FutureWorks

LTE-M – Optimizing LTE for the Internet of Things

White Paper

Contents

Executive Summary

The Internet of Things (IoT) is expected to be 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]. Numerous services are envisioned for cellular IoT, 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. In addition, different devices such as e-book readers, GPS navigation aids and digital cameras are already connected to the Internet.

The key requirements for cellular IoT to enable these services and to compete with non-cellular technologies are:

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

This white paper outlines a cellular IoT solution based on LTE that complies with these requirements and enhances the radio and core networks. The radio network needs to be optimized to enable simple, low cost devices. The transmission and higher layer protocols need to be optimized for device power consumption to enable more than ten-year battery life and finally, enhanced coverage is required for deep indoor and rural areas.

Network elements need to handle charging, subscription and massive support for small packages. The development of LTE for IoT will be phased with the initial version in Rel. 12 already available for low cost and low power and the final version in Rel. 13 optimized for coverage and even lower cost. The target for Rel. 13 includes two versions:

- NB LTE-M deployment (200 kHz)
- LTE-M deployment (1.4 MHz)

These two cellular IoT systems will support a scalable solution for data rates. Both solutions are deployable either in shared spectrum together with normal LTE, or as stand-alone, in a refarmed GSM carrier with as narrow a bandwidth as 200 KHz or 1.4 MHz. Nokia believes that LTE-M, NB LTE-M, and EC-GSM are better able to satisfy the connectivity profiles and requirements for IoT since they provide for an easy software upgrade of existing networks while providing optimized device KPIs, battery life, coverage and cost.

IoT Market Landscape

The Internet of Things (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. To support IoT, Machine-to-machine (M2M) communication is needed. 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].

The bulk of connections will be addressed by fixed and short range communication. However, there is also a significant number (around seven billion by 2025) of connections expected via cellular IoT and Low-Power Wide-Area (LPWA) networks (Figure 1)

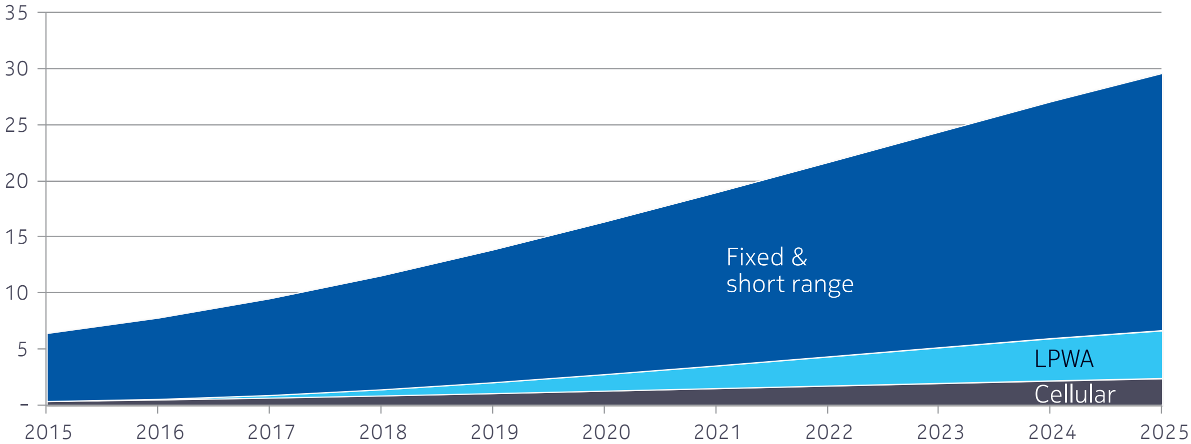

Figure 1. Billion global connections, 2015-2025 (Machina Research, May 2015)

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 will be 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.

LPWA IoT M2M applications and services vary widely in terms of their service requirements, data throughput, latency and connectivity reliability.

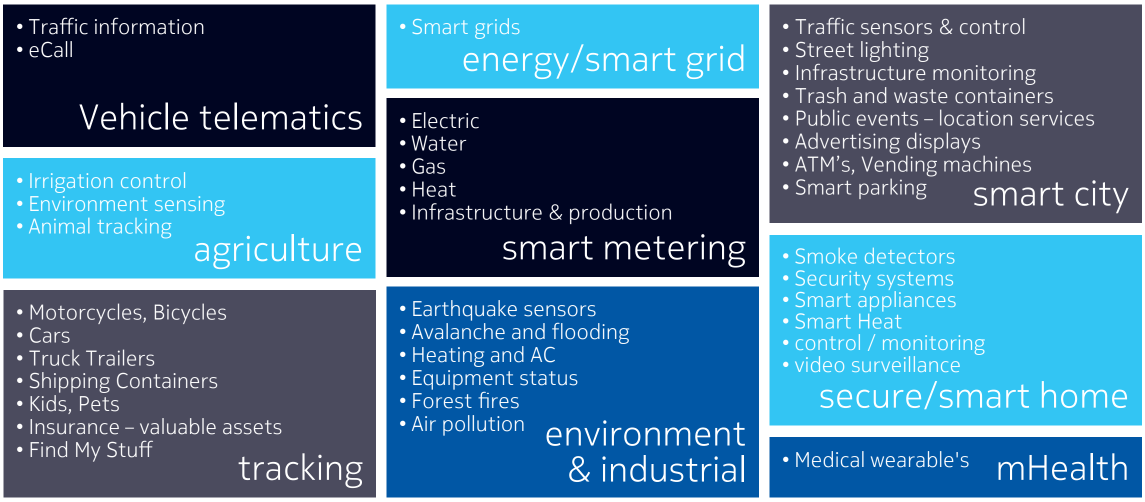

Figure 2. Cellular IoT use cases: low date rate, long battery life, latency tolerant

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

- Home & Consumer (29 percent)
- Connected Car & Fleet (20 percent)
- Industry (20 percent including building automation/security)
- Utilities & Environment (13 percent).

LPWA IoT requirements

The key requirements for LPWA networks to successfully support massive M2M deployment are:

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

Long battery life

Mobile phone and especially smartphone users are used to frequent charging of the device batteries. However, many IoT devices must operate for very long times, often years. A good example is a fire alarm device sending data directly to a fire department. The battery change interval in such a device is a very important cost factor.

Long battery life would also enable completely new connected device applications not yet invented. Many objects around us currently do not have a cord, but are battery operated or even work without a battery. These devices can also be brought into the network.

The industry target is a minimum of 10 years of battery operation for simple daily connectivity of small packages.

Low device cost

IoT connectivity will mostly serve very low ARPU users with a ten-fold reduction 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.

Low deployment cost

The network cost of IoT connectivity, including initial CAPEX and annual OPEX, must also be kept to a minimum. Deploying LPWA IoT connectivity on top of existing cellular networks can be accomplished by a simple, centrally-pushed software upgrade, thus avoiding any new hardware, site visits and keeping CAPEX and OPEX to a minimum.

Full coverage

Enhanced coverage is important in many IoT applications. Simple examples are smart meters, which are often in 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 IoT connectivity link budget is an enhancement of 15-20 dB. The coverage enhancement would typically be equivalent to wall or floor penetration, enabling deeper indoor coverage.

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 have very high numbers of devices connected. Therefore, LPWA IoT connectivity needs to be able to handle many simultaneous connected devices.

LPWA IoT technology landscape

Today, 2G modules are the dominating solution for IoT, but the fastest growth will be LTE modules. Low power, wide area and low cost modules are key enablers for the rapid changes in the forecasts. It is believed that 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 WiFi. The key LPWA IoT solutions are shown in Figure 3.

	SIGFOX	LoRa	clean slate cIoT	NB LTE-M Rel. 13	LTE-M Rel. 12/13	EC-GSM Rel. 13	5G (targets)
Range (outdoor) MCL	<13km 160 dB	<11km 157 dB	<15km 164 dB	<15km 164 dB	<11km 156 dB	<15km 164 dB	<15km 164 dB
Spectrum Bandwidth	Unlicensed 900MHz 100Hz	Unlicensed 900MHz <500kHz	Licensed 7-900MHz 200kHz or dedicated	Licensed 7-900MHz 200kHz or shared	Licensed 7-900MHz 1.4 MHz or shared	Licensed 8-900MHz 2.4 MHz or shared	Licensed 7-900MHz shared
Data rate	<100bps	<10 kbps	<50kbps	<150kbps	<1 Mbps	10kbps	<1 Mbps
Battery life	>10 years	>10 years	>10 years	>10 years	>10 years	>10 years	>10 years
Availability	Today	Today	2016	2016	2016	2016	beyond 2020

Figure 3. LPWA IoT connectivity overview

As mentioned above, LPWA IoT solutions can be divided into proprietary LPWA technologies and Cellular IoT. SigFox and LoRa are both proprietary technologies deployed in the 8-900 MHz license exempt bands. 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 and further optimization will be included in Rel. 13 with specifications complete in Q1 2016.
- EC-GSM (Extended Coverage GSM) is an evolutionary approach being standardized in GERAN Rel. 13 with specifications complete in Q1 2016.
- A new narrowband radio interface (Clean Slate Cellular IoT) is also being discussed as part of RAN Rel. 13 standardization starting in Q4 2015 with specifications to be completed by Q2 2016. Two solutions are being proposed for the narrowband Clean Slate Cellular IoT, a NB Cellular IoT solution based on narrowband FDMA in the uplink and narrowband OFDMA in the downlink; and a 200 kHz narrowband evolution of LTE-M.

Finally, a 5G solution for Cellular IoT is expected to be part of the new 5G framework by 2020. The link budget is similar among all solutions with a slight improvement for the narrow band solutions like NB LTE-M and EC-GSM. LoRa and SigFox are planned to share spectrum with other solutions in the license-exempt bands.

NB Cellular IoT will operate in a dedicated 200 kHz band refarmed from GSM and does not support spectrum sharing with LTE and GSM networks. This is why Nokia supports NB LTE-M, which is also designed to operate in a 200 kHz band 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 and EC-GSM will equally operate in spectrum shared with existing LTE or GSM networks, LTE-M and NB LTE-M would be supplementary solutions addressing different use cases with higher capacity on LTE-M and slightly lower cost and better coverage on NB LTE-M.

The deployment options for the Cellular IoT solutions are different and depend on the mobile operator's installed base. All solutions should ideally be deployed in sub 1 GHz bands to benefit from good propagation and penetration characteristics. Some operators may have GSM deployed in the 900 MHz band without enough spectrum to deploy 1.4 MHz LTE-M in the band. In such cases, EC-GSM could enable sharing of the carrier capacity in the band. Alternatively, a refarmed GSM carrier would enable deployment of NB LTE-M operating in 200 kHz spectrum.

Deploying an unlicensed technology would require a new network deployment potentially reusing existing sites but with new hardware needing to be installed. All the 3GPP-based solutions would be software upgradeable. Finally, the deployment may also be based on use cases where some of the solution like SigFox provides only 100 bps while LTE-M supports up to 1 Mbps.

LTE-M evolution for Cellular IoT

LTE supports both frequency division duplex (FDD) and time division duplex (TDD) modes using a common subframe structure of 1ms. Having such a short subframe length allows for latency to be minimized, thus 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 ongoing to further enhance coverage, battery life, and lower complexity compared to existing LTE devices. 3GPP for LTE-M 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 1.4 MHz in downlink and uplink.
  - Reduced maximum transmit power of 20 dBm.
- Provide an LTE coverage improvement – corresponding to 15 dB 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 LTE-M proposal is set for approval in 3GPP Rel. 13 with the following improvements over LTE-M:

- Reduced device bandwidth of 200 kHz in downlink and uplink.
- Reduced throughput based on single PRB operation.
- Provide LTE coverage improvement corresponding to 20 dB (5 dB better than LTE-M)

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 up to about five weeks standby time. This would require a change of batteries on a monthly basis which would not be feasible.

A device power saving mode (PSM) was introduced in Rel.12 to significantly improve device battery life. 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 is not reachable as it does not check for paging, but it 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 2.56 sec. 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 4 shows the two key features in LTE-M for enhanced battery life.

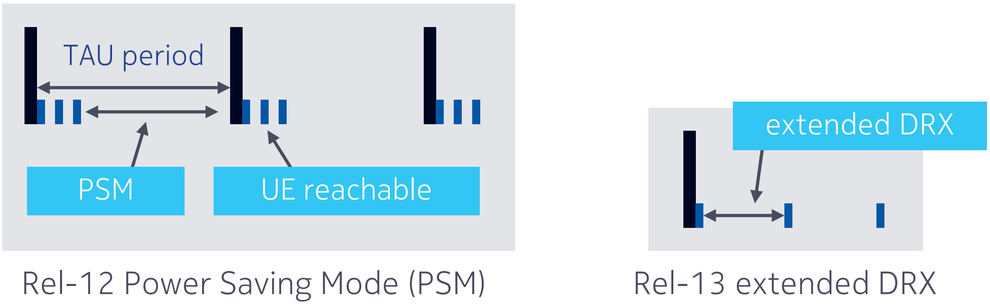

Figure 4. LTE-M enhanced battery options

Depending on the current consumption model, many years of battery operation can be achieved. Using the 3GPP model in 45.820, we can achieve up to 36 years of battery operation for LTE-M and NB LTE-M 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.

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 optimization of performance and has created rising complexity. Rel. 12 looks at how to reduce complexity of LTE with lower performance Key Performance Indicators (KPIs) while still complying with the LTE system. These complexity reductions provide significant cost reductions.

Further cost reductions are needed to make LTE a competitive M2M solution and these are being addressed in Rel. 13 and beyond. Figure 5 summarizes the complexity/cost reductions from Rel. 8 Cat-4 devices towards potential Rel. 13 low cost LTE-M devices.

	Release 8	Release 8	Release 12	Release 13	Release 13
	Cat. 4	Cat. 1	Cat. 0	"Cat. 1.4MHz"	"Cat. 200kHz"
Downlink peak rate	150 Mbps	10 Mbps	1 Mbps	1 Mbps	200 kbps
Uplink peak rate	50 Mbps	5 Mbps	1 Mbps	1 Mbps	144 kbps
Number of antennas	2	2	1	1	1
Duplex mode	Full duplex	Full duplex	Half duplex	Half duplex	Half duplex
UE receive bandwidth	20 MHz	20 MHz	20 MHz	1.4 MHz	200 kHz
UE transmit power	23 dBm	23 dBm	23 dBm	20 dBm	23 dBm
Modem complexity	**100%**	**80%**	**40%**	20%	<15%

Figure 5. Complexity/cost reductions for LTE-M and NB LTE-M evolution

LTE-M Rel. 12 cost optimizations

Rel.12 introduces a new low complexity device category ("Cat-0"). This low cost category defines a set of reduced requirements enabling lower complexity and cost of 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.
- Reducing the device receive bandwidth to 1.4 MHz allows for substantial complexity reduction. The device will still be able to operate in all existing LTE system bandwidths up to 20 MHz.
- Single receive chain. This removes the dual receiver chain for MIMO.
- Lower data rates. Introducing a lower data rate requirement, the complexity and cost for both processing power and memory will be reduced significantly.

LTE-M Rel. 13 cost optimization

Further simplification of devices will be achieved in Rel-13 (ref. TR 36.888).

- Low RF bandwidth support (e.g. 1.4 MHz). This would further reduce complexity as a narrowband RF design would be sufficient
- A lower device power class of 20 dBm will allow integration of the power amplifier in a single chip solution.

NB LTE-M Rel. 13 cost optimization

The narrow band NB LTE-M proposal is an evolution of the LTE-M cost optimizations with the following improvements compared with LTE-M:

- Reduced device bandwidth of 200 kHz 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 further reduce cost beyond what is being standardized in 3GPP. Many ways to optimize implementation costs follow the lowest cost technology that 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

Low deployment cost

A key challenge for mobile operators providing IoT connectivity is how to enable low cost deployment of IoT networks. Figure 6 shows how LTE-M shares capacity with legacy LTE networks.

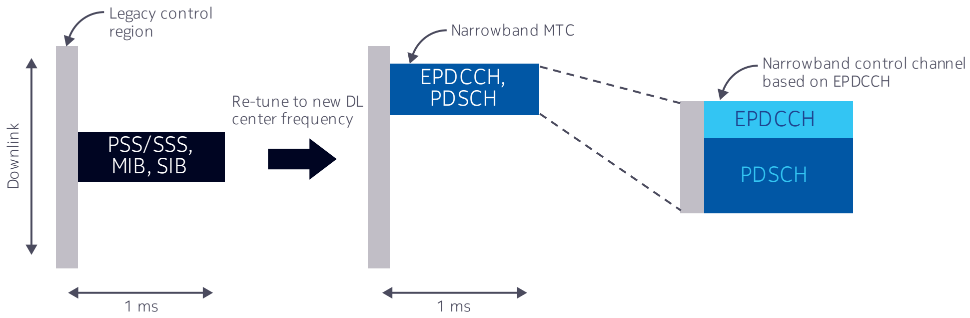

Figure 6. LTE-M sharing carrier capacity in legacy LTE configuration

LTE-M operates on a 1.4 MHz carrier or 6 PRB. The IoT device will always listen to the center 6 PRB for control information 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 1.4 MHz carrier within a, for example, 20 MHz 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.

The NB LTE-M proposal operates on a single PRB allowing either stand alone deployment in a 200 kHz refarmed GSM carrier or integrated within a normal LTE deployment. To enable both of these narrowband deployments, the data/control channels need to be time multiplexed from 6 PRBs to a single PRB as shown in Figure 7.

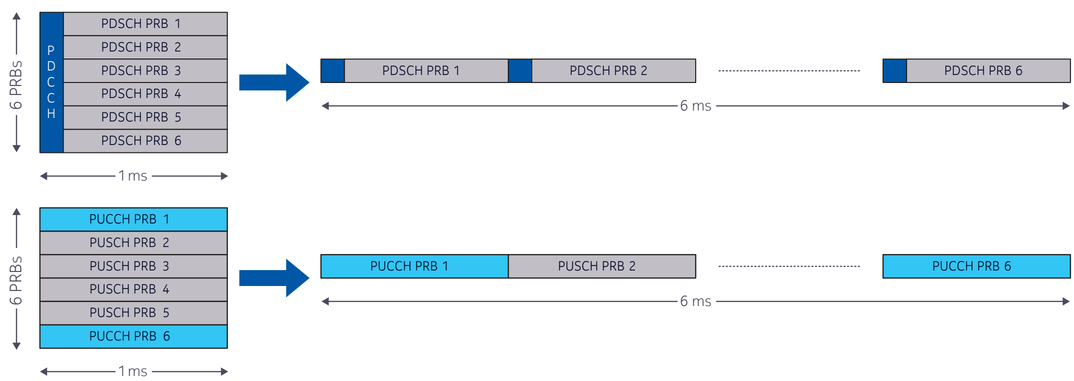

Figure 7. NB LTE-M channel mapping for 1 PRB deployment

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

In 2020, the average mobile subscriber will use several Gbytes of mobile broadband data per day. A connected thing may use 100s 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 is as simple as a software upgrade to the radio interface to enable a full IoT network with significantly better coverage than the legacy LTE network.

Full coverage

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

- LTE-M provides 15dB additional link budget enabling about seven times better area coverage
- NB LTE-M provides 20dB additional link budget enabling about ten times better area coverage

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

In LTE-M 1.4 MHz and NB LTE-M 200 kHz, 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 PDCCH, PCFICH and PHICH. Only the EPDCCH is supported. An illustration of the downlink is shown in Figure 8. In normal coverage, the entire bandwidth can be utilized. In enhanced coverage mode, PSD boosting and repetition are used to reach devices in poor coverage.

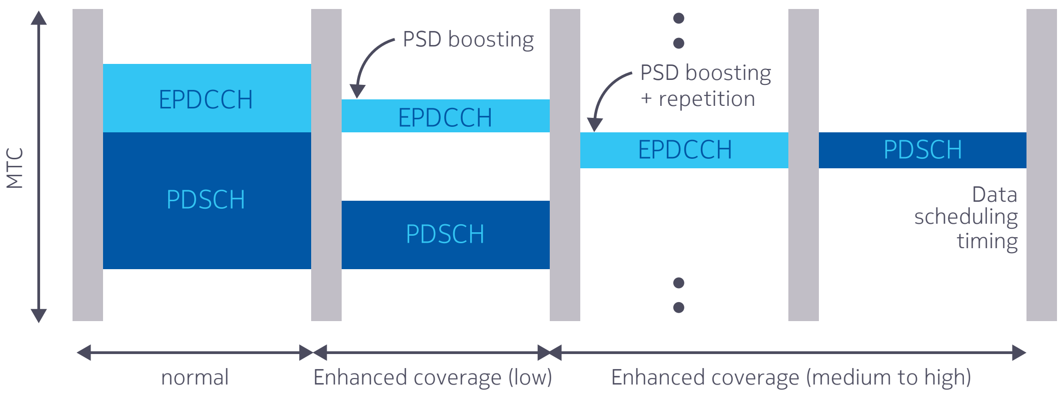

Figure 8. LTE-M design with 1.4 MHz bandwidth - downlink

Figure 8 shows how control and data are multiplexed beyond the legacy control information. Coverage is increased by simply operating in 200 kHz or 1.4 MHz compared to 20 MHz; yielding 20 dB and 11.5 dB improvement respectively. LTE-M further allows output power to be reduced by 3 dB for lower implementation cost. Furthermore, control and data signals can be repeated to reach the required coverage enhancements.

An important feature of NB LTE-M 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.

Massive number of devices

LTE was designed for few simultaneous users with high data rates. IoT traffic requires support for many users each having a very low data rate. Therefore, the core network can support IoT but optimizations would be highly beneficial, especially once the number of connected devices increases. Figure 9 shows some areas in the core network that can be further optimized for LTE-M.

Optimize the 3GPP system to allow use of so-called constrained devices in PSM. **High Latency Communications**	Activating monitoring of specific events, event detection and reporting **Monitoring Enhancements**	Defines architecture to expose 3GPP service capabilities to 3rd party providers via API. Service Exposure Framework for all M2M features. **AESE**
Select core network nodes based on subscription information (e.g. special MME for M2M users) **Dedicated Core Networks**	Optimization of user profile and its signalling when large set of UEs share the same subcription data. **Subscription and signalling optimization**	Optimized handling of similar class of M2M devices: group based messaging, congestion control **Group based Enhancements**

AESE = Architecture Enhancements for Service Capability Exposure

Figure 9. LTE-M – High Capacity Core Network

Some of the optimizations for the core network include:

- Normal mobile broadband traffic is latency critical and needs to be scheduled immediately. IoT traffic may be very latency tolerant, such as utility reading where a daily reading may be sufficient. This is handled with PSM and other protocols to optimize for high latency communications.
- Monitoring of certain events or sensors may be correlated and could be detected in the network, e.g. water leakage based on multiple water utility readings.
- An interface exposing the IoT data to an application platform needs to be provided.
- A dedicated MME may be required for subscription management as the pricing and changing models for IoT may be very different compared to voice and data.
- Subscription and signaling optimization may be required for a large set of devices haring the same subscription data such as water meters within a city.
- Finally, group-based paging may be needed to optimize signaling in the network.

Conclusion

IoT changes the requirements for connectivity significantly, mainly with regards to long battery life, low device costs, low deployment costs, full 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 LTE-M, and EC-GSM are the superior solutions to satisfy the connectivity profiles and requirements for IoT since cellular IoT provides an easy software upgrade of existing networks while providing optimized device KPIs, battery life, coverage and cost.

The LTE evolution for NB LTE-M and LTE-M 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 via low complexity devices category
- Low network deployment cost by enabling shared carrier capacity
- Full coverage via new coding, repetition and power spectral density boosting
- 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 will further reduce the cost of devices and provide 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 will comprise a 200 kHz solution for narrowband deployment and a 1.4 MHz solution for higher capacity IoT. All three solutions are fully supported by the core network and can be rolled out as software upgrades on top of current LTE networks to achieve significantly lower TCO than other LPWA technologies.

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

Reference sources

1 Machina Research, May 2015

Glossary of Abbreviations

3GPP Third Generation Partnership Project

AESE Service Capability Exposure

CAGR Compound Annual Growth Rate

CAPEX Capital expenditures

CMOS Complementary metal–oxide–semiconductor

DRX Discontinuous Reception

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

LPWA Low power wide area

LTE Long Term Evolution

LTE-M LTE for M2M

M2M Machine-to-Machine

MIMO Multiple Input Multiple Output

MME Mobility Management entity

NB LTE-M narrowband LTE-M for M2M

OPEX Operating expenditure

PCFICH Physical Control Format Indicator Channel

PDCCH Physical Downlink Control Channel

PDSCH Physical Downlink Shared Channel

PHICH Physical channel HybridARQ 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

TBS Transport Block Size

TDD Time Division Duplex

TX Transmission

UE User Equipment

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