands to be designated for the coordinated introduction of the GSM digital pan-European communications system".

[i.38] Machina Research: "With 3 billion connections, LPWA will dominate wide area wireless connectivity for M2M by 2023".

NOTE: Available at https://machinaresearch.com/news/with-3-billion-connections-lpwa-will-dominate-wide-area-wireless-connectivity-for-m2m-by-2023.

[i.39] ReportsnReports: "The LPWA (Low Power Wide Area) Networks Ecosystem: 2015 - 2030 - Opportunities, Challenges, Strategies, Industry Verticals & Forecasts".

NOTE: Available at http://www.reportsnreports.com/reports/435673-the-lpwa-low-power-wide-area-networks-ecosystem-2015-2030-opportunities-challenges-strategies-industry-verticals-forecasts.html.

[i.40] Real Wireless Ltd.: "A Comparison of UNB and Spread Spectrum Wireless Technologies as used in LPWA M2M Applications".

[i.41] Directive 1999/5/EC of the European Parliament and of the Council of 9 March 1999 on radio equipment and telecommunications terminal equipment and the mutual recognition of their conformity (R&TTE Directive).

NOTE: Available at http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:31999L0005.

[i.42] Directive 2014/53/EU of the European Parliament and of the Council of 16 April 2014 on the harmonisation of the laws of the Member States relating to the making available on the market of radio equipment and repealing Directive 1999/5/EC (RE Directive).

NOTE: Available at http://eur-lex.europa.eu/eli/dir/2014/53/oj.

[i.43] IEEE 802.11ah-2016™: "IEEE Standard for Information Technology-Telecommunications and Information Exchange Between Systems-Local and Metropolitan Area Networks-Specific Requirements-Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications: Amendment 2: Sub 1 GHz License Exempt Operation".

NOTE: Available at http://standards.ieee.org/findstds/standard/802.11ah-2016.html.

3 Definition of terms, symbols and abbreviations

3.1 Terms

For the purposes of the present document, the following terms apply:

base-station: fixed part of the network which transmits and receives radio signals from and to end-points within its area of coverage

downlink: unidirectional radio link for the transmission of signals from a base-station to one or more end-point

end-point: mobile or fixed part (low complexity) of the network, which transmits and receives radio signals from and to base-station within its transmission range

occupied bandwidth: width of a frequency band such that, below the lower and above the upper frequency limits, the mean powers emitted are each equal to 0,5 % of the total mean power of a given emission

uplink: unidirectional radio link for the transmission of signals from an end-point to a base-station

3.2 Symbols

For the purposes of the present document, the following symbols apply:

bps	bits per second
C	carrier
dB	decibel
dBi	decibels of antenna gain referenced to a hypothetical isotropic antenna
dBm	decibels of the power referenced to one milliwatt
I	interferer

3.3 Abbreviations

For the purposes of the present document, the following abbreviations apply:

3GPP	3rd Generation Partnership Project
ALD	Assistive Listening Device
BER	Bit Error Rate
BS	Base-Station

CEPT	European Conference of Postal and Telecommunications Administrations (Conférence Européenne des administrations des Postes et Télécommunications)
CO	Carbon Monoxide
DAA	Detect And Avoid
DC	Duty Cycle
DL	Downlink
DR	Demand Response
e.r.p.	effective radiated power
EC	European Commission
ECC	Electronic Communication Committee (of the CEPT)
ECG	Electro Cardio Graph
EP	End-Point
ERC	European Radiocommunications Committee
ER-GSM	GSM for railways, extended band
FCC	Federal Commission for Communications
FPI	Fault Passage Indicator
GDP	Gross Domestic Product
GPS	Global Positioning System
GSM	Global System for Mobile communications
GSM-R	Global System for Mobile communication for Railways applications
IHD	In Home Display
IMT	International Mobile Telecommunications
IoT	Internet of Things
ITU	International Telecommunication Union
LAN	Local Area Network
LBT	Listen Before Talk
LPG	Liquid Petroleum Gas
LPWA	Low Power Wide Area
LPWAN	Low Power Wide Area Network
LTE	Long Term Evolution
LTN	Low Throughput Network
MCV	Mobile Communications on board Vessels
NB-IoT	Narrow Band Internet of Things
NBN	Narrow Band Networked
OTA	Over The Air
PAN	Personal Area Network
PT	Project Team
RBW	Resolution Bandwidth
RE	Radio Equipment
RFID	Radio Frequency Identification
RTC	Real Time Clock
RX	Receiver
SDR	Software Defined Radio
SE	Spectrum Engineering
SLA	Service Level Agreement
SRD	Short Range Devices
TRR	Tactical Radio Relay
TTE	Telecommunications Terminal Equipment
TTT	Transport and Traffic Telematics
Tx	Transmitter
UAS	Unmanned Aircraft System
UE	User Equipment
UHF	Ultra-High Frequency
UK	United Kingdom
UL	Uplink
UNB	Ultra-Narrow Band
US	United States
VOC	Volatile Organic Compounds
WBN	Wide Band Networked
WG	Working Group

4 Comments on the System Reference Document

None.

5 System Description

An UNB system is a dedicated solution for the IoT connection. It is a general-purpose low power and long range IoT connection that can address a large range of IoT applications.

A UNB system consists of end-points and a network. End-points are scattered in the field (outdoor or indoor) and communicate with the network over bidirectional radio links. The network itself is made of base-stations and a service centre, which connects the UNB system to the internet and/or application servers (see Figure 1).

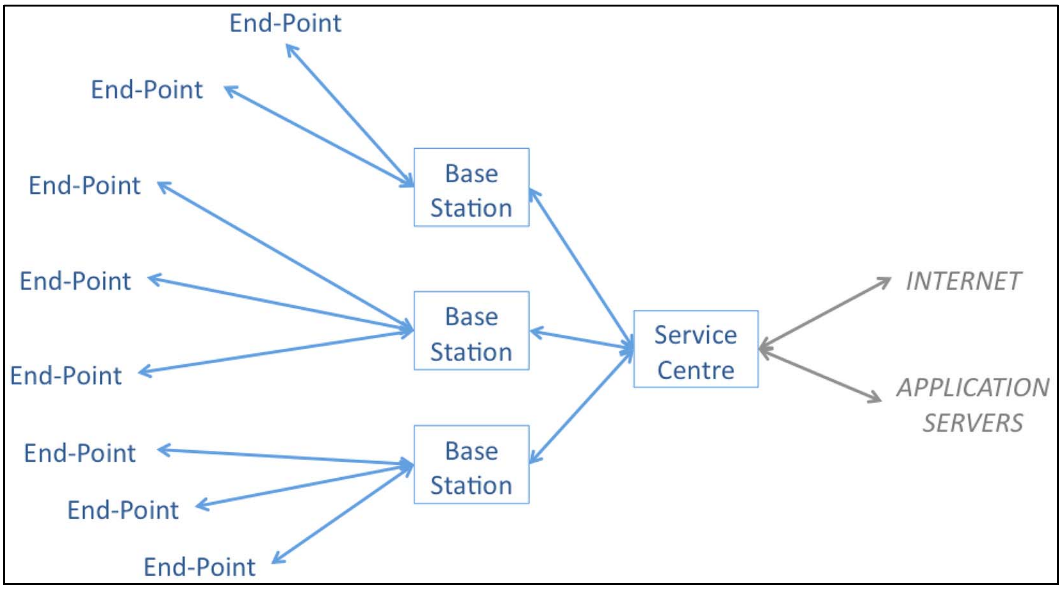

Figure 1: Star topology of a UNB system

The topology of a UNB system is a star with the service centre as its hub. Compared to other non-specific SRDs, a UNB system is massively asymmetrical, i.e. it connects tens to hundreds of thousands of end-points to one base-station. The expected node density of UNB systems is the following:

- end-points: up to 100 k end-points per square kilometre;
- base-stations: typically 1 per 10 square kilometres (or 0,1 per km^2).

UNB systems are intended for carrying a low volume of traffic per end-point, typically up to 1 kbyte of user data per day in each direction: uplink, from an end-point to a base-station, and downlink from a base-station to an end-point. The pattern of data flow depends on the application, examples are described in clause 6.3. UNB systems operate under General Authorization and share the spectrum with other users and/or systems.

UNB systems use Ultra-NarrowBand (UNB) radio communication that gives a high link budget, even with a low power transmitter in the devices. This feature, along with many radio optimizations, allows battery-powered devices with operation times beyond 15 years.

UNB systems as described in the present document are a key means of implementing Low Power Wide Area networks. Such UNB systems can bring low cost, long battery-life solutions for the very wide range of applications where the wireless exchange of small amounts of data can bring real benefits for users, the wider society and the economy.

The potential contribution of UNB systems to the management of health can bring wide benefits, from efficient equipment and resources management to patient monitoring. The societal benefits arising from effective environmental monitoring and management, from pollution control to timely response to extreme weather events are widely recognized. UNB systems offer an effective means of gathering and responding to data from a wide range of sensors and controllers which can be deployed on a grand scale with low outlay and ongoing cost. Such data-gathering is well-placed to exploit the possibilities of "big data", bringing new efficiencies, enabling new applications and creating new business opportunities.

UNB systems can bring benefits to society through the minimization of the environmental footprint of "smart cities", providing optimized control and monitoring of power-consuming systems such as street lighting, as well as supporting efficient infrastructure services such as utility distribution, waste management, transport logistics and traffic management.

The economic benefits of the Internet of Things will be great: revenues have been forecast in a study for the European Commission [i.12] to bring EU28 revenues rising to over €1 000 bn in 2020 (including hardware, software and services). Analysts have forecast [i.2] that the accumulated global connectivity revenues from LPWA services will reach US$34 bn by 2023. In the present document an assumption is made that UNB systems will secure 40 % of the LPWA market.

6 Market Information

6.0 General

UNB-based LPWA systems are an effective and efficient means of enabling the control and monitoring of a large number of devices (sensors, controllers etc. attached to end-points) spread over a relatively large geographical area where the volume of traffic to/from each end-point is low [i.40]. UNB systems are already deployed and operating successfully, addressing a variety of market needs. Current systems operate under General Authorization between 863 MHz and 870 MHz and are compliant with SRD regulatory requirements; these systems are able to meet today's demanded capacity within today's spectrum and regulatory constraints.

A number of analysts have published forecasts of strongly growing demand for LPWA network connections (i.e. number of devices connected to LPWAN) and extracts from these forecasts are used in the present document as a measure of the growing demand for UNB LPWA systems. UNB technology is one of a number of technologies which can be used to address the forecast demand, access to more spectrum will be required if UNB systems are to continue to play a substantial role in meeting market demand.

6.1 Internet of Things market segmentation

The Internet of Things is a catch-all phrase that encompasses various use cases, various business models and various technologies for the radio connectivity. This clause categorizes the various types of technologies that are foreseen for addressing IoT connectivity, of which UNB is one.

Although many connectivity techniques can be employed for the IoT, a large subset of IoT devices shares a common requirement: they are battery operated and expected to live for several years. Three main types of connectivity share this requirement (see Figure 2).

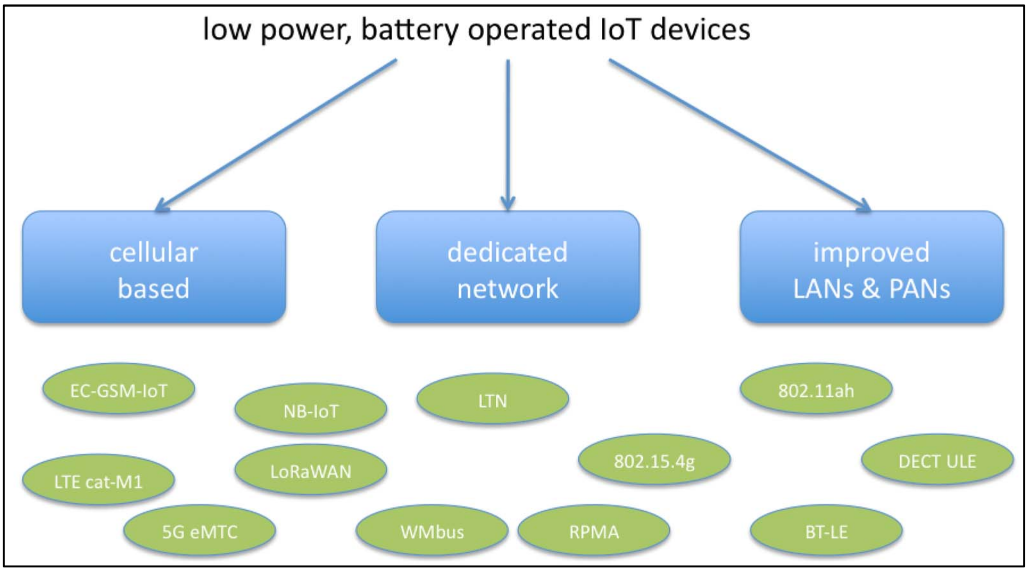

Figure 2: Main types of connectivity techniques for the IoT

The first category encompasses the legacy cellular technologies, optimized to address the challenges of the IoT: low power, long range, low complexity and huge number of connected devices per base-station. The 3GPP ecosystem hosts several radio technologies for the IoT.

The second category encompasses the wide area networks dedicated to IoT connectivity. They are designed and optimized to meet the requirements of those IoT devices with low throughput needs, employing a low modulation rate to achieve extended radio coverage even with low transmit power. The present document is about UNB radio connections, which is one of the dedicated networks.

The third category encompasses the reduced-power versions of the well-known LAN and PAN protocols. They address the market segment of limited range (personal or local area) networks and mainly indoor deployments. These low power radio technologies are mainly intended for private networks. Their primary spectrum range is the licence-exempt band 2,4 GHz, but recent revisions target the sub-gigahertz band also.

6.2 Application Domains for LPWA systems

A large and varied range of applications is envisaged for LPWA systems. This clause provides an overview of the main applications foreseen and estimates the numbers of devices to which these applications may give rise.

Analysts see the market as largely additive to cellular technology [i.2]. Table 1 sets out some of the application domains that can be covered by LPWA systems (including UNB).

The data presented in this clause (from various references as shown) are used in Annex A to forecast capacity requirements.

Table 1: Domains of application and use cases

Domain	Sub-domain	Use case
Metering	Water & Gas distribution	Collect data 3-4 times daily water and gas usage data
	Electricity distribution	Collect data daily or hourly electricity usage data
Infrastructure networks	Water & Gas transportation	Water and Gas infrastructure network surveillance (alarm, metering parameters)
	Electricity transportation	Electricity transport status monitoring and command/control
	Road/traffic management	Traffic light control, traffic level monitoring, emergency gate status control, digital signage status and updates
	Pipelines	Collect data on Metrics (temperature, pressure), alarms, leakage, vibration
	Drains	Collect data on Levels, turbidity ratio
Environment/Smart City	Waste management	Collect data on Levels, location

Domain	Sub-domain	Use case
	Air pollution monitoring and alerting	Collect data on Humidity, temperature, VOC, CO2, CO, etc.
	Acoustic noise monitoring	Noise level monitoring
	Street Lighting	Control of on/off times and dimming profile; monitoring of electricity usage; support of asset management locations
	Parking Management	Availability monitoring; support for enforcement and payment systems
	Self Service bike rental	Bike & rack availability, status monitoring, location
	Digital board monitoring	Status, screen display rotation/timeslot control
	Water pipe leakage monitoring	Leakage monitoring
Environment/Country side	Soil quality monitoring	Acidity, humidity, nitrogen, landslide prevention
	Livestock surveillance	Geolocation, health status, wolf prevention (accelerometer), geofencing, teleguidance
	Cattle & pet monitoring	Geolocation
	Climate	Rain, wind, temperature, humidity (pressure)
	Irrigation	Leakage
	Run off monitoring	Landfill liquor, nitrates, phosphates monitoring
Remote monitoring (telesurveillance)	House	Fire detection, smoke, CO, flood, leakage, intrusion, temperature, home automation (blinds, etc.)
	Building	Fire detection, smoke, CO, flood, leakage, intrusion, temperature, building automation (blinds, heating, air conditioning, etc.), telesurveillance
Industrial	Water tank management	Water level, leakage, refill management
	Asset tracking	Location, anti-theft
	Industrial plant condition monitoring	Generators, compressors, pumps: bearing temperatures, oil levels, vibration
Automotive	Vehicle tracking	Location, anti-theft
	Impact detection	Send message when vehicle is stopped abruptly
	Pay-As-You-Drive	Send message to the conductor about the driving behaviour Collect data about driving behaviour
	Assistance request, Break down call, Comfort Call	Send a localization message to request support
	Fault, service interval reporting	Send condition and mileage parameters periodically or on fault
Logistics	Goods tracking	Localization of goods
	Off grid fuel delivery	LPG, Oil, Biomass, Coal automatic re-supply
	Refrigerated container monitoring	Set, control, monitor containers for temperature, low fuel, load integrity
	Conservation parameters	Send message alarms related to temperature/shock for sensitive products
Healthcare	Patient monitoring	Fall down detection, out of area detection, ECG monitoring, activity monitoring, Alert
	Home Medical Equipment status and usage	Control of correct usage of medical equipment and status
	Attendance tracking	Care staff SLAs, compliance and billing data
Conventional Cellular Cooperation	Alarm sending	Send alarm message and activation of 3G for sending data (video, etc.)
House appliances	Pet tracking	Localize pets
	White goods	Usage identification Preventive maintenance
	Personal asset	Location of luggage, clothes, satchel, phone (when battery down), etc.
Truck	Tyre monitoring	Check pressure and tyre usage

Domain	Sub-domain	Use case
Identification	Authentication	Additional level of security for exchange Identification/authentication data

Analysts predict that the total addressable market for LPWA devices will exceed 12 bn devices by 2020 with predictions of 1 bn connections by that time. Table 2 shows a forecast of accumulated connectivity revenue [i.2]. Table 3 shows the estimated number of end-points per 100 M inhabitants for different application domains.

Table 2: Forecast connectivity revenues (US$ bn)

2016	2017	2018	2019	2020	2021	2022	2023
0,1	0,6	1,3	2,5	3,4	6	8,3	10,7

Table 3: Number of end-points per 100 M inhabitants by application domain

Application Domain	100 M inhabitants basis (see notes)
Water smart meter	30 M
Gas smart meter	16 M
Electricity smart meter	57 M
Waste management	25 M
Air Pollution	200 k
Acoustic Noise	200 k
Public Lighting	1 M
Parking management	4 M
Self Service Bike rental	200 k
Automotive	60 M
Paper Advertising Board monitoring	50 k
Patient Monitoring	1 M
TOTAL number of Eps	185 M
NOTE 1: The above numbers are based on a population of 100 M inhabitants and estimate the number of EP per different UNB/LPWA use cases. NOTE 2: 100 M inhabitants, 55 % individual houses/45 % apartment buildings [i.8]. NOTE 3: 41 M households with an average of 2,4 people/households [i.8], 23 M residential house, 18 M apartment buildings, dustbin: 10 % of apartment buildings, 50 000 cities. NOTE 4: Parking excludes: indoor parking (use wire line connectivity), private parking. NOTE 5: Self Service Bike Rental: based in France [i.8], Automobile: based in France [i.8].	

6.3 Example applications and use cases for LPWA systems

6.3.0 General

A range of typical use cases with their individual characteristics and associated constraints is described below.

6.3.1 Smart City

6.3.1.0 Smart City applications

Example Smart City applications are listed in Table 4, with more details on two important examples below.

Table 4: Smart City Applications

Need	Period	Payload (note 1)	Communication mode (note 2)
Street Parking	1/min to 1/hour, depends on traffic. ~ 30 s Uplink latency required	1 to 15 bytes	1-way or 2-way
Street Lighting	2/day Uplink (event log + meter reading); downlink commands as necessary (none if everything is operating correctly).	100 to 200 bytes	2-way
pH Level monitoring	1/day	1 to 15 bytes	1 or 1,5-way
Bicycle rental	1/day to 20/day	1 to 15 bytes	1-way, 1,5-way or 2-way
Smart garbage collection	1/day to 5/day	1 to 15 bytes	1-way, 1,5-way or 2-way
Watering/irrigation	1/day to 5/day	1 to 15 bytes	1-way, 1,5-way or 2-way
Sewage management	1/day to 5/day	1 to 15 bytes	1-way, 1,5-way or 2-way
Flood Management (incl. highway gully monitors)	1/day to 5/day	1 to 15 bytes	1-way, 1,5-way or 2-way
Pollution monitoring	1/day to 5/day	1 to 15 bytes	1-way, 1,5-way or 2-way
Tracking dust storms	Occasionally	10 to 100 bytes	1-way, 1,5-way or 2-way
Weather monitoring to mitigate icy roads	1/day to 20/day	1 to 15 bytes	1-way, 1,5-way or 2-way
Automated safety alert networks	Occasionally	10 to 100 bytes	1-way, 1,5-way or 2-way
Networked road barriers	1/day to 5/day	1 to 15 bytes	1-way, 1,5-way or 2-way
Infrastructure safety e.g. bridges	1/day to 5/day	10 to 100 bytes	1-way, 1,5-way or 2-way
Tracking prisoners on parole	1/day to 20/day	1 to 15 bytes	1,5-way or 2-way
Gunshot monitoring	Occasionally	10 to 100 bytes	1-way or 1,5-way
Earthquake monitoring	Occasionally	10 to 100 bytes	1-way, 1,5-way or 2-way
NOTE 1: These payload figures are application payloads optimized for LPWA/UNB networks. Different UNB systems use different mechanisms in the transmission of application payloads, see clause 7. NOTE 2: "Communication mode" describes the direction of application information flow; 1,5-way describes a flow which is mainly uplink but also requires a lower level of DL flow.			

6.3.1.1 Street parking

Street parking monitoring systems monitor the state of parking spaces equipped with sensors typically embedded into the road in the parking space. Each sensor communicates whether the space is occupied or not. Such systems may also involve communication with tags placed in the car and given to disabled drivers or residents. These systems are used in conjunction with street signs or mobile applications to guide cars to empty spaces. They can also be used for enforcement of illegal parking by guiding enforcement officers to cars which have over-stayed in a place or parked in a space in which they are not authorized. The determination of whether a car is allowed to park in a space may involve the use of radio tags to identify the car, but other solutions are possible for this. If the reliability of the parking sensors is high then such systems can be used to support parking payment.

6.3.1.2 Street lighting

Street lighting central management systems monitor the performance of street lights for electricity consumption and lamp performance. They also allow the (re-) configuration of the profile of light level over the day. Such systems aim to reduce the power consumption of the street light by only having them on when necessary. They also control the light level to be at that necessary to provide sufficient illuminance on the road below taking into account the time of day, the season. Other factors such as the weather and traffic conditions can also be used to affect the lighting time profile. For more information see example in [i.1].

6.3.2 Automotive

6.3.2.0 Automotive Applications

Automotive telematics applications vary greatly in their communications requirements. The subset of applications best supported by UNB systems is given in Table 5 (see also [i.3], [i.4] and [i.5]). Typically UNB is deployed as an "after-market" installation for vehicle fleet management, Pay-As-You-Drive insurance or remote assistance where the small equipment size, long life from batteries, improved signal penetration into garages, basements, and low radio signal emission levels are required by the applications.

Table 5: Automotive Applications

Need	Period	Payload (raw data)	Communication mode
Geo-location assistance	Occasionally	250 to 1 k bytes	1,5-way or 2-Way
Shock detection	Occasionally	10 to 100 bytes	1-way, 1,5-way or 2-way
Driver profiling	1/day to 4/day	250 to 1 k bytes	1-way, 1,5-way or 2-Way
Exception reports	Weekly	100 to 200 bytes	1-way or 2-Way
Out of hours driving	Occasionally	100 to 200 bytes	1-way or 2-Way
Remote vehicle diagnostics/fault reporting	1/week to 1/day	100 to 750 bytes	1-way or 2-Way
Pay-As-You-Drive insurance	2/day to 4/hour	100 to 500 bytes	2-way
Fuel efficiency monitoring	Daily	100 to 500 bytes	1-way or 2-way
Car share management	Hourly	100 to 500 bytes	2-way

Likely implementation technologies for UNB will limit the vehicle speed at which communication is reliable. Therefore the use cases above should be viewed with this in mind.

6.3.2.1 Stand-alone anti-theft

Automotive anti-theft applications rely on a concealed installation of an end-point on a vehicle, trailer, container, generator or other movable asset. The systems can typically be set to detect unexpected motion, or be activated remotely once theft has been detected to enable vehicle recovery. Typical use cases involve activation of a beacon signal on theft to allow location via suitable detectors used by law enforcement agencies and give rise to the traffic shown in Table 6, Alternative implementations augmenting UNB with GPS and/or cellular to accurately send the location of the stolen vehicle are also possible.

UNB stand-alone anti-theft systems require a small and therefore physically easy to conceal end-point. These should also be hard to detect whether through physical size, local oscillator, intermediate frequency stage or other radio frequency emissions. They should operate with challenging link budgets typical of the high penetration loss into garages, car-parks and shipping containers and may be vehicle or internally powered.

A very large number of UNB devices may be installed for anti-theft applications. [i.5] indicates 2 % of vehicles may be fitted with stand-alone anti-theft devices in 5 years. [i.6] states that there are 334 m road vehicles in Europe. Together they indicate the European 5 year stand-alone anti-theft market to be over 6 m devices.

Table 6: Stand-alone anti-theft

Need	Period	Payload (raw data)	Communication mode
Stolen Vehicle Recovery/ stand-alone anti-theft	1/min to 1/hour, depends on traffic. ~ 30 s Uplink latency required	10 to 20 bytes	1-Way or 2-Way

6.3.3 Smart Grid

6.3.3.0 Transformer monitoring characteristics

Table 7: Transformer monitoring characteristics

Need	Period	Payload (raw data)	Communication mode
Fault passage indicator	1/hour	3 bytes typical	1-way
Low voltage sensors	1/15 minutes	3 bytes typical	2-way
Transformer status monitoring	1/hour	10 bytes typical 20 bytes max	1-way
Alarm detection	once every two years	3 bytes typical	1,5-way

6.3.3.1 Fault Passage Indication

A Fault Passage Indicator (FPI) is a device which provides visual or remote indication of a fault on the electric power system. The device is used in Medium Voltage electrical power distribution networks as a means of automatically detecting and identifying faults to reduce outage time. Overhead indicators are used to visualize the occurrence of an electrical fault on an overhead electrical system. An improvement of the existing system is to use long range radio in order to monitor the system and centralize the information at the control centre level. For this kind of application, one radio technology with long range and low power is mandatory. Indeed the power supply of the device can be photovoltaic cells or energy harvesting system or batteries. The distance for communication (radio range) would be 30 km. One radio message can be sent regularly (every day or every hour) to test the communication. The message size is a few Bytes: Fault passage indicator ID, and binary information (Fault or No Fault).

6.3.3.2 Low Voltage Network monitoring

Because of the generalization of photovoltaic energy production, the low voltage on the electrical grid is less stable and this requires new sensors In order to monitor and control the voltage. The new voltage sensors should be easy to install low power (batteries or energy harvesting if possible) and equipped with long range radio for the communication. Low voltage sensors will be used to monitor voltage on Low Voltage networks by measuring voltage at customer connection level. The distance for communication (radio range) would be 10 km. One radio message giving the value of the voltage can be sent regularly every 15 minutes. In the event of significant change in the value of the voltage, a notification (radio message) is sent. The message size is a few Bytes: Voltage sensor ID, and the measured voltage value. Bidirectional communication would be a "nice to have" in order to "Ping" the devices. These long range radio sensors will increase photovoltaic production insertion capacity.

6.3.3.3 Electric network fault monitoring

Nation-wide electric networks connect power plants and consumption points with power lines, dispatch centres, circuit breakers and many other specific elements. They are deployed all over a country and even more, they are interconnected all across Europe for load balancing and outage protection.

The voltage of each line is optimized across length, voltage and line current. To get it, high power/voltage transformers connect high voltage lines with medium voltage lines. In the same way, there are medium and low power/voltage transformers. As an example, the French metropolitan territory has over 1,5 M of these transformers requiring monitoring in view of achieving a good level of service.

Parameters to be monitored are for example: internal & external temperatures, internal pressure. A specific case is given by oil-filled transformers: they are equipped with Buchholtz relay for failure detection. Whenever there is a fault in the transformer, the oil pressure increases rapidly and trigged the Buchholtz relay, which, in turn, triggers an alarm and a circuit break.

Monitoring the transformer status, the relay status and the alarm status with UNB solution might be very useful because many transformers are half-buried or installed in harsh environment, where other communication means are not easily available. In this case, the key advantage of a UNB solution is its high link budget and its low power consumption that allows battery operation (i.e. without any high voltage insulation issues).

6.3.3.4 Multicast load control - Management of Electricity Demand

The use of UNB is foreseen in a wide range of Demand Response (DR) applications ranging in scale from a few buildings through to cities and regions. Typically the energy provider uses DR to cope with peaks of demand and/or supply and will use UNB to rebalance supply and demand - e.g. by switching off non-essential loads, by switching dual-fuel customers to switch from say gas to electric water heating. The increasing use of renewable (especially solar and wind) is leading to both over-supply (sunny windy day) and under-supply (foggy still day) and DR is increasingly needed as high capacity electrical storage is expensive and inefficient. A specific example is the experience in South Africa where DR is aimed at avoiding costly black outs (about 10 per year in South Africa). This is performed via an innovative relay in the panel board which is easily deployable and enabling remote energy management via the cloud. The operated radio network can be used by every utility company for this usage. The distance for communication (radio range for multicast downloading) would be 20 km. The latency of the system should be better than 5 mn (time between the alarm detection and the disconnection of the loads) for devices which are not permanently power supplied. The latency of the system should be better than a few seconds for devices which are permanently power supplied. The multicast message size is a few bytes: voltage sensor group ID (for multicast) and binary information (load should be disconnected or load allowed to be connected).

6.3.4 Smart Metering

6.3.4.0 General

"Metering" is a broad domain that covers multiple areas including those listed below.

Water and gas metering normally require battery operated end-points while Electricity metering can normally employ EPs with external power.

6.3.4.1 Water & gas metering

Typical segmentation of the water and gas metering domain includes high-end needs with sophisticated features, and low-end needs that are more basic.

Table 8: High-expectation metering characteristics

Need	Period	Payload (raw data)	Communication mode
Consumption sampling (log)	4/hour to 1/hour	N/A	N/A (local storage)
Index transmission	4/day to 1/day, periodic	→ 10 bytes (one log) → 200 bytes + header (optional)	1-way 1,5-way
Downlink command (valve, tariff modification, etc.)	1/month to 1/year	5 to 50 bytes	1,5-way or 2-way
Firmware upgrade (OTA)	1/year to 1/device life time	Several kbytes	1,5-way or 2-way
Alarm transmission	Occasionally	6 to 25 bytes	1-way or 1,5-way
Connectivity (check-alive)	1/hour to 1/day	At least 1 byte	1,5-way or 2-way
Real Time Clock (RTC) update	1/day to 1/week	Up to 10 bytes	1,5-way or 2-way
Battery status update	1/day to 1/month	Up to 10 bytes	1 or 1,5-way
Encryption key update	1/day to 1/year		2-way
In-Home Display (IHD) communication (see note)	1/hour → to 1/day →	→ 10 bytes → 200 bytes	1 or 1,5-way
Maintenance	1/day to 1/year	10 bytes to 1 kbyte	1,5-way or 2-way
NOTE: A fast update, fully featured, In Home Display (IHD) is considered to be part of a separate Home Area Network not suitable for implementation with UNB technology. A low update rate remote display of a meter reading is the Use Case envisaged here.			

Table 9: Low expectation metering characteristics

Need	Period	Payload (raw data)	Communication mode
Consumption sampling (log)	1/hour to 1/day	N/A	N/A (local storage)
Index transmission	1/day to 1/month, periodic	→ 10 bytes (one index) → 200 bytes + wake up preamble (optional)	1-way 1,5-way
Downlink command (valve, tariff modification, etc.)	1/month to 1/year	5 to 50 bytes	1,5-way or 2-way
Firmware upgrade Over-The-Air (OTA)	Optional		1,5-way or 2-way
Alarm transmission	Occasionally	6 to 25 bytes	1-way or 1,5-way
Connectivity (check-alive)	1/day to 1/month	At least 1 byte	1,5-way or 2-way
Real Time Clock (RTC) update	1/day to 1/month	Up to 10 bytes	1,5-way or 2-way
Battery status update	1/day to 1/month	Up to 10 bytes	1 or 1,5-way
Encryption key update	Optional		2-way
In-Home Display (IHD) communication (see note)	1/day (optional)	→ 10 bytes → 200 bytes	1 or 1,5-way
Maintenance	1/month to 1/year	10 bytes to 1 kbyte	1,5-way or 2-way
NOTE: A fast update, fully featured, In Home Display (IHD) is considered to be part of a separate Home Area Network not compatible with UNB technology. A low update rate remote display of a meter reading is the use case envisaged here.			

6.3.4.2 Electricity metering

Electricity metering has a similar segmentation as the tables above, with high expectations and low expectations requirements.

Table 10: High expectation electricity metering characteristics

Need	Period	Payload (raw data)	Communication mode
Consumption sampling (log)	1/min to 1/hour	N/A	N/A (local storage)
Index transmission	6/hour to 1/day, periodic	several hundreds of bytes + header (optional)	1-way or 1,5-way
Downlink command (contact, tariff modification, etc.)	1/month to 1/year	5 to 1 kbytes	1-way, 1,5-way
Firmware upgrade Over-The-Air (OTA)	1/year to 1/device life time	Several kbytes	1,5-way or 2-way
Alarm transmission	occasionally	6 to 200 bytes	1,5-way or 2-way
Connectivity (check-alive)	1/hour to 1/day	At least 1 byte	1,5-way or 2-way
Real Time Clock (RTC) update	1/day to 1/week	Up to 10 bytes	1 or 1,5-way
Encryption key update	1/day to 1/year	N/A	2-way
In-Home remote meter display (see note)	1/hour to 1/day	10 to 200 bytes	1-way or 2-way
Maintenance	1/day to 1/year	10 to several kbytes	2-way
Pre-pay credit management	1/day to 1/month	Several hundred bytes	2-way
NOTE: A fast update, fully featured, In Home Display (IHD) is considered to be part of a separate Home Area Network not compatible with UNB technology. A low update rate remote display of a meter reading is the use case envisaged here.			

Table 11: Low-end electricity metering characteristics

Need	Period	Payload (raw data)	Communication mode
Consumption sampling (log)	1/min to 1/hour	N/A	N/A (local storage)
Index transmission	6/hour to 1/day, periodic	several hundreds of bytes + header (optional)	1-way or 1,5-way
Downlink command (contact, tariff modification, etc.)	1/month to 1/year	5 to 1 kbytes	1-way, 1,5-way
Firmware upgrade Over-The-Air (OTA)	Optional	N/A	N/A
Alarm transmission	Occasionally	6 to 200 bytes	1,5-way or 2-way
Connectivity (check-alive)	1/hour to 1/day	At least 1 byte	1,5-way or 2-way
Real Time Clock (RTC) update	1/day to 1/week	Up to 10 bytes	1 or 1,5-way
Encryption key update	Optional	N/A	N/A
In-Home Display (IHD) communication (see note)	1/hour → to 1/day →	10 to 200 bytes	1-way or 1,5-way
Maintenance	1/day to 1/year	10 to several kbytes	1,5-way or 2-way (local)
NOTE: A fast update, fully featured, In Home Display (IHD) is considered to be part of a separate Home Area Network not compatible with UNB technology. A low update rate remote display of a meter reading is the Use Case envisaged here.			

6.3.5 Agriculture and/or environment

Use cases of agricultural and environmental applications include:

- Monitoring of soil quality of e.g. cropland, vineyards, golf courses by measuring humidity, PH-value, nutrients ground to optimize and control of watering and fertilizing.
- Monitoring of plant growth by measuring soil quality together with environmental conditions like temperature, humidity and light intensity in open sky or greenhouse environment.
- Monitoring of air quality by measuring gas concentration like CO_2, NO, etc. in the air (e.g. smart cities).
- Animal Tracking: monitoring location and health status of individual animals of a herd like sheep, cows, etc. over a pasture (similar to asset tracking).

Table 12: Agriculture/environment application characteristics

Need	Period	Payload (raw data)	Communication mode
Transmission of sensor data for soil quality	1/day to 1/hour (depending on application)	Sensor data (depending on sensor)	1-way
Transmission of sensor data for air quality	1/day to 1/hour (depending on application)	Sensor data (depending on sensor)	1-way
Transmission of object position	1/hour to 4/hours	Position information	1-way

6.4 LPWA and UNB Market Evolution

6.4.1 Market growth and capacity demand

A number of analysts have published forecasts of demand for LPWA network connections (i.e. number of devices forecast to be connected to LPWAN). Extracts from these forecasts are used in the present document as an indication of the future demand for LPWA systems which can help estimate demand for UNB-based LPWA systems.

Note that "connection" can be considered synonymous with "end-point connected to a LPWA network".

Example analyst reports are:

$34 bn service revenue by 2023, [i.2].

3 billion devices by 2023,[i.38].

$27 bn service revenue by 2020, [i.39].

Analysis Mason forecasts for global LPWA connections include Figure 3 (Machina Research report very similar numbers of LPWA connections by 2023). (Note that analysts carefully distinguish this market for LPWA from that which can be addressed by traditional cellular solutions, with only a very small overlap.)

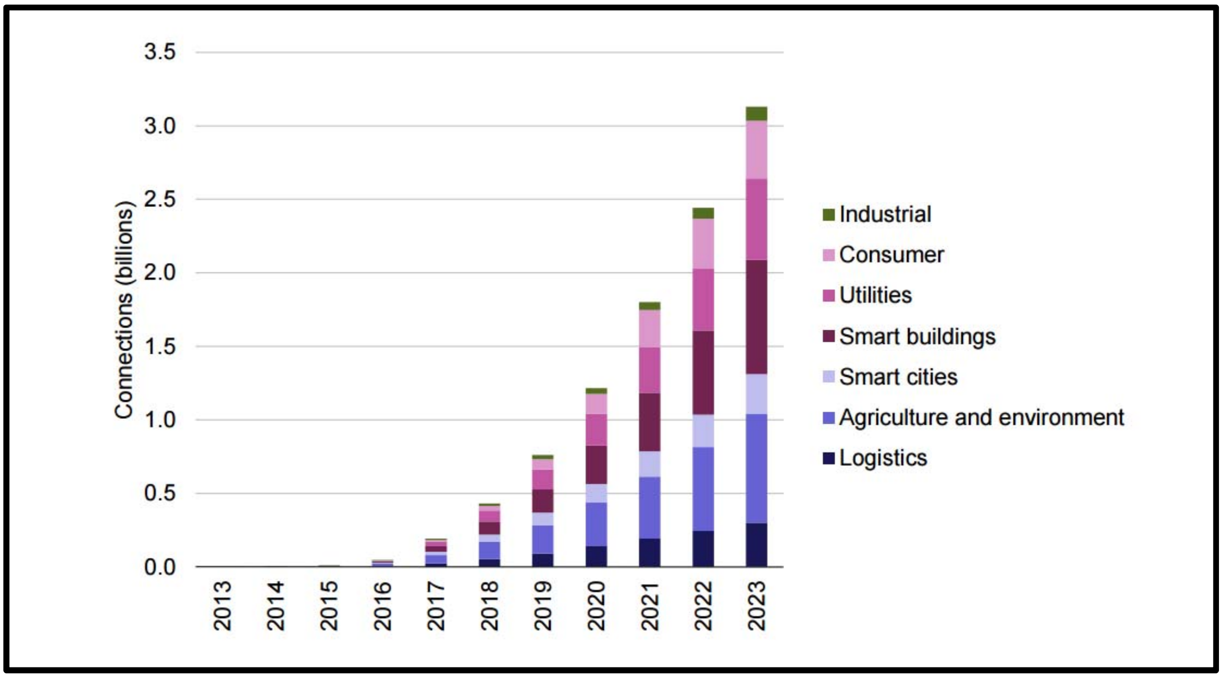

Figure 3: LPWA Connections Forecast (Source: Analysis Mason 2014 [i.2])

The ability of LPWA systems to satisfy these forecasts will depend not only on the absolute number of connections required but also on the geographical density of connections, as a high density of connected devices will place greater demands on spectrum and on measures taken to employ it efficiently. The forecasts in Figure 3 can be used to model the requirements for capacity in geographical regions where the demand (connections/km^2) is likely to be highest, see Annexes A and B.

Note that LPWA systems can be enabled through various "technologies", e.g. NB-IoT, spread spectrum, UNB. UNB is very well suited to the mass of IoT devices that will mainly require high autonomy/battery life, low cost devices, low throughput and global coverage, a working assumption is required in order to estimate requirements for UNB capacity based on LPWA market forecasts: for this purpose UNB systems are assumed to represent 40 % of deployed LPWA systems during the lifetime of these forecasts.

7 Technical information

7.1 Detailed technical description of current UNB technologies already deployed

7.1.0 General

This clause gives technical details on the radio interface of UNB systems already deployed. Parameters and values detailed hereunder are neutral within UNB technology, i.e. they are common to all UNB technologies and protocol stacks which may be used to build a UNB system.

7.1.1 UNB Radio Interface

7.1.1.1 UNB Uplink

The target link budget in UNB uplink is 150 dB - 155 dB. Given the maximum output power in frequency bands dedicated to non-specific devices (i.e. +14 dBm) and the limited amount of energy available in battery operated end-points, such a high link budget is obtained with improved sensitivity and improved selectivity (compared to existing off-the-shelf sub-GigaHertz chipsets) in the base-station (i.e. sensitivity of -140 dBm), which implies the use of ultra-narrowband communication in uplink. The typical bandwidth of the transmitted carrier is about 250 Hz (see Table 13), but also lower and higher bandwidths are possible. The signal is sent in the operational frequency band (in current deployment, about 200 kHz), using only a very small part of it (as said previously, typically 250 Hz).

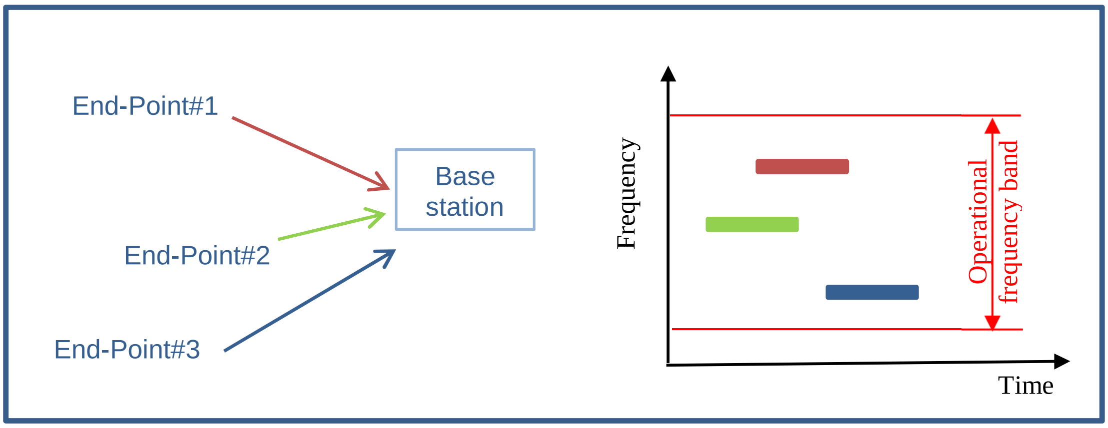

Figure 4: Principle of spectrum use by UNB end-points in uplink

A range of data rates and modulations is possible.

The low bandwidth results in low on-air data rates, which means UNB-based systems are well-matched with applications requiring low volumes of data as described in clause 6.2. This aspect also results in relatively long transmissions, typically around 2 s but implementation-dependent.

7.1.1.2 UNB Downlink

The downlink transmission in a UNB system requires the same link budget value as in uplink. Nevertheless, the trade-off is different because more energy is available in the (mains-powered) base-stations, and because BS are required to support communication with a very large number of end-points. For these reasons, downlink transmission occurs with more power and higher symbol rates than uplink (see Table 13). Message lengths tend to be similar to those in the uplink (around 2 s).

7.1.1.3 Multi-Carrier in Downlink

The use of software-defined radio technology enables, in some implementations, the use of more than one UNB carrier (see Figure 5) which can provide an increased UNB system downlink capacity. Multi-carrier operation can be used when the path loss experienced by a single downlink carrier is relatively low and therefore the link can be maintained when the transmit power in the carrier can be reduced significantly below the regulatory maximum. In this case power remaining (within regulatory limits) can be employed in one or more additional ultra-narrow carriers within the same operational frequency band. The duty cycle of the base-station is measured taking all carriers into account, and limited by regulation.

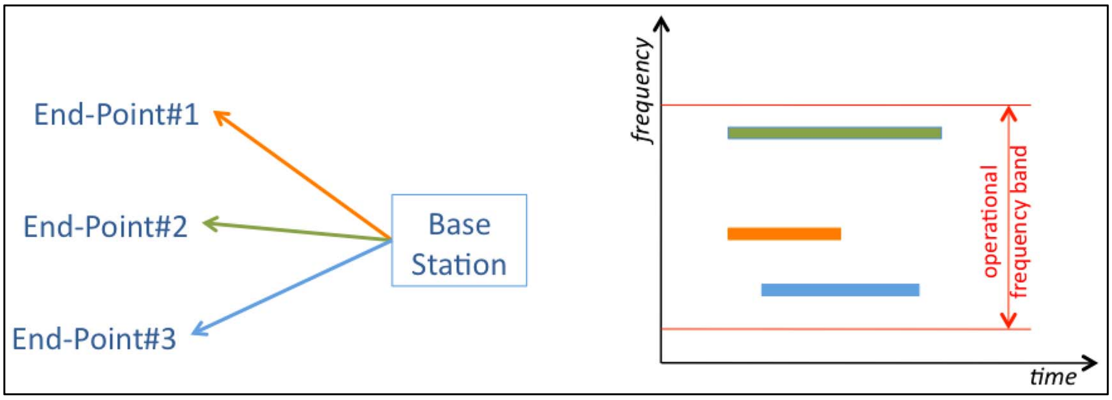

Figure 5: Principle of UNB multi-carrier operation in downlink

7.1.2 Technical parameters

7.1.2.1 Transmitter parameters

In UNB systems, the transmit parameters differ greatly in UL and DL, because the system is highly asymmetrical. UNB transmissions are characterized by the very narrow bandwidth of the transmitted signal, the selected centre frequency of such transmissions (allowing for other factors such as frequency error and drift) being distributed within the operational frequency band used by the device. Table 13 gives the main radio parameters for the transmitters.

Table 13: Main transmitter radio parameters

Parameters	Uplink	Downlink
Tx power per transmitter	Up to 25 mW e.r.p. omnidirectional antenna	Up to 500 mW e.r.p. omnidirectional antenna
Duty cycle	1 %	10 %
Typical signal bandwidth (single carrier)	250 Hz	1 kHz
Typical transmission duration	2 s	2 s
Range of transmission duration	1 to 4 s	1 to 4 s

The transmit spectrum masks differ between UL and DL.

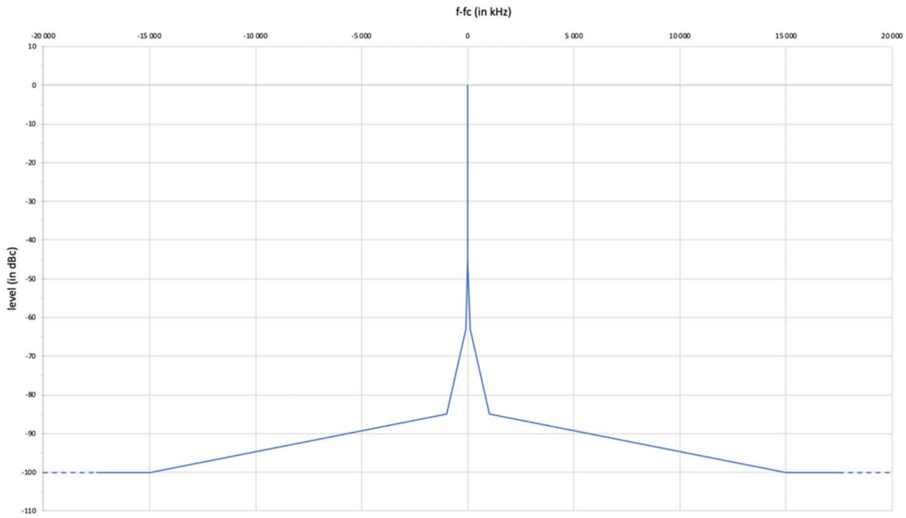

Figure 6: Uplink Emission Mask

Figure 6 shows the spectral shape of an UNB uplink emission mask. Table 14 gives its levels in dBc, with a reference level of +14 dBm, normalized to a bandwidth of 250 Hz.

Table 14: Uplink Emission levels

f-fc (in kHz)	**level (in dBc, see note)**
below -15 000	-100
-15 000	-100
-1 000	-85
-100	-63
-1	-45
-0,125	0
+0,125	0
+1	-45
+100	-63
+1 000	-85
+15 000	-100
above +15 000	-100
NOTE: Reference level is +14 dBm, normalized with a bandwidth of 250 Hz.	

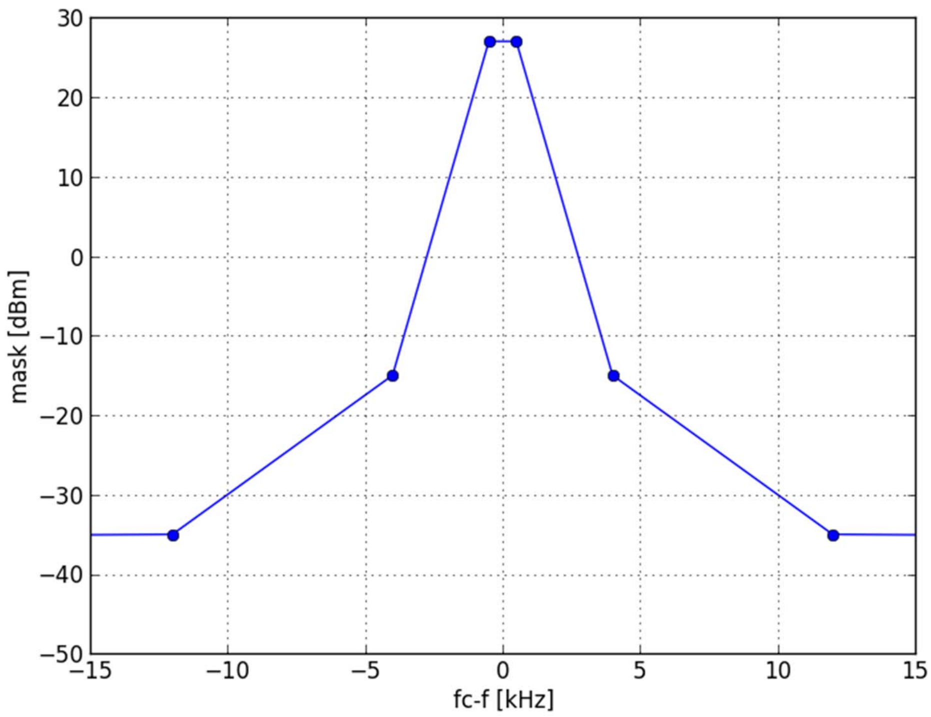

Figure 7: Downlink Emission Mask

Figure 7 shows the spectral shape of an UNB downlink transmission. The levels refer to the maximum transmit power of 27 dBm e.r.p. allowed by the current regulation. The transmit spectrum of an UNB DL transmission does not exceed the transmit emission mask.

Table 15: Downlink Emission levels

f-fc	Level (see note) (dBm e.r.p.)
±500 Hz	27 dBm
±4 kHz	-15 dBm
±12 kHz	-35 dBm
±1 000 kHz	-56 dBm
±2 000 kHz	-56 dBm
±10 000 kHz	-56 dBm
NOTE: RBW = 1 kHz.	

7.1.2.2 Receiver parameters

The receiver parameters are critical in a UNB system because they set the overall link budget value, considering the fact that transmission power is constrained by regulations and power consumption. Table 16 gives the main radio parameters for UNB receivers.

Table 16: Main receiver radio parameters

Parameters	Uplink	Downlink
Typical Rx sensitivity	-136 dBm in 250 Hz -140 dBm in 100 Hz	-124 dBm in 1,5 kHz -126 dBm in 1 kHz
Raw BER for sensitivity measurements	10^{-3}	10^{-3}
Antenna gain (typical)	+5 dBi (omnidirectional base-station antenna)	0 dBi (omnidirectional end-point antenna)
Interference criteria (typical)	C/I = 7 dB	C/I = 8 dB

Some UNB receivers (especially in the uplink) make use of digital filtering to manage interference from unwanted signals. The Receiver blocking masks differ between UL and DL.

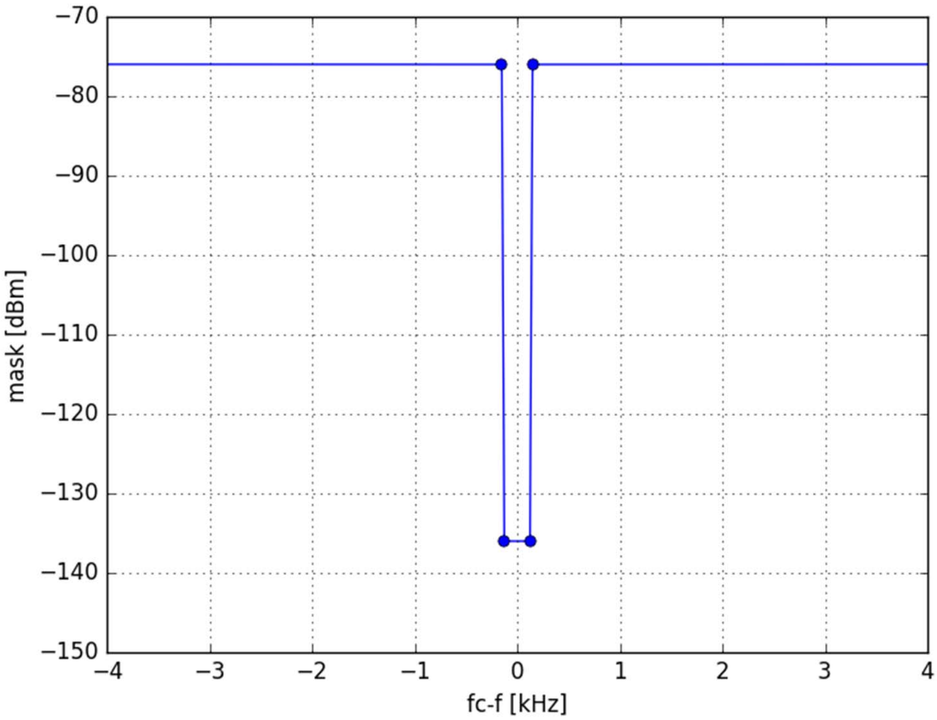

Figure 8: Uplink RX blocking mask (with digital filtering)

Table 17: Uplink blocking levels

f-fc	Limit
±0,125 kHz	-136 dBm
±0,15 kHz	-76 dBm
±2 000 kHz	-66 dBm
±10 000 kHz	-44 dBm

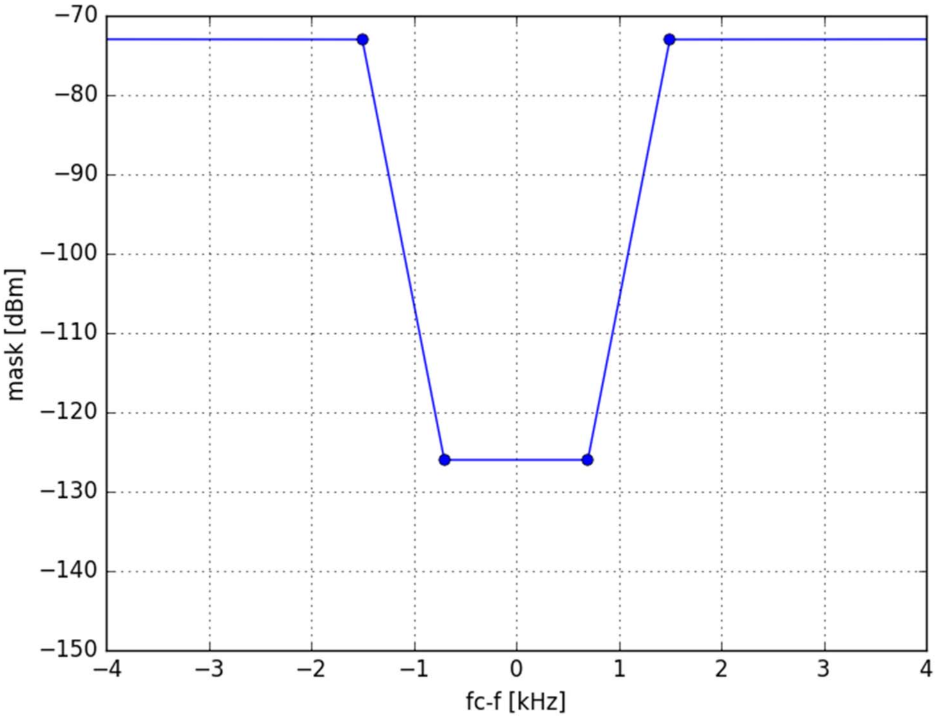

Figure 9: Downlink RX blocking mask

Table 18: Downlink blocking levels

f-fc	Limit
±0,7 kHz	-126 dBm
±1,5 kHz	-73 dBm
±2 000 kHz	-51 dBm
±10 000 kHz	-44 dBm

7.1.2.3 Channel access parameters

The channel access parameters are part of the protocol stack of the UNB systems. As such, they are related to each specific implementation of a UNB system. For example, the quality of service for the transport of an application payload in UL may be obtained with various algorithms, such as convolutional code, blind retransmission, Acknowledgement, parity check, etc.

On the other hand, several parameters and features are common to all UNB systems, because they aim at reducing the complexity of the overall system. For example, a common aspect of all UNB implementations relates to UL frequency selection. Because of the very narrow bandwidth of UL transmission, which is in the order of a few ppm of the carrier frequency, the centre frequency of an UL transmission is not defined a priori. It is just pseudo randomly selected by the end-point before each transmission. The selection process ensures an even distribution of the UL frequency across the declared operating channel. The bandwidth of the operating channel depends on the specific implementation and may cover a range of up to 200 kHz, in the current UNB systems.

7.1.3 Cooperative reception

Cooperative reception is a very specific feature of LTN systems, that can be compared to a kind of basic "spatial diversity" for the UL transmission. The principle of cooperative reception is the following.

When EPs are scattered in a place (see Figure 10 (a)), their UL transmission can be seen as a given density of UL messages per square kilometres. This density depends on the EP density and the traffic model, generated by EPs. For receiving this UL traffic, a grid of receivers (i.e. base-stations) is deployed to get the full coverage of the area (see Figure 10 (b)).

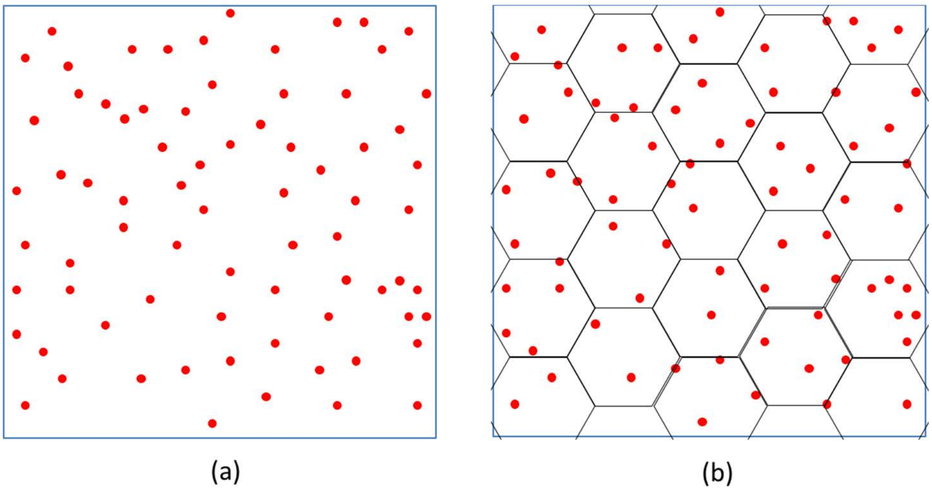

Figure 10: Scattered EPs (a) and a grid of cellular BSs (b)

This approach is well known in the case of cellular networks: each EP is attached to one single base-station. Each base-station operates with a different radio resource (i.e. a different frequency band in 2G or a different code in 3G) and serves only the EPs that are in its vicinity. This type of implementation implies dedicated signalling messages between EPs and the BSs.

The case of UNB system is different because signalling overhead should be kept as low as possible, considering that EPs transmit limited amount of user data (typically 1 kB per day).

To cope with this constraint, the network design is different from the common cellular design rules. Instead of maximizing the coverage of each base-station (see Figure 11 (a)), the design rules tend to get significant overlap between adjacent cells. All base-stations listen to the full UL frequency band; EPs transmit when needed and select their UL frequency randomly in the full UL frequency band.

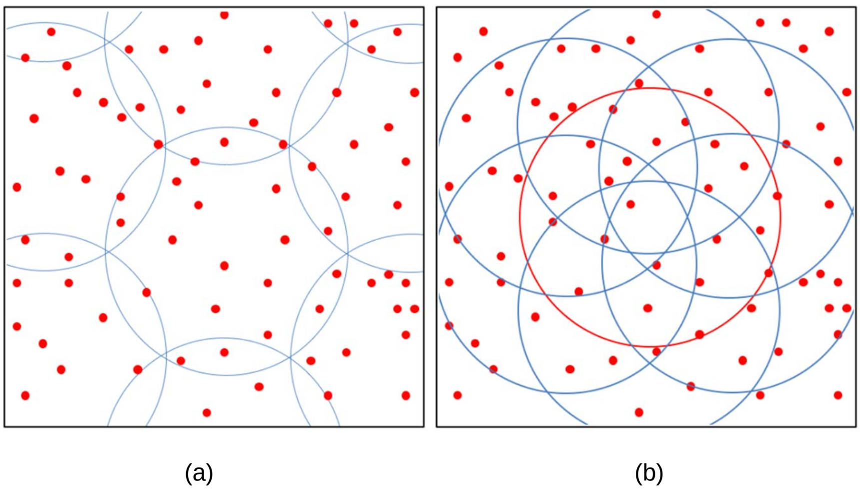

Figure 11: Minimal coverage (a) and actual overlap (b) in UNB systems

Having the same UL message received simultaneously by several base-stations increases the probability of good reception without adding any extra load to the spectrum.

It is also worth to note that cooperative reception has no impact on the spectrum usage for DL communication, because the number of DL messages is given by the EP density and the EP traffic model in DL and not by the density of BSs.

7.2 Current frequency allocations

7.2.1 ITU allocations

Current allocation of the candidate range in the ITU Radio Regulations [i.29] is as follows:

Table 19: 862 MHz - 890 MHz ITU allocations

Allocation to services		
Region 1	**Region 2**	**Region 3**
862 - 890 FIXED MOBILE except aeronautical mobile 5.317A BROADCASTING 5.322	**806 - 890** FIXED MOBILE 5.317A BROADCASTING	**610 - 890** FIXED MOBILE 5.313A 5.317A BROADCASTING

Table 20: 890 MHz - 942 MHz ITU allocations

<table>
<tr><th colspan="3">Allocation to services</th></tr>
<tr><th>Region 1</th><th>Region 2</th><th>Region 3</th></tr>
<tr><td rowspan="3">890 - 942
FIXED
MOBILE except aeronautical mobile 5.317A
BROADCASTING 5.322
Radiolocation</td><td>890 - 902
FIXED
MOBILE except aeronautical mobile 5.317A
Radiolocation
5.318 5.325</td><td rowspan="3">890 - 942
FIXED
MOBILE 5.317A
BROADCASTING
Radiolocation</td></tr>
<tr><td>902 - 928
FIXED
Amateur
Mobile except aeronautical mobile 5.325A
Radiolocation
5.150 5.325 5.326</td></tr>
<tr><td>928 - 942
FIXED
MOBILE except aeronautical mobile 5.317A
Radiolocation
5.325</td></tr>
</table>

5.313A
The band, or portions of the band 698 MHz - 790 MHz, in Bangladesh, China, Korea (Rep. of), India, Japan, New Zealand, Pakistan, Papua New Guinea, Philippines and Singapore are identified for use by these administrations wishing to implement International Mobile Telecommunications (IMT). This identification does not preclude the use of these bands by any application of the services to which they are allocated and does not establish priority in the Radio Regulations. In China, the use of IMT in this band will not start until 2015. (WRC-12)

5.317A
Those parts of the band 698 MHz - 960 MHz in Region 2 and the band 790 MHz - 960 MHz in Regions 1 and 3 which are allocated to the mobile service on a primary basis are identified for use by administrations wishing to implement International Mobile Telecommunications (IMT) - see ITU Radio Regulations [i.29] Res. **224 (Rev.WRC-15)** and Res. **749 (Rev.WRC-15)**, as appropriate. This identification does not preclude the use of these bands by any application of the services to which they are allocated and does not establish priority in the Radio Regulations. (WRC-12)

5.318
Additional allocation: in Canada, the United States and Mexico, the bands 849 MHz - 851 MHz and 894 MHz - 896 MHz are also allocated to the aeronautical mobile service on a primary basis, for public correspondence with aircraft. The use of the band 849 MHz - 851 MHz is limited to transmissions from aeronautical stations and the use of the band 894 MHz - 896 MHz is limited to transmissions from aircraft stations.

5.322
In Region 1, in the band 862 MHz - 960 MHz, stations of the broadcasting service are limited in the African Broadcasting Area (see Nos. **5.10** to **5.13**) excluding Algeria, Burundi, Egypt, Spain, Lesotho, Libya, Morocco, Malawi, Namibia, Nigeria, South Africa, Tanzania, Zimbabwe and Zambia, subject to agreement obtained under No. **9.21**. (WRC-12)

5.325
Different category of service: in the United States, the allocation of the band 890 MHz - 942 MHz to the radiolocation service is on a primary basis (see No. 5.33), subject to agreement obtained under No. 9.21.

5.325A
Different category of service: in Cuba, the allocation of the band 902 MHz - 915 MHz to the land mobile service is on a primary basis. (WRC-2000)

5.326
Different category of service: in Chile, the band 903 MHz - 905 MHz is allocated to the mobile, except aeronautical mobile, service on a primary basis, subject to agreement obtained under No. 9.21.

7.2.2 European common allocations

Current common allocation of the candidate bands in Europe is given in ERC Report 25 [i.7].

Table 21: 862 MHz - 890 MHz European common allocations

Utilization	ERC/ECC Documentation	European Standard
Aids for hearing impaired	-	-
Alarms (Within the 868,6 MHz - 869,700 MHz band)	ERC/REC 70-03 [i.8]	ETSI EN 300 220-1 [i.9]
GSM-R (Within the 876 MHz - 880 MHz band, paired with 921 MHz - 925 MHz)	ECC/DEC/(02)05 [i.30] ECC/REC/(05)08 [i.31]	ETSI EN 301 502 [i.13] ETSI EN 301 511 [i.14]
GSM (Within the 880 MHz - 890 MHz band)	ECC/REC/(05)08 [i.31] ERC/DEC/(97)02 [i.32]	ETSI EN 301 502 [i.13] ETSI EN 301 511 [i.14] ETSI EN 300 609-4 [i.15]
IMT	ECC/DEC/(06)13 [i.33] ECC/REC/(08)02 [i.34]	ETSI EN 301 908-1 [i.16]
Land military systems (Harmonised military band) - (see note)	-	-
Maritime military systems	-	-
MCV	ECC/DEC/(08)08 [i.35]	-
Non-Specific SRDs (Within the 863 MHz - 876 MHz band)	ERC/REC 70-03 [i.8]	ETSI EN 300 220-1 [i.9]
PMR/PAMR (Within the 870 MHz - 876 MHz band paired with 915 MHz - 921 MHz)	ECC/DEC/(04)06 [i.36] ECC/DEC/(02)05 [i.30]	ETSI EN 301 166-1 [i.17] ETSI EN 301 449 [i.18] ETSI EN 301 526 [i.19] ETSI EN 302 426 [i.20] ETSI EN 302 561 [i.21]
Radio microphones and ALD (Within the 863 MHz - 865 MHz band)	ERC/REC 70-03 [i.8]	ETSI EN 300 422-1 [i.22] ETSI EN 301 357-1 [i.24]
RFID (Within the 865 MHz - 868 MHz band)	ERC/REC 70-03 [i.8]	ETSI EN 302 208-1 [i.23]
Tracking, tracing and data acquisition (Within the band 870 MHz - 875,6 MHz for Metropolitan/Rural Area Networks)	ERC/REC 70-03 [i.8]	ETSI EN 303 204-1 [i.25]
TTT (Within the 870 MHz - 875,8 MHz band)	ERC/REC 70-03 [i.8]	ETSI EN 300 220-1 [i.9]
Wireless Audio/Multimedia (Within the band 863 MHz - 865 MHz) (Narrow band analogue voice devices within the 864,8 MHz - 865,0 MHz band)	ERC/REC 70-03 [i.8]	ETSI EN 300 220-1 [i.9] ETSI EN 301 357-1 [i.24]
NOTE: The bands 870 MHz - 876 MHz and 915 MHz - 921 MHz are used for land naval systems specifically for unmanned systems. In countries where these bands are or will be in civil use according to ERC/ECC Deliverables, shared use of the bands should be considered on a national basis. Other sub-bands within the tuning range 610 MHz - 960 MHz may also be used on a national basis according to the national requirements.		

Table 22: 890 MHz - 942 MHz European common allocations

Utilization	ERC/ECC Documentation	European Standard
GSM-R (Within the 921 MHz - 925 MHz band, paired with 876 MHz - 880 MHz)	ECC/DEC/(02)05 [i.30] ECC/REC/(05)08 [i.31]	ETSI EN 301 502 [i.13] ETSI EN 301 511 [i.14]
GSM (Within the 890 MHz - 915 MHz and 935 MHz - 960 MHz bands)	ECC/REC/(05)08 [i.31] ERC/DEC/(97)02 [i.32] ERC/DEC/(94)01 [i.37]	ETSI EN 301 502 [i.13] ETSI EN 301 511 [i.14] ETSI EN 300 609-4 [i.15]
IMT	ECC/DEC/(06)13 [i.33] ECC/REC/(08)02 [i.34] ECC/REC/(05)08 [i.31]	ETSI EN 301 908-1 [i.16]
Land military systems (Harmonised military band) - (see note)	-	-
Maritime military systems	-	-
MCV	ECC/DEC/(08)08 [i.35]	-
Non-Specific SRDs (Within the 915 MHz - 921 MHz band)	ERC/REC 70-03 [i.8]	ETSI EN 300 220-1 [i.9]
PMR/PAMR (Within the 915 MHz - 921 MHz band paired with 870 MHz - 876 MHz)	ECC/DEC/(04)06 [i.36] ECC/DEC/(02)05 [i.30]	ETSI EN 301 166-1 [i.17] ETSI EN 301 449 [i.18] ETSI EN 301 526 [i.19] ETSI EN 302 426 [i.20] ETSI EN 302 561 [i.21]
Radio microphones and ALD (Indoor digital assistive listening device systems within the 915 MHz - 921 MHz band)	ERC/REC 70-03 [i.8]	ETSI EN 300 422-1 [i.22]
RFID (Within the 915 MHz - 921 MHz band)	ERC/REC 70-03 [i.8]	ETSI EN 302 208-1 [i.23]
NOTE: The bands 870 MHz - 876 MHz and 915 MHz - 921 MHz are used for land naval systems specifically for unmanned systems. In countries where these bands are or will be in civil use according to ERC/ECC Deliverables, shared use of the bands should be considered on a national basis. Other sub-bands within the tuning range 610 MHz - 960 MHz may also be used on a national basis according to the national requirements.		

7.3 Sharing and Compatibility studies

7.3.1 Sharing and Compatibility studies already available

7.3.1.1 Sharing studies

A number of sharing and compatibility studies have already been carried out with various SRDs and other systems. Whilst they do not explicitly refer to UNB technology, they help to build the scene for the compatibility studies to be carried out with UNB systems.

The following sharing study has already been conducted:

- "Co-existence studies for proposed SRD and RFID applications in the frequency band 870 MHz - 876 MHz and 915 MHz - 921 MHz (ECC Report 200)" [i.10].

This Report considers a range of SRDs and their ability to share spectrum in the 870 MHz - 876 MHz and 915 MHz - 921 MHz bands. UNB devices were not part of these studies, however UNB base-stations share some of the characteristics of Smart Metering NAPs (e.g. transmit power and duty cycle, but with much smaller bandwidth) which are part of the ECC Report 200 [i.10]. The devices with which UNB devices would have to share this spectrum are those included in this Report.

7.3.1.2 Compatibility studies

The following compatibility studies have already been conducted:

- "Compatibility of planned SRD applications with currently existing radio communication applications in the frequency band 863 MHz - 870 MHz (ECC Report 37)" [i.26].

This Report (as updated in May 2008) analyses the co-existence between existing and proposed new systems in the core SRD band of 863 MHz - 870 MHz. Compatibility with other users in the adjacent bands are also covered by ECC Report 37 [i.26]. The impact of Radio Frequency Identification systems (RFID) with power levels up to 2 W, on the other SRDs is another aspect examined by the report. In particular, the proposed 4 channel plan in the 865 MHz - 868 MHz band for RFID interrogators is considered. These are the two issues having relevance to UNB systems.

- "Adjacent band co-existence of SRDs in the band 863 MHz - 870 MHz in light of the LTE usage below 862 MHz (ECC Report 207)" [i.11].

This Report describes the likely impact of adjacent band LTE transmissions, to be operated below 862 MHz, on SRDs operating in the 863 MHz - 870 MHz range. It covers mainly the case of LTE UE use in an indoor environment where an SRD receiver is present. The analysis presented may be relevant to UNB devices, although some parameters would be different for UNB.

7.3.1.3 Ongoing sharing/compatibility studies

At the time of writing the following sharing/compatibility studies are being carried out by ECC PT SE24:

- "Short Range Devices in the frequency range 862 MHz - 870 MHz (Draft ECC Report WI42-2)" [i.27].

The draft ECC Report being developed for WI42-2 considers the use of frequency band 863 MHz - 870 MHz, in the light of latest developments since the publication of ECC Report 37 in 2008 [i.26]. The main objective of this work is to review the applicable regulatory SRD requirements with the view on facilitating SRD innovation and more efficient use of the band with respect to new and existing services. The report also looks at the feasibility of utilizing the previous guard-band 862 MHz - 863 MHz for SRDs in the presence of LTE in the adjacent band below 862 MHz. In addition, the feasibility of introducing new Narrowband/Wideband Networked SRD applications in the band 862 MHz - 868 MHz is considered.

Work item WI42-2 has a wide scope and includes intensive activity. Many aspects of the work may have relevance to UNB devices (although these are not explicitly referenced). In particular the potential for high power SRDs sharing the 865 MHz - 868 MHz band is considered.

- "Wideband and Higher DC Short Range Devices in 870 MHz - 875,8 MHz and 915,2 MHz - 920,8 MHz (Draft ECC Report 246 [i.28] - companion to ECC Report 200)" - (SE 24 WI54) [i.10].

The Draft ECC Report 246 [i.28], developed for WI54, complements the ECC Report 200 [i.10] due to the industry demand for more relaxed Duty Cycle (DC) limits for 25 mW non-specific SRD applications and for implementation of wideband technologies allowing channel bandwidth of up to 1 MHz which warranted additional look at the situation in the sub-bands 870,0 MHz - 875,8 MHz and 915,2 MHz - 920,8 MHz.

UNB devices are not specifically included in many of the conclusions drawn in ECC Report 246 [i.28], however they may be relevant also to UNB.

7.3.2 Sharing and compatibility issues still to be considered

7.3.2.0 General

The following coexistence issues should be considered in the two bands under consideration.

7.3.2.1 865 MHz - 868 MHz band

SE24 project team of WG SE is currently conducting sharing and compatibility studies in the band 862 MHz - 870 MHz within the context of WI42-2. This study examines the potential impact of proposed high power (500 mW) narrow band networked (NBN) SRDs and wideband networked (WBN) SRD applications in the band 863 MHz - 870 MHz on RFID systems that are currently deployed in the band 865 MHz - 868 MHz. It also reviews the coexistence of proposed NBN SRD and WBN SRD applications against incumbent low power (25 mW) SRDs.

The preliminary conclusions of this study show good prospect for long term sharing between NBN SRDs and the RFID/incumbent SRDs in the band 865 MHz - 868 MHz in particular in the 865,6 MHz - 868 MHz portion, They also show that WBN SRDs can co-exist across the entire range of 863 MHz - 870 MHz with e.r.p. of 25 and no duty cycle restriction if employing LBT+AFA or equivalent technique, such as CSMA-CA employed by IEEE 802.11ah-compliant devices [i.43]. Finally, these studies additionally show that most likely mutual coexistence of NBN SRD and WBN SRD may be encountered in the band 865 MHz - 868 MHz.

The conclusions of the present document will be significant for UNB SRDs in this band, and the need for further studies will depend upon these conclusions.

7.3.2.2 915 MHz - 921 MHz band

In Europe, the bands 870 MHz - 876/915 MHz - 921 MHz were identified as the prime candidates for the extension of existing SRD core band 863 MHz - 870 MHz, since they are close to the core band and assumed to be unused. In particular, the frequency range 915 MHz - 921 MHz is widely used by SRDs and RFID in many countries outside Europe, which makes it an attractive band for systems deployed on an international basis. In this context, studies have been conducted by ECC of which the results are given in ECC Report 200 [i.10].

915 MHz - 921 MHz band was considered by ECC Report 200 [i.10] mainly for RFID use. Some SRD applications were also considered.

Summary of the conclusions of Report 200 [i.10] is as follows:

- Countries where band 915 MHz - 921 MHz is used for Tactical Radio Relay links (TRR), sharing between RFID and TRR will not be feasible if the TRR is allowed to be used in all parts of a country. Physical separation is needed.
- Countries where band 915 MHz - 921 MHz is used for unmanned aircraft system (UAS) co-frequency sharing between RFID (915 MHz - 921 MHz) and UAS will not be feasible in general.
- Sharing conditions may be improved if SRD/RFID could employ additional, more sophisticated mitigation mechanisms, such as DAA.
- Countries where the 918 MHz - 921 MHz band may be used for ER-GSM, co-frequency sharing with ER-GSM is not generally possible without mitigation.
- As a general conclusion, for the countries that do not use the band 915 MHz - 921 MHz at all for the moment, ECC Report 200 [i.10] indicates that intra-SRD sharing of the investigated uses is feasible, assuming the SRD parameters set out in the relevant SRdocs. Even Network Access Points (NAPs) with up to 10 % DC may be easily accommodated in most typical co-existence situations.

These conclusions are based on the following frequency arrangement assumptions:

- Higher-power SRDs and RFIDs are placed in four "high power" channels.
- Lower-power SRDs are interleaved between the "high power" channels.
- Assistive Listening Devices (ALD) with DC up to 25 % is also placed in the four RFID channels, assuming co-location is unlikely.

The final conclusion of ECC Report 200 [i.10]: Where the interrelationship between power, DC and deployment density has been used, further consideration may be necessary in developing regulations.

Co-existence with other SRDs and interference to other radio systems in this spectrum should be analysed during sharing/compatibility studies by using the system parameters given in this System Reference Document. Note that for these simulations in 915 MHz - 921 MHz band, 2 options could be studied: UNB DL in Tags response channels (and UL in Interrogator channels), and UNB DL in Interrogator channels (and UL in Tags response channels).

7.4 Information on relevant standards

UNB systems are already deployed and operated in many countries. It is envisaged that in these systems, end-points and base-stations are fully in compliance with the harmonised standard ETSI EN 300 220-1 [i.9] on non-specific SRDs. The uplink transmission of end-points operates in the 868,0 MHz - 868,6 MHz band, whereas the downlink transmission of the base-stations is in 869,40 MHz - 869,65 MHz band.

ETSI is expected to develop dedicated European Harmonised Standard(s) after the designation of the requested frequency band(s) for UNB system.

8 Radio spectrum request and justification

8.0 General

The spectrum occupied by each link in a UNB system is inherently very narrow, and the wide BS coverage area (enabled by the narrow bandwidth and the resulting link budget), the star topology and the very limited relaying of messages minimizes the number of spectrum-consuming links. Independent analysts have concluded, based on example assumptions, that an isolated UNB system would have approximately 5 times the uplink capacity of an isolated spread spectrum LPWA network, and that UNB systems are "good neighbours" amongst LPWA deployments [i.40]. Thus UNB systems can meet the needs of many LPWA applications with the efficient use of spectrum, and current traffic demands can be met within today's spectrum regulation constraints. However, the forecast growth in the demand for LPWA suggests that steps should be taken to ensure the ongoing ability of UNB systems to meet the evolving market needs in an efficient fashion, including the identification of additional spectrum where UNB systems can be deployed without unacceptable problems in co-existence with other users.

UNB systems are strongly asymmetric: each (mains-powered) BS communicates with many (often battery-powered) EPs. The result is that a UNB BS transmits at a higher data rate and higher power level than an EP, as well as at a higher DC; as a result, spectrum access requirements suitable for an EP are not suitable for a BS, and therefore different bands (and associated access requirements) are typically employed.

An advantage (when considering the coexistence of UNB systems with other systems) of the asymmetry of UNB systems is that the resulting geographical density of BSs can be kept low, even for a very high number of EPs: a typical figure for UNB BS density is 0,1 BS/km^2.

In order to preserve these coexistence benefits as the deployment of UNB systems grows, the targeted ongoing maximum BS density for UNB systems is 0,1 BS/km^2. Furthermore, UNB BS are typically planned and installed professionally in outdoor locations, and the nature of UNB systems gives considerable flexibility in positioning the BS: these factors are also helpful in minimizing any coexistence issues. Annexes A and B present estimates of the capacity of typical UNB systems and demonstrates that the forecast demand for LPWA systems in 2023 will require approximately 600 kHz (based on current power/DC, etc.) in both UL and DL.

8.1 Uplink

8.1.0 General

The vast majority of UNB devices are end-points (typically many thousands of EPs can be supported by a single BS). EPs transmit at low power and low data rate. In some systems EPs are static, in others they may not be.

Because UNB EPs transmit a low volume of data per hour, they can tolerate a relatively low DC level (typically designed to meet 1 % limit, measured over one hour). Similarly UNB systems are typically designed to support 25 mW$_{e.r.p.}$ EPs.

These general access requirements are expected to continue to be appropriate as UNB systems grow to support future demand.

8.1.1 Flexible DC for "exception" cases

Whilst a general DC limit of 1 % is appropriate for EPs, there are certain applications (for example devices whose purpose is theft-protection by the tracking of a vehicle in the rare event that it is stolen) for which the general 1 % limit is adequate *except* in certain "exception" cases (e.g. the protected vehicle has been stolen). This application is described in clause 6.3.2.1. To meet market needs such an application should, under these exception conditions, transmit location and status information up to once per minute for a period of up to 24 hours, equivalent to a DC of up to 5 % for this limited period. It is proposed that such flexible DC for exception cases be introduced in 915 MHz - 921 MHz band only. The detailed specification of these exception transmissions is given in Annex C.

The incidence of such vehicle thefts is low and only a fraction of these will justify tracking of this type. It is estimated that in a major city the "exception" traffic will be less than 0,01 % of the capacity of each BS. Therefore it is hoped that the coexistence implications of such higher DC in these rare cases will be acceptable.

8.2 Downlink

8.2.0 General

The asymmetric nature of UNB systems means base-stations should transmit more data at a higher data rate than EPs, and the access requirements of the 869,40 MHz - 869,65 MHz band (band h1.6) currently used for the DL permit operation at 500 $mW_{e.r.p.}$ and 10 % DC. As the demand for UNB-based connectivity rises it will be important that DC and e.r.p. requirements do not inhibit growth in DL (and therefore UNB system) capacity, and do not result in an untoward increase in BS density. LPWA systems currently deployed typically use channels in 869,4 MHz - 869,65 MHz. This band is heavily used in an uncoordinated fashion today, principally by devices with wider bandwidth than UNB devices, and the provision of additional spectrum with similar access requirements will support the growth in UNB LPWA systems and minimize the co-existence issues.

8.2.1 Duty Cycle

UNB-based LPWA systems operate satisfactorily with a duty cycle of 10 % in the DL. This is required to maintain a balance of UL/DL capacity in UNB systems, with a lower DC there would be a need for increased geographical density of BS to support a certain density of EPs. To allow the BS density of 0,1 BS/km^2 to be maintained, the access and mitigation requirements should not be more restrictive than those of h1.6.

CEPT SE.24 WI42 is ongoing at the time of writing (see clause 7.3.1.3) and its scope includes Duty Cycle-related aspects. Coexistence and sharing issues with UNB BSs are eased by the low geographical density of UNB BS deployment (typically lower than the densities currently considered in WI42) and the professional selection of their location and installation outdoors, with BSs typically being installed well away (and isolated by building walls) from co-existing systems (such as RFID installations). Such aspects, considered with the outcomes of WI42, may be sufficient to allow CEPT to recommend that UNB BS be permitted to operate at 10 % DC on these two new frequency bands excepted for UNB: 865 MHz - 868 MHz and 915 MHz - 918 MHz.

8.2.2 Transmit power

The same mitigating factors (professional site selection and installation outdoors) and the resulting isolation from other SRDs will have an effect on the coexistence of UNB BSs with other SRD systems. If studies were to show that increasing the permitted transmit power to 2 W in some or all of the bands (or frequencies) to be used for UNB DL transmitters did not result in undue interference to other spectrum users, this would enable the support of higher downlink data rates and thus more EPs by each BS. The result would be that the target BS density could be further reduced.

8.2.3 Multi-Carrier

Current access requirements limit the total transmit power in a single "frequency band" (defined in ERC Recommendation 70-03 [i.8]) to the value applicable to that band. Thus if (for example) 500 mW SRD operation were to be permitted on the four "high power" channels in 865 MHz - 868 MHz (RFID interrogator) simultaneously, it would be possible to achieve total DL capacity on those channels equivalent to that of h1.6 by permitting a single BS to transmit on each of the four channels with 500 mW, i.e. with an aggregated power of 2 W but only 500 mW on any one channel. As above, outdoor installation would mitigate any co-existence issues.

The same principle of simultaneous transmission in several frequency bands is also expected for UNB DL communication in 915 MHz - 921 MHz.

8.3 Candidate mitigation techniques

8.3.0 General

If it is determined that significant co-existence issues would be created by the adoption of the changes identified in clauses 8.1 and 8.2 then a range of additional mitigation techniques might helpfully reduce that impact.

8.3.1 Outdoor installation

The very sparse deployment of UNB BS (i.e. DL transmitters), as well as the professional nature of the installation, presents opportunities to respond to co-existence issues at the time of installation. The nearby presence of (for example) an RFID installation can be detected and the UNB BS installed at an appropriate distance from it. The (typically) indoor deployment of RFID and the outdoor deployment of UNB BS provides a level of isolation which will minimize this issue.

8.3.2 Managed spectral density

It is possible that coexistence studies will show that increasing transmit power to 2 W on certain frequencies (as described in clause 8.2.2) will adversely impact the operation of other SRD systems (despite the identified mitigating factors) such as to prevent the recommendation that this be permitted. In that event, some improvement may be achieved by ensuring the power is distributed over multiple 25 kHz channels within an overall 200 kHz band, with a maximum of 500 mW in any one of the 25 kHz channels.

8.3.3 Listen Before Talk

Although Listen Before Talk (LBT) is defined in ETSI EN 300 220-1 [i.9] for non-specific SRDs in the band used by existing UNB systems, this mitigation technique is not used in current UNB systems. Nevertheless, in the case that co-existence studies show harmful interference from UNB systems to the other systems, LBT techniques might be envisaged, especially for the 915 MHz - 921 MHz band.

9 Regulations

9.1 Overview of current UHF 865 MHz - 868 MHz and 915 MHz - 921 MHz Spectrum Regulations

Table 23: Extract from ERC Recommendation 70-03 - Annex 1
Regulations for non-specific SRDs operating in 865 MHz - 868 MHz and 915 MHz - 921 MHz [i.8]

Frequency Band		Power/ Magnetic Field	Spectrum access and mitigation requirements	Modulation/maximum occupied bandwidth
h1.1	863 MHz - 870 MHz	25 mW e.r.p.	≤ 0,1 % duty cycle or LBT	≤ 100 kHz for 47 or more channels
h1.2	863 MHz - 870 MHz	25 mW e.r.p.	≤ 0,1 % duty cycle or LBT+AFA	Not specified

Frequency Band		Power/ Magnetic Field	Spectrum access and mitigation requirements	Modulation/maximum occupied bandwidth
h1.3	863 MHz - 870 MHz	25 mW e.r.p.	≤ 0,1 % duty cycle or LBT+AFA	≤ 100 kHz for 1 or more channels; modulation bandwidth ≤ 300 kHz
h3	915 MHz - 921 MHz	25 mW e.r.p.	≤ 0,1 % duty cycle. For ER-GSM protection (918 MHz - 921 MHz, where applicable), the duty cycle is limited to ≤ 0,01 % and limited to a maximum transmit ontime of 5 ms/1 s	≤ 600 kHz
h3.1	915 MHz - 920,8 MHz	25 mW e.r.p.	≤ 1 % duty cycle (see note 1). For ER-GSM protection (918 MHz - 920,8 MHz, where applicable), the duty cycle is limited to ≤ 0,01 % and limited to a maximum transmit ontime of 5 ms/1	≤ 600 kHz except for the 4 channels identified in note 2 where ≤ 400 kHz applies
NOTE 1: The available channel centre frequencies are 916,3 MHz, 917,5 MHz, 918,7 MHz and 919,9 MHz. The channel bandwidth is 400 kHz. NOTE 2: RFID tag emissions responding to RFID interrogators operating on centre frequencies 916,3 MHz, 917,5 MHz, 918,7 MHz and 919,9 MHz are not duty cycle limited.				

Table 24: ERC Recommendation 70-03 - Annex 11
Regulations for RFID operating in 865 MHz - 868 MHz and 915 MHz - 921 MHz [i.8]

Frequency Band		Power/ Magnetic Field	Spectrum access and mitigation requirements	Modulation/ maximum occupied bandwidth	ECC/ERC deliverable	Notes
a1	865,0 - 865,6 MHz	100 mW e.r.p.	No requirement	≤ 200 kHz		
a2	865,6 - 867,6 MHz	2 W e.r.p.	No requirement	≤ 200 kHz		
a3	867,6 - 868,0 MHz	500 mW e.r.p.	No requirement	≤ 200 kHz		
b	915 - 921 MHz	4 W e.r.p. (see note)	For ER-GSM protection (918 MHz - 921 MHz, where applicable), DAA is required	≤ 400 kHz		The frequency band is also identified in Annexes 1 and 10. Operation only when necessary to perform the intended operation, i.e. when RFID tags are expected to be present
NOTE: Interrogator transmissions in band c at 4 W e.r.p., are only permitted within the four channels centred at 916,3 MHz, 917,5 MHz, 918,7 MHz and 919,9 MHz; each with a maximum bandwidth of 400 kHz.						

9.2 Existing regulation used by UNB today

9.2.0 General

UNB systems are not assigned to a specific EC category, both EPs and BSs are considered to be Non-Specific SRDs and ETSI EN 300 220-1 [i.9] can be used in the presumption of compliance to the R&TTE Directive [i.41]/RE Directive [i.42].

As described above, UNB systems are massively asymmetrical, therefore bands in current use and associated access requirements are different for EPs and BSs.

9.2.1 Regulation for end-points

UNB end-points are working at transmit power of 25 $mW_{e.r.p.}$ and duty cycle of 1 %. End-points typically transmit in the ERC Recommendation 70-03 h1.4 band (868 MHz - 868,6 MHz).

9.2.2 Regulation for base-stations

UNB base-station are working with a transmit power of 500 $mW_{e.r.p.}$ and a Duty Cycle of 10 %.

Due to the need for higher power than EPs (to support the higher DL data rate required by the asymmetry) BSs transmit in the ERC Recommendation 70-03 h1.6 band (869,4 MHz - 869,65 MHz). This band provides only 250 kHz available spectrum (see clause 9.2.1).

9.3 Proposed Regulation and justification

The UNB systems that are currently deployed and operated use the licence-exempt non-specific SRD bands 868,0 MHz - 868,6 MHz in uplink and 869,4 MHz - 869,65 MHz in downlink. At the present time, these bands are appropriate for UNB systems, however forecasts show growing demand for LPWA connectivity in unlicensed-bands employing various radio technologies, not only dedicated networks but also the low power versions of LAN/PAN standards (see clause 6.1 above). Therefore ensuring the capacity to meet those demands of the IoT market is meaningful.

Spectrum allocated for the uplink of UNB systems should be 600 kHz in each band. The allocated spectrum should be contiguous to avoid a large increase in the design complexity of a receiver in a base-station.

For the most efficient downlink implementation the allocated spectrum should be contiguous, but Software Defined Radio transmitters (SDR Tx) in the base-station may accommodate several blocks provided they are all in a 1 MHz - 1,5 MHz frequency band.

Two bands are likely to offer new opportunities for both the UL and the DL of UNB systems:

- 915 MHz - 921 MHz, which may allow a first level of harmonisation with countries under FCC regulation.
- 865 MHz - 868 MHz, where coexistence studies will show how RFID interrogators and RFID tags a well as other SRDs can co-exist with UNB systems.

These proposals are summarized in Figure 12.

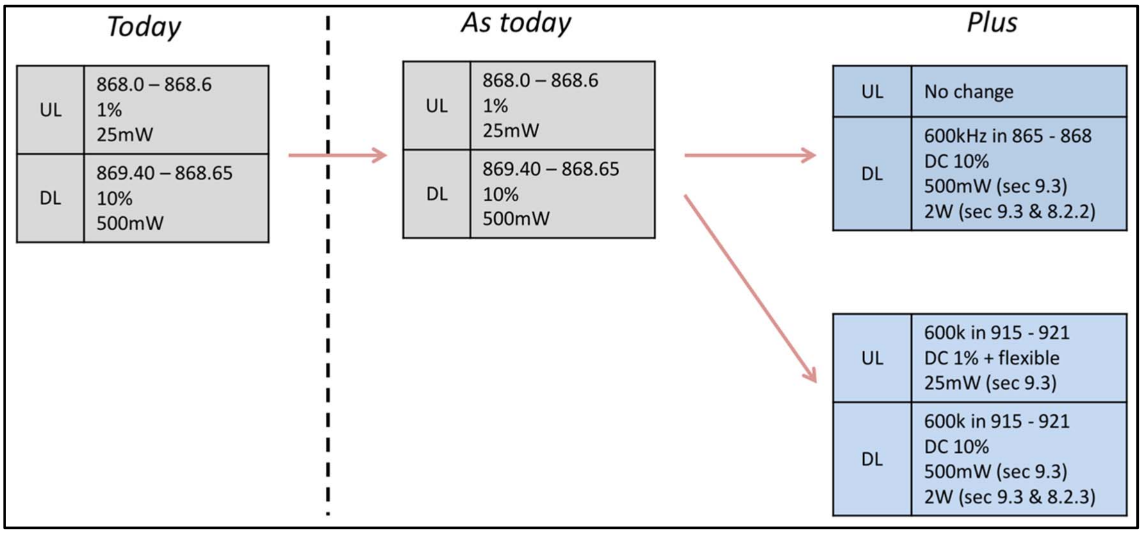

Figure 12: Summary of spectrum and regulation requests

10 Conclusions

The present document gives an overview of the expected evolution of the LPWA market and justifies the need for additional spectrum measures in the UHF 865 MHz - 868 MHz and 915 MHz - 921 MHZ bands to support future growth, particularly of UNB Systems.

UNB Systems today are working in the legacy SRD bands 868,0 MHz - 868,6 MHz in Uplink and in the 869,4 MHz - 869,65 MHz in Downlink. Current spectrum (and associated regulations) in these bands cannot provide the capacity to cover the predicted market growth for future UNB deployment. Based on the technical characteristics of UNB Systems, the present document proposes modifications to the regulations outlined in ERC Recommendation 70-03 [i.8]:

- More flexibility in evaluating the duty cycle of end-point transmission in future SRD bands for UNB uplink communication in the 915 MHz - 921 MHz band.

- Usage of bands 865 MHz - 868 MHz and 915 MHz - 921 MHz for UNB systems.

Co-existence with other SRDs and interference to other radio systems in the requested spectrum should be analysed during sharing/compatibility studies by using the system parameters given in the present document.

ECC is expected to conduct the necessary sharing/compatibility studies and develop regulations for the implementation of UNB system in Europe accordingly.

Annex A: Modelling of traffic and base-station capacity - Example 1

A.1 Modelling of connection (i.e. device) density

A.1.1 Method

The following approach to modelling the demand for LPWA capacity in dense urban areas has been taken:

- Identify a subset of LPWA connection (i.e. end-point device) types which are household-based (see Table A.1) as leading to the highest density of connections.
- Select Greater London, UK as an example of a dense urban area.
- Estimate the total number of LPWA devices forecast to be connected in UK in 2023, assuming connections in any nation will be proportional to national GDP (i.e. as a share of Global GDP).
- Apply a correction factor to reflect that not all LPWA connections will be based on UNB systems.
- Calculate the number of relevant UK UNB-based LPWA devices likely to be connected in 2023 in Greater London, assuming these connections will be proportional to the population of the area (i.e. as a share of the population of UK); "relevant" devices means those whose deployment is correlated with household density.
- Use the overall growth of devices depicted in Figure 3 to forecast growth in relevant London devices in earlier years.
- From the above, calculate forecasts of the number of devices per household in Greater London.
- Calculate the average number of households per hectare in Greater London (in order to model the density of devices *on the assumption that households and devices are uniformly distributed*).
- Calculate the required number of devices per hectare (or km^2).
- Additionally, consider the impact of non-uniform household density on the connection density.

A.1.2 Inputs to Modelling

Although the demand for LPWA connectivity will in general depend on specific local needs, an assumption made in this modelling is that the highest levels of demand are likely to be in dense urban areas where several of the above categories of connected devices are likely to contribute. In these areas is estimated that the density of connections (of the connection types relevant in these areas) will be correlated with the density of households in the area.

Table A.1 describes the proportion of each of the above categories which modeled as correlated to household density in dense urban areas.

Table A.1: LPWA Connection (or end-point) Category

Category	%-age correlated to household density	Comment
Industrial	0 %	Relatively low in dense urban areas
Consumer	100 %	Likely to used "at home", at least some of the time
Utilities	100 %	Mainly "at home"
Smart Buildings	100 %	Mainly "at home" or in other buildings in dense urban areas
Smart Cities	50 %	Some infrastructure applications are not necessarily correlated to household density
Agriculture and Environment	0 %	Relatively low in dense urban areas
Logistics	0 %	Relatively low in dense urban areas

The parameters in Table A.2 were also used in modelling the forecast device density as described above.

Table A.2: Other Inputs to Device Density Modelling

Parameter	Value	Comment/references
LPWA EP devices globally (2023)	3 100 M	2023 figures are used, but model allows earlier years to be modelled as a proportion of 2023 figures (Analysis Mason as above)
Household dense-urban related connections globally (2023)	1 805 M	Applying Table A.1
UK GDP as fraction of global	3,8 %	https://en.wikipedia.org/wiki/List_of_countries_by_GDP_(nominal)
Area of Greater London	1 572 km^2	https://en.wikipedia.org/wiki/Greater_London
Population of UK	64,1 M	UK Office for National Statistics
Population of Greater London	8,2 M	https://en.wikipedia.org/wiki/Greater_London
Number of households in Greater London	3,3 M	Assumed constant to 2023 Assumed uniformly-distributed and with peaks
Max large-area household density in individual London boroughs	5 000 Ho/km^2	"Islington" and "Kensington and Chelsea" have this density; these are relatively large areas with populations > 150 k

Table A.3: Global LPWA connections forecast by year (from Figure A.1):

Year	Global connections (bn)
2017	0,2
2018	0,43
2019	0,76
2020	1,21
2021	1,78
2022	2,45
2023	3,1

A.1.3 Results

Based on the above data and method, the forecast growth in LPWA connections (or devices) per household is as Figure A.1.

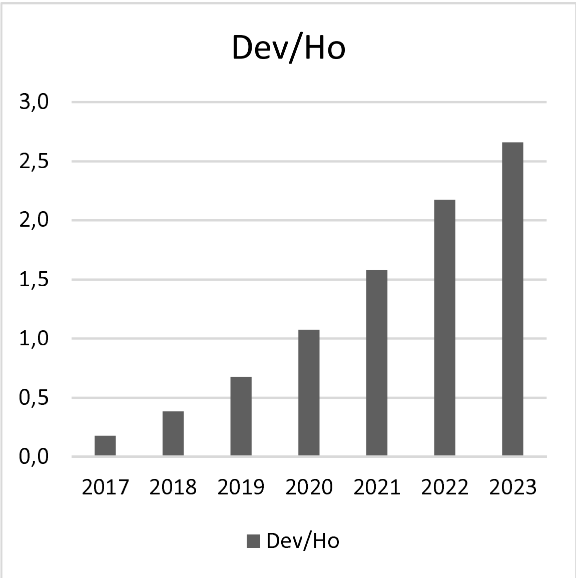

Figure A.1: Greater London devices/household forecast by year

Based on the given LPWA forecasts and the modelling described, connection of > 5 600 devices per km^2 in dense urban areas can be anticipated in 2023.

Furthermore these results are based on a uniform distribution of connections (and base-stations) across the urban area. In reality distributions will not be uniform, and current London peak household densities (measured over a sufficiently large area, for example the borough of Islington) lead to forecasts of over 13 000 devices/km^2. These results are summarized in Table A.4.

Table A.4: Modelled Device Densities

Year	Global connections (bn)	Greater London connection density (conn/km^2) - uniform density	Greater London connection density (conn/km^2) - peak density
2017	0,2	360	857
2018	0,43	774	1 843
2019	0,76	1 368	3 258
2020	1,21	2 179	5 187
2021	1,78	3 204	7 631
2022	2,45	4 411	10 503
2023	3,1	5 582	13 290

These figures describe expected densities of LPWA devices. Of these, not all will be supported by UNB systems. Noting that analysts [i.3] see the LPWA market as incremental to the traditional cellular market as LPWA devices are able to offer a combination of features which cellular devices cannot (low power, wide coverage, low cost) the share of the LPWA market for UNB devices is estimated to be 40 %, see clause A.3.

A.2 Modelling of traffic and support by UNB system

A.2.1 Method

By comparing the capacity (messages/day) of a UNB base-station with forecasts of UNB device deployment (connections) and likely traffic levels from different types of device the base-station densities (BS/km^2) likely to be required can be estimated.

The following method has been applied:

- The capacity (msgs/day) of a base-station of a UNB system commercially deployed today is presented.
- The level of traffic likely to be presented by end-points is estimated (various methods).
- The peak device geographical densities (of UNB-based LPWA devices) already estimated in clause A.1 is used to forecast the density of presented UNB traffic (msgs/day/km^2).
- The UNB base-station density which supports that traffic density is calculated.

A.2.2 Base-station (BS) capacity

A range of UNB systems can be designed according to a range of requirements (e.g. applications to be supported). This clause describes the capacity of a base-station in a typical commercially-deployed UNB system.

Input parameters for UNB system modelling are detailed in Table A.5.

Table A.5: Input parameters UNB system modelling

Parameter	Value	Comment/references
DC (DL)	10 %	Limit from ERC/REC 70-03 [i.8], Annex 1, h1.6
Proportion of UL traffic acknowledged by BS	100 % or 50 %	See text
DL Tx power	27 dBm e.r.p.	Limit from ERC/REC 70-03 [i.8], Annex 1, h1.6
		Other parameters inherent in currently-deployed systems

The computed capacity (number of end-points) of a single BS (UL and DL) as a function of receiver bandwidth available at the BS is presented in Figure A.2 (multi-cell network, cell-edge results for planned DL and shared UL).

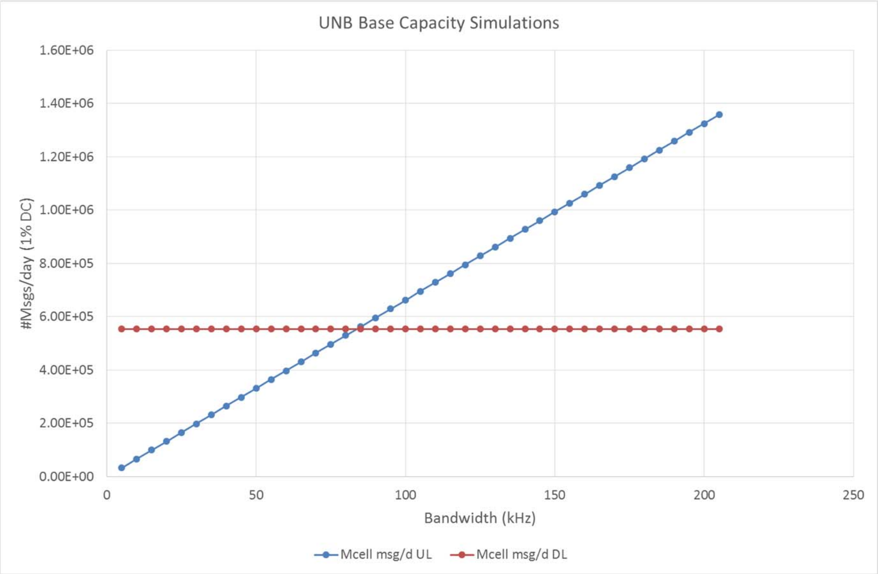

Figure A.2: Capacity of BS (UL and DL) in typical UNB system

Figure A.2 shows that the UL capacity (number of messages per day) increases linearly with the bandwidth available to the UL; however the DL capacity to transmit downlink messages or acknowledgements is governed by the BS Duty Cycle limit, which may in turn limit the UL traffic for applications requiring acknowledgement.

It can be seen that a balanced system (i.e. one in which UL and DL are similarly limited) can (based on the above parameters) support around 550 000 UL messages per day in a bandwidth of a little under 100 kHz, if all UL traffic is acknowledged on the DL (and no other DL messages are required).

If the level of message acknowledgement can be reduced, then the number of messages supported in 200 kHz UL bandwidth rises to 1,35 M/day.

A.2.3 Offered traffic density

A.2.3.0 General

Geographical traffic density can be estimated by considering the specific traffic demands of the many types of applications supported by the devices deployed, in conjunction with the forecasts of the number of such devices and their geographical densities.

The following method is adopted:

- The "domain" and "sub-domain" information (i.e. the application type) presented in the present document is taken as a description of the range of applications addressed by UNB networks.
- A typical level of daily traffic is estimated for each of the sub-domains.

- Noting that devices are categorized differently in the analysts' reports referenced in clause A.1, a weighted mapping between the sub-domains described in the present document and the analysts' categories (i.e. "what percentage of its equivalent category is represented by each sub-domain?") is proposed.
- Based on that mapping and the associated weighting, the typical (average) msgs/day/EP for each of the categories (Table A.6) is calculated.
- The categorized device density forecasts presented in clause A.1 is used to calculate traffic density forecasts.

A.2.3.1 Inputs

Table A.6 shows the domain and sub-domain messaging assumptions.

Table A.6: Traffic from each sub-domain

Domain	Sub-domain	Analysis Mason category	Estimated msg/day/dev	Proportion of category (weighting)	Average msg/day from category
Metering	Water & Gas distribution	Utilities	24	0,5	
	Electricity distribution	Utilities	24	0,5	**24**
Infrastructure networks	Water & Gas transportation				
	Electricity transportation				
	Road/traffic management				
	Pipelines				
	Drains				
Environment/Smart City	Waste management	Smart City (50 %)	5	0,12	
	Air pollution monitoring and alerting	Smart City (50 %)	24	0,06	
	Acoustic noise monitoring	Smart City (50 %)	24	0,04	
	Street Lighting	Smart City (50 %)	5	0,4	
	Parking Management	Smart City (50 %)	30	0,24	
	Self Service bike rental	Smart City (50 %)	20	0,03	
	Digital board monitoring	Smart City (50 %)	20	0,05	
	Water pipe leakage monitoring	Smart City (50 %)	6	0,06	**14,16**
Environment/Country side	Soil quality monitoring				
	Livestock surveillance				
	Cattle & pet monitoring				
	Climate				
	Irrigation				
	Run off monitoring				
Remote monitoring (telesurveillance)	House	Smart Building	24	0,5	
	Building	Smart Building	48	0,5	**36**
Industrial	Water tank management				
	Asset tracking				
	Industrial plant condition monitoring				
Automotive	Vehicle tracking	Consumer	100	0,05	
	Impact detection	Consumer	5	0,09	
	Pay-As-You-Drive	Consumer	50	0,05	
	Assistance request, Break down call, Comfort Call	Consumer	4	0,08	
	Fault, service interval reporting	Consumer	4	0,13	

Domain	Sub-domain	Analysis Mason category	Estimated msg/day/dev	Proportion of category (weighting)	Average msg/day from category
Logistics	Goods tracking				
	Off grid fuel delivery				
	Refrigerated container monitoring				
	Conservation parameters				
Healthcare	Patient monitoring	Consumer	48	0,15	
	Home Medical Equipment status and usage	Consumer	10	0,07	
	Attendance tracking	Consumer	20	0,07	
Conventional Cellular Cooperation	Alarm sending				
House appliances	Pet tracking	Consumer	40	0,08	
	White goods	Consumer	5	0,23	**22,44**
	Personal asset				
Truck	Tyre monitoring				
Identification	Authentication				

A.3 Results

A.3.0 General

Based on the traffic model a calculation of the density of BS required can be made. It should be noted that the location and density of BS required in a real-world network will be impacted by the irregular coverage geometries brought about by propagation variability and other factors; furthermore the traffic model does not reflect time-domain variation and peaks in required capacity. Practical experience suggests that a factor of around 2 might be an appropriate level of de-rating to address such factors, although this would vary across specific UNB-based systems and the nature of the markets they address. DL traffic typically comprises both application data and acknowledgements of UL traffic (as described above), the overall capacity of a BS can be maximized by managing the level of acknowledgment supported. Table A.7 shows the results for the domain-based traffic model described above, assuming 200 kHz bandwidths used for each of UL and DL (with the level of acknowledgements optimized to maximize traffic capacity - in this case approximately 40 % of UL packets are acknowledged).

Table A.7: Required UNB BS density to support device forecasts: 200 kHz UL and DL

YEAR	Peak UNB end-point density EP/km^2 (Table A.4)	Resulting UNB UL traffic density kmsg/day/km^2	Resulting BS density BS/km^2
2017	343	9,65	0,01
2018	737	20,74	0,03
2019	1 303	36,66	0,05
2020	2 075	58,37	0,09
2021	3 052	85,87	0,13
2022	4 201	118,19	0,18
2023	5 316	149,55	0,22

Thus to maintain a base-station density below 0,1/km^2 such a system requires more than 400 kHz of spectrum.

A.3.1 Variability and other Considerations

The results presented above are based on many assumptions, as detailed in the text.

There are many reasons why tomorrow's reality may make higher or lower demands on UNB capacity, including:

- There may of course be inaccuracies in the analysts' forecasts, however they are described as neither optimistic nor pessimistic, with a justification of why this is true.
- Daily average traffic levels are modelled. In practice there will be random variations as well as cyclic patterns (e.g. diurnal) for many applications. Whilst such variation is modelled here, the simple model used may need refinement.
- Extraordinary events (e.g. natural disasters, civil unrest, police incidents and traffic congestion) will increase the demand for peak LPWA capacity.

Annex B: Modelling of traffic and base-station capacity - Example 2

B.0 General

This annex evaluates the IoT traffic for a UNB system deployed in Singapore by 2023 and shows how this traffic can be carried with 600 kHz of frequency spectrum.

B.1 Traffic evaluation

The traffic evaluation in Singapore is based on a preliminary evaluation made by Sigfox company for getting the coverage for 90 % of the Singaporean population by 2023. The penetration of IoT devices uses figures from market analysts. Figure B.1 details the calculation and gives the traffic density in uplink.

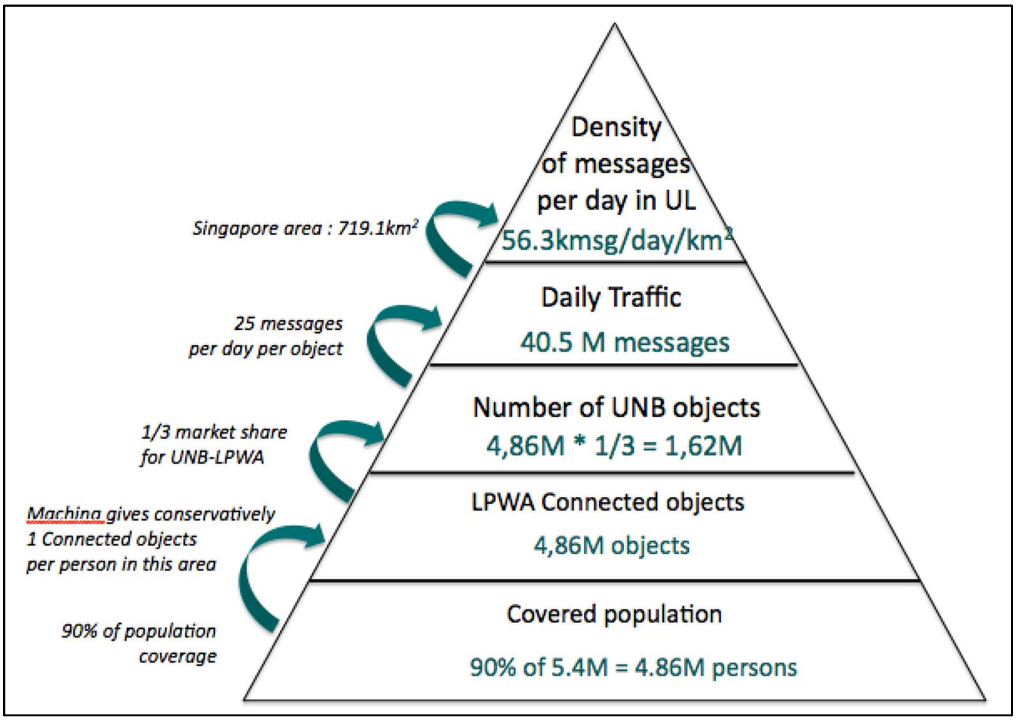

Figure B.1: UL traffic density for UNB messages in Singapore by 2023

The UL traffic generated by end-points is received by UNB base-stations that are deployed with a maximum density of one BS per 10 km^2. This density is roughly equivalent to a coverage radius of 1,7 km (i.e. square-root of 10 km^2/Pi) but the actual reception range of a UNB base-station is much higher. This difference is used to get large overlaps in the reception areas of UNB bases stations (see Figure B.2), which allow a UL message to be received by multiple base-stations at a time (feature known as "cooperative reception").

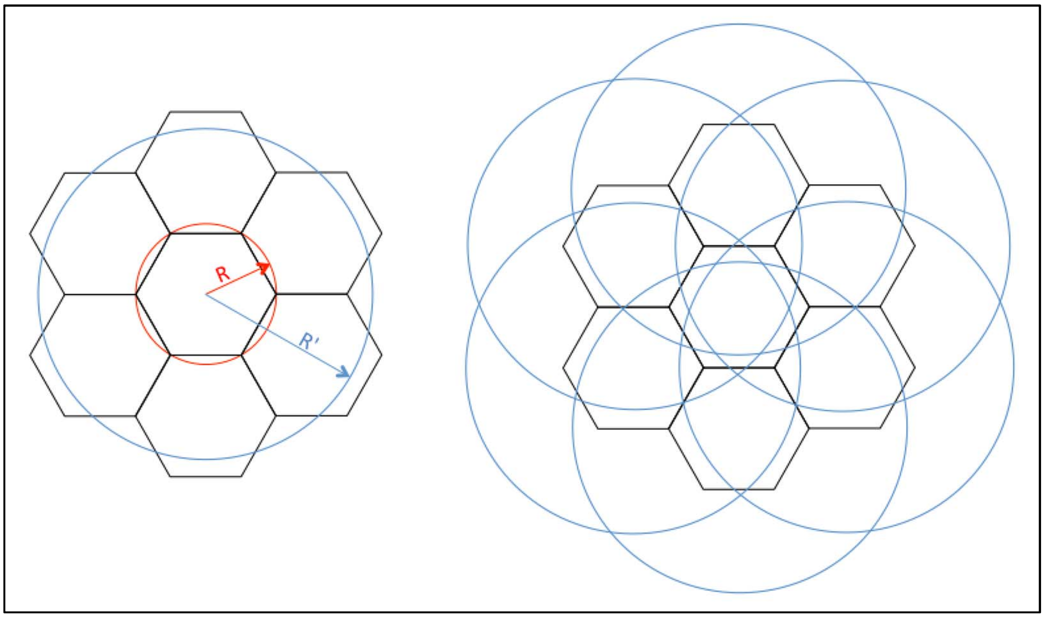

Figure B.2: radius (R) for base-station grid and actual coverage radius (R') for cooperative reception

With this deployment scenario, the daily traffic of UL messages, seen by a UNB base-station, is the one of coverage radius R'. Therefore the total UL traffic received by a BS is as follows:

$$total\_UL\_traffic = traffic\_density \times total\_reception\_\text{coverage} = 56.3 \times 10^3 \times 7 = 3.94\,Mmsg/day$$

B.2 Spectrum bandwidth requirement

The spectrum bandwidth needed to carry such a traffic depends on the protocol efficiency (i.e. protocol overheads and modulation efficiency). Nevertheless, the spectrum requirements are evaluated considering the following average assumptions:

- application messages are 16 bytes long;
- protocol overhead is 50 %;
- coding and error protection give 1/3 efficiency;
- UNB modulation rate is about 100 bps;
- occupied bandwidth of a UNB transmission is about 200 Hz (i.e. twice the modulation rate).

The above value of the protocol overhead assumes very basic procedures to access and share the medium. In such a case, the best protocol is quasi-Aloha, where end-points transmit whenever they need and without exchanging any signalling data with the base-station prior to their transmission. This very simplistic protocol is efficient only at low level of offered load (e.g. 10 %), where collision occurrence is kept low.

The above ratio for the coding and error protection (i.e. 1/3) is a rough estimate of the efficiency of various algorithms (i.e. convolutional code, blind retransmission, Acknowledgement, parity check, etc.) aimed at giving the required Quality of Services for the application payload transport in UL.

With the above numbers, the required bandwidth to cope with 3,94 Mmsg/day is given by formula (B.2):

$$msg\_footprint = \frac{16 \times 8 \times (1 + 50\ \%)}{1/3} \times \frac{200\ Hz}{100\ bps} = 1\ 152 \tag{B.1}$$

$$required\_bandwidth = \frac{msg\_footprint \times dayly\_traffic}{duration\_of\_a\_day} \times load\_ratio = \frac{1152 \times 3.94M}{86400s} \times \frac{1}{10\ \%} \approx 525\ kHz \tag{B.2}$$

Formula (B.2) shows that a total of 600 kHz is a reasonable spectrum for carrying the UL messages in Singapore by 2023.

DL transmission occurs in the same way as UL, i.e. randomly in time and in frequency. Market analysts assume that the DL traffic is 10 % of the UL traffic. From the DL traffic assumption, one can conclude that the required spectrum is only one tenth of the UL spectrum. But this reasoning needs to include the fact that BS transmit only 10 % of the time. Therefore, the spectrum needed for DL is the same as the UL one, i.e. about 600 kHz.

B.3 Conclusion

This annex gives a concrete example of the deployment of a UNB system in the very dense urban environment of Singapore in 2023. When the base-station density is set at 0,1 BS/km^2, the only way to cope with the traffic, generated by the large amount of devices expected by market analyst in this case, is to have 600 kHz of available spectrum.

Annex C: Flexible duty cycle for exception messages

The duty cycle for SRDs is precisely defined in ECC Report 207 [i.11], it is evaluated over one hour. When use cases require transmission of application data in UL every minute (see clause 6.3.2.1), the existing DC values for non-specific SRDs give the following transmission times (see Table C.1).

Table C.1: TX time for existing DC value

Duty cycle	0,1 %	1 %	10 %
TX over 1 minute	0,06 s	0,6 s	6 s

The two first value are not adequate for high link budget and transmit power as low as 25 mW. The 10 % DC may lead to quite unfair access to the spectrum. Therefore, the new SRD regulation in the frequency band 915 MHz - 921 MHz can be taken as an opportunity to define a relaxed duty cycle value that allows the transmission of exception messages.

The relaxed specifications for the duty cycle are possible only when the device is in a specific state called "exception mode". (The exception mode, defined here, may be compared to the well-known myth of the "swan song" (see https://en.wikipedia.org/wiki/Swan_song.)) It is expected that the ratio of devices that enter exception mode per day (in a dense urban environment such as Paris area) is 1/10 k.

The exception mode is defined as followed:

- a non-specific SRD enters "exception mode" only once when deployed in the field;
- when in exception mode, a SRD cannot resume to normal mode, unless it is refurbished by its manufacturer or its representatives;
- refurbishing of a device in exception mode is not possible on line or over the air;
- the duration of the exception mode is limited to 24 hours;
- the exception mode ends after the max duration of the exception mode or by a deliberate action of the user;
- once the exception mode is over, the SRD transceiver is off, until it is refurbished by the device manufacturer or its representatives.

During the exception mode, a SRD can transmit with the following rules:

- one single transmission per minute;
- the maximum Tx on period is 3 s;
- the maximum Tx power is 25 mW;
- the Tx centre frequency in exception mode is pseudo randomly selected within the declared operational frequency band;
- the value of the centre frequency is generated with a pseudo noise sequence of at least 10 coefficients;
- the seed of the random number generator should include the serial number of a SRD, or any equivalent unique ID;
- the minimum step between the centre of two consecutive transmissions is half of the declared occupied bandwidth.

History

Document history		
V1.1.1	February 2017	Publication
V1.2.1	October 2020	Publication