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TECHNICAL REPORT

Low Throughput Network (LTN);
Use Cases and System Characteristics

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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 contains use cases and system requirements to support the development of an LTN standard.

Modal verbs terminology

In the present document "**should**", "**should not**", "**may**", "**need not**", "**will**", "**will not**", "**can**" and "**cannot**" are to be interpreted as described in clause 3.2 of the ETSI Drafting Rules (Verbal forms for the expression of provisions).

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Introduction

Low Throughput Network (LTN) is a wide area wireless network technology with specific characteristics compared to existing radio networks. Deployments of LTN Systems include Base Stations and End Points which communicate over an air interface. End Points (typically a large number) are arranged predominantly in a star configuration around each base station, each base station is connected to the core network. In a small minority of cases (e.g. to provide connectivity in a hard-to-reach location) relays are used.

LTN enables long range data transportation (distances up to 40 km in open field) whilst being suited for mains or battery powered End Point operation. Typical Use Cases include communicating with underground equipment where high radio path losses and extremely long operating life from batteries are required, as well as street lighting control where high densities of End Points are required. LTN systems connect indoor and outdoor End Points, in urban and rural environments. Furthermore, the low throughput transmission combined with advanced signal processing provides effective protection against interference. As a consequence, LTN is particularly well adapted for low throughput reliable machine to machine (M2M) communication.

LTN can be applied to autonomous battery operated M2M devices that sends only a few bytes per day, week or month.

The elements provided in the document are intended to identify Use Cases and System Requirements for LTN Systems.

Clause 4 provides an overview of the main applications foreseen for LTN networks and estimates the numbers of LTN devices that applications may give rise to.

Clause 5 lists typical Use Cases with their individual characteristics and associated constraints and goes into some use cases in more detail than Clause 4.

Clause 6 summarizes the key attributes that LTN technology should exhibit to allow the above Use Cases to be realized.

Clause 7 describes characteristics of LTN systems, mainly arising from the use cases analysis.

These LTN system characteristics are expected to be used in the development of the architecture and protocols specifications of LTN.

1 Scope

The present document provides illustrative use cases for LTN Systems and key characteristics of such systems to support the development of the LTN Standard.

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.

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 not necessary for the application of the present document but they assist the user with regard to a particular subject area.

[i.1] ETSI GS LTN 001 (V1.1.1): "Low Throughput Networks (LTN); Use Cases for Low Throughput Networks".

[i.2] TALQ: "TALQ Specification Overview".

NOTE: Available at http://www.talq-consortium.org/data/downloadables/2/4/20150318-talq-specification-overview-white-paper.pdf.

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

NOTE: Available at http://www.analysysmason.com/Research/Content/Reports/Low-powered-wireless-solutions-have-the-potential-to-increase-the-M2M-market-by-over-3-billion-connections/White-paper-PDF/.

[i.4] Energy Saving Trust: "A Guide to Telematics".

NOTE: Available at http://www.energysavingtrust.org.uk/businesses/sites/default/files/Telematics%2Bguide_WEB%2BONLY.pdf.

[i.5] 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.6] IPPR: "Implementing Pay-As-You-Drive Vehicle Insurance".

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

[i.7] 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.8] Insurance Europe aisbl: "European Motor Insurance Markets Nov 2015".

NOTE: Available at https://www.insuranceeurope.eu/european-motor-insurance-markets.

[i.9] ERC Recommendation 70-03 (Annex 1 h1.6): "Relating to the use of Short Range Devices (SRD)".

NOTE: Available at http://www.erodocdb.dk/docs/doc98/official/pdf/rec7003e.pdf.

[i.10] ETSI EN 300 220: "Short Range Devices (SRD) operating in the frequency range 25 MHz to 1 000 MHz".

[i.11] FCC CFR Part 15.247: "Operation within the bands 902–928 MHz, 2400–2483.5 MHz, and 5725–5850 MHz".

[i.12] ARIB STD/T108: "920MHz-Band Telemeter, Telecontrol and Data Transmission Radio Equipment".

[i.13] FIPS PUB 197: "National Institute of Standards and Technology Federal Information Processing Standard Advanced Encryption Standard (AES)".

3 Definitions and abbreviations

3.1 Definitions

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

1-way: user data transmission to/from a specific End Point in either uplink or downlink direction, not both

NOTE: No acknowledgement of message receipt is possible.

1,5-way: user data transmission to/from a specific End Point in either uplink or downlink direction, not both, but where limited return channel capacity is available for acknowledgement messages to be sent

2-way: user data transmission between a specific End Point and Base Station in both uplink and downlink directions

NOTE: Acknowledgement of message receipt is possible.

Base Station (BS): radio hub of an LTN system

core network: one or more servers connecting base stations to network applications

downlink: wireless link from the Base Station towards the End Point

end point: leaf node of an LTN system

link budget: maximum tolerable path loss from the transmitter antenna connector to that at the receiver for acceptable link performance on a static channel

LTN family: instantiation of the LTN standard with tailored technical parameters

LTN standard: technical specifications developed by ETSI which describe the architecture and protocols of LTN systems

LTN system: high capacity star-based network, with high rejection of interference and noise, dedicated for low power IoT connectivity over shared spectrum

NOTE 1: The geographical deployment of an LTN system may vary on scale between local and global, including discontinuous coverage.

NOTE 2: See clause 6.2.1 for the categorization of deployment areas used in the present document.

multicast: downlink communication from a Base Station to multiple End Points

relay point: radio node that relays radio packets for a small number of end points

static channel: radio channel with no impairments other than attenuation

EXAMPLE: Channel with no time variance, fading or multipath.

unicast: 1-way, 1,5-way or 2-way communication between a Base Station and a specific End Point

uplink: wireless link from the End Point towards the Base Station

3.2 Abbreviations

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

3G	3^{rd} Generation Cellular
BS	Base Station
CO	Carbon Monoxide
CO2	Carbon Dioxide
DC	Duty Cycle
DL	Downlink
DR	Demand Response
ECG	ElectroCardioGram
EP	End Point
EPC	Electronic Product Code
ERC	European Radio communication Committee
ERP	Effective Radiated Power
FCC	Federal Communication Commission
FPI	Fault Passage Indicator
GDP	Gross Domestic Product
GPS	Global Positioning System
IHD	In Home Display
LPG	Liquified Petroleum Gas
LPWA	Low Power Wide Area
LTN	Low Throughput Network
LV	Low Voltage
M2M	Machine to Machine
MCL	Minimum Coupling Loss
MV	Medium Voltage
OTA	Over The Air
RFID	Radio Frequency Identification
RTC	Real Time Clock
RTLS	Real Time Location System
SLA	Service Level Agreement
UK	United Kingdom
UL	Uplink
UNB	Ultra-Narrow Band
VOC	Volatile Organic Compounds

4 Application Domains

A large and varied range of applications is envisaged for LPWA systems, and LTN systems are a subset of LPWA systems. Analysts see the LPWA market as largely additive to cellular technology [i.3]. This clause provides an overview of the main applications foreseen and estimates the numbers of LPWA devices to which these applications may give rise.

Table 1 sets out some of the application domains in which LTN can be used.

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
	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, antitheft
	Industrial plant condition monitoring	Generators, compressors, pumps: bearing temperatures, oil levels, vibration
Automotive	Vehicle tracking	Location, antitheft
	Impact detection	Send message when vehicle is stopped abruptly
	"Pay As You Drive"	Send message to the driver 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 SLA's, compliance and billing data
Conventional Cellular Cooperation	Alarm sending	Send alarm message and activation of 3G for sending data (video, etc.)

Domain	Sub-domain	Use case
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
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.3].

Table 2: Forecast connectivity revenues (US$ bns)

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

The estimated number of End Points per 100 M inhabitants for different application domains is shown in Table 3 [i.3].

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 (around 2 per inhabitants)
NOTE 1: The above numbers are based on a population of 100 M inhabitants and estimate the number of EPs per different use case. NOTE 2: 100 M inhabitants, 55 % individual houses/45 % apartment buildings [i.1]. NOTE 3: 41 M households with an average of 2,4 people/households [i.1], 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.1], Automobile: based in France [i.1].	

5 Example applications and use cases

5.1 Smart Metering

5.1.0 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 End Points with external power.

5.1.1 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 4: 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)	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 1: 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 LTN technology. A low update rate remote display of a meter reading is the Use Case envisaged here. 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.			

Table 5: 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 LTN technology. A low update rate remote display of a meter reading is the Use Case envisaged here.			

5.1.2 Electricity metering

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

Table 6: 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 LTN technology. A low update rate remote display of a meter reading is the Use Case envisaged here.			

Table 7: 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 LTN technology. A low update rate remote display of a meter reading is the Use Case envisaged here.			

5.2 Smart City

5.2.1 Example Smart City applications

Example Smart City applications are listed in Table 8.

Table 8: Smart City Applications

Need	Period	Payload (see note)	Communication mode
Street Parking	1/min to 1/hour, depends on traffic. ~30 s Uplink latency required	bytes	1-way or 2-way
Street Lighting	2/day Uplink (event log + meter reading); downlink commands as necessary (none if everything is operating OK)	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
Traffic Management			
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 prevent 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: These payload figures are application payloads optimized for LTN - type networks.			

More details on two important examples are given below.

5.2.2 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.

5.2.3 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 for example [i.2].

5.3 Automotive

5.3.1 Example Automotive applications

Automotive telematics applications vary greatly in their communications requirements. The subset of applications best supported by LTN is given in Table 9, [i.4], [i.5], [i.6] and [i.8]. Typically LTN 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 9: Automotive Applications

Need	Period	Payload (raw data)	Communication mode
Geo-location assistance	Occasionally	250 to 1 kbytes	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 kbytes	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 technologies for LTN will limit the vehicle speed at which LTN communication is reliable. Therefore the use cases above should be viewed with this in mind.

5.3.2 Stand-alone antitheft

Automotive antitheft 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 10, Alternative implementations augmenting LTN with GPS and/or cellular to accurately and constantly send the location of the stolen vehicle are also possible.

LTN stand-alone anti-theft systems require a small and therefore physically easy to conceal End Point. These are also hard to detect through local oscillator, intermediate frequency stage or other radio frequency emissions. They 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 LTN devices may be installed for antitheft applications. [i.6] indicates 2 % of vehicles may be fitted with stand-alone antitheft devices in 5 years. [i.7] states that there are 334 m road vehicles in Europe. Together they indicate the European 5 year stand alone antitheft market to be over 6 m devices.

Table 10: 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

5.4 Cellular/LTN cooperation

Cellular and LTN have different capabilities, and a number of use cases could benefit from combining the two networks, by using LTN as a back-up to cellular network to carry small critical packets when the cellular network is out of reach, or accidently out of service, or as a default network for small payload traffic.

Figure 1 shows a hybrid solution for Mobile Carriers that could complement their existing mobile network services with a LTN network solution.

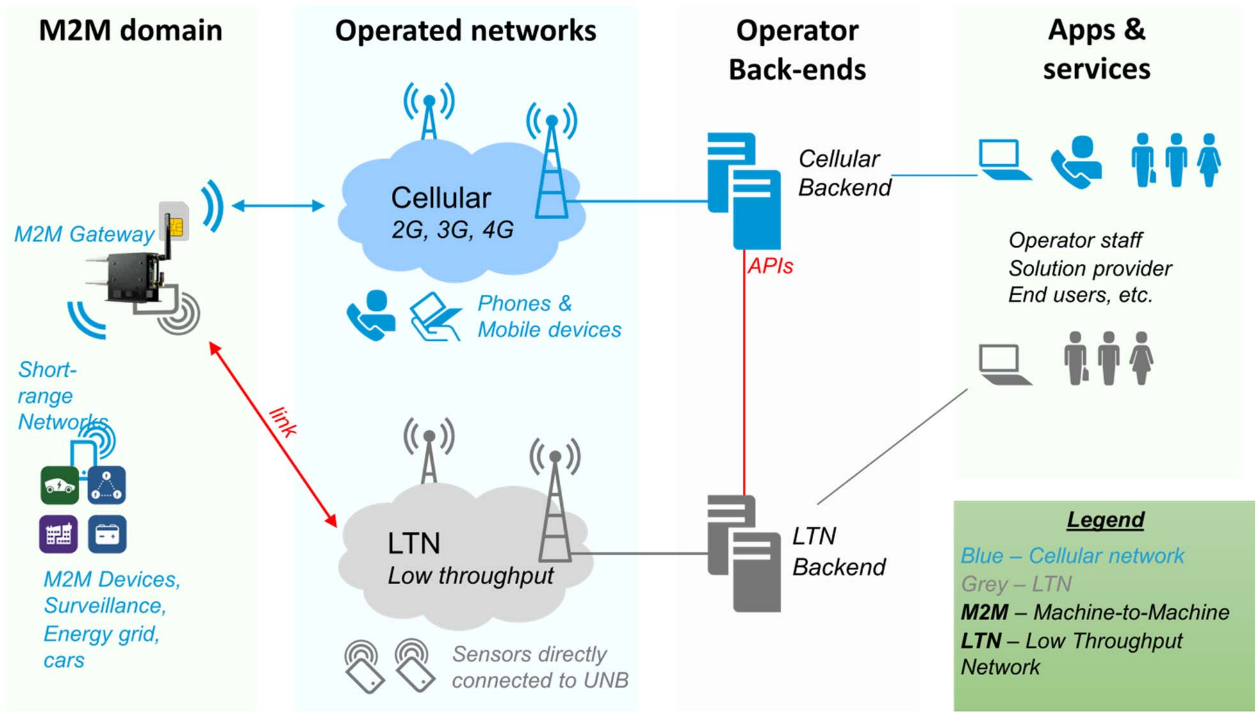

Figure 1: Cellular collaboration with LTN

The following scenarios could be envisioned, providing a bidirectional LTN network:

- Battery saving: 3G back end sends command to LTN to wake up the gateway 3G modem to send data via 3G.
- Keep alive: LTN is used for low power keep alive; 3G is used for data transmission, etc.
- Wake up device via LTN alarms, then transmit via 3G (i.e. video).
- E.g.: call flow.
- Sensor => Gwy => LTN back end "OK".
- Sensor => Gwy (alarm) => activate cellular modem => send data via cellular.
- Sensor => Gwy (alarm) => back end => activate cellular modem => Send data via cellular.
- Redundancy: send data via both LTN and cellular (secured services).
- Security: LTN to collaborate with cellular to increase security.
- Fall-back: When 3G is out of service, limited coverage => LTN is used as fall back to carry limited throughput.

5.5 Asset tracking

The Use Case Asset Tracking means the tracking and tracing of objects, especially valuable goods by monitoring the position and status of the objects within a certain facility like warehouses or industrial plants, within a certain region like a construction site or an agricultural field or on a worldwide basis to improve the visibility within the global supply chains.

Some examples for asset tracking are:

- Fleet Management: Tracking of trucks and vehicles for route optimization and theft prevention.
- Tracking of medical equipment in hospitals.
- Tracking of construction machines and tools on a construction site.
- Tracking of farming machines and equipment on a farm site.
- Tracking of vehicles on the apron of airports for security reasons.
- Container tracking: worldwide tracking of containers.
- To determine of the status of the goods within the container: light to monitor the opening of the container, temperature for temperature sensitive goods, accelerometer to monitor mechanical shock to the goods, gas to monitor the status of perishable goods, battery lifetime of up to 15 years.

Solutions today use combinations of GPS and cellular modem for global tracking (e.g. for container or fleet Management), passive Barcode or RFID based solutions with fixed reading points within warehouses or Real Time Location (RTLS) Systems within a dedicated area. The location information does not always need to have the same accuracy as GPS, sometimes knowing the LTN cell ID is enough.

The RFID Electronic Product Code (EPC), if required, should be handled at the application level.

Data to be transmitted are the unique identity (as above), position information, if the object uses self-localization like GPS and additional sensor information if required. Possible sensor information could be:

- temperature for monitoring the cold chain of heat sensitive food;
- shock sensor to monitor mechanical forces on fragile goods;
- light sensor to control the opening of a container;
- gas sensor to monitor the spoilage of food.

Instead of using global positioning, the position of the item can be determined using RTLS Systems or using the communication network itself. Position determination can be afforded on a regular basis or on demand by a request of the base station.

Potential traffic requirements are outlined in Table 11.

Table 11: Asset Tracking Applications

Need	Period	Payload (raw data)	Communication mode
Transmission of position information	1/min … 1/day (depending on application)	Position information (if determined by the object)	1-way
Determine object position on demand	Upon request (e.g. stolen vehicle)	Position information	2-way
Transmission of object status	1/hour … 10/hour	Sensor data (depending on sensor)	1-way

5.6 Smart grid

5.6.1 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 (MV) 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).

5.6.2 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 (LV) 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.

5.6.3 Electric network fault monitoring

Nationwide electric networks connect power plants and consumption points with power lines, dispatch centers, 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 achieve this, high power/voltage transformers connect high voltage lines with medium voltage lines. In a similar way medium and low power/voltage transformers are used. As an example, the French metropolitan territory has over 1,5 M of these transformers. Each of them has to be monitored 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, trigs an alarm and a circuit break.

Monitoring the transformer status, the relay status and the alarm status with LTN 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 LTN solution is its high link budget and its low power consumption that allows battery operation (i.e. without any high voltage insulation issues). Typical traffic requirements are outlined in Table 12.

Table 12: Key figures for transformer fault monitoring

Need	Period	Payload (raw data)	Communication mode
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

5.6.4 Multicast load control - Management of Electricity Demand

The use of LTN 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 LTN 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 blackouts (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 is 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 is 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 connection is/is not allowed).

5.7 Agriculture and 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 $CO2$, 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 13 outlines typical traffic requirements.

Table 13: Agriculture/environment application characteristics

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

5.8 Security Threat analysis

The LTN rapporteurs have considered the security threats relevant to the above Use Cases and consider the following threats to be relevant:

- man in the middle attack;
- unauthorized devices;
- unauthorized network;
- data corruption on the air and in the core network;
- eavesdropping on the air and in the core network;
- unauthorized network application;
- network operator eavesdrops on the application data.

6 Commonalities in LTN use cases

6.1 Introduction

The previous clauses describe various use cases suitable for LTN solutions and give order of magnitude and/or specific needs and expectations. The present clause details main features and characteristics that are common to the above use cases. Levels of commonality are derived from use case descriptions, the results are presented in clause 6.3.

6.2 Criteria for commonality evaluation

6.2.1 Network scale

LTNs should be able to be deployed at different scales depending on the application domain and business model. The four expected scales are:

- S: single base station for deployment in premises, yard, depot, campus, farm, etc.
- L: local cluster of base stations, for town, city or region coverage.
- D: distributed clusters of base stations for getting a coverage on multiple separated yards, depots, or in a county, territory or region.
- C: contiguous network to get a full coverage over a country or series of countries.

6.2.2 LTN type

LTNs are deployed in licence exempt spectrum and are not subject to a Public Network Operator licence so the normal definitions of Public and Private networks are not used here. The simplest LTN system consists of one BS serving one application. The most complex LTN may be national networks serving multiple applications and supporting roaming or re-registration of EPs from other countries or partner LTNs. In addition, multiple LTNs may cover a single geographic location.

For the purpose of commonality evaluation, the four types of LTNs are used:

- type 1: single customer and single application;
- type 2: multiple customer and single application;
- type 3: single customer and multiple application;
- type 4: multiple customer and multiple application.

6.2.3 End Point density

Even if LTNs address the IoT market where billions of devices are foreseen, the use cases listed here above show discrepancies in the density of EPs. Table 14 evaluates the EP density with two criteria: the minimum density and the maximum density of EPs per BS. EP density is measured:

- S: less than 100 EPs per BS.
- M: 100 to 1 000 EPs per BS.
- L: 1 000 to 10 000 EPs per BS.
- V: 10 000 to 100 000 EPs per BS.
- H: over 100 000 EPs per BS.

6.2.4 Data flow direction

LTNs have bidirectional radio links for carrying user data and/or acknowledgements both in uplink and downlink. Nevertheless, the LTN use cases show that the application data flow is not always bidirectional. In some cases, the main data flow required by the application is only unidirectional. Table 14 identifies the use cases with the following criteria:

- U: mainly uplink flow of application data.
- D: mainly downlink flow of application data.
- B: application data use both directions extensively.

6.2.5 End Points' power mode

It is clear that low power operation is a differentiator of most IoT applications. Nevertheless, the LTN use cases show that power mode is a valid criteria for commonality evaluation. Table 14 identifies the LTN use cases with the following values:

- B: EPs battery powered mainly.
- M: EPs mains powered mainly.
- 2: both battery and mains are possible.

6.2.6 Latency

This criteria measures the time constraint for the main flow of application data. Three levels of latency are used in Table 14:

- 10 s: expected latency for main flow of application data is about a few 10 s of seconds.
- 1 mn: expected latency for main flow of application data is about a few minutes.
- N: no latency constraint or constraint above 10 minutes.

6.3 Table of use cases commonalities

LTN use cases presented in clauses 4 and 5 are listed in Table 14 with their commonalities based on the criteria detailed in clause 6.2.

Table 14: LTN use cases commonality

Domain	Sub-domain	Scale	Type	Min EP /BS	Max EP /BS	Main data stream	Main EP power mode	Latency constraint on main data stream
Metering	Water & Gas distribution	S,L,D,C	1,2,3,4	S	V	U	B	N
	Electricity distribution	S,L,D,C	1,2,3,4	S	V	U	M	N
Infrastructure networks	Water & Gas transportation	L,D,C	1,2,3,4	S	M	B	B	10 s
	Electricity transportation	D,C	1,2,3,4	L	M	B	M	10 s
	Road/traffic management	L,D,C	1,2,3,4	S	L	B	2	1 mn
	Pipelines	D,C	1,2,3,4	S	L	B	2	10 s
	Drains	D,C	1,2,3,4	S	L	B	2	N
Environment/Smart City	Waste management	L,D,C	1,2,3,4	S	L	U	B	N
	Air pollution monitoring and alerting	L,D,C	1,2,3,4	S	L	U	B	N
	Acoustic noise monitoring	L,D,C	1,2,3,4	S	L	U	B	N
	Street Lighting	S,L,D,C	1,2,3,4	L	V	D	M	1 mn
	Parking Management	S,L,D	1,2,3,4	S	V	U	B	1 mn
	Self Service bike rental	S,L,D	1,2,3,4	S	L	U	2	1 mn
	Digital board monitoring	S,L,D	1,2,3,4	S	L	U	M	N
	Water pipe leakage monitoring	S,L,D,C	1,2,3,4	S	L	U	B	N

Domain	Sub-domain	Scale	Type	Min EP /BS	Max EP /BS	Main data stream	Main EP power mode	Latency constraint on main data stream
Environment/Country side	Soil quality monitoring	S,L,D,C	1,2,3,4	S	L	U	B	N
	Livestock surveillance	S,L,D,C	1,2,3,4	S	L	U	B	N
	Cattle & pet monitoring	S,L,D,C	1,2,3,4	S	M	U	B	N
	Climate	S,L,D,C	1,2,3,4	S	L	U	B	N
	Irrigation	S,L,D	1,2,3,4	S	L	B	2	N
	Run off monitoring	S,L,D	1,2,3,4	S		U	B	N
Remote monitoring (telesurveillance)	House	S	1,2,3,4	S	L	B	2	1 mn
	Building	S,L,D,C	1,2,3,4	S	M	B	2	1 mn
Industrial	Water tank management	S,L,D,C	1,2,3,4	S	L	B	2	N
	Asset tracking	S,L,D,C	1,2,3,4	S	H	U	2	N
	Industrial plant condition monitoring	S,L,D,C	1,2,3,4	S	M	U	M	1 mn
Automotive	Vehicle tracking	D,C	1,2,3,4	S	V	U	2	N
	Impact detection	D,C	1,2,3,4	S	V	U	M	1 mn
	"Pay As You Drive"	D,C	1,2,3,4	S	M	U	M	N
	Assistance request, Break down call, Comfort Call	D,C	1,2,3,4	S	V	D	M	10 s
	Fault, service interval reporting	S,L,D,C	1,2,3,4	S	V	U	M	N
Logistics	Goods tracking	D,C	1,2,3,4	S	V	U	B	N
	Off grid fuel delivery	D,C	1,2,3,4	S	M	U	2	N
	Refrigerated container monitoring	S,L,D,C	1,2,3,4	S	M	U	2	N
	Conservation parameters	S,L,D,C	1,2,3,4	S	L	U	B	N
Healthcare	Patient monitoring	S,L,D,C	1,2,3,4	S	M	U	B	1 mn
	Home Medical Equipment status and usage	S,L,D,C	1,2,3,4	S	L	U	2	N
	Attendance tracking	S,L,D,C	1,2,3,4	S	M	U	B	N
Conventional Cellular Cooperation	Alarm sending	S,L,D,C	1,2,3,4	S	V	U	B	10 s
House appliances	Pet tracking	S,L,D,C	1,2,3,4	S	M	U	B	N
	White goods	S,L,D,C	1,2,3,4	S	H	B	M	1 mn
	Personal asset	S,L,D,C	1,2,3,4	S	V	U	B	N
Truck	Tyre monitoring	S,L,D,C	1,2,3,4	S	M	U	B	10 s
Identification	Authentication	S,L,D,C	1,2,3,4	S	H	B	2	10 s

6.4 Conclusions

Through a consideration of Table 14 the following general conclusions can be drawn:

- LTN should be deployable at any Scale or Type required by the Use Case.
- Multiple LTNs will occur in the same geographic area and frequency band.
- An existing LTN should be largely unaffected by the deployment of a new LTN BS or EP close by.
- Some of the Use Cases lead to high densities and numbers of End Points per Base Station.
- 1-Way and 1,5-way communication prefer the Uplink to the Downlink.
- Latency requirement is not a critical feature for LTNs and may vary significantly.

It can also be noted that there are some battery-powered and some mains-powered Use Cases.

7 LTN key characteristics

7.1 Network topology

As described above, LTN systems are focussed on the communication of many short messages between many End Points and a network application via a Base Station over a large coverage areas. This is achieved with a star network topology with a single hop from BS to EPs.

In limited cases, relay points connect a limited number of end points in order to extend local coverage in harsh propagation conditions.

7.2 Traffic and protocol aspects

The protocol (signalling and packet header) overheads on each link are optimized for low throughput and small packet sizes (e.g. as small as 10 bytes) so that the spectrum can be used efficiently to achieve high capacity even at datarates below 1 kbps.

The radio protocol implemented in an LTN System ensures a Base Station meeting the European Radio Regulations and compliant to ETSI EN 300 220 [i.10] is capable of collecting at least 1M application messages of 10 bytes to 14 bytes per day randomly generated by EPs randomly scattered in the whole coverage of the Base Station; some LTN systems achieve this capacity in less than 200 kHz bandwidth, others may require more. Annexes A and B present examples of the capacity of LTN systems.

LTN Systems are not intended to support real time applications. Therefore the latency of an LTN system may be several tens of seconds in uplink. Similarly, to achieve battery savings in the End Points, the packet latency of a downlink can be several hours.

The need for acknowledgement of messages in applications supported by LTN varies between applications and within applications. For this reason LTN systems support the sending of acknowledged or unacknowledged packets in both directions between End Points and a network application (via base stations and a core network).

Similarly some applications benefit from a multicast capability from a network application to End Points, so some LTN systems support this capability.

LTN systems support mobility of end points with speeds of at least 30 km/h in flat Rayleigh fading environments. LTN systems also avoid the need for frequent signalling (e.g. registration update) from mobile End Points.

Some applications and use cases can benefit from roaming of End Points between LTN systems, so some LTN systems support such roaming.

7.3 Identifiers and Addressing

Each LTN End Point has an 'identifier' which provides a unique means of referencing a specific End Point. In LTN systems this identifier has a length of at least 64-bits. In order to achieve global uniqueness of such identifiers, the IEEE OID/OUI scheme is used.

In the unusual case of an End Point with more than one independent physical LTN interface supporting independent LTN connections, separate identifiers may be assigned for each interface.

LTN systems can support large numbers of end points in a 'star' topology, which influences the addressing mechanisms used; each LTN system can discriminate between its own packets and packets on other LTN systems.

7.4 Deployment and radio aspects

With a transmit power of not more than 25 mW erp in the uplink, LTN systems achieve a Maximum Coupling Loss (MCL) of at least 150 dB in both directions between the end point and the Base Station, excluding antenna gains. This is achieved through advanced interference and noise rejection techniques in the receiver.

LTN systems support a difference in path loss between different End Points and the base station of at least 100 dB.

Some LTN systems incorporate power control and/or data rate adaptation techniques over the LTN air interfaces.

LTN systems can operate with geographically-overlapping coverage. This may mean that an end point at full range from its closest Base Station is located as little as 10 m from a Base Station in another LTN system, which is also serving its end points at full range.

More than one LTN Base Station may be installed on a single site or mast.

LTN End Points and Base Stations are compliant with ETSI EN 300 220 [i.10] radio regulations (and some are compliant with FCC CFR Part 15.247 [i.11] and/or ARIB STD/T108 [i.12]); LTN systems include measures to facilitate coexistence with other LTN networks as well as supporting interference mitigation techniques.

7.5 Security aspects

LTN systems provide origin authentication, integrity protection, replay protection and encryption for the uplink and downlink frames exchanged between the device and the network, and rely on security algorithms at least equivalent in strength to AES128 [i.13]. Cryptographic keys may be provided by an over-the-air exchange (which constitutes mutual entity authentication between the end-point and the network) or by some out-of-band mechanism (e.g. factory pre-provisioning). Security-related aspects of the protocol are optimized to operate efficiently within the constraints of an LTN system.

7.6 End Point implementation

LTN systems are designed to support the implementation of an End Point using a low current transceiver such that its battery life can exceed 10 years on small primary batteries, for example 2 × AA cells.

Similarly they support the implementation of an End Point with low peak transceiver current demand such as can be provided by small primary batteries (e.g. button cells).

Annex A: Capacity Example 1

A.1 Introduction

Capacity of an LTN solution is its ability to convey a certain amount of messages per a given period of time, in UL and DL. Capacity value depends on the radio technology and on the spectrum available for LTN. When addressing a given market or a set of use cases, the capacity request is based on demographic, market shares and market penetration figures.

In this annex a capacity evaluation and spectrum requirement of an LTN system which runs a UNB Radio Access Technology in Paris area (France) is given. The logic of this annex is the following:

- Market analyst figures on the total number of Iot devices for the global IoT market are used to derive device figures for a single network deployed in Paris area.
- The traffic generated by this number of devices is evaluated.
- The traffic density per day per base station is evaluated by using the coverage of a UNB base station in a typical urban environment.
- The last step is the spectrum evaluation, considering the footprint of messages in the selected UNB technology.

A.2 Traffic generated

The traffic evaluation is based on market analysts' figures for market penetration in 2024 of LPWA systems, and on the market share for UNB systems.

As these figures assume low penetration of connected devices by 2024, a base station density limited by the communication range (3,5 km in dense urban areas) and not by the traffic generated by objects is assumed.

As a result, the generated traffic is evaluated to 1,22 M msg/day/BS (see Figure A.1).

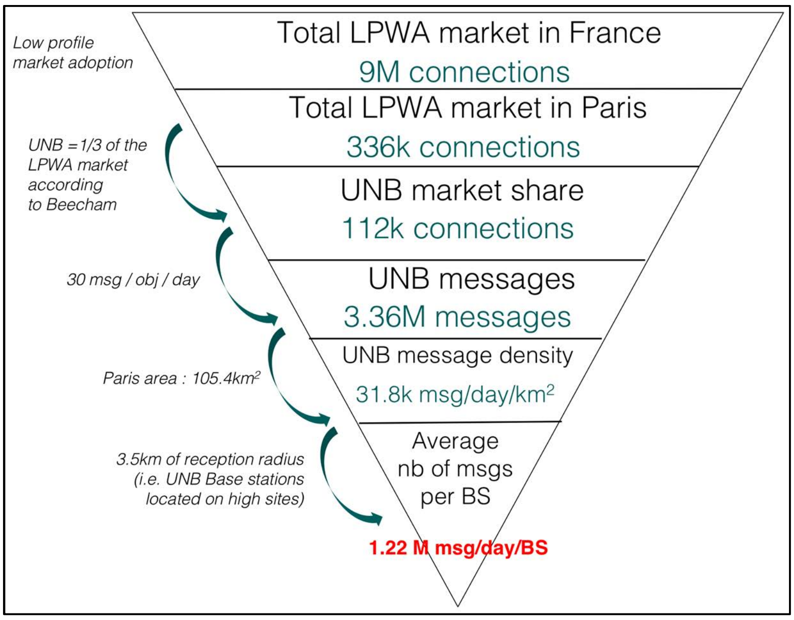

Figure A.1: Traffic in a base station per day (low profile assumption)

A.3 Spectrum needed

As described in the above introduction, the spectrum bandwidth needed to carry such a traffic depends on the protocol efficiency (i.e. protocol overheads and modulation efficiency). Nevertheless, an evaluation of the spectrum requirements can be made considering the following 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 (ie twice the modulation rate).

With these figures, the message footprint (i.e. the frequency x time surface) of a UNB message is roughly:

$$msg\_footprint = \frac{16 \times 8 \times (1 + 50\,\%)}{1/3} \times \frac{200\,Hz}{100\,bps} = 1\,152\,Hz.s \qquad \text{(A.1)}$$

The value of the protocol overhead given above assumes very basic procedures to access and share the medium. In such a case, the best protocol is the aloha one 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 at low level of offered load, because collision occurrence is kept low. Assuming that the offered load is 10 % of the maximum theoretical throughput of a UNB system, the spectrum bandwidth needed to carry 1,22 M messages per day per base station is given by formula A.2:

$$required\_bandwidth = \frac{msg\_footprint \times daily\_traffic}{duration\_of\_a\_day \times load\_ratio} = \frac{1\,152 \times 1{,}22\ M}{86\ 400 \times 10\ \%} \approx 163\ kHz \qquad \text{(A.2)}$$

Limited crystal accuracy in the End Point suggests an increase in this value of a few percent: assuming a guard band of 5 kHz on both sides of the used spectrum, the required bandwidth for LTN solution is 173 kHz, which is of the order of magnitude of the commonly used 200 kHz spectrum bands.

A.4 Conclusion

This annex evaluates the capacity and required spectrum of an LTN System that runs a UNB radio interface. The evaluation is based on figures for the Paris area by 2024 and shows that a 200 kHz band is appropriate for this service.

Annex B: Capacity Example 2

B.0 Introduction

In this annex the forecasts of analysts are used to estimate device/connection densities in a typical, dense urban area, and the implications of supporting these densities with an existing deployed UNB-based system are considered, in particular in relation to base station density and spectrum requirements.

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

B.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 B.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 LTN systems.
- Calculate the number of relevant UK LTN-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 Fig 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.

B.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 it is assumed that the density of connections (of the connection types relevant in these areas) will be generally correlated with the density of households in the area.

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

Table B.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 B.2 were also used in modelling the forecast device density as described in the Method in clause B.1.1.

Table B.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 B.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 B.3: Global LPWA connections forecast by year (from Figure B.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

B.1.3 Results

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

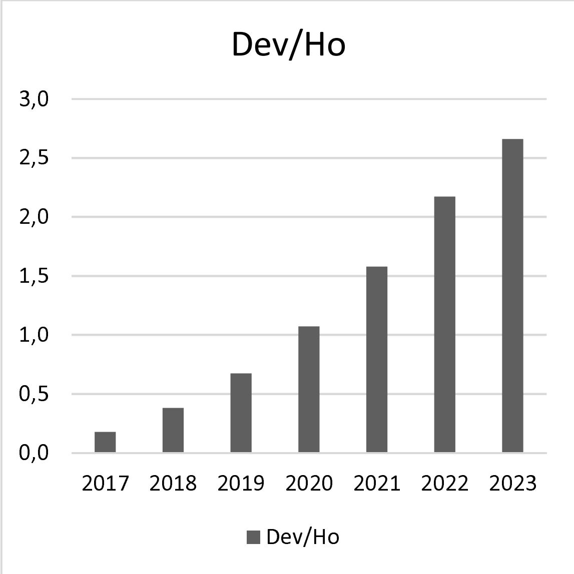

Figure B.1: Greater London devices/household forecast by year

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 B.4.

Table B.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 LTN 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 LTN devices is estimated to be 40 %, see clause B.3.

B.2 Modelling of traffic and support by LTN system

B.2.1 Method

The system modelled in this annex is a UNB technology, and for this purpose may be considered a representative example of an LTN-compliant system. By comparing the capacity (messages/day) of a UNB base station as currently deployed with forecasts of UNB device deployment (connections) and likely traffic levels from different types of device, base station densities (BS/km^2) likely to be required can be estimated.

The following method has been employed:

- 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 (various methods) is estimated.
- The peak device geographical densities (of LTN-based LPWA devices) already estimated in clause B.1.3 is employed to forecast the density of presented LTN traffic (msgs/day/km^2).
- The LTN base station density required to support that traffic density is calculated.

B.2.2 Base station (BS) capacity

This clause describes the capacity of a base station in a typical commercially-deployed UNB system.

Input parameters for LTN system modelling are detailed in Table B.5.

Table B.5: Input parameters UNB system modelling

Parameter	Value	Comment/references
DC (DL)	10 %	Limit from ERC Rec 70-03 Annex 1 h1.6 [i.9]
Proportion of UL traffic acknowledged by BS	Up to 100 %	
DL Tx power	27 dBm ERP	Limit from ERC Rec 70-03 Annex 1 h1.6 [i.9]
		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 B.2 (multi-cell network, cell-edge results for planned DL and shared UL).

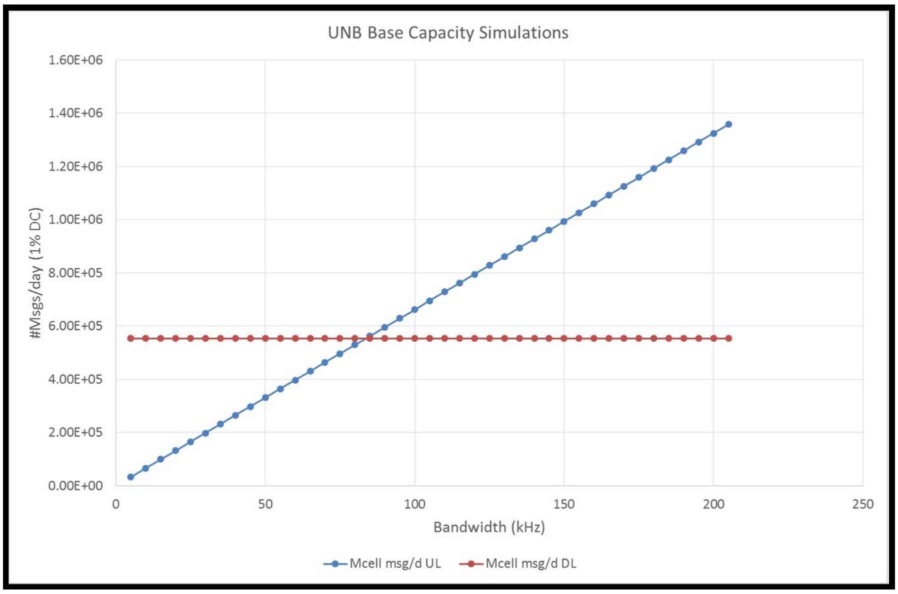

Figure B.2: Capacity of BS (UL and DL) in modelled LTN system

Figure B.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.

B.2.3 Offered traffic density

B.2.3.1 Method

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 LTN networks.
- A typical level of daily traffic for each of the sub-domains is estimated.
- Noting that devices are categorized differently in the analysts' reports referenced in clause B.1, a weighted mapping between the sub-domains described in the present document and the analysts' categories is proposed (i.e. "what percentage of its equivalent category is represented by each sub-domain?").
- Based on that mapping and the associated weighting, figures for typical (average) msgs/day/EP for each of the categories (Table B.6) are calculated.
- The categorized device density forecasts presented in clause B.1.2 are used to calculate traffic density forecasts.

B.2.3.2 Inputs

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

Table B.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	**14,6**
Environment/Country side	Soil quality monitoring				
	Livestock surveillance				
	Cattle & pet monitoring				
	Climate				
	Irrigation				
	Run off monitoring				
Remote monitoring	House	Smart Building	24	0,5	

Domain	Sub-domain	Analysis Mason category	Estimated msg/day/dev	Proportion of category (weighting)	Average msg/day from category
(telesurveillance)	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	
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				

B.3 Results

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 LTN 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 B.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 approx. 40 % of UL packets are acknowledged).

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

Year	Peak UNB end point density EP/km² (Table B.4)	Resulting UNB UL traffic density kmsg /day/km²	Resulting BS density BS/km²
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 may require more than 400 kHz of spectrum.

B.4 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 LTN 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 C: Change History

Date	Version	Information about changes
June 2015	0.0.1	Table of Content
09 September 2015	0.0.2	with requirements reviewed in meeting LTN#6
9th May 2016	0.0.6	Range of editorial updates, ERMTG28(16)013006 includes revision marking
28th June 2016	0.0.7	Added capacity annexes
8th July 2016	0.0.8	Revised after LTN#15, especially ERMTG28(16)015007r3_LTN_-_use_case_document_requirements_revision_
10th October 2016	0.0.9	Changes post- LTN#15 and #16, especially ERMTG28(16)016002r1 and ERMTG28(16)016009r1
27th October 2016	0.0.10	Changes agreed at LTN#17
2nd December 2016	0.0.11	Changes agreed at LTN#18

History

Document history		
V1.1.1	October 2017	Publication