A Choice of Future m2m Access Technologies for Mobile Network Operators

Contributors:

Alcatel Lucent  Sony
Ericsson  TU Dresden
Huawei  u-blox
Neul  Verizon Wireless
NSN  Vodafone
Executive Summary

It is predicted that by the early years of the next decade over 20 billion devices will be wirelessly connected in the Internet of Things (IoT). Many of these will use short-range wireless systems such as Bluetooth Smart, Wi-Fi or Zigbee, but, if so, they will depend on some private infrastructure being in-place, accessible and reliable. A ubiquitous public cellular network that was easy to use, penetrated deeply into almost all locations, and allowed for truly low-cost/low-energy devices capable of operating for years on a small battery, would be of enormous benefit. It would serve many existing machine-to-machine (m2m) applications such as metering, remote sensing, and telemetry; but more importantly would fuel the rapid development of the mass Internet of Things market by providing reliable and accessible connectivity for even the most low-cost/low-energy device. It would be a platform for substantial revenue growth for mobile network operators globally.

Today’s cellular networks have a few shortcomings in relation to the new demands from IoT. Whilst existing cellular technologies give in-building service they do not provide sufficiently deep coverage for some m2m applications such as metering. No current cellular technology (Rel-11 and earlier) can support very long terminal operating life on a small battery. Today, cellular GSM/GPRS comes closest to serving this market but does not sufficiently provide all characteristics of the ubiquitous cellular network for IoT. LTE, the latest cellular radio access technology, has been designed from the ground up to provide efficient mobile broadband data communications. Both LTE and UMTS/HSPA devices in their current forms are significantly more expensive than GSM/GPRS.

This White Paper discusses two alternative approaches to address these concerns: an evolution of LTE; or the development of a dedicated new radio access technology. Either approach must combine the following characteristics:

- Use licensed spectrum to allow controlled quality of service and provide global coverage, ideally over existing cellular bands using existing sites, transceivers and antennas
- Support deep coverage for low-rate services into highly-shadowed locations such as basements, meter closets, manholes and even under ground
- Support low-cost devices that could even be disposable.
- Provide an adapted IPR licensing regime based on the FRAND principles and reflecting the reduced functionality that the new standard will provide for the specific M2M market (low cost, high volume).
- Support very low device energy consumption allowing devices to operate for a decade or more on small primary batteries without recharging
- Optimized for small payloads, as needed for remote monitoring and control applications with low signalling and control overhead
- Deployable as extensions in GSM/GPRS, UMTS/HSPA or LTE networks.

The purpose of this paper is to share across the industry a vision of how a low-cost m2m solution could be developed, either as an integrated part of or a complement to the evolution of current cellular
technology. This would allow operators to provide connectivity for all sorts of devices in the future in the mass Internet of Things (IoT) market.
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1 Introduction

Machine-to-Machine (m2m) communications has been one of the more successful growth stories for cellular network operators in recent years, with annual growth in the region of 30% and around 200 million\(^1\) global network connections by end 2013.

As new applications take advantage of low cost connectivity to large numbers of sensors and controllers, new services are being generated which provide exciting and revenue-generating opportunities to improve our lives and businesses and further optimize the use of valuable natural and human resources. These opportunities are at the heart of the mass Internet of Things explosion; they are necessarily and rapidly changing the shape of the m2m market.

Already the ratio of connected Things to People on the planet has reached almost 2.0, with Cisco estimating there were 8.7 billion connected Things at end-2012 and 10.8 billion today\(^2\). The vast majority of these Things are quite familiar to us - cellphones (6.8 billion in 2012)\(^3\), tablets (0.2 billion in 2012) and PCs (1.1 billion in 2012, the majority of which are connected)\(^4\). Cisco, NSN\(^5\) and Ericsson\(^6\) each believe that the ratio of connected Things:People will rise sharply over the next 5-10 years, perhaps reaching around 7:1 by 2020, meaning there could be as many as 50 billion connected Things that year. In a similar vein, GSMA\(^7\) believes the total figure for connected Things could grow to 24 billion by 2020 whilst Gartner\(^8\) forecasts that number at 30 billion. Those connections will span automotive, intelligent building, metering, smart city, healthcare and consumer electronics applications; the exact number is not easy to determine, but all analysts agree it will be huge.

One segment analyst, Machina Research, has constructed a bottom-up projection which aggregates to 15.0 billion connected devices, other than cellphones, PCs and tablets, by 2020, consistent with the GSMA and Gartner estimates, of which 2.0 billion\(^9\) will be connected on cellular m2m networks and the remaining 13.0 billion will be connected using short-range wireless systems such as Bluetooth Smart, Wi-Fi or Zigbee. Their analysis identified that a proportion of those connections could be carried over a wide-area network if it met the requirements of low terminal power, extended coverage, and low cost. Not only could 5.5 billion of the projected 13.0 billion LAN/PAN connections in 2020 be addressable fully by such a technology but the existence of such a technology could accelerate additional WAN connections on top, adding a further 5.7 billion connections that same year, expanding the whole mass IoT connectivity market to over 20 billion.

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1 GSMA, “Mobile Operators’ Global M2M Footprint.”
2 Tillman, “Cisco Blog.”
3 Wikipedia, “List of Countries by Number of Mobile Phones in Use.”
4 “How Many Computers in the World?”.
5 Nokia Siemens Networks (NSN), “Cumulocity - The Key to the World of Machine-to-Machine Connectivity.”
6 Ericsson, “More Than 50 Billion Connected Devices.”
7 GSMA, “Europe Response to the European Commission Public Consultation on the Internet of Things.”
Identified and included in this total is a large class of new products and services that are very difficult to develop and roll-out if they depend on a short-range link. If, for example, they depend on opportunistic Wi-Fi access, it may disappear or access may be hard to engineer; if they depend on adding Zigbee access points and backhaul links, the business case may vanish. What is needed is a reliable connection; available “everywhere”; that only needs a low cost radio to access; and has a low service cost that can be absorbed either in an overall service charge or even in the up-front cost of the product.

The growing market is already leading to the development and partial roll-out of proprietary or lightly-standardized systems. Inevitably these operate in various types of licence-exempt spectrum, such as ISM, SRD or PLMR bands or even TV white space. All such bands allow only limited transmit power and many are regulated by duty cycle restrictions or listen-before-talk provisions. Whilst they can be used by a wide variety of products, that also means there is no guarantee of service availability, coverage, or capacity.

An Internet of Things (IoT) network operating in licensed spectrum offers the best of all worlds: a much lower cost of connectivity, a true "plug and play" experience, a vastly increased battery life, robust device authentication and reliable connectivity. This sector is the target of the systems that are discussed in this report, and will be referred to as the "Cellular IoT" sector.

Many network operators see addressing the Cellular IoT sector as a priority – not as a defensive step to guard existing m2m revenue streams, although this would be a consequence – but primarily as a means to build the customer relationship and widen the range of higher-value service layers delivered to enterprise and consumer users of such a network.
The Industry Challenge

The technology evolution in cellular from 2G to 3G and 4G has delivered enormous spectral efficiency gains and much improved resource utilization with availability of greater peak data rates and lower latency. For high-end m2m applications this improved functionality has value, but for low-end m2m applications, it may add unnecessary cost and complexity to the terminal. It is partially for this reason that the vast majority of m2m devices are GSM-based, where the cost of a GSM module in high volume may be around $10, roughly one third of the cost of a m2m dual-band UMTS 3G module, and one quarter that of current LTE (Rel-11 and earlier) m2m modules\(^\text{10}\).

The increasing importance of low-end m2m applications has motivated and triggered standardization activities in 3GPP in order to facilitate development of low-cost m2m devices by stripping them of functionality which is not required to be supported for many low-end m2m applications. As can be seen from the proposals in this paper, there is a potential for further evolution in this direction.

For innovators in the IoT market, the challenge is to obtain the connectivity needed to unlock the potential for connecting billions of devices and develop novel products and services. The operator’s challenge is therefore how to continue the evolution towards more efficient mobile broadband platforms supporting billions of smartphones; whilst also providing the connectivity that the IoT needs.

Requirements

In recognition of this challenge, this paper addresses the Cellular IoT sector identified above.

The requirements for the technology are as follows:

- Use licensed spectrum to allow controlled quality of service and provide global coverage, ideally over existing cellular bands using existing sites, transceivers and antennas
- Support deep coverage of low-rate services into highly-shadowed locations including basements, meter closets, manholes and even underground
- Support low-cost devices that can be regarded as disposable.
- Support a very large number of devices per cell
- Provide an adapted IPR licensing regime based on the FRAND principles and reflecting the reduced functionality that the new standard will provide for the specific M2M market (low cost, high volume).
- Support very low device energy consumption allowing operation for a decade or more on small primary batteries
- Optimized for small payloads, as needed for remote monitoring and control applications, with low signalling and control overhead
- Deployable multiplexed with LTE carriers; in individual GSM sub-carriers or multiple GSM sub-carriers; in niches created by re-farming GSM; in the guard bands of LTE; or perhaps also in an LTE physical resource block

\(^{10}\) Machina, “Global M2M Modules Report: Advancing LTE Migration Heralds Massive Change in Global M2M Modules Market.”
• Deployable as extensions in GSM/GPRS, UMTS/HSPA or LTE networks.

**Scope of this paper**

This paper analyses two feasible radio access technology options for Cellular IoT that address the requirements noted above. The purpose of the analysis is to present options that can be deployed in licensed cellular spectrum bands and thereby re-use much of the radio and core network infrastructure. The focus of this paper is the radio access and physical layer; the higher layers and security model are being worked on too, but are out of scope.

## 2 Industry trend and standards progress

**Positioning Cellular IoT in the Hierarchy of Solutions**

Today, most m2m applications use GPRS for wide-area connectivity; in some markets cdma2000 is also used. HSPA currently has a relatively low penetration for m2m devices, partly as its broadband capabilities are irrelevant for many m2m applications, though dual-mode m2m devices including HSPA support are used, for example in situations where the user is concerned about longevity of GPRS. LTE-based m2m devices are also appearing, still primarily for applications that need broadband and/or very-low-latency connectivity (security cameras, feedback control in Smart Grid, etc.).

In addition, there are m2m services relying on other, typically short-range technologies, in some cases including mesh functionality. But today there is no technology solution providing the combination of very low cost and deep coverage needed to address the full set of potential Cellular IoT applications.

![Cellular IoT hierarchy diagram](image)

At the high end, applications will benefit from the data-rate capability of LTE and the associated high-end device categories. With regards to device cost, in Release 12 LTE a new terminal type (Category 0) with more limited mandatory capabilities is also introduced, specifically targeting lower-cost m2m devices that will approach the bill of materials cost associated with GSM. But in general, there is an area of m2m applications, indicated by the base of the pyramid in the above figure,
for which there is still room for new technology solutions, solutions that might be a candidate for Release 13 and beyond.

In markets where 2G, 3G, and 4G are currently available a possible roadmap in technology evolution may emerge as follows.

<table>
<thead>
<tr>
<th>2014</th>
<th>2015-2016</th>
<th>2017-2018</th>
</tr>
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<tbody>
<tr>
<td>2G m2m solutions dominate</td>
<td>4G solutions based on LTE Release 12 will emerge in greater volume and terminal costs will reduce. 4G becomes cost-competitive relative to other existing cellular technologies</td>
<td>Cellular IoT will be deployed on a larger scale offering an optimised solution for ultra low-cost m2m connectivity and deeper coverage.</td>
</tr>
<tr>
<td>3G used to supplement bespoke solutions.</td>
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<tr>
<td>4G (Rel-9, Cat-3) devices begin to be used in relatively small volume, and for high value connectivity.</td>
<td></td>
<td></td>
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<tr>
<td>Proprietary wide area access technologies using licence-exempt spectrum.</td>
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**Summary**
The high level trends, and market opportunity have been described, and the requirements for a mass-market-potential low-cost/deep-coverage m2m radio access technology have been outlined. The availability of such a solution, with the ability to operate in licensed spectrum, and reusing existing cellular network assets, offers a potential technology roadmap for m2m network evolution.
3 Cellular IoT technology overview

The challenge of delivering cellular IoT could potentially be met in various ways. In this section, two alternative solution classes will be introduced. Each has various benefits and disadvantages, and different consequences in terms of the standardization and regulatory routes that could be followed.

Option 1 – based on an evolution from LTE Rel-12

Develop an enhanced Cellular IoT solution based on an evolution of LTE, allowing for either a stand-alone Cellular IoT carrier, or support for enhanced Cellular IoT multiplexed with other services such as conventional mobile broadband on the same carrier.

Such a solution would build on the evolution steps\(^\text{11}\) towards lower device cost, enhanced coverage and reduced power consumption taken already in LTE Rel-12. Regarding the transmission bandwidth for the Cellular IoT service of such a solution, there are two possibilities:

- Rely on any of the existing LTE bandwidths, with a cellular IoT device bandwidth of 1.4MHz (option 1a).
- Extend to even lower bandwidth, down to a bandwidth corresponding to a single LTE resource block (roughly 200 kHz bandwidth) (option 1b)

The reduction of the device bandwidth to 1.4 MHz serves the purpose to reduce the device complexity and hence the device cost. Reduction of the device bandwidth below 1.4 MHz allows deployment in very narrow system bandwidths (e.g. 200 kHz).

It should be noted that a narrow-band Cellular IoT device bandwidth does not prevent co-existence in the same spectrum with mobile-broadband services using a much wider bandwidth. However, the use of a bandwidth smaller than 1.4 MHz would require the design of new synchronization signals and channels for system information to be used for/by the Cellular IoT devices.

The benefits of this approach are

- Less standardization/development effort as the approach would reuse any existing functionality when applicable (especially option 1a)
- Full spectrum-compatibility with LTE allowing for efficient utilization of existing LTE spectrum resources
- Smooth migration of GSM spectrum in 200 kHz blocks (option 1b)

An evolution of other cellular technologies such as GSM and UMTS to address the Cellular IoT requirements could also be considered but this is beyond the scope of this white paper.

\(^{11}\) 3GPP, “TR 36.888 Study on Low-Cost Machine Type Comms (MTC).”
Option 2 – a new radio access technology for Cellular IoT

Develop a new clean-slate radio access solution specifically targeting the Cellular IoT application.

A solution is proposed that can operate in a narrow 200 kHz spectrum bandwidth and would specifically target low-rate long-range and low-cost devices with low energy consumption.

The proposal uses half-duplex FDD and single carrier modulation with frequency and time division multiple access for downlink and uplink. It uses a 15 kHz carrier spacing on the downlink and an integral division of 15 kHz for the carrier spacing on the uplink (either 3 kHz or 5 kHz), with allowance for uplink channel bonding to provide higher data rates.

The benefit of this clean-slate approach is that the design can be fully optimized for the Cellular IoT application with no consideration for any legacy functionality. Thus, this approach should have the potential for driving major benefits e.g. enabling ultra-low cost/low energy devices.

The Cellular IoT carrier could operate in refarmed GSM spectrum. Alternatively/additionally it is proposed that it can operate within the guardbands of an LTE carrier (the impact on the traffic on the LTE carrier and adjacent systems is an area being carefully researched and characterized.

Summary

The presented broad options towards offering a solution for Cellular IoT requirements and some of their benefits and drawbacks are summarized in the table below.

<table>
<thead>
<tr>
<th>Technology option</th>
<th>Key characteristics</th>
<th>Benefits</th>
<th>Drawbacks</th>
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<tbody>
<tr>
<td>1a Evolution of Rel-12 using existing bandwidth</td>
<td>Operation on a normal LTE carrier with system bandwidth 1.4-20 MHz and 15 kHz sub-carrier spacing Further enhancements for M2M compared to Rel-12, e.g. reduced RF receive bandwidth in the device</td>
<td>Full spectrum compatibility with current LTE releases Lowest standardization and development effort Allowing for dedicated m2m carrier as well as overlay with mobile broadband services on same carrier</td>
<td>Less smooth migration of GSM spectrum Not fully optimized for the low-cost/low-energy use case (benefit of further optimization unclear)</td>
</tr>
<tr>
<td>1b Evolution of Rel-12 using narrower</td>
<td>Operation on an LTE carrier with a new narrow (200 kHz) system bandwidth and 15 kHz sub-carrier</td>
<td>Full spectrum compatibility with current LTE releases Allowing for</td>
<td>More standardization and development effort compared with option 1a Not fully optimized for</td>
</tr>
<tr>
<td>bandwidth spacing.</td>
<td>Further enhancements for M2M compared to Rel-12, e.g. reduced UE RF bandwidth</td>
<td>dedicated m2m carrier as well as overlay with mobile broadband services on same carrier</td>
<td>Smooth migration of GSM spectrum</td>
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<tr>
<td>2 Clean-slate, based on single carrier using asymmetric channel spacings</td>
<td>Operation in 200-kHz bandwidth Sub carrier spacing of 15 kHz in the downlink and an integral division of 15 kHz in the uplink, typically 3 kHz or 5 kHz, with allowance for channel bonding on the uplink</td>
<td>Development effort can fully focus on optimization for low cost/energy Smooth migration of GSM spectrum</td>
<td>More standardization and development effort compared with option 1b Limited data rate scalability</td>
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4 Modem Costs

For this price-sensitive market a key objective is to ensure a competitive cost of the modem: significantly less than that of GPRS in comparable volumes, and competitive with alternative proprietary solutions that operate in licence-exempt spectrum.

There are several key contributors to the modem cost:

- Core transceiver and baseband IC, with protocol stack software;
- RF components such as PA, antenna switch (if needed) and antenna;
- External components such as crystal, memory and discrete components for decoupling & matching and for power management;
- PCB, connectors and screening can.

Depending on design and implementation, power supply components and secure element for authentication and security could be integrated in a single baseband/transceiver IC or provided through discrete components.

A final module cost comprises not just the above bill of electronic materials but will include additional expense associated to manufacturing, assembly and testing, yield loss, swap, packaging, freight, royalties and OEM margin. Current LTE licensing costs do not take into account the reduced functionality that the new standard will provide for the specific M2M market. Further optimisation on licensing costs can therefore be expected and should reflect the specific anticipated dynamics of this market (low cost, high volume).

Current estimates place the price of an LTE m2m module (Rel-11) around $40\(^{12}\). The ongoing cost reduction efforts in Rel-12\(^ {13}\) may result in a cost level for LTE based on an electronic bill of materials that approaches that of GPRS.

For the Cellular IoT market the module price evolution is one of the critical issues; module pricing should reach the $5 region, and preferably even lower levels in future.

5 Conclusions and recommendations

The opportunity space for Cellular IoT is much larger than that served by today’s mobile market. LTE is designed to deliver high-peak data rates and spectrum efficiency for smartphones and tablets, and there is a need to improve the support for devices that are cost-sensitive, tolerant to latency, power constrained, located in deep shadows, and have small data payloads.

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\(^{12}\) Ibid.

\(^{13}\) 3GPP, “TR 36.888 Study on Low-Cost Machine Type Comms (MTC).”
Two broad options exist to address this challenge and potentially open a much greater business opportunity for mobile network operators by going beyond the improvements introduced in LTE Release 12. Each has their own advantages and challenges.

In the first case, existing cellular radio access technologies, e.g. LTE, are evolved (potentially within Release 13) to better suit IoT requirements. This approach offers an evolutionary route using the established standardization process and regulatory framework but may have to overcome legacy issues that limit its ability to meet the target cost-point, use spectrum efficiently, achieve low energy consumption and attain high coverage.

In the second case, a solution optimised according to the specific requirements of Cellular IoT is proposed. The challenge is that the departure from current LTE technology will require wider industry support to initiate a new standards activity, and gather regulatory support.

Both options could be deployed in an operator’s licensed spectrum band to deliver improved coverage and have low complexity in the m2m module which should lead to lower cost. Options 1a and 1b can be embedded into existing allocated LTE spectrum carriers. Options 1b and 2 can also be deployed in 200-kHz narrowband allocations of spectrum allocations which may operate alongside LTE or arise from 2G spectrum refarming.

This paper has been written to seek views across the industry, and particularly from mobile network operators, that have an interest in addressing this market opportunity.

Feedback is requested on the following:

Do you have a preference towards a solution based on an evolution of LTE using existing physical layer characteristics (Option 1) or a new access solution built specifically for low-end m2m (Option 2).
This paper reflects the outcome from an industry working group, initiated to accelerate the provision of a 3GPP standardised technology for mass-market, low-cost, low-data rate, low-power, machine to machine communications with ubiquitous coverage. Further details on each option are available on request from the members that participated in this working group.

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<tr>
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<th>Email Address</th>
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<tbody>
<tr>
<td>Vodafone</td>
<td>David Lister</td>
<td><a href="mailto:david.lister@vodafone.com">david.lister@vodafone.com</a></td>
</tr>
<tr>
<td>Alcatel Lucent</td>
<td>Stephan Saur</td>
<td><a href="mailto:stephan.saur@alcatel-lucent.com">stephan.saur@alcatel-lucent.com</a></td>
</tr>
<tr>
<td>Ericsson</td>
<td>Johan Bergman</td>
<td><a href="mailto:johan.bergman@ericsson.com">johan.bergman@ericsson.com</a></td>
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<tr>
<td>Huawei</td>
<td>Gaoke Du (Gavin)</td>
<td><a href="mailto:dugaoke@huawei.com">dugaoke@huawei.com</a></td>
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<td>Stan Boland</td>
<td><a href="mailto:stan.boland@neul.com">stan.boland@neul.com</a></td>
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<td><a href="mailto:amitava.ghosh@nsn.com">amitava.ghosh@nsn.com</a></td>
</tr>
<tr>
<td>Sony</td>
<td>Chris Clifton</td>
<td><a href="mailto:chris.clifton@eu.sony.com">chris.clifton@eu.sony.com</a></td>
</tr>
<tr>
<td>TU Dresden</td>
<td>Prof. Dr. Gerhard Feitweis</td>
<td><a href="mailto:gerhard.fettweis@vodafone-chair.com">gerhard.fettweis@vodafone-chair.com</a></td>
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