LTE evolution for IoT connectivity

Contents

1. Executive summary

The Internet of Things (IoT) is the next revolution in the mobile ecosystem. IoT services are likely to be a key driver for further growth in cellular. An estimated 30 billion connected devices will be deployed by 2025 [Machina Research, May 2015], of which cellular IoT (i.e. 2G, 3G and 4G technologies used for IoT but not specifically optimized for IoT) and Low-Power Wide-Area (LPWA) modules are forecast to account for 7 billion units in 2025 [Machina Research, May 2015].

Cellular IoT is expected to provide numerous services, including utility meters, vending machines, automotive (fleet management, smart traffic, real time traffic information to the vehicle, security monitoring and reporting), medical metering and alerting. Already, devices such as e-book readers, GPS navigation aids and digital cameras are connected to the internet.

The key requirements for cellular IoT to enable these services and be competitive are:

- Long battery life
- Low device cost
- Low deployment cost
- Extended coverage
- Support for a massive number of devices.

This white paper outlines a cellular IoT solution based on LTE that meets these requirements and enhances the radio and core networks. The radio network needs to work with simple, low cost devices. The transmission and higher layer protocols need to help devices consume less power, with the aim of achieving a battery life of over ten years. Finally, extended coverage is required for deep indoor and rural areas.

Network elements need to handle charging, subscription and massive support for small packages. Today, LTE supports IoT with so-called Cat.1 devices, while LTE-Advanced extends device battery life to ten years with a power saving mode. LTE-Advanced Pro further optimizes coverage, device battery life and costs, as well as capacity for a massive number of connected devices with the introduction of two new technologies: eMTC (enhanced Machine Type Communication, often referred to as LTE-M) and NB-IoT (NarrowBand-Internet of Things).

These two systems will support a scalable solution for data rates. Both solutions can be deployed either in shared spectrum together with legacy LTE, or as stand-alone, in a refarmed GSM carrier with a bandwidth as narrow as 180kHz for NB-IoT. Nokia believes that LTE-M, NB-IoT, and EC-GSM-IoT (Extended Coverage GSM for IoT) are better able to satisfy the connectivity profiles and requirements for IoT than legacy cellular networks. This is because by upgrading existing networks with an easy software upgrade, they provide optimized device KPIs, battery life, coverage and cost, along with the expected benefits from the use of licensed spectrum, such as no coexistence issue with other cellular networks.

2. IoT market landscape

The IoT interconnects "things" and autonomously exchanges data between them. "Things" may be machines, parts of machines, smart meters, sensors or even everyday objects such as retail goods or wearables. This capability will bring about tremendous improvements in user experience and system efficiency. Support for IoT requires Machine-to-Machine (M2M) communication. M2M is defined as data communication among devices without the need for human interaction. This may be data communication between devices and a server, or device-to-device, either directly or over a network. Examples of M2M services include security, tracking, payment, smart grid and remote maintenance/monitoring. The total M2M market is estimated to be 30 billion connected devices by 2025 [Machina Research, May 2015].

Fixed and short-range communication will be used for most connections. However, there is also a significant number (around seven billion by 2025) of connections expected via traditional cellular IoT and LPWA networks (Figure 1).

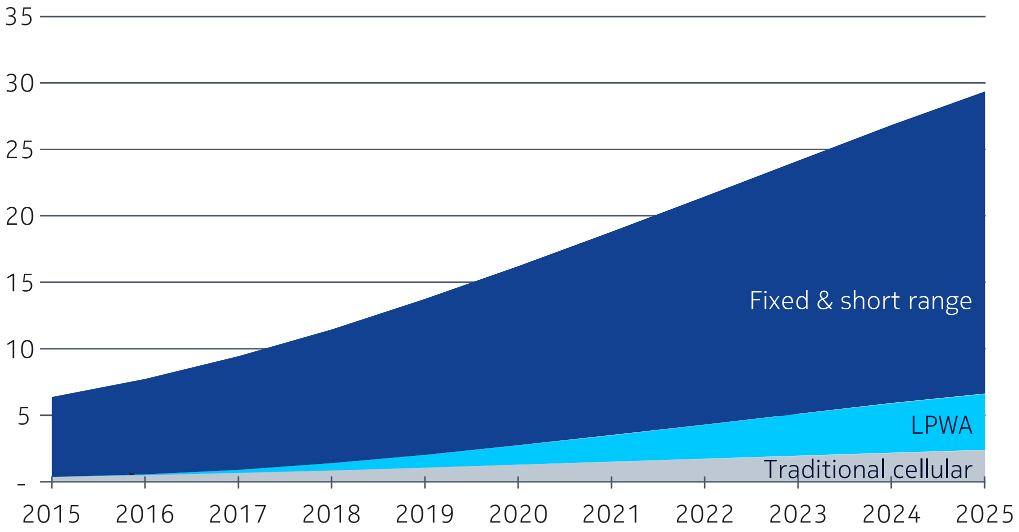

Figure 1: Billion global connections, 2015-2025 (Machina Research, May 2015)

LPWA is split into two separate sub-categories. On the one hand, there are the current proprietary LPWA technologies, such as SigFox and LoRa, which typically operate on unlicensed spectrum. On the other hand, there are the forthcoming 3GPP standardized cellular IoT technologies, in short cellular IoT, which typically operate on licensed spectrum.

Designing cellular IoT to meet the key requirements laid out in Figure 2 will enable it to address the combined market of traditional cellular IoT and LPWA IoT connections shown in Figure 1. To reach the total potential volume of seven billion units by 2025, the cellular IoT market will need to grow 35 percent annually on average.

IoT applications and services vary widely in terms of their service requirements, data throughput, latency and connectivity reliability.

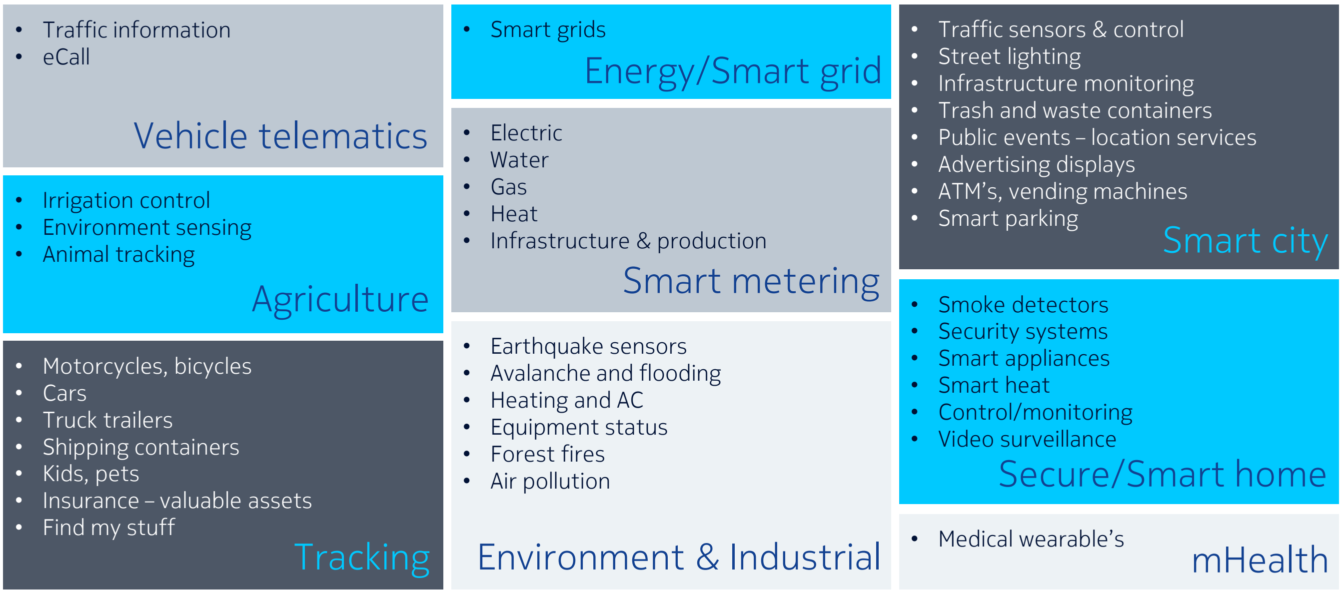

Figure 2: Cellular IoT use cases

The main vertical sectors for cellular IoT connections will have the following market shares [Machina Research, May 2015]:

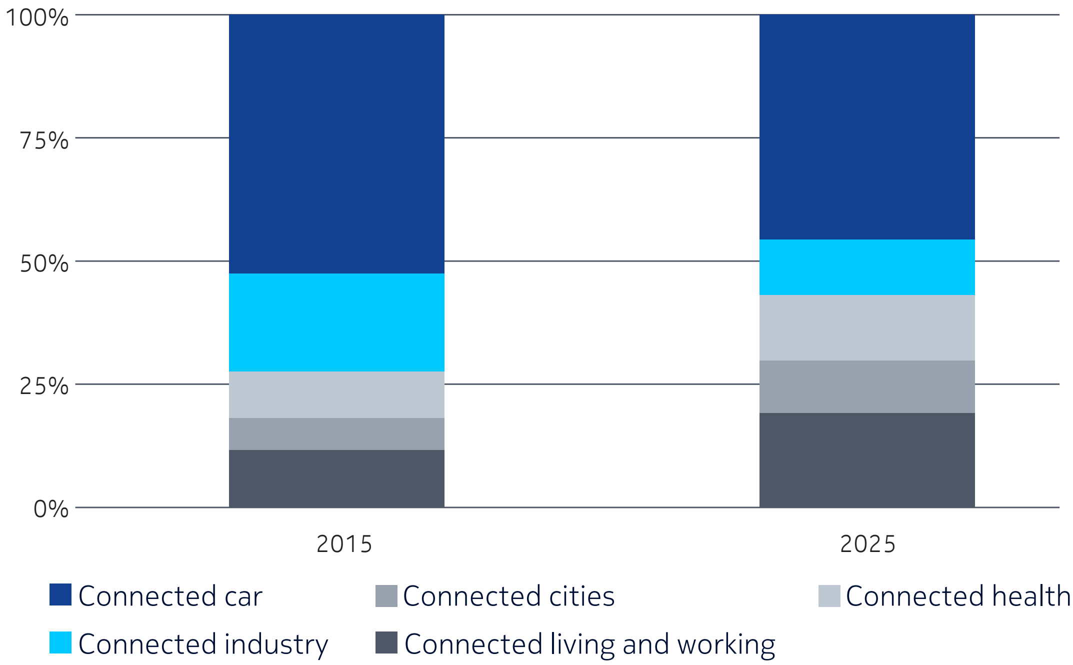

Figure 3: Vertical sectors for IoT market share, 2015/2025 (Machina Research, May 2015)

3. LPWA IoT requirements

The key requirements for LPWA networks to successfully support massive IoT deployment are:

- Long battery life
- Low device cost
- Low deployment cost
- Extended coverage
- Support for a massive number of devices.

3.1 Long battery life

Mobile phone and especially smartphone users are accustomed to charging their device batteries frequently. However, many IoT devices must operate for very long times, often years, without human intervention. A good example is a fire alarm device sending data directly to a fire department. The interval between battery changes in such a device is a very important cost factor.

Long battery life would also enable completely new connected device applications not yet deployed. Many objects around us are not connected to an external power supply, but are battery operated or even work without a battery. These devices can also be brought into the network.

The industry aims to achieve a minimum of 10 years of battery operation for simple daily connectivity with a small amount of data exchanged.

3.2 Low device cost

IoT connectivity will mostly serve very low ARPU users, giving a ten-fold reduction in revenue compared to mobile broadband subscriptions. The current industry target is for a module cost of less than 5 USD. To enable a positive business case for cellular IoT, the total cost of ownership (TCO) including the device must be extremely low.

3.3 Low deployment cost

The network cost of IoT connectivity, including initial CAPEX and annual OPEX, must also be kept to a minimum. A simple, centrally pushed software upgrade can deploy LPWA IoT connectivity on top of existing cellular networks to avoid any new hardware and site visits and keep CAPEX and OPEX to a minimum.

Marketing and sales have a better understanding on new services that are being launched and how these perform.

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3.4 Extended coverage

Extended coverage is important in many IoT applications. Simple examples are smart meters, which are often in the basements of buildings behind concrete walls. Industrial applications such as elevators or conveyor belts can also be located deep indoors. This has driven the M2M community to look for methods to increase coverage by tolerating lower signal strength than is required for other devices. The target for the IoT connectivity link budget is an enhancement of 15-20dB. This coverage enhancement would typically be equivalent to the signal penetrating a wall or floor, enabling deeper indoor coverage.

3.5 Support for a massive number of devices

IoT connectivity is growing significantly faster than normal mobile broadband connections and by 2025 there will be seven billion connected devices over cellular IoT networks. This is equivalent to the current number of global cellular subscriptions. The density of connected devices may not be uniform, leading to some cells having very high numbers of connected devices. This means that LPWA IoT connectivity needs to handle many simultaneous connected devices.

4. LPWA IoT technology landscape

Today, 2G modules are the dominant solution for IoT, but the fastest growth will be in LTE modules. Low power, wide area and low cost modules are key enablers for the rapid changes expected. A module cost below 5 USD is needed for LPWA IoT devices to gain market share from short-range connectivity standards and wireless sensor networks like ZigBee, BT LE and Wi-Fi. The key LPWA IoT solutions are shown in Figure 4.

	LoRa	GSM (Rel.8)	EC-GSM-IoT (Rel.13)	LTE (Rel.8)	eMTC (Rel.13)	NB-IoT (Rel.13)
LTE user equipment category	N/A	N/A	N/A	Cat.1	Cat.M1	Cat.NB1
Max. coupling loss	155dB	144dB	164dB	144dB	156dB	164dB
Spectrum	Unlicensed <1GHz	Licensed GSM bands	Licensed GSM bands	Licensed LTE bands In-band	Licensed LTE bands in-band	Licensed LTE in-band guard-band stand-alone
Bandwidth	<500kHz	200kHz	200kHz	LTE carrier bandwidth (1.4 – 20MHz)	1.08MHz (1.4MHz carrier bandwidth)	180kHz (200kHz carrier bandwidth)
Max. data rate*	<50kbps (DL/UL)	<500kbps (DL/UL)	<140kbps (DL/UL)	<10Mbps(DL) <5Mbps(UL)	<1Mbps (DL/UL)	< 170kbps (DL) < 250kbps (UL)

*Max data rates provided are instantaneous peak rates.

Figure 4: LPWA IoT and legacy LTE connectivity overview

LPWA IoT solutions can be divided into proprietary (i.e. non-3GPP) LPWA technologies and (3GPP) cellular IoT; SigFox and LoRa are both proprietary technologies deployed in unlicensed bands. For all these technologies, deployment in spectrum lower than 1GHz spectrum helps achieve maximum coverage, but higher bands in the spectrum may still be used.

Three separate tracks for licensed cellular IoT technologies are being standardized in 3GPP:

- LTE-M, an evolution of LTE optimized for IoT in 3GPP RAN. First released in Rel.12 in Q4 2014, further optimization is being included in Rel.13 with specifications completed in Q1 2016.
- NB-IoT, the narrowband evolution of LTE for IoT in 3GPP RAN, included in Rel.13 with specifications completed in Q2 2016.
- EC-GSM-IoT, an evolution of GSM optimized for IoT in 3GPP GERAN, included in Rel.13 with specifications completed in Q2 2016.

Finally, a 5G solution for cellular IoT is expected to be part of the new 5G framework by 2020. The link budget is similar in all solutions, with a slight improvement for narrowband solutions such as NB-IoT and EC-GSM-IoT. LoRa and SigFox are planned to share spectrum with other solutions in the unlicensed bands.

Some alternative proposals for NB-IoT operate in a dedicated 200kHz carrier refarmed from GSM, but do not support spectrum sharing with LTE networks. This is why Nokia has supported the NB-IoT proposal from the 3GPP Study Item phase. Based on an LTE narrowband evolution, this is designed to operate in a 200kHz carrier refarmed from GSM but has the further advantage of being able to operate in shared spectrum with an existing LTE network, thus requiring no additional deployment of antennas, radio or other hardware. The solutions for LTE-M, NB-IoT and EC-GSM-IoT will equally operate in spectrum shared with existing LTE or GSM networks - LTE-M and NB-IoT would be supplementary solutions addressing different use cases, with higher capacity on LTE-M and slightly lower cost and better coverage on NB-IoT.

The deployment options for the cellular IoT solutions are different and depend on the mobile operator's installed base. To benefit from good propagation and penetration characteristics, all solutions should ideally be deployed in sub 1GHz bands. Some operators may have GSM deployed in the 900MHz band without enough LTE spectrum to deploy LTE-M or NB-IoT within the LTE band. In such cases, EC-GSM-IoT could enable sharing of the carrier capacity in the GSM band. Alternatively, a refarmed GSM carrier would enable deployment of NB-IoT operating in 180kHz bandwidth.

More precisely, deployment options for NB-IoT are shown in figure 5.

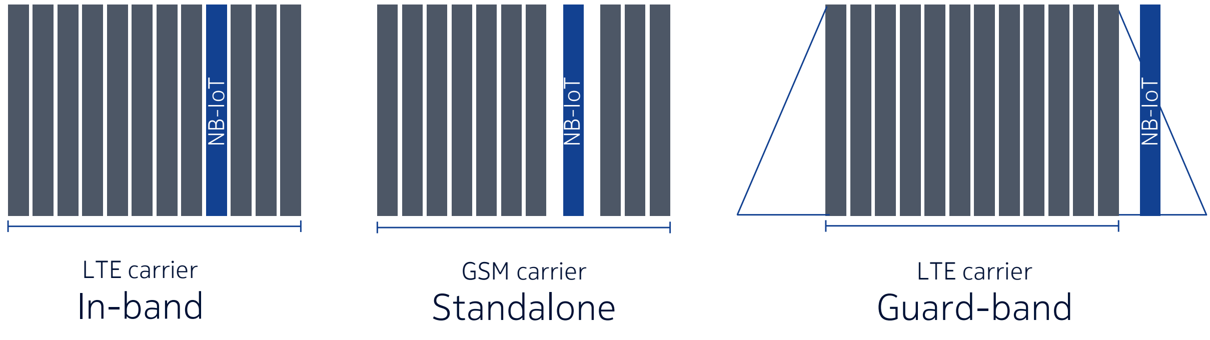

Figure 5: NB-IoT deployment options

Additionally:

- LTE-M may be deployed in-band within a LTE carrier
- EC-GSM-IoT may be deployed in-band within a GSM carrier.

Deploying an unlicensed technology would require a new network deployment, potentially reusing existing sites but requiring the installation of new hardware. All the 3GPP-based solutions would be software upgradeable.

5. LTE evolution for cellular IoT

LTE supports both frequency division duplex (FDD) and time division duplex (TDD) modes using a common subframe structure of 1ms. Such a short subframe length allows us to minimize latency, ensuring a good user experience.

3GPP Rel.12 has specified low cost M2M devices (Cat-0), the details of which are summarized in the next section. In Rel.13, standardization is continuing to further enhance coverage and battery life and reduce complexity compared to existing LTE devices. 3GPP for eMTC has the following objectives:

- Specify a new device category for M2M operation in all LTE duplex modes based on the Rel.12 low complexity device category supporting the following:
  - Reduced device bandwidth of 1.4MHz in downlink and uplink
  - Reduced maximum transmit power of 20dBm.
- Provide an LTE coverage improvement – corresponding to 15dB for FDD – for the device category defined above and other devices operating delay tolerant M2M applications with respect to nominal coverage.
- Enhance the DRX cycle in LTE to allow for longer inactivity periods and thus optimize battery life.

The narrow band NB-IoT proposal is set for approval in 3GPP Rel.13 with the following improvements over eMTC:

- Reduced device bandwidth of 180kHz in downlink and uplink
- Reduced throughput based on single PRB operation
- Provide LTE coverage improvement corresponding to 20dB (5dB better than eMTC).

On the other hand and as for LTE-M, both power saving mode and enhanced DRX are available to increase battery life and fulfill the “minimum 10 years battery life” requirement.

5.1 Long battery life

Providing M2M support for locations with no direct power source such as water meters and sensors requires battery operated devices. Today’s mobile handsets can offer a standby time of up to about five weeks. This would require changing batteries monthly, which would not be feasible.

A device power saving mode (PSM) was introduced in Rel.12 to improve device battery life significantly. A device that supports PSM will request a network for a certain active timer value during the attach or tracking area update (TAU) procedure. The active timer determines how long the device remains reachable (by checking for paging according to the regular DRX cycle) for mobile terminated transaction upon transition from connected to idle mode. The device starts the active timer when it moves from connected to idle mode. When the active timer expires, the device moves to power saving mode. In power saving mode, the device cannot be reached as it does not check for paging, but is still registered with the network. The device remains in PSM until a mobile originated transaction (e.g. periodic TAU, uplink data transmission) requires it to initiate any procedure towards the network.

In Rel.13, further improvements in battery life will be standardized to enable enhanced DRX (eDRX). eDRX enables the device to be configured beyond the previous upper limit of 2.56sec. eDRX can be used when downlink traffic is not delay-tolerant (and a long TAU cycle cannot be used) or in extreme coverage scenarios (when physical channels are repeated many times). Figure 6 shows the two key features in eMTC and NB-IoT promoting enhanced battery life.

Figure 6: LTE-M/NB-IoT enhanced battery options

Depending on the current consumption model, many years of battery operation can be achieved. Using the 3GPP model in TR 45.820, we can achieve up to 36 years of battery operation for eMTC and NB-IoT with a daily update of 200 bytes. In reality, taking into account leakage current and battery self-discharge, a battery option of 10 years is more realistic.

5.2 Low device cost

LTE was designed in 3GPP Rel.8 to provide affordable mobile broadband and has been developed by subsequent 3GPP releases. Yet the focus has always been on optimizing performance, a factor that has created increasing complexity. Rel.12 looks at how to reduce the complexity of LTE with lower performance Key Performance Indicators (KPIs) while still complying with the LTE system. This reduced complexity helps cut costs significantly.

Further cost reductions are needed to make LTE a competitive M2M solution and these are being addressed in Rel.13 and beyond.

Figure 7 summarizes the complexity/cost reductions as we move from Rel.8 Cat-4 devices towards potential Rel.13 low cost LTE-M devices.

	Release 8	Release 8	Release 13	Release 13
Modem/device chip category	**Category 4**	**Category 1**	**Category M1 (eMTC)**	**Category NB1 (NB-IoT)**
Downlink peak rate	150Mbps	10Mbps	1Mbps	170kbps
Uplink peak rate	50Mbps	5Mbps	1Mbps	250kbps
Number of antennas	2	2	1	1
Duplex mode	Full duplex	Full duplex	Full/Half duplex	Half duplex
UE receive bandwidth	1.08-18MHz	1.08-18MHz	1.08MHz	180kHz
UE transmit power	23dBm	23dBm	20/23dBm	20/23dBm
Multiplexed within LTE	Yes	Yes	Yes	Yes/No
Modem complexity	**100%**	**80%**	**20%**	**15%**

Figure 7: Complexity/cost reductions for LTE-M and NB-IoT evolution

LTE-M Rel.12 UE optimizations

Rel.12 introduces a new low complexity device category (Cat-0). This low cost category defines a set of reduced requirements, enabling less complex, lower cost devices. The key reductions agreed in Rel.12 are:

- Half duplex FDD operation allowed. This makes it possible to operate LTE FDD time multiplexed, avoiding the duplex filter
- Single receive chain. This removes the dual receiver chain for MIMO
- Lower data rates. With a lower data rate requirement, the complexity and cost for both processing power and memory will be reduced significantly.

LTE-M Rel.13 UE optimization

Further simplification of devices have been achieved in Rel.13 (ref. TR 36.888).

- Low RF bandwidth support (1.08MHz). This reduces complexity as a narrowband RF design is sufficient.
- A lower device power class of 20dBm allows integration of the power amplifier in a single chip solution.

NB-IoT Rel.13 UE optimization

NB-IoT is an evolution of the LTE-M cost optimizations, with the following improvements compared with LTE-M:

- Reduced device bandwidth of 180kHz in downlink and uplink
- Reduced throughput based on single PRB operation to enable lower processing and less memory on the modules.

Standardization-independent cost optimization

There are many options to reduce costs further beyond the methods being standardized in 3GPP. Many ways to optimize implementation costs follow the lowest cost technology, which evolves over time. Some of the key drivers to further reduce implementation costs are:

- Optimized technology for RF and mixed signal processing. With higher integration, some of the technology components can be integrated in CMOS technology to cut costs
- With higher volume, the integration of single one-chip solutions becomes feasible
- Support for only single RAT and single band RF
- Cost erosion of CMOS technology.

5.3 Low deployment cost

Enabling low cost deployment of IoT networks is a key challenge for mobile operators providing IoT connectivity. Figure 8 shows how eMTC shares capacity with legacy LTE networks.

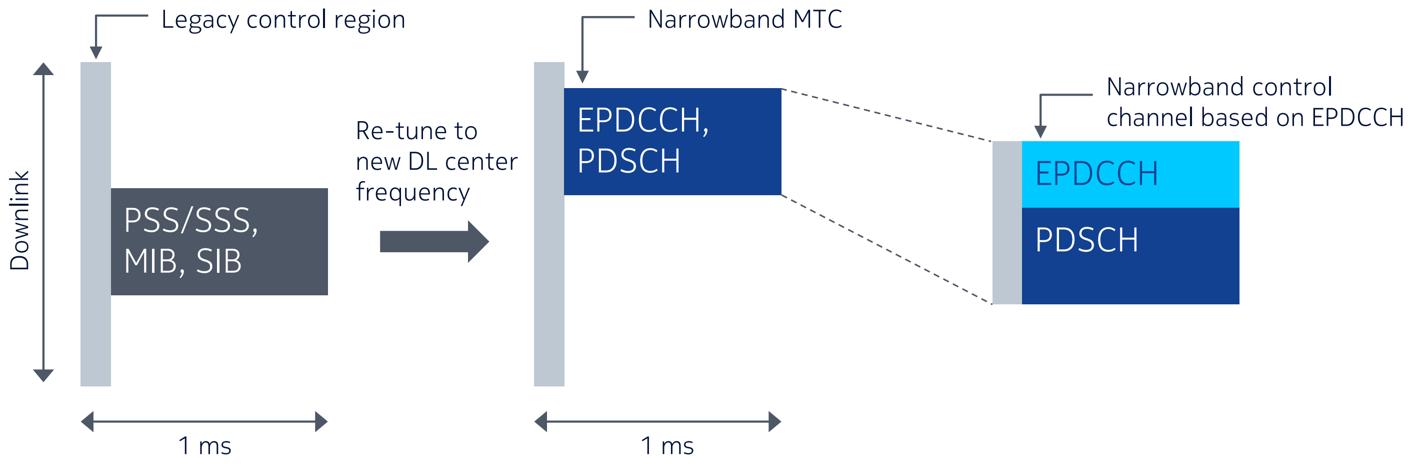

Figure 8: eMTC sharing carrier capacity in legacy LTE configuration

eMTC operates on a 1.4MHz carrier or 6 PRB. The IoT device will always listen to the center 6 PRB for control information, just like any normal device. When the device is scheduled for IoT traffic, it will be allocated a number of PRBs (up to 6) at any consecutive location within the spectrum of operation. This means that the device will be allocated a 1.4MHz carrier within, for example, a 20MHz carrier. The dedicated control and data is multiplexed in the frequency domain ignoring the legacy control information. This enables LTE IoT devices to be scheduled within any legacy LTE system and share the carrier capacity, antenna, radio and hardware at the site.

Reusing LTE for narrowband IoT systems (eMTC and NB-IoT) takes advantage of existing technology as well as the installed system base. It is possible to reuse the same hardware and share spectrum by making LTE-M and NB-IoT compatible with LTE, without running into coexistence.

In 2020, the average mobile subscriber will use several Gbytes of mobile broadband data per day. By contrast, a connected 'thing' may use hundreds of kbytes per day on average. The IoT traffic will in this example only consume about 0.01 percent of the mobile broadband data. Furthermore, most of the IoT traffic will not follow the same peak data consumption as mobile broadband and most IoT traffic can be scheduled overnight.

Therefore, deploying LTE-M and NB-IoT is as simple as a software upgrade to enable a full IoT network with significantly better coverage than the legacy LTE network.

5.4 Extended coverage

To provide ubiquitous network coverage for IoT services, 3GPP introduces a coverage enhancement feature in Rel.13:

- eMTC provides 15dB additional link budget, enabling about seven times better area coverage.
- NB-IoT provides 20dB additional link budget, enabling about ten times better area coverage.

The enhanced coverage can be achieved using a combination of techniques, including power boosting of data and reference signals, repetition/retransmission and relaxing performance requirements, for example, by allowing a longer acquisition time or higher error rate.

In eMTC 1.08MHz and NB-IoT 180kHz, the basic LTE design is retained except for some modifications to allow efficient support of coverage enhancements. This includes the elimination of some LTE downlink control channels including PCFICH and PHICH. Only the EPDCCH is supported for eMTC. An illustration of the downlink is shown in Figure 9. In normal coverage, the entire bandwidth can be used. In extended coverage mode, PSD boosting and repetition are used to reach devices in areas of poor coverage.

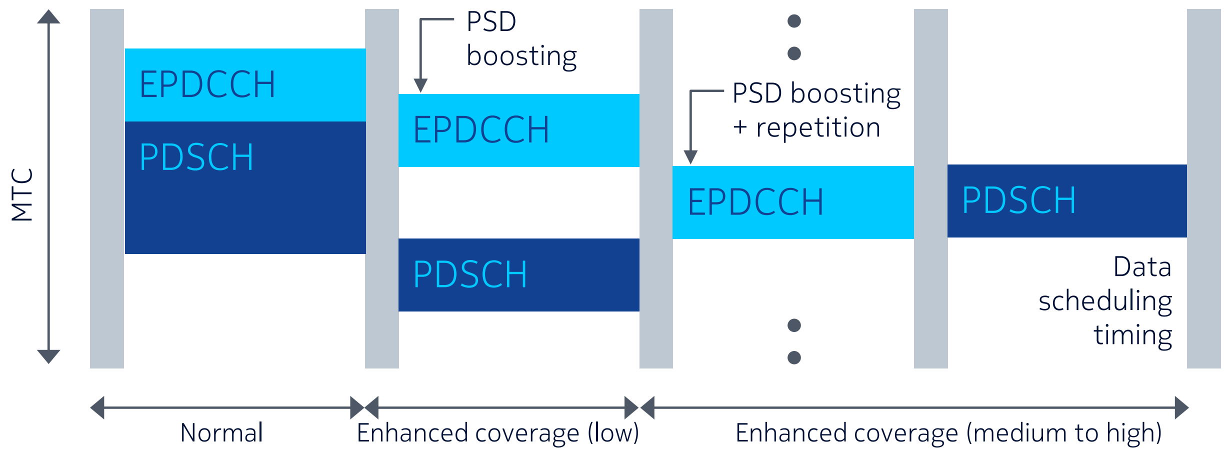

Figure 9: eMTC design with 1.08MHz bandwidth - downlink

Figure 9 shows how control and data are multiplexed beyond the legacy control information. Coverage is increased by simply operating in 180kHz or 1.08MHz compared to 20MHz LTE carrier bandwidth, yielding 20dB and 11.5dB improvement respectively. LTE-M further allows output power to be reduced by 3dBm, giving a lower implementation cost. Furthermore, control and data signals can be repeated to reach the required coverage enhancements.

An important feature of NB-IoT and LTE-M is that they share the same numerology as LTE. This allows spectrum to be shared between the two systems without causing mutual interference.

Additionally and for NB-IoT, a 3.75kHz subcarrier spacing numerology is available for the uplink (15kHz for LTE), the slot duration being extended to 2ms to remain compatible with the LTE numerology.

5.5 IoT optimization in the core

LTE was designed for users of mobile broadband with high data rates. IoT traffic requires support for a massive number of devices, many having a very low data rate. Figure 10 shows some areas in the core network that can be optimized for LTE-M and NB-IoT.

Dedicated core network Overlay core to serve and fulfill requirements of IoT devices	**Signalling reduction/overload control** Prevention of overload situations cause by signaling storms	**Resource optimization** Optimizing resource usage both in IoT devices and in network
Subscription optimization Optimizations for subscriber data storage and retrieval	**Small data transmission** Transmission of small data from/to IoT devices	**Monitoring** Reporting connectivity status of IoT devices to IoT applications

Figure 10: LTE-M/Nb-IoT – High capacity core network

Some of the optimizations for the core network include:

- A dedicated core network can be deployed to serve IoT devices in an optimized manner. Typically the dedicated core network contains the PGW and HSS but may also contain the MME and control elements. IoT specific features are supported in the dedicated core network. Cloud deployment is beneficial for IoT as it brings scalable capacity, elasticity and efficient use of resources
- Signaling can be reduced by guiding IoT devices to perform periodic location updates less frequently and by optimizing paging. Reducing signaling destined for overloaded elements can help avoid overload situations
- We can increase the battery lifetime of IoT devices by, for example, allowing the IoT devices to switch off functionality and go to sleep
- For a large number of IoT devices sharing the same subscriber attributes, we can optimize the subscriber data storage in the HSS as well as the signaling to retrieve subscriber data
- We can optimize network resource use for IoT devices doing small data transmission infrequently using methods such as bearerless solutions.
- Monitoring can allow IoT applications to get information on the connectivity status of IoT devices.

6. Conclusion

IoT changes the requirements for connectivity significantly, mainly with regards to long battery life, low device costs, low deployment costs, extended coverage and support for a massive number of devices. Based on these requirements, several different non-cellular LPWA connectivity solutions are emerging and are competing for IoT business and the overall connectivity market.

While operators and vendors are reviewing their connectivity roadmaps against the IoT requirements and the potential threats from new entrants and start-ups, Nokia's view is that LTE-M, NB-IoT, and EC-GSM-IoT are the superior solutions to satisfy the connectivity profiles and requirements for IoT. This is because cellular IoT provides an easy software upgrade of existing networks while providing optimized device KPIs, battery life, coverage and cost.

The LTE evolution for LTE-M and NB-IoT will enable cellular IoT for low cost, low power and wide area deployments that provide:

- Long battery life through power saving mode and eDRX
- Low device cost by using simpler devices
- Low network deployment cost by enabling shared carrier capacity
- Full coverage via new coding, repetition and boosting power spectral density
- Optimized core network for IoT.

The first release of LTE for cellular IoT has been published in 3GPP Rel.12, supporting long battery life and lower cost. 3GPP Rel.13 further reduces the cost of devices and provides additional coverage enhancements while still enabling high use case flexibility, for example for downlink messages, over-the-air software upgrades and selective transmission of bigger data volumes. The Rel.13 solution comprises a 180kHz solution for narrowband deployment and a 1.08MHz solution for higher throughput IoT. All three solutions are fully supported by the core network and can be rolled out as software upgrades on top of current LTE and GSM networks to achieve significantly lower TCO than other LPWA technologies.

Nokia is driving the enhancements in 3GPP and working with ecosystem partners to enable future IoT networks.

7. Reference sources

1 Machina Research, May 2015

8. Glossary of Abbreviations

ARPU:	Average Revenue Per User
BT LE:	Bluetooth Low Energy
CMOS	Complementary Metal–Oxide–Semiconductor
DRX	Discontinuous Reception
EC-GSM-IoT	Extended Coverage GSM for IoT
EGPRS	Enhanced Data rates for GSM Evolution (EDGE)
EPDCCH	Enhanced Physical Downlink Control CHannel
FDD	Frequency Division Duplex
GERAN	GSM EDGE Radio Access Network
IoT	Internet of Things
KPI:	Key Performance Indicator
LPWA	Low Power Wide Area
LTE-M	LTE for M2M
M2M	Machine-to-Machine
MIMO	Multiple Input Multiple Output
MME	Mobility Management Entity
NB-IoT	NarrowBand LTE for IoT
PCFICH	Physical Control Format Indicator CHannel
PDCCH	Physical Downlink Control CHannel
PDSCH	Physical Downlink Shared CHannel
PHICH	Physical channel Hybrid ARQ Indicator CHannel
PRB	Physical Resource Block
PUCCH	Physical Uplink Control CHannel
PUSCH	Physical Uplink Shared CHannel

PSD	Power Spectral Density
PSS/SSS	Primary and Secondary Synchronization Signals
PSM	Power Saving Mode
RAN	Radio Access Network
RAT	Radio Access Technology
RF	Radio Frequency
TAU	Tracking Area Update
TCO	Total Cost of Ownership
TBS	Transport Block Size
TDD	Time Division Duplex
TX	Transmission
UE	User Equipment

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