



FutureWorks

# Nokia LTE M2M

Optimizing LTE for the Internet of Things

White Paper

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## Executive summary

The Internet of Things (IoT) is expected to be the next big thing in the mobile ecosystem, with IoT services being a key driver for further growth in cellular. Numerous services are envisioned for IoT over cellular networks, including utility meters, vending machines and automotive applications. The latter has many categories such as fleet management, smart traffic, real time traffic information to the vehicle, security alerts and reporting, medical metering and alerts. Different connected devices such as E-book readers, GPS navigation devices and digital cameras are already connected to the Internet.

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

- Support of device volumes
- Low cost connected devices
- Long battery life
- Enhanced coverage

This white paper outlines LTE-based solutions to comply with these requirements through enhancements to the radio network, the core network and the subscription database. The radio network needs to be optimized to enable simple, low cost devices. The transmission and higher layer protocols need to be designed to draw minimum power to enable a more than 10-year battery life and enhanced coverage is required to reach deep indoors and into rural areas. The network elements need to handle charging and subscription without physical Universal Integrated Circuit Card (UICC) cards, as well as admission control and overload in the network, including massive support for small packages.

## M2M technology and market landscape

The IoT refers to interconnection and autonomous exchange of data among devices which are machines or parts of machines. This capability will bring about tremendous improvements in user experience and system efficiency. M2M communication is needed to support IoT. 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.

M2M services are expected to be a key driver for growth in cellular.

## Volume growth

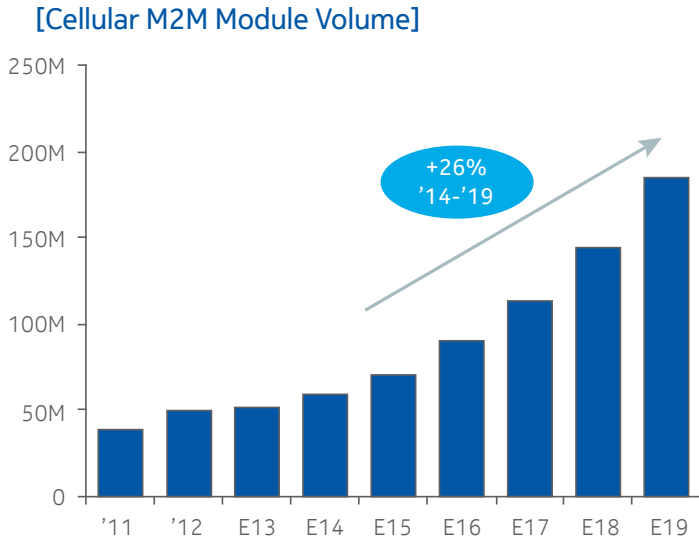


Figure 1 ABI Research volume forecast for M2M Embedded Modules, Jan2014,<sup>1</sup>

ABI Research estimates that total Cellular M2M module volumes will be around 200 million units by 2020 with a Compound Annual Growth Rate (CAGR) of 26%. Machina Research also has module volume forecasts, but with more aggressive estimates<sup>2</sup>.

Independently of these figures, M2M applications and services have widely differing requirements, connectivity data throughput and latency and connection reliability. Most of the module volumes are expected to come from the automotive sector, including factory or aftermarket installed base, safety, security, infotainment, mobile broadband to car, and fleet management.

Another large application area is expected to be stationary and lower cost modules for Utility Meters, representing roughly one fifth of the market. After these, there are several applications and services with smaller volumes, in areas such as security, telehealth and vending machines.

In summary, Cellular M2M modules will be dominated by 2G/3G units, but the fastest growth will be seen in LTE modules. The availability of low power, low cost LTE-based M2M modules could change these forecasts radically. Nokia believes that with a retail cost below 10 USD, LTE modules could grab market share from other cellular standards and wireless sensor networks, like Zigbee, Bluetooth and Wi-Fi, and thus increase these volume forecasts by a factor of two to ten or even more. However, low cost and low power LTE modules would be primarily targeted at Utility Meters, while other cellular M2M applications might also be affected by other factors.

For wide area M2M connectivity, there are several different technologies. Starting from standardized solutions like 2G, 3G and LTE i.e. cellular and in some cases Wi-Fi, these will be followed by semi-standardized technologies like Weightless on TV White Spaces and Wave2M.org, in addition to proprietary solutions such as SIGFOX, OnRamp Wireless and Nwave. Big differences exist in the business models, services and technical characteristics of wide area M2M networks. Proprietary networks typically offer end-to-end solutions, from modules to base stations, as well as operated and maintained networks and services and data modeling.

While these technologies will coexist with LTE, it is also possible that LTE enhancements will eventually enable parts of these technologies to migrate to LTE networks. In LTE Rel-12, low cost M2M devices with material costs comparable to EGPRS devices have been introduced. In addition, coverage enhancement techniques, which would be required to support M2M, are being standardized. However, LTE was designed for high data-rate broadband services. Even with M2M features being added in Rel-12, LTE is not yet optimized for low data-rates and wide area M2M services such as smart meters, remote sensors and consumer devices. Additionally, the cellular network architecture and core network elements are not suited to the growth of M2M devices.

## M2M requirements for LTE

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

- Wide service spectrum
- Support of device volumes
- Low cost connected devices
- Long battery life
- Enhanced coverage

## Wide spectrum of services

M2M communication shows a huge diversity in the type of services, traffic characteristics and requirements for availability, reliability or bandwidth. A growing number of smartphone Apps can be also be regarded as M2M applications, for example apps to remotely control devices at home like the refrigerator, security system and thermostat. The following list of some M2M applications gives a first impression of the wide applicability of these Apps:

- Utility meters: electricity, water and gas
- Vending machines: monitoring potential faults, cashless payment, applying smart tariffs

- Automotive: fleet management, smart traffic, real time traffic information to the vehicle, in-car entertainment
- Security alerting and reporting: intelligent monitoring and control of buildings, item tracking
- Medical metering and alerting: vital body functions that are supervised remotely
- Connected devices: E-book reader, GPS navigation, digital cameras

## Number of devices

With the Electricity Directive (Ref: C13-RMF-54-05), the European Union (EU) has regulated that 80% of consumers shall be equipped with intelligent metering systems by 2020, meaning that around 180 million electricity meters will be connected within EU countries. The average number of cars is about 0.5 per capita, thus car connections could surpass the number of electricity meters. The total number of M2M devices could be orders of magnitude greater than the number of “traditional” devices.

The number of smart meters, household automation and vehicular applications are proportional to the number of inhabitants in the country. Additionally, industrial applications will arise from the need to automate objects in various transport industries, factories, public service machines like vending machines and elevators.

## Cost of device

Even if the connectivity of objects brings value to many applications, the cost of connecting the device can be a major hurdle. Connecting to a cellular network requires a cellular modem in the device. Current modems in LTE networks target high performance, with speed in the order of tens of megabits to enable high resolution imaging and video content, games and other entertainment. While the modem chips have been built to support these extreme speeds they have become complex and expensive pieces of hardware - many M2M applications produce perhaps hundreds of bits of measurement data. Therefore, one specific requirement is to reduce the M2M system cost by simplifying the chipset.

## Long battery life

Mobile phone and especially smartphone users are used to frequent charging of the device batteries. It is important to extend battery use time in these devices for the convenience of the end user. However, in several machine types, it is crucial that the device can remain in operation for very long periods of time, even years. A depleted battery would stop the machine communicating, a major problem if the device happens to be a fire alarm sending a signal directly to the fire

department. The battery change interval in such a device is therefore a very important cost factor.

A long battery life time would also enable the development of completely new connected device applications. There are numerous objects which are not mains powered, but which are battery operated or even work without a battery, which could also be brought onto the network.

## Enhanced coverage

Coverage is important in many M2M applications. A simple example is smart meters, which are often in basements of buildings behind concrete walls. Industrial applications such as elevators or conveyor belts can also be located inside challenging constructions. This has driven the M2M community to look for methods that increase coverage by tolerating lower signal strength than that employed by devices used by people.

## Other specific characteristics of M2M devices

Although the M2M requirements described above are the most important, there are many other lesser requirements.

Following a power outage, all the connected machines in the affected area will most probably start to send their statuses immediately to the cloud application. Millions of smart meters can be ordered to send their messages, all at around 07:00 in the morning. This mass behavior creates signaling storms which can temporarily cause trouble for the network. Tolerating overload situations should be handled, for example by built-in delays.

In the connectivity domain, machines seldom make a voice call, although this can be the case in security applications, to listen to the site. Most simply send or receive data and so data only subscriptions are expected to be standard.

Addressing of M2M devices has specific requirements. There is a need to save or pool MSISDN numbers, which are not essential in many M2M applications. In some countries like the United States, shortage of E.164 numbers is an additional driver for optimization in mobile networks. Such improvements may be provided by the home and visited mobile network operator.

Some M2M devices have soldered UICCs, so called embedded UICCs (eUICCs) to make logistical handling of the machines easier. An eUICC enables the subscription of the device to be changed remotely without the need to manually change the UICC card in the device. This means that a machine imported from abroad can be packaged with no need for it to be opened at the place of purchase to insert a local UICC. However, it would still need to be configured to choose the local operator - the machine is shipped with a provisional subscription, which is then used to choose the desired operator.

Millions of mostly dormant yet connected devices enable network resources to be used in the best way. Programming M2M devices while allowing them to be disconnected to save power can be achieved through SMS, not only for messaging but also as a tool for paging and waking up the device. Following SMS activation, the device can take a connection to the network, obtain an IP address, send data to the M2M application, release the connection and sleep again.

Roaming of M2M devices is somewhat different than for human users and typically requires special roaming agreements for M2M UICCs to keep costs in control when machines cross borders.

## Architectural evolution

From the architecture perspective, some common service requirements include:

- Congestion and overload control for M2M devices: methods to identify and control M2M traffic in the event of congestion and overload
- M2M device triggering: the network shall be able to trigger devices to initiate communication with the server
- Addressing and Identifiers: IPv4/IPv6 addresses and identifiers not based on MSISDN must be supported
- Charging requirements: best methods for charging for data collection from groups of M2M devices
- Security requirements: no degradation of security for M2M devices when compared to non-M2M devices
- Remote M2M device management: management of M2M devices should use existing mechanisms such as Mobile Alliance (OMA) Device Management (DM) or over-the-air (OTA)

## Congestion control

Considering that existing networks experience congestion and overload caused by high signaling load from M2M applications, overload and congestion control was considered as a high priority in 3GPP during Rel-10.

Terminals considered as M2M devices can be configured in Rel-10 with a so-called “low access priority indicator” (LAPI) during manufacturing or via OMA DM and OTA. This indicator is sent by the device to the network so that the Radio Access Network (RAN) and core network can take it into account in the event of congestion or overload situations – for example, reject a higher percentage of connection requests coming from low access priority devices.

The full range of M2M congestion and overload control methods become available when terminals are configured to make use of “low priority access”. If the priority of a device is changed, new Packet Data Network



(PDN) connections that are established will take the new value of the priority indicator into account. Devices accessing the network with access classes 11 – 15 and accessing the network for emergency services are in general exempted from congestion and overload control procedures. Extended Access Barring (EAB) allows barring of certain types of device (configured for EAB) and devices roaming-in from foreign networks (not the Home Public Land Mobile Network (HPLMN) or Equivalent Home Public Land Mobile Network (EHPLMN)). Some of these functionalities are also available for terminals that are not specifically considered as low priority access terminals, for example smartphones. Furthermore, some M2M devices already deployed generally use “normal” access, that is, they do not provide the low priority access indicator.

## M2M features

An improvement was developed for M2M devices in Rel-11. Because of the huge number of M2M features in the set of service requirements, each feature was given a priority level. The following are the main features introduced as part of this work and documented in TS 23.682 [63]:

- Enhanced architecture including new functional entities called M2M Interworking Function (M2M-IWF) and M2M-AAA
- Identifiers (MSISDN-less) – Use of Internet-like identifiers, external interface between PLMN and service provider domain to replace MSISDN
- Addressing – IPv6 was recommended for use with M2M devices
- Device Triggering – MT-SMS with a standardized interface to the Short Message Service Center (SMSC)
- Optimizations for devices with packet-switched only subscription
- Dual-priority devices – certain applications can override low access priority configuration
- Extended Access Barring (EAB): ability to bar certain devices from accessing the network due to RAN or core network overload.
- SMS in MME configuration (architecture option for networks with no UTRAN or GERAN CS domain where a direct interface from SMSC to MME for SMS delivery is deployed).

## LTE evolution for low cost and low power M2M

LTE supports both frequency division duplex (FDD) and time division duplex (TDD) modes using a common sub frame structure of size 1ms. Having such a short sub frame length allows latency to be minimized, 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, a new work item will be proposed by Nokia and Ericsson to specify a new device for M2M operation in LTE that also allows for enhanced coverage compared to existing LTE networks, with the following detailed objectives:

- Specify a new group of device category/type for M2M operation in all LTE duplex modes based on the Rel-12 low complexity device category/type and supporting the following capabilities:
  - Reduced device bandwidth of 1.4 MHz in downlink and uplink. The use of 200 kHz bandwidth will be the subject of further study.
  - Reduced maximum transmit power of [20 dBm].
  - Reduced support for downlink transmission modes.
  - Further device processing relaxations can also be considered within this work item:
    - Restricted downlink modulation scheme
    - Reduced number of blind decoding attempts
    - Relaxed downlink Hybrid Automatic Repeat Request (HARQ) time line
    - Reduced support for Channel quality indicator / Channel state information (CQI/CSI) reporting modes
- Provide a relative LTE coverage improvement – corresponding to [20 dB] for FDD – for the device category/type defined above and other devices operating delay tolerant M2M applications according to their nominal coverage.

## Rel. 12 optimizations for low-cost M2M devices

In Rel-12, low-cost M2M devices with reduced capability are being introduced. The bill-of-material cost of the modem for this device is approximately 40-50% of regular LTE devices and is comparable to that of an EGPRS modem. These low-cost devices will be restricted to M2M services and will have the following reduced capabilities:

- 1 Rx antenna compared to a minimum of 2 Rx antennas for other device categories.
- Transport Block Size (TBS) restriction. Low-cost device can receive or send at most 1000 bits of unicast traffic per sub frame. This reduces the peak data rates to 1 Mbps in downlink/uplink (DL/UL) compared to peak data rates of 10 Mbps/5 Mbps in DL/UL for the lowest category of non-M2M LTE device.

In addition, half-duplex FDD devices will be supported as an optional feature. Half-duplex FDD devices can provide additional cost saving due to the removal of duplexer and switches. Furthermore, they are assumed to have only one Phase-Locked Loop (PLL), further reducing cost at the expense of longer switching time.

## LTE-M current consumption optimization

Providing M2M support for locations with no direct power source, such as water meters, and sensors, requires battery operated devices. Today's mobile handset offers up to about five weeks standby time. Using this type of battery for remote M2M devices would require the batteries to be changed every month, which would not be feasible. Therefore, we believe that battery operated devices should allow operation for more than 10 years on two long life AA batteries. This section describes what is needed to reach this 10+ year battery life.

In Rel.12, a device power saving mode (PSM) was introduced, enabling a significant improvement in device battery life. If the device supports PSM, it asks the network for a certain active timer value during an attach or Tracking Area Update (TAU) procedure. The active timer determines the duration for which the device remains reachable (checks for paging based on regular discontinuous reception (DRX) cycle) for a mobile terminated transaction moving from connected to idle mode. The device starts the active timer when it transitions from connected to idle mode. When the active timer expires, the device moves to power saving mode. While the device remains in power saving mode, it 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, UL data transmission) requires the device to initiate any procedure towards the network.

In Rel. 13, further improvements to battery lifetime can be envisioned. One example is 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). This is a trade-off between reachability and lifetime using extended sleep cycles. Further, the reduction of signaling overhead using optimized Radio Resource Control (RRC) procedures may be addressed in Rel. 13. Figure 2 shows an example of extended battery life when increasing the DRX cycle from 2.56 sec to 2 min for two AA-size batteries. The battery life time increases from 13 months to 111 months with this simple change.

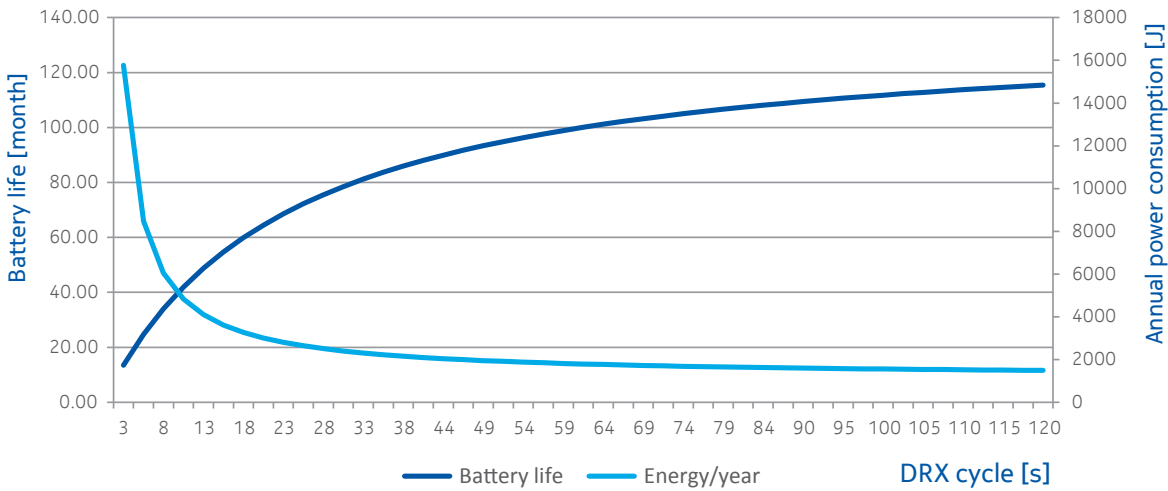


Figure 2 Extended battery life for one 100 byte daily transmission with extended DRX cycle.

Depending on the use case, the current consumption can be further increased. The method to conserve battery life is to limit the idle mode activity beyond the required transmission of data from the device. Thus, for sensors and metering devices, the device should only be active when there is data to transmit and should not have a regular paging cycle. Table 1 shows the tradeoff between paging cycle and transaction cycle for LTE-M operating with two AA long life batteries.

Table 1 Device battery life [month] with different paging and transaction cycles.

Paging cycle / Transaction cycle	2.56s Rel. 8	10.24s	1 min	10 min Rel. 12	1 h	2 h	1 day
15 min	3,7	4,5	4,9	4,9	4,9	4,9	4,9
1 hour	8,1	13,8	17,0	17,8	17,9	17,9	17,9
1 day	13,2	39,1	84,9	108,0	110,8	111,1	111,3
1 week	13,5	42,0	99,4	132,1	136,2	136,6	137,0
1 month	13,6	42,3	101,6	135,9	140,2	140,7	141,1
1 year	13,6	42,5	102,3	137,1	141,4	141,9	142,3

Using the Rel. 12 power savings mode with 10 min DRX cycle and weekly transaction cycle, we can provide a 132 month (11 years) battery life.

## LTE-M cost optimization

LTE was designed to provide reliable mobile broadband in 3GPP Rel. 8. LTE has been further optimized through the subsequent releases of 3GPP. The focus has always been optimization of performance with the

associated complexity. Rel. 12 assessed how to reduce the complexity of LTE with lower performance Key Performance Indicators (KPIs) while still complying with the LTE system. These reductions in complexity provide significant cost reductions. To enable LTE to be a competitive solution for low cost M2M, further cost reductions are required and can be addressed in Rel. 13 and beyond. Table 2 summarizes the complexity/cost reductions from Rel. 8 Cat-4 devices towards potential Rel. 13 low cost LTE-M devices.

Table 2 Complexity/cost reduction for LTE-M evolution

	Rel-8 Cat-4	Rel- 8 Cat-1	Rel-12 Cat-0	Rel-13
Downlink peak rate	150 Mbps	10 Mbps	1 Mbps	~200 kbps
Uplink peak rate	50 Mbps	5 Mbps	1 Mbps	~200 kbps
Max number of downlink spatial layers	2	1	1	1
Number of UE RF receiver chains	2	2	1	1
Duplex mode	Full duplex	Full duplex	Half duplex (opt)	Half duplex (opt)
UE receive bandwidth	20 MHz	20 MHz	20 MHz	1.4 MHz
Maximum UE transmit power	23 dBm	23 dBm	23 dBm	~~20 dBm
<b>Modem complexity relative to Cat-1</b>	<b>125%</b>	<b>100%</b>	<b>50%</b>	<b>25%</b>

## LTE-M Rel. 12 cost optimizations

Rel-12 introduces a new low complexity device category (“Cat-0”). This defines a set of reduced requirements enabling these devices to achieve lower complexity and cost. 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.
- Reduced device receive bandwidth to 1.4 MHz allows them to be much simpler. 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 received chain for RX diversity.
- Lower data rates. By introducing a lower data rate requirement, the complexity and cost for both processing power and memory will be reduced significantly.

## LTE-M cost optimizations beyond Rel. 12

Further reduction in device complexity can be achieved in Rel-13 (ref. TR 36.888).

- Removal of Tx diversity. A new device category “sub Cat-0” would be required with a reduced transmission mode not supporting Multiple Input Multiple Output (MIMO).
- Low RF bandwidth support (e.g. 1.4 MHz). This would further reduce complexity as narrowband RF design would be sufficient.
- Even lower data rates. For low cost metering and sensor only, very low data rates would be required. Support for data rates beyond ~200 kb/s would not be required, thus lowering complexity still further.
- A lower device power class of 20 dBm will allow integration of a power amplifier in a single chip solution.

## Standardization independent cost optimizations

There are many options to further reduce cost beyond what is being standardized in 3GPP. Many of the implementation-specific cost optimizations follow the lowest cost technology that evolves over time. Some of the key drivers to further reduce implementation cost are:

- Optimized technology for RF and mixed signal processing. With higher integration, some of the technology components can be integrated in CMOS technology and follow the trend of lower cost
- With higher volume, the integration of single chip solutions becomes feasible
- Support for only single radio access technology (RAT) and single band RF
- Cost erosion for CMOS transistors

## LTE-M link budget optimizations

To provide ubiquitous network coverage for M2M services, 3GPP will introduce a coverage enhancement feature in Rel-13. From 36.388, up to 20 dB coverage enhancement 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 longer acquisition time or higher error rate. Table 3 summarizes potential coverage enhancement techniques for each LTE channel.

Table 3 Potential coverage enhancement techniques

Technique	PUCCH	PRACH	PUSCH	PDCCH	PBCH	PDSCH	PSS/SSS
PSD Boosting				x	x	x	x
Repetition	x	x	x	x	x	x	x
Retransmission			x			x	
Relaxed Requirement		x					x

In addition to the techniques listed in Table 3, receiver-based techniques such as multi-sub frame channel estimation and multiple decoding attempts can also be considered. Table 4 illustrates the link budget for LTE-M with 1.4 MHz system bandwidth and 20dB coverage enhancement. From the link budget, it is seen that the uplink channels will require a large coverage gain while the downlink channels require only a moderate gain.

Table 4 Link budget for LTE-M (1.4 MHz).

Physical channel name	PUCCH	PRACH	PUSCH	PDSCH	SCH	PBCH	EPDCCH
<b>Transmitter</b>							
Max Tx power (dBm)	23	23	23	46	46	46	46
(1) Actual Tx power (dBm)	23.0	23.0	23.0	46.0	46.0	46.0	46.0
<b>Receiver</b>							
(2) Thermal noise density (dBm/Hz)	-174	-174	-174	-174	-174	-174	-174
(3) Receiver noise figure (dB)	5	5	5	9	9	9	9
(4) Interference margin (dB)	0	0	0	0	0	0	0
(5) Occupied channel bandwidth (Hz)	180000	1080000	360000	180000	1080000	1080000	180000
(6) Effective noise power = (2) + (3) + (4) + 10 log((5)) (dBm)	-116.4	-108.7	-113.4	-112.4	-104.7	-104.7	-112.4
(7) Required SINR (dB)	-7.8	-10	-4.3	0	-3.8	-3.5	-0.7
(8) Coverage enhancement technique	13.8	19.3	20.3	2.6	6.5	6.8	1.9
Repetition and/or PSD boosting	13.8	14.7	15.0	2.6		4.8	1.9
Relaxed requirement		4.6			6.5	2.0	
HARQ retransmission			3.0				
(9) Receiver sensitivity = (6) + (7) - (8) (dBm)	-138.0	-138.0	-138.0	-115.0	-115.0	-115.0	-115.0
(10) MCL = (1) - (9) (dB)	161.0	161.0	161.0	161.0	161.0	161.0	161.0

## LTE-M radio solution

A LTE-M system bandwidth of 1.4 MHz is being considered for Rel. 13 for both RF and baseband. For M2M communication, a narrowband system is attractive for a number of reasons:

- Low cost, particularly on the device side. Narrow bandwidth requires less expensive RF components. In addition, there is also a cost reduction on the baseband side due to the corresponding lower data rates to be supported.
- Coverage improvement due to the ability to concentrate transmission (Tx) power in a narrow bandwidth.

- Efficient use of spectrum as a smaller bandwidth is needed. For example, LTE-M can be deployed by re-farming only one GSM channel, or it can be deployed on a guard band of an existing LTE system.

The motivation for reusing LTE design for a narrowband M2M system is to take advantage of existing technology as well as the installed system base. By making LTE-M compatible with LTE, it is possible to reuse the same hardware and also to share spectrum without coexistence issues. In addition, LTE-M can simply plug into the LTE core network. This allows all network services such as authentication, security, policy, tracking, and charging to be fully supported.

In LTE-M 1.4MHz, the basic LTE design is kept except for some modifications to allow efficient support of coverage enhancement up to 20dB. This includes the elimination of some LTE downlink control channels including Physical Downlink Control Channel (PDCCH), Physical Control Format Indicator Channel (PCFICH) and Physical channel HybridARQ Indicator Channel (PHICH). Only the Enhanced Physical Downlink Control Channel (EPDCCH) is supported. An illustration of the downlink is shown in Figure 3. In normal coverage, the entire bandwidth can be used. In enhanced coverage mode, Power Spectral Density (PSD) boosting and repetition are used to reach devices in poor coverage areas.

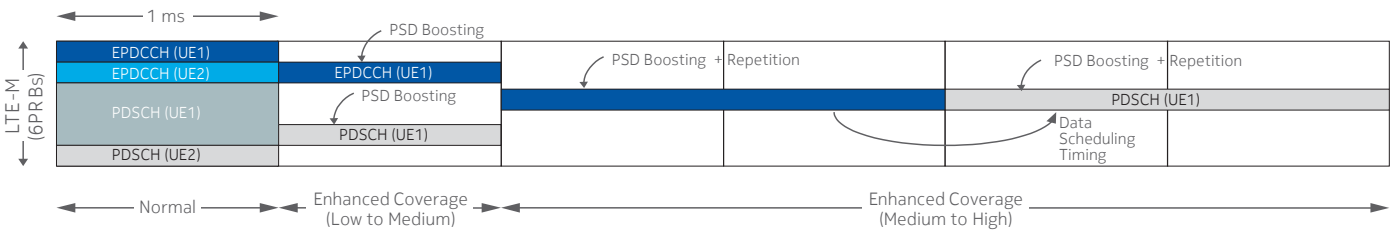


Figure 3. LTE-M design with 1.4 MHz bandwidth - downlink.

The uplink of LTE-M 1.4 MHz is illustrated in Figure 4. Similar to the downlink, the basic LTE design is kept except for some modifications to allow efficient support of coverage enhancement. For devices in poor coverage, PSD boosting and repetition can be used. In this case, PSD boosting may be extended to allow for RE-level transmission (using less than 1 Physical Resource Block (PRB) per Transmission Time Interval (TTI)) for additional PSD boosting.

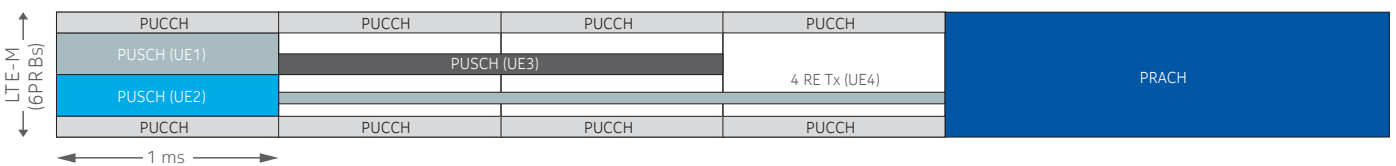


Figure 4. LTE-M design with 1.4 MHz bandwidth - uplink.



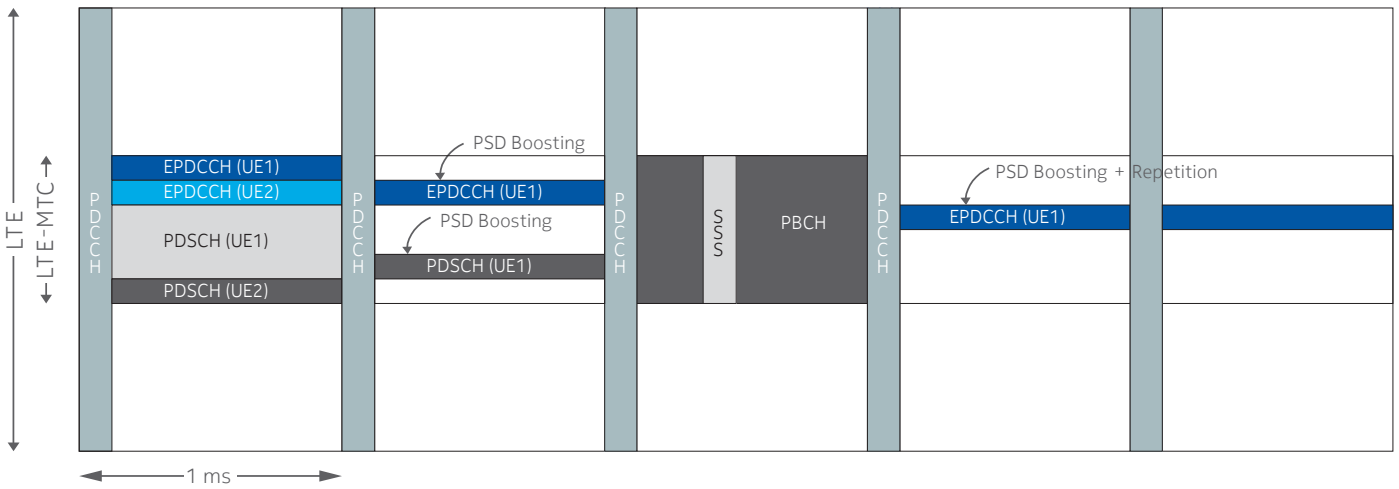


Figure 5. LTE-M 1.4 MHz multiplexed into wideband LTE system.

An important feature of LTE-M is that it shares the same numerology as LTE. This allows for sharing spectrum between the two systems without causing mutual interference. In the uplink, the two systems can be frequency multiplexed together. In the downlink, however, LTE contains a TDM control portion. In this case, the LTE-M downlink channels will need to be shortened to accommodate the LTE control channels. This is illustrated in Figure 5. In addition, LTE-M requires a null Direct Current (DC) subcarrier, which creates a slight shift in the PRBs of LTE and LTE-M.

## Further enhancements beyond Rel. 13

Further enhancements beyond Rel. 13 are being considered to reduce cost and complexity. One of the main areas where we can drive down costs is to further reduce the system bandwidth from 1.4 MHz to 200 kHz. Figure 6 illustrates the design for a LTE-M 200 kHz system using either existing or modified LTE channels. Some of the channels, such as data channels, already fit into 200 kHz (equivalent to using 1 PRB in LTE). Other channels will need some modifications to fit into 200 kHz. However, the same design principle will be kept, allowing as much reuse from LTE as possible.

The details of 200 kHz LTE-M are being assessed for further standardization.

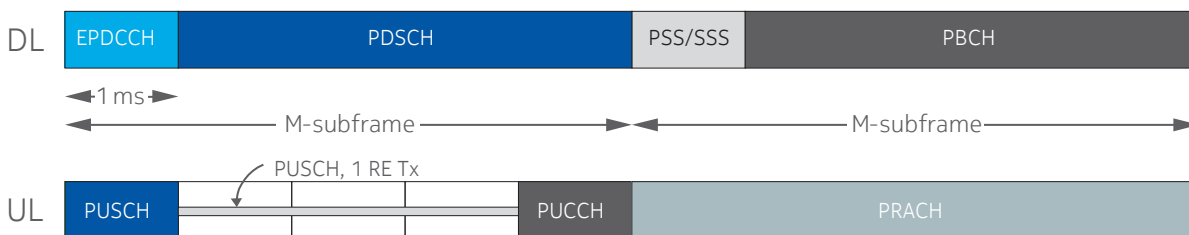


Figure 6. LTE-M design with 180 kHz bandwidth.

## Other cellular radio networks

Currently, existing 2G networks form the majority of cellular M2M connectivity numbers today. In GSM network markets, this is because of the ubiquitous coverage and the relatively low price of GSM modem modules. This situation is anticipated to continue, assisted, by for example, multiradio solutions where 2G, 3G and 4G technologies can coexist on base stations. The reasons for changing this might come from the need to refarm frequencies to higher productivity services if and when operators have to renew their frequency licenses at a higher cost.

It is also possible to further develop GSM/2G radio capabilities, principally in the same manner as the LTE evolution proposed below.

- 3GPP Rel. 12 power savings mode is applied to GSM in a similar manner as for LTE and thus we can address the low current consumption with similar numbers as those for LTE-M.
- The additional coverage is being addressed in GERAN Rel. 13 with repetition of GSM burst in which the same burst of information is transmitted multiple times to achieve coverage gain at the receiver. An additional 20 dB can be achieved on top of Rel. 99 specifications with little or no hardware modification in the device
- The lower cost can be addressed through relaxation in the US specifications and potential US categories. This is also being addressed currently in GERAN Rel. 13.

3G WCDMA networks started with implementation on the 2.1 GHz frequency and even though there are already 80 WCDMA 900 networks in operation around the world, it is unlikely that they will ever achieve the global presence that GSM and LTE already have. This means that for M2M applications they will most likely play a local role, as will CDMA networks.

## Core network impact of M2M

A mobile core network is a relatively complex system which contains elements for mobility management, subscriber management, voice services, data services, network management, charging and interfaces to external networks, other operators and the Internet. In this paper we take a simplified view of those parts of the core network which are affected most when increasing numbers of machines are connected.

M2M means new requirements mainly for the part of the network handling data sessions. These originate from end-to-end system and traffic characteristics that are genuine for machines. The fundamental things visible in the core network are very similar to those in the radio side but some are amplified. This is because typical network architecture aggregates the traffic to only a few core sites from big geographical areas.

## Packet core

M2M optimized packet core elements (Physical or Virtual MME, S/P gateways) need to support M2M specific capabilities originating from the architectural evolution requirements of the network. The evolution leads to enhancements such as:

- Admission control and overload control (in various interfaces)
- Service bandwidth / quality / policy management (for group handling)
- Paging and signaling optimization (e.g. for stationary devices)
- Power saving modes for devices (timers)
- Specific SMS handling procedures

Traditional core solutions have been based on purpose built hardware and scaling of such systems may not be optimal. A new customer with electricity meters might mean adding millions of new devices in a rather quick roll-out period, resulting in reaching the scalability limit of, for example Serving/Packet (S/P) data network gateways. Cloud and virtualization technologies with flexible implementations provide answers to this challenge. With virtualization, it is more straightforward to respond to the demand for scalability.

A modern Enhanced Packet Core (ePC) is built with virtualization (Cloud) technologies. This means a few very important things in the M2M context:

- Virtually unlimited number of devices, sessions and objects in the network. Processing capacity can be increased on demand very flexibly, for example, offering another million meters requires only a few more computing cores allocated for the new task.
- Virtual network elements can share the same hardware but they can be dimensioned separately for different purposes. The same computer rack is running one instance of a MME for stationary meters, another MME for very mobile vehicles. (The option for an overlay core network is specified in Rel.12)

A Virtualized Enhanced Packet Core adapts flexibly to the different needs of the growing numbers of existing and emerging M2M applications, while it can also efficiently support device numbers far exceeding those of human beings.

## Registers and subscriber repository (One-NDS)

Registers (HLR, HSS, Repository) maintain the subscription information and characteristics of the network. Initially, M2M subscriptions will be built in the same repository as any other network users. However, special configurations may also become feasible in extensively M2M-oriented environments. Deployment scenarios include:

1. Common integrated repository for all users, human and machine
2. A dedicated “device class” according to their behavior.
3. Virtual network operator arrangements. In some cases virtual operators offer the M2M service and they may have their own subscriber repository.
4. Capabilities for multi-national services, roaming.

These are business related decisions, and it is important that the options are enabled by the repository solution architecture and technology.

Likewise in EPC, the repositories should be optimized for M2M subscriptions. Scalability is particularly important. There also needs to be an ability to manage the particular directory system architecture to allow for an increasing number of subscriptions and the consequent larger databases. This results in more capacity for identities in Directory Service Agents, the number of DSAs and the ability to manage them.

## eUICC

The GSMA embedded UICC has been developed to promote a common global remote provisioning architecture for the new era of M2M technology. The specification of eUICC is intended to enable over-the-air installation and management of operator policies and their subscription. It should be noted that embedded UICC is not a soft or virtual UICC. It embeds existing hardware UICCs into devices and evolves the existing credential distribution mechanisms into over-the-air mechanisms:

- UICCs can be embedded using the new M2M form factors (MFF1, MFF2) or use existing removable UICC form factors such as mini-UICC or micro-UICC.
- By using removable UICC processes and relationships, Embedded UICC can be deployed in the market in the least possible time and with appropriate security, as standardized by ETSI.

Soft or Virtual UICC is a completely different concept that does not use existing UICC hardware form factors and raises a number of strong security issues:

- Soft UICC would store the operator secret credentials in software within the mobile device operating system - the same system that is often attacked to modify the handset IMEI, perform UICC-Lock hacking and ‘jail-break’ mobile OSs.
- Operators are advised to be concerned about the lower security for their credentials through the use of Soft UICC. Any UICC approach not based on a certified hardware secure element will be subject to attack by the hacking community and if compromised, result in a serious loss of customer confidence in the security of operator systems.

- Multiple Soft UICC platforms carrying credentials in differing physical platforms, all requiring security certification and accreditation would become an unmanageable overhead – both in terms of resource and proving their security in a non-standardized virtual environment.

Figure 7 shows the basic architecture for eUICC:

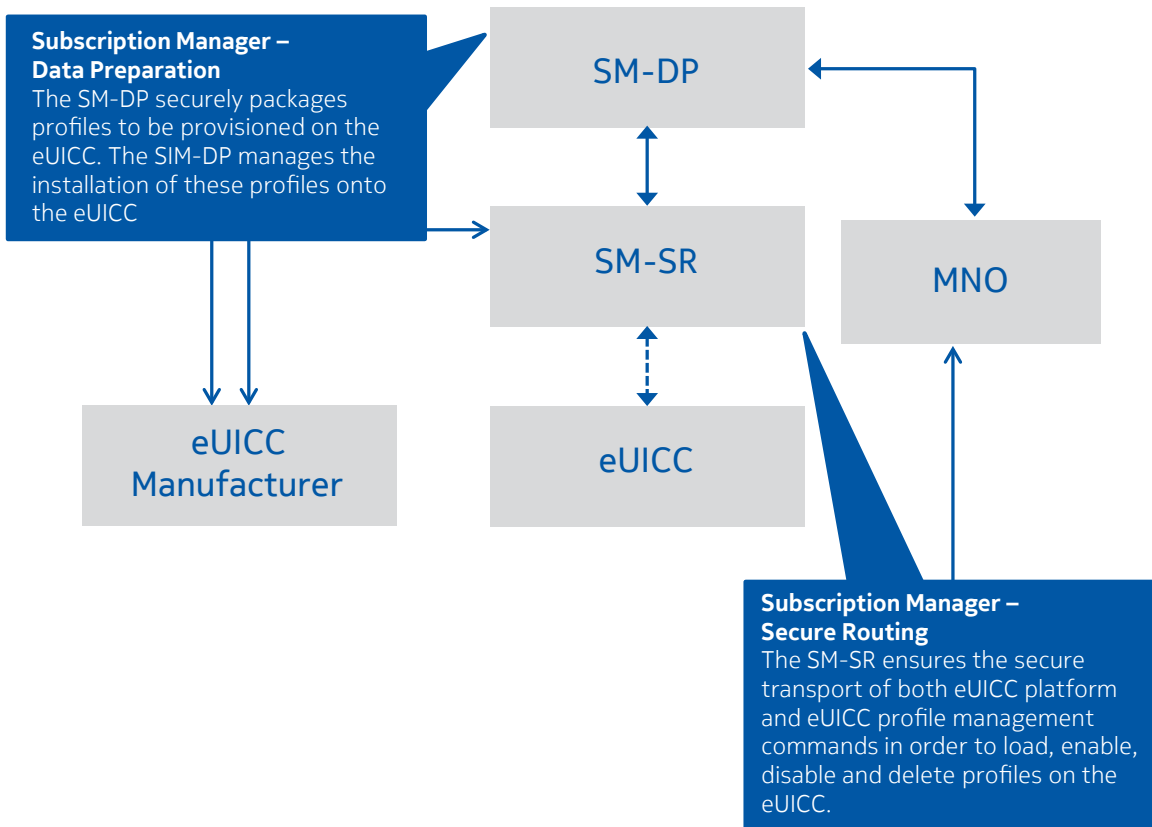


Figure 7 Basic eUICC architecture

## Conclusion

This white paper describes solutions to enable LTE to provide low cost and long battery life M2M services with high reliability. To realize these aims, the following changes are considered in 3GPP Rel. 13:

- Lower complexity devices category: A new device category needs to be defined without MIMO support, low RF bandwidth support (for example 1.4 MHz), even low data rates (e.g. 200 kb/s) and a lower device power class (for example 20 dBm)
- Coverage enhancements: New coding, repetition and power spectral density boosts are required to provide a Maximum Coupling Loss (MCL) of 160 dB.

- Dedicated Core Networks (DECOR): Select core network nodes based on subscription information – for example, special MME for M2M users.
- Service Capability Exposure (AESE): To define an architectural framework to expose 3GPP services to third parties via APIs. APIs are not in the scope of 3GPP.
- Monitoring: Define monitoring as a value added service (service enabler) for mobile network operators.
- Group: Group based policies and group based addressing.

## Reference sources

- 1 ABI Research
- 2 Global M2M Modules Report: Advancing LTE migration heralds massive change in global M2M modules market, Nov 2013

## Glossary of Abbreviations

3GPP	Third Generation Partnership Project
AESE	Service Capability Exposure
API	Application Programming Interface
CAGR	Compound Annual Growth Rate
CDMA	Code Division Multiple Access
CMOS	Complementary metal-oxide-semiconductor
CQI	Channel quality indicator
CSI	Channel state information
DC	Direct Current
DL	Downlink
DECOR	Dedicated Core Networks
DRX	Discontinuous Reception
EAB	Extended Access Barring
EGPRS	Enhanced Data rates for GSM Evolution (EDGE)
EHPLMN	Equivalent Home Public Land Mobile Network
ePC	Enhanced Packet Core
EPDCCH	Enhanced Physical Downlink Control Channel
ETSI	European Telecommunications Standards Institute
eUICC	embedded Universal Integrated Circuit Card
EU	European Union
FDD	Frequency Division Duplex
GERAN	GSM EDGE Radio Access Network
GSMA	GSM Association
HARQ	Hybrid Automatic Repeat Request
HLR	Home Location Register
HPLMN	Home Public Land Mobile Network
HSS	Home Subscriber Server

IMEI	International Mobile Station Equipment Identity
IoT	Internet of Things
LAPI	Low Access Priority Indicator
LTE	Long Term Evolution
M2M	Machine-to-Machine
M2M-IWF	M2M Interworking Function
MCL	Maximum coupling loss
MIMO	Multiple Input Multiple Output
MME	Mobility Management entity
MSISDN	Mobile Station International Subscriber Directory Number
OS	Operating System
PBCH	Physical Broadcast Channel
PCFICH	Physical Control Format Indicator Channel
PDCCH	Physical Downlink Control Channel
PDSCH	Physical Downlink Shared Channel
PHICH	Physical channel HybridARQ Indicator Channel
PRACH	Physical Random Access Channel
PRB	Physical Resource Block
PSD	Power Spectral Density
PSS/SSS	Primary and Secondary Synchronization Signals
PUCCH	Physical Uplink Control Channel
PUSCH	Physical Uplink Shared Channel
OMA DM	Mobile Alliance (OMA) Device Management (DM)
OTA	Over-The-Air
PDN	Packet Data Network
PLL	Phase-locked loop
PS	Packet-switched
PSM	Power Saving Mode
RAN	Radio Access Network
RAT	Radio Access Technology
RF	Radio Frequency
RRC	Radio Resource Control
S/P	Serving/Packet Data Network
SINR	Signal to Interference and Noise Ratio
SMS	Short Message Service
SMSC	Short Message Service Center
TAU	Tracking Area Update
TBS	Transport Block Size
TDD	Time Division Duplex
TDM	Time Division Multiplexing
TTI	Transmission Time Interval
Tx	Transmission
UICC	Universal Integrated Circuit Card
UL	Uplink
UTRAN	Universal Terrestrial Radio Access Network
WCDMA	Wideband Code Division Multiple Access



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