Redefining LTE for IoT

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Introduction

The ‘Internet of Things’ or 'IoT’ represents an exciting opportunity for device manufacturers, service providers and consumers alike. The ability to connect billions of 'things’ to the internet is set to profoundly change the way we all interact and make use of countless devices that we encounter in our day to day lives.

There is of course nothing specifically new about this vision, machine-to-machine services (M2M) have been in existence for decades now and are well established in terms of service and application. M2M service providers have long been using existing cellular networks to enable these services delivering applications such as logistics and asset tracking as well as some more recent examples such as in vehicle telematics.

The challenge for cellular operators moving forwards is how to continue the investment in this space in order to enable the so called IoT revolution. Today the majority of cellular M2M services are based on 2G networks such as GSM which although being a 20+ year old technology still offers many advantages in terms of low cost, low power and extensive network coverage. Increasingly 2G networks are being switched over to LTE based services to free up precious spectrum and add capacity.

Cellular today is all about the shift to LTE. This all IP technology is the fastest growing cellular technology in history with major LTE (or 4G) deployments across all major continents worldwide and subscriber rates are growing at over 130% annually according to the GSA[2]. From the outset, LTE was conceived to deliver high throughput, low latency mobile broadband data to mobile devices to enable devices such as smartphones and tablets and services including video on demand that require high throughput capable connectivity.

The standards body 3GPP who are responsible for LTE have been working on defining a new profile of LTE in the forthcoming Release 12 specification. The profile is termed ’Category 0’ (Cat-0) and promises to address the major challenges and open LTE for IoT (3GPP uses the term ‘MTC’ for IoT which refers to ‘Machine Type Communications’).

This paper looks from an operator’s perspective at the attributes that Cat-0 devices will offer and how in turn this will help to drive new business opportunities. It then goes on to explain the major technical enhancements to the LTE specification that will enable a new breed of IoT devices and then takes the reader through the design choices that will help in turn spawn a new breed of connected low power LTE devices that are capable of making use of the existing LTE infrastructure.

Predictions estimate close to 30 billion internet-connected devices by 2020 [4]. IoT brings an enormous breadth of requirements and countless applications. How LTE Cat-0 will come to enable a portion of that market presents a fascinating prospect.

The Importance of MTC in LTE for Network Operators

The specification of the new category (Cat-0) for MTC has been largely driven by mobile operators with Vodafone acting as the Rapporteur in the 3GPP standards organization.

This is not surprising because from an operator's perspective LTE is where most significant future investment will reside: it is the technology of choice for wide-area cellular communications delivering the best mobile broadband experience for customers and it is the most spectrally efficient technology, which enables operators to extract most value from their spectrum. This improvement in spectrum efficiency will continue to drive the re-farming of a proportion of GSM spectrum to LTE and it is therefore important LTE is evolved to also fully address the requirements of machine-to-machine (M2M) communications.

As discussed in the introduction to this paper, many M2M requirements are well served today by GSM/GPRS which has been cost optimized over several decades of operation and will remain as an important technology offering for many years to come. For LTE to gain significant market share from GSM/GPRS it is imperative to minimize cost and include only the essential capabilities of LTE.

The Cat-0 introduction is an important step that will accelerate this transition, offering suppliers of M2M modules the opportunity to develop products at much lower cost than existing solutions, Combined with the increasing economies of scale associated with LTE deployments around the world, the likelihood is that LTE MTC will become the dominant form of machine connectivity for devices requiring good quality, reliable, low-latency, communications up to 1Mbps.

For operators, this transition towards LTE with the improved performance (relative to GSM/GPRS) will enable a range of new services to be associated with machine connectivity and customers will be less constrained with data rates which are typical in GSM/GPRS (less than 20kbps on average). As just one example, the data available from a car's energy management system can become very large and it may be unrealistic to use a GSM/GPRS modem to transfer much of the data that is available. The integration of a Cat-0 LTE module will enable a cost-effective solution for the transfer of larger payloads, enabling cloud-based services to process the data and for operators such as Vodafone to offer improved services to insurers, fleet-managers, car manufacturers and private owners.

Overview of LTE Cat-0

Internet-of-Things connectivity (or M2M) is served by a growing number of wired and wireless technologies such as cellular (2G, 3G, LTE), Wi-Fi, personal area networks like Bluetooth-Smart, Zigbee, 802.15.4 and other emerging low power wide area technologies like Weightless, Sigfox and others. All of these technologies bring particular attributes that allow them to serve particular use cases.

Cellular technology, which currently equates to 15% [3] of the number of overall M2M connections, will represent the higher revenue value segment and will continue to be prevalent in many verticals where network operators can leverage higher returns from M2M connections offering greater mobility, flexibility, coverage and simple connection management, together with the massive re-use and economy of scale of existing cellular networks.

However several limitations affect the percentage of cellular connections in M2M and ultimately the success of the cellular industry in M2M depends mainly on addressing cost, power saving and coverage.

<u>Cost</u> is a key enabler of many M2M applications: cellular has to compete with other long range systems where the cost of the devices has been set below $5. The current cost of a 2G device (in the order of ~$10) may be competitive enough for a good range of applications, while current cost of ~$40 for LTE modules is too high for the low margin, high number of connections that many M2M applications require.

<u>Power saving</u> is of great importance since many M2M devices are battery powered, the deployment and maintenance costs implied by reduced battery life has a significant impact. In certain applications, battery durations of up to several years can be required and this needs to be possible with a low cost solution such as combining energy harvesting with standard battery technology.

<u>Coverage</u> improvements are also required as there is a substantial market for the use cases of M2M devices deployed deep inside buildings. Within the cellular segment, the market volume of 2G devices still represents the vast majority of M2M connections (approximately 60% of the segment) as low average revenue per user(ARPU) low data rate applications are served very efficiently in existing GSM networks.

However with the continuing global growth of M2M installations, the reliance on existing GSM networks will present a dilemma for mobile operators who will need to re-farm frequencies to gain greater spectrum efficiency and consolidate other access technologies; at this regard decommissioning of 2G mobile network services in the US has already started, with existing customers being moved over to LTE. Also, other wireless operators without access to 2G spectrum allocation will increasingly see LTE as the future-proof option for M2M.

3GPP has addressed these M2M device ('User Equipment' or UE) challenges with a specific work item for complexity reduction (and in turn thus allow cost of devices to be reduced) and enhanced coverage of MTC devices in LTE, which is part of Release 12 and subsequent specification work.

In particular a 'low complexity User Equipment' is being specified in Release 12, whereas a MTC UE can identify itself to the network as a Cat-0 User Equipment. This type of UE can be developed at lower cost, whilst still providing capability to support low latency and data rates of up to 1Mbps appropriate for the vast majority of M2M applications. Release 12 will also introduce new power saving modes enabling MTC devices to go into deep sleep mode when not requiring active communication with the network.

In Release 12 it is defined that the Cat-0 MTC modem is characterized by:

- One Rx/Tx antenna only (single RF Chain)
- Peak rate reduction to 1Mbps in downlink and uplink, via reduced transport block sizes
- Half duplex capability

3GPP estimates that the cost reduction measures of Release 12 can bring down the bill of materials (BoM) of a Cat-0 LTE module by about 50% relative to a single band Category 1 LTE module.

Further improvements and optimizations for cost reduction are being discussed and will be planned after Release 12:

- Reduction of baseband and RF channel bandwidth. Further reduction of processing requirement (e.g. via block size or modulation scheme restrictions)
- Reduction of uplink power requirements ('new power class') with the possibility to use an on-chip power amplifier with power and cost reduction.

Whereas enhanced coverage was originally part of the same 3GPP work Item for Release 12 and several possible improvements have been discussed (e.g. repetitions of physical control channels, sub-frame bundling and retransmissions, changes in common channel encoding and relaxations of acquisition times), the core specification work for enhanced coverage has been re-planned for Release 13 (expected to be concluded in March 2016), with the objective to achieve 20dB improvement in the maximum available link budget.

Machine Type Communications (MTC) terminal power saving improvements in 3GPP Release 12 is the subject of a separate Work Item (UEPCOP) that is implementing Power Saving Mode (PSM) for procedural optimization of idle mode procedures, which can be used in MTC devices irrespective of the category. The PSM feature (like many others e.g. SMS, location, half-duplex, TTI bundling etc..) can be optionally implemented in the M2M device to allow the best cost and performance trade-off in specific applications and the operator's set of requirements.

Good Practice in LTE Cat-0 Modem and Protocol Implementation

The functional architecture of a Cat-0 stack is similar to a protocol stack supporting higher throughput. However, there are important considerations which can influence the designer to propose an implementation explicitly for M2M rather than trying to optimize a generic solution.

In many aspects, M2M is a novel requirement for LTE devices, where traditional trade-offs between cost and performance needs to be re-assessed and re-designed.

As mentioned in previous sections, cost and energy efficiency are key factors for LTE Cat-0 UEs. Protocol stack features, memory footprint, processing requirements, choice of processor architecture and number of cores are key attributes to control cost and improve energy efficiency. Existing modem architectures typically have two cores: an ARM-based core for the protocol stack, and a second ARM-based core (or DSP) for the physical layer control software.

An example implementation of a LTE Cat-0 protocol stack, known as "ALPS Lite", from NextG-Com has been developed which has the potential to be integrated on a single core with physical layer control software, removing extra cost in the module. This builds on the following good-practice design guidelines to minimize memory foot-print and lower MIPS.

- Design and Implementation:
    - Simple and efficient horizontal layer thread architecture for control plane and vertical thread/functional combination architecture for data plane. Such design results in reduced code size and faster data plane code.
    - Efficient zero copy vertical memory management for L2 buffer, once copied from PHY Buffer. Such design avoids the need of extra memory pools and messages.
    - Usage of centralized data structures, whenever possible without affecting simplicity and code maintainability.

- Flexible Features:
    - For complete offering of LTE protocol stack also includes cross layer features e.g. uplink HARQ, timing related MAC procedures. Depending on selection of modem architecture, these procedures may be performed by L1 due to time critical nature of such procedures. These will further reduce the memory footprint and MIPS requirement in the ARM processing domain.
    - Addition and removal of 3GPP LTE features based on end applications of LTE Cat-0 M2M devices by simple compile time flags e.g. The NAS (Non Access Stratum) should be scalable (e.g. depending on the triggering mechanism and geo-location requirements of the application, SMS and/or LPP) and should implement critical MTC

3GPP features like power saving modes and small data optimizations (depending on operators network configuration).

- Platform Software Features:
    - An ASN.1 complier which produces optimized code is required.
    - Highly optimized embedded RTOS (Real Time Operating System) is needed.

A typical MTC UE configuration for FDD (including TTI bundling) with ALPS Lite will have below memory requirements:

Memory	Size (Typical)	Comments
Flash	< 600KB	Memory required for code
RAM	< 400KB	Memory required for data and heap
EEPROM	< 30KB	Static data required for UE initialization excluding calibration.

The design principles outlined above enable the memory footprint of the protocol stack to be minimal. This allows designers to select various low-cost, low-power, on-chip memory configurations, avoiding the cost and extra power associated with external memories.

The reduction in data rate for LTE Cat-0 together with the design of NextG-Com's ALPS Lite makes it possible for modem designers to select a relatively less processing-intensive ARM Cortex® architecture to achieve a target goal of a cost and energy-efficient LTE Cat-0 modem.

Optimizing LTE Modem Design for IoT

From the smallest ultra-low power Bluetooth® Smart devices running on Cortex-M0+ through to LTE-Advanced high throughput modems running on Cortex-R7, the ARM Cortex family powers the full breadth of the connected world. Today, over 90% of all cellular modems shipped worldwide run on ARM.

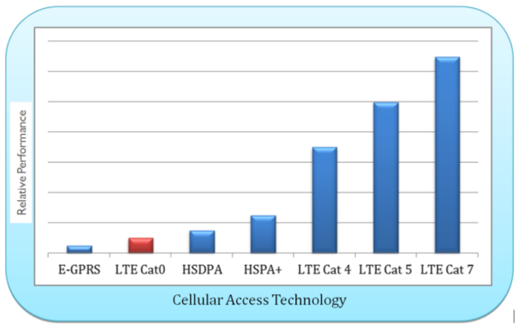

Figure 1: Cat-0 profile brings LTE connectivity to a new performance point for IoT

Redefining LTE for IoT brings a new set of design challenges compared to traditional LTE platforms. Currently, most LTE modems are designed to support high throughput in excess of 300Mbps. New IoT classes of LTE modems will only be required to support up to 1Mbps which represents a 300x reduction in throughput requirements. As can be seen in Figure 1 above, this throughput reduction moves LTE to a much lower class of performance. This reduction in throughput offers modem designers the opportunity to significantly optimize the processing capabilities of their devices to achieve cost and power savings which in turn opens LTE to new use cases and markets in IoT.

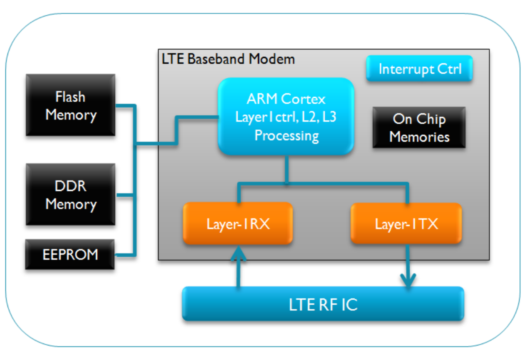

Figure 2: High Level LTE Modem System Architecture

Figure 2 above gives a high level overview of the major architectural blocks in a typical LTE modem. When optimizing LTE for IoT the overarching modem architecture remains mostly unchanged, however at each stage of the processing chain we find optimization opportunities that can be realised:

- LTE RF IC – This portion manages the transmission and reception of the radio signals to the base station. Since LTE Cat-0 devices have to interoperate with traditional LTE networks this portion remains mostly unchanged i.e. it needs to be able to receive up to a full 20MHz of bandwidth. Reduced throughput requirements achieve energy savings, particularly through overall reduced transmission power.
- Layer 1 Processing – Managing the low level signal processing of the receive and transmit chain. Whilst overall functionality remains the same, the overall processing requirements are reduced due to small block sizes and lower throughput.
- Layer 1 CTRL, Layer 2 and Layer 3 – As we have seen in the previous section, there are a number of efficiency savings in protocol stack implementation when targeting LTE for IoT. The reduced processing requirements can also lead to slower clock frequencies which in turn give energy efficiency improvements.
- Interrupt Controller: Fast interrupts coupled with real time response are required to service the low latency requirements of LTE.
- On Chip Memories: Smaller block sizes lead to small HARQ buffer requirements. Significant optimization of die area and on-chip memory requirements can be realized vs traditional LTE modems.
- Flash & DDR Memories – The memory footprint of the stack is optimized to be minimal in IoT applications and reduce the overall external memory requirements.
- System clock and process node – As the overall LTE baseband processing requirement is reduced, so the system clock can also be reduced. Designers have the opportunity to tune the system to operate on lower clock frequencies which in turn reduces the system power consumption. Also, by reducing the system clock speed, it also opens up the possibility to target LTE Modems to lower leakage energy efficient silicon process nodes.

As we can see above, there are a number of design optimizations that can be made to a traditional LTE modem to target it towards IoT. The design optimizations which lead to reduced processing and memory requirements in turn reduce to cost and power optimization, both of which are critical factors in IoT applications.

Conclusions

With the explosive growth in LTE deployments worldwide, cellular operators are looking increasingly for ways to leverage their investment in these networks into the rapidly expanding IoT sector. 2G GSM networks are reaching maturity and in many territories cellular operators are looking into re-farming the valuable 2G spectrum across to LTE, creating an increased urgency to deploy LTE technology into markets traditionally served by 2G.

Today, LTE is the fastest growing wireless standard in history with over 300 commercial networks already launched as of mid-2014 and LTE subscriptions predicted to reach 1.6 billion by 2018 [2]. With this huge worldwide investment and momentum building, network operators are looking at how they can leverage that investment into the rapidly growing IoT space.

Building on the success of LTE, 3GPP have defined a new profile of MTC in Release 12 specification to enable a new class of devices that exhibit low power and low cost vs traditional LTE devices, making the transition across from 2G a reality. The new specification offers designers the opportunity to optimize traditional LTE modems into the IoT space though a combination of software and SoC design enhancements.

This paper has taken the reader through the upcoming changes in the LTE standard and what that will mean in terms of device design and in turn the opportunities that it brings to network operators. ARM and Next-G bring a wealth of cellular experience into this exciting new area of connected devices helping device vendors and semiconductor companies develop market leading next generation devices ready for the cellular connected Internet of Things.

References

For more information on ARM please visit: http://www.arm.com
For more information on NextG-Com please visit: http://www.nextgcom.co.uk/

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