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Shaping Cellular IoT Connectivity

Emerging Technologies in Wide-Area Connectivity

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June, 2015

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1 Introduction

Creating networks of things is widely considered as the next engine for economic growth valued in the trillions of dollars. Yet creating the Internet of Things (IoT) is not a trivial activity as demonstrated by inflated expectations that have been slow to materialize as anticipated by market research analysts. The IoT market remains highly fragmented with multitudes of applications, each with its own set of requirements that adds constraints on the type of connectivity solution. While connectivity is only one element of the IoT ecosystem stack, it is a prerequisite to all other layers for without connectivity, IoT would not exist. From this perspective, IoT can only take off with the availability of cost effective connectivity solutions that meet both business case and the technology requirements of the applications.

One segment of IoT revolves around wide area connectivity of devices. Cellular technologies such as GPRS and 3G UMTS dominate this market today. Where these technologies have proved expensive, mesh solutions are used to create wide area networks based on relatively short connectivity segments. Satellite is used in remote areas where the business case works. In this paper, we discuss the emerging low-power wide-area (LPWA) connectivity technologies which have unique characteristics as they are purposely designed to meet wide-area IoT application requirements unlike the other technologies which are adapted for IoT. LPWA technologies are typically narrowband (with some exceptions) and operate in the ISM license-exempt spectrum bands. In recent months, GERAN and 3GPP standards organizations embarked on a process of standardizing narrowband technology for use in mobile spectrum. Several proponents of LPWA technologies have put forward their technologies. The competition in the standards race extends to 3GPP, where the roadmap for cost reduced LTE module for IoT applications is under development (LTE-M), and other standard organizations that are focusing on 5G technologies.

This paper is divided into two parts. The first is focused on technology where we provide an overview of narrowband LPWA technologies. We also discuss the roadmap for LTE-M to compare and contrast the solutions. The review of technology allows us to better understand the implications strategy, markets and ultimately the potential success of each approach. In the second part of the paper, we present a discussion on evolving market dynamics where high stakes are in play to determine the winners of the next round of market growth drivers.

In the context of this paper, we define 'device' as a connected object that excludes consumer electronics including smartphones, tablets, dongles, e-readers and such devices. We also use the term IoT instead of machine-to-machine (M2M) connectivity which is traditional in industry circles because we seek to emphasis an encompassing value proposition beyond connectivity.

2 Recent Developments in Cellular Device Connectivity

Cellular device connectivity constitutes a relatively small fraction of total connected devices – estimated at 243 million in 2014, or about 3.5% of total connected devices. The vast majority of these devices, 77%, use 2G GPRS which is a technology first commercialized in 2000[1]. The cost of 2G modules have dropped in recent years to reach about $10/module in volume while the cost of LTE modules are around $50. By 2020, 1 billion cellular connected devices are expected with 2G accounting for 44% of connectivity while 3G and LTE will account for 33% and 23%, respectively.

[1]*GSMA Intelligence, "Global cellular M2M technology forecasts and assumptions," March 2015.*

Applications of cellular connectivity remain concentrated in traditional applications such as transportation, automotives, and location management. Cellular 2G connectivity provides the benefit of world-wide coverage and almost-unified frequency spectrum allocation (900 MHz most of the world, 850 MHz in North America). The Embedded SIM technology (eUICC) simplifies the process of providing service through different operators which enables the mobility market. Nevertheless, there are limitations to cellular connectivity which LPWA addresses. These limitations fundamentally center on two key issues: high power consumption that does not allow battery operation over an extended period of time reaching into the years, and the cost of service which includes the cost of the device and the supporting infrastructure that factors into the return on investment for the service provider. The result is a bifurcation of wide area IoT technologies along three axes:

2.1 *LTE evolution:* LTE is fundamentally a technology for broadband connectivity. It was not designed to address connected devices. LTE consumes too much power and offers much higher capacity than required by many IoT applications. The modems are relatively expensive to integrate but into high-value applications with a good power supply such as a vehicle. The 3GPP standards body is addressing the shortcomings of LTE in IoT connectivity by incorporating enhancements in network access and defining new device categories that consume less power and reduce module cost by eliminating many of the broadband features such as multiple transceivers and antenna systems. New device categories include Category 0 (Cat0) which is defined in 3GPP Release 12 and sub-Cat0 which is in the process of being defined.

2.2 *LPWA technologies – unlicensed band:* Designed to cater to wide-area IoT connectivity, these technologies feature a protocol stack optimized for device access which typically consists of short messages sent in bursts. The physical layer is typically kept simple with low modulation scheme for robustness and low complexity. The medium access control layer is efficient with low overhead signaling in low data-rate, low network access periodicity use cases. LPWA technologies are designed for scalability on the order of thousands of devices per cell. They are deployed in license-exempt spectrum such as the ISM band (e.g. 902-928 MHz in North America, 866 – 870 MHz in Europe, 2400 – 2483.5 MHz world-wide). The LPWA market is dominated by startups and structured around verticals where two operational modes are emerging: private networks addressing a specific client, and public networks shared between different clients.

2.3 *LPWA technologies – licensed-band:* Although LPWA technologies are hardened against interference which is built into the protocol stack, licensed-spectrum operations enables greater assurance of reliability. Standardization coalesces focus on a technology, enables the creation of a wide ecosystem and improves economics. Availability of a standard gives service providers a greater incentive to enter the IoT market for new applications. For these reasons, standardization activities of narrowband LPWA technologies have began at GERAN, the standard body responsible for GSM standardization, and has recently moved to 3GPP where 3G and LTE are standardized – a very significant development with high implications on wireless operators IoT roadmaps. Semtech, SigFox, Huawei/Neul, Qualcomm have put forward proposals to meet GERAN guidelines for narrowband IoT connectivity. We review these technologies later noting that there are some differences from the original unlicensed-band technologies in order to accommodate new requirements for compatibility with cellular networks operating in licensed spectrum.

The nascent LPWA market is set to disrupt the scene with mobile network operators taking different positions on how to address these upcoming technologies. Market forecasts for LPWA vary between a low of 1 billion and a high of 3 billion connected devices by 2020, most of which in North America, Europe and the Asia Pacific region deployed in lead applications including smart cities, smart buildings, agriculture & environment, and utilities.

While LTE-M falls along the preferred roadmap for MNOs, its availability is later than LPWA technologies; and even when it becomes available, it would not meet all the requirements for wide-area IoT connectivity. LPWA in unlicensed bands represent a departure from the modus operandi of MNOs which revolves on licensed spectrum, reliability and personal broadband connectivity to which the core network and support systems are designed to for. Finally, LPWA in licensed spectrum appears as an attempt to harmonize the first two axes, but there are doubts that it would provide true differentiation from LTE-M, or even beat the timelines of LTE-M which may leave it with little market relevance. In fact, some contend that licensed-spectrum LPWA is a decoy against unlicensed spectrum LPWA. How the market will shape up in the coming months and years and what moves the different ecosystem players are making to assure a position in an emerging sector is beyond the scope of this paper. But we would provide some of the context for further analysis by covering essential elements of technology roadmap for LTE and a four LPWA technologies submitted for standardization at GERAN.

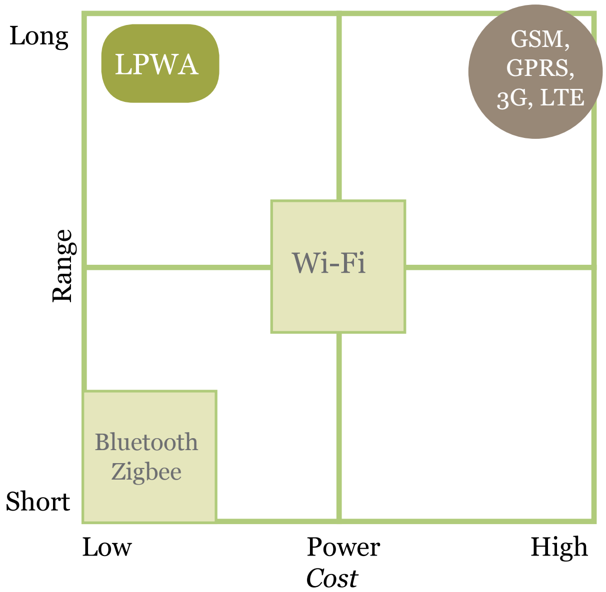

Figure 1: IoT connectivity technologies feature matrix.

3 LTE IoT Connectivity

The early LTE specifications defined in 3GPP Release 8 and 9 are focused on meeting requirements for mobile broadband connectivity in macro cellular network topology. 3GPP Release 10 first introduced the low access priority indicator (LAPI) to enable congestion and overload control mechanisms where the network can, for example, reject or delay connection request from low-priority devices in a congestion scenario. This is followed in Release 11 by incorporating architectural improvements that include the introduction of new functional entities for device connectivity (M2M-IWF and M2M-AAA) and eliminating the requirement for a phone number (MSISDN) in favor of IPv6 identifier.

LTE Release 8 through 11 presents several challenges for device connectivity:

- Range: insufficient system gain to reach deep into buildings and basements particularly for stationary devices.
- Complexity: multiple transmit and receive antenna configuration that is costly for IoT applications.
- Scalability: cannot support high number of devices which impacts the business case.
- Power: high power consumption does not allow operating on battery for extended periods
- Inefficiency: high signaling overhead in relationship to the amount of transmitted data for many applications.

LTE Release 12 begins to address these shortcomings by defining a new category of devices termed Category 0 targeted for device IoT connectivity. Some of Release 12 features include the following:

- One receive (Rx) antenna compared to a minimum of 2 Rx antennas for other device categories which reduces cost and complexity at the expense of losing diversity reception.
- Limited peak data rate to 1 Mbps in downlink and uplink in comparison with peak rate of 10 Mbps/5 Mbps in DL/UL for Cat1 device which is the lowest category of non-M2M LTE device. This is accomplished by reducing the transport block size.
- Optional half-duplex FDD mode that reduces the cost of the modem by eliminating a few hardware components (e.g. duplexer, switches).
- Enhanced Power Saving Mode (PSM). A device remains registered on the network but not reachable in PSM mode which eliminates registration setup and connection signaling. This optimizes modem turn-on for device-originated data or scheduled transmissions. It improves battery life and reduces overhead signaling.
- Extended Discontinuous Reception (DRX). DRX is designed for paging mobile user devices accounts for large amount of device power consumption. Increasing the DRX/paging cycle reduces energy consumptions by increasing the length of the sleep cycle but lowers device responsiveness which is acceptable in many IoT applications.
- Reduced Tracking Area Updates (TAU) and measurements for stationary devices.

While Rel-12 Cat0 device brings performance improvements for IoT applications, it is considered as a stepping stone for further improvements. Currently, a new device category is being defined as part of Release 13 specifications. It promises further reduction in complexity and cost by reducing the channel bandwidth to 1.4 MHz, lowering the data rate and reducing transmit power among other modifications to the protocol stack. It also targets improving the system gain by 20 dB over that for current 2G and 4G devices (typical maximum coupling loss of 140 dB) to over 160 dB maximum coupling loss.

Table 1 Feature list comparison for different UE categories. [Adapted from RP140845]

	Rel-8 Cat-4	Rel-8 Cat-1	Rel-12 Cat0	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 DL spatial layers	2	1	1	1
Number of UE RF receiver chains	2	2	1	1
Modulation DL/UL	64 / 16 QAM	64 / 16 QAM	64 / 16 QAM	
Transport block size DL/ UL (bits)	150752/51024	10296/5160	1000/1000	
Duplex mode	Full duplex	Full duplex	Half duplex (optional)	Half duplex (optional)
UE receive bandwidth	20 MHz	20 MHz	20 MHz	1.4 MHz
Maximum UE transmit power	23 dBm	23 dBm	23 dBm	~20 dBm
Modem complexity relative to Cat-1	125%	100%	50%	25%

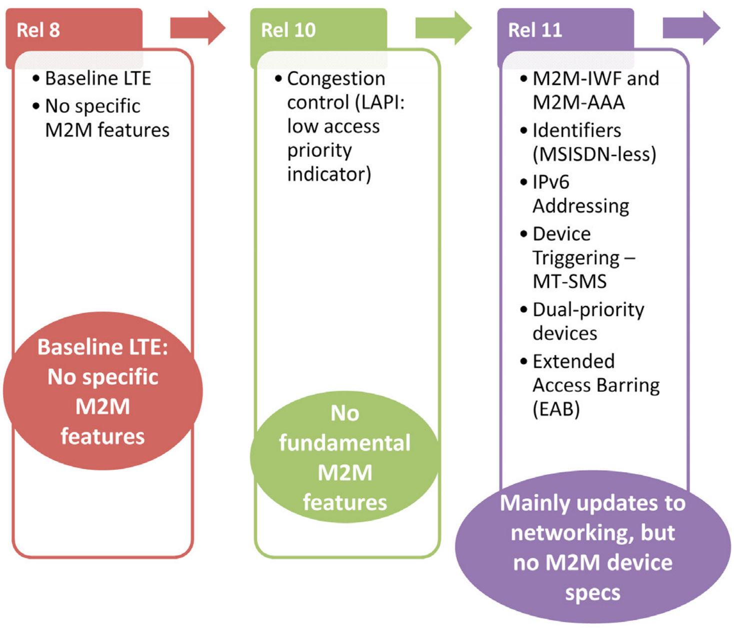

Figure 2: LTE roadmap to support machine-type communications.

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4 LPWA in Licensed Bands

4.1 Semtech – LoRa Technology (Long Range)

The proposal by Semtech to GERAN revolves on adapting the current LoRa technology which operates in sub 1 GHz ISM bands. The LoRa technology defines two physical layer modes:

1. Narrowband mode targeted at fixed devices.

2. Chirp spread spectrum (CSS) targeted at mobile devices and devices embedded deep into buildings. This mode provides positioning information at the cost of lower spectral efficiency than narrowband mode.

Both physical layer modes operate in 200 kHz channel bandwidth similar to GSM. In the narrowband mode, the uplink is divided into 72 channels of different bandwidth ranging from 400 Hz channel placed at the band edge to 12.8 kHz placed at the center of the band. The downlink is divided into 28 channels the narrowest is 3.2 kHz placed at the center of the band and the widest is 12.8 kHz at the center of the band. All channels uses GMSK modulation scheme similar to GSM. The downlink includes a spread-spectrum beacon signal used for fast device frequency and timing acquisition. It also carries information that enables downlink multicast service.

The CSS mode allows a frequency reuse of 1. It features variable spreading factors from 32 to 4096 with a chip rate of 125 Ksps. This mode provides positioning capability by locating uplink transmissions received by multiple BTS using time difference of arrival (TDOA) techniques with 10 – 100 m accuracy.

The LoRa narrowband mode provides for over 160 dB maximum coupling loss whereas the CSS mode provides lower MCL that tops at 160 dB.

4.2 SigFox Cooperative Ultra Narrowband (C-UNB)

SigFox technology in the uplink is based on ultra-narrowband channels of 160 Hz called ad-hoc micro-channels. There are 1250 such micro-channels in 200 kHz bandwidth where each micro-channel has a pseudo-random center frequency in the full 200 kHz band. Each micro-channel is modulated with D-BPSK to leverage existing sub GHz radio chipset market for low cost devices. The data rate per micro-channel is 160 bps. In the downlink, the subchannel bandwidth is 600 Hz channels with bit rate of 600 bps using 2GFSK modulation scheme. C-UNB is primarily an uplink technology as the MAC PDU support between 7 – 25 bytes in the uplink and 1 – 8 bytes in the downlink.

The device randomly selects three uplink micro-channels and transmits three repetitions of the data to increase robustness. C-UNB does not support device attachment to any base station and the device transmits without knowing which base station is in its range. All base stations listen to the same 200 kHz band. This allows for cooperative reception by multiple base stations where a message sent by a device is received by one or more base stations.

Transmission in the downlink is based on ‘time-delayed piggy-backing’ where downlink packets are stored in the core network and forwarded to the device after an uplink transmission. C-UNB does not support a paging mechanism and there are no means to wake up a device to push downlink packets towards it. In the case of multiple receptions by several base stations, the core network selects the most appropriate base station for transmitting the downlink packet. There is no MAC-level acknowledgement in C-UNB which is left for applications to implement and manage through the application server.

C-UNB provides about 164 dB maximum coupling loss in both uplink and downlink with 24 dBm and 34 dBm transmit power, respectively.

4.3 Huawei/Neul

Neul has been developing its own IoT access protocol called Weightless which targeted TV whitespace bands in its broadband version and ISM band in its narrowband version. After the acquisition by Huawei, Neul proposed to GERAN a narrowband technology to slot into existing GSM channel allocations as well as potentially into LTE guard bands that are created by the null sub-carriers.

The uplink physical layer consists of 36 uplink sub-channels of 5 kHz for total channel bandwidth of 180 kHz. Each sub-channel is individually modulated with D-QPSK, D-BPSK or GMSK. Uplink sub-channels can be bonded by x2, x4 or x8 sub-channels and are used in a similar manner to OFDMA technology. The maximum data rate for a bonded sub-channel is 45 kbps (minimum per channel is 250 bps).

In the downlink, each 180 kHz channel is divided into 12 downlink sub-channels spaced by 15 kHz. Each sub-channel is individually modulated with BPSK, QPSK or 16QAM. The maximum data rate per sub-channel is 36 kbps for a total downlink rate of 432 kbps (minimum data rate per sub-channel is 375 bps). One downlink channel is reserved for synch /broadcast for network acquisition.

4.4 Qualcomm – NB-OFDMA

This access technology features narrowband OFDMA in the downlink and SC-FDMA in the uplink similar in many ways to LTE. The 200 kHz channel is divided into 72 active sub-carriers of 2.5 kHz in bandwidth with 10 kHz guard band at either end of the channel. This results in relatively long symbol size, where a single NB-OFDMA symbol is as long as 6 LTE symbols. In the time domain, the frame length is 1 second which is divided into a number of slots. The downlink includes a total of 171 slots (163 normal which carry data and 8 special slots for synchronization). The uplink includes two frame structures: structure 1 for normal cells with radii less than 8 km and structure 2 for large cells with radii up to 35 km. Uplink frame structure 1 consists of 142 normal slots and 24 extended slots where as frame structure 2 consists of 137 normal slots and 24 extended slots. NB-OFDMA allows for sub-carrier hopping to average inter-cell interference and to allow frequency reuse one deployment where all sub-carriers are used in every cell.

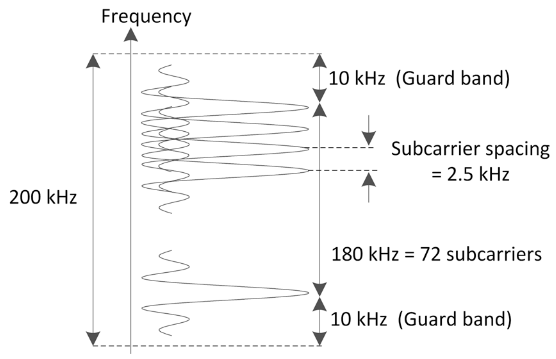

Figure 3: NB-OFDMA downlink and uplink frequency domain structure. [Source: Qualcomm]

NB-OFDMA provides about 164 dB of maximum coupling loss with BPSK modulation to the cell edge.

5 The Implications

Wide-area IoT access technologies approach device connectivity from opposing directions. From one direction, LTE-M strips out many of the features required for mobile broadband connectivity to reduce cost and better match IoT application requirements especially for stationary devices. For example, LTE-M reduces channel bandwidth, defines single antenna operation, modifies medium access control layer to meet the intermittent, low data rate characteristics of many IoT applications. However, many of the fundamental design aspects of LTE cannot change which limits the extent to which LTE can be adapted to meet IoT application requirements.

From another direction, LPWA technologies are designed from the start to cater to IoT applications with an optimized air interface. LPWA are optimized for intermittent low-data rate transmissions. The access protocol is designed to support a large number of devices without coordination from the base station (or gateway) and build redundancy in transmissions to increase the robustness and reliability of the link. The access to the air interface is not scheduled, but rather based on contention which is typical of many systems operating in license-exempt spectrum. LPWA technologies build a higher system gain than today's GSM and LTE systems for longer reach, a feature that the evolution of LTE for machine communications is working to address.

In the balance, there are tradeoffs between these technological approaches that can only be viewed within a larger context that is not limited to the air interface. Some considerations include the following:

The network 'backend'. This is a general term we use here to denote functions such as network control and management, device management, billing, security, and other such functions that are required for both operational and business processes. These are critical functions that have been in development for many years by service providers and are optimized for consumer services. Adapting these functions for IoT applications carries both advantages and disadvantages for established mobile operators. On the other hand, LPWA systems are relatively new and the network backend remains fragmented and does not measure to the same level of maturity as that of the mobile network. However, there is no burden of legacy which provides an opportunity to define optimized systems and solutions in this space.

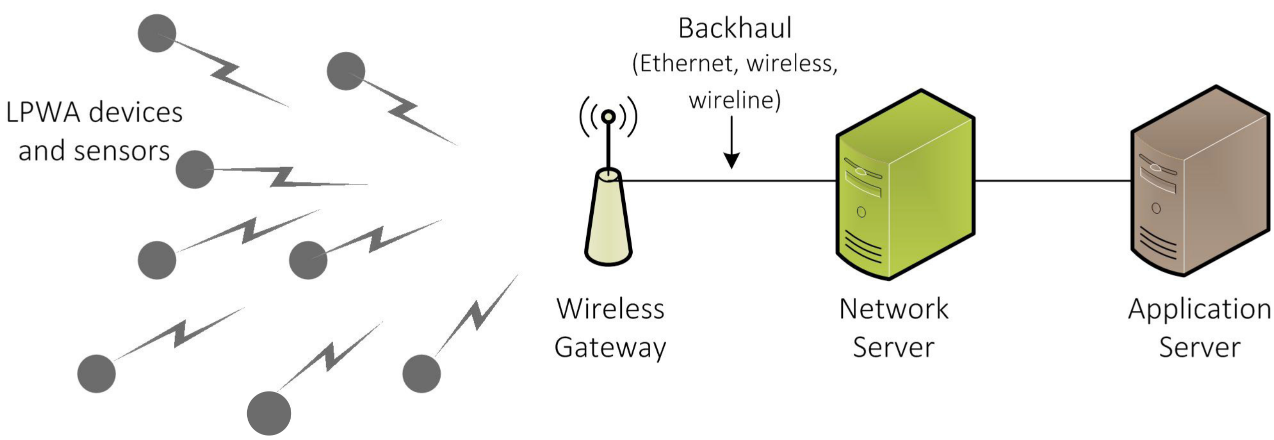

Figure 4: LPWA networks architecture.

We foresee a significant degree of innovation related to the LPWA network core/backend coming to market over the next 2-3 years. This is primarily due to 2 reasons: First, the Greenfield nature of LPWA networks provides an opportunity to design solutions taking full advantage of cloud services delivery models, data management architectures and intelligent data processing technologies; and second, the relative decoupling from the 3GPP protocols/standards that have led to very specific product and solutions architectures in the core of the network.

With legacy constraints relaxed, the new core/backend solutions will emphasize agility, costs elasticity and scaling efficiency, which in turn will allow the delivery of IoT-centric services with superior cost/value economics. They will also tackle the challenges around IoT service security and synergistically integrate the network into the value chain of different industry verticals.

This will be a space to watch closely especially as LPWA technologies are set to bifurcate as they are brought under the 3GPP umbrella to accommodate mobile network operators. As LPWA solutions converge towards industry standards, the resulting core is likely to be different from the solutions deployed today. It is this combination of alternative wireless access technologies, as is the case with LPWA, along with fundamentally different core/backend systems, that would enable the business case for the deployment of certain IoT services.

Spectrum. Sub 1 GHz licensed spectrum is expensive and owned by mobile network operators. 2G technologies typically operate in older grants of this spectrum while newer grants represented in digital dividend spectrum typically operate LTE. Whatever the case, operators around the world plan to refarm this spectrum to LTE eventually as 2G and 3G technologies near their end-of-life cycle (for example, in the United States, AT&T will turn off 2G while European operators will tend to turn off 3G first). Hence, narrowband technologies will have to coexist with LTE in a defined spectrum or operate in unlicensed spectrum such as the ISM band. MNOs have based their business model on service reliability and high availability would seek to deploy IoT solutions in licensed spectrum bands as there's always the risk that interference in license-exempt spectrum would reduce reliability and service availability. This is bound to raise the cost of service. On the other hand, LPWA technologies are designed to deal with interference by defining an air interference with greater tolerance, redundancy and robustness than cellular technologies as it supports low data rate. These two approaches are bound to collide although they can be viewed as complementary whereby applications with intermittent low data rate can use license exempt spectrum leaving applications requiring frequent access with service assurance to use licensed spectrum.

The business case. A critical challenge in enabling IoT service has been validating the return on investment. Assessing the costs and benefits of IoT is a challenge due to many reasons that transcend the cost of the module which has been the focus on the telecom industry. Enabling IoT requires integrating connectivity to derive intelligence from which value is extracted. Connectivity is fundamental but it is not the sole driver for adoption. Yet, connectivity introduces both capital (system integration) and operational expenditures that must be accounted for by the user. The cost of connectivity is then a key hurdle that must be cleared. The lower the cost of connectivity, the fewer objections or hurdles IoT would face.

While a comprehensive overview of the business case is beyond the scope of this whitepaper, we touch upon the cost of the device which, as stated, has been a focus for the industry. The general requirement for narrowband technologies as specified by GERAN and 3GPP is below $5/module.

Several LPWA system and module providers claim meeting this number and reaching values as low as $1 in large volumes. This is a drastically different from the cost of cellular devices where as we mentioned a GSM/GPRS module costs around $10 and an LTE module close to $50.

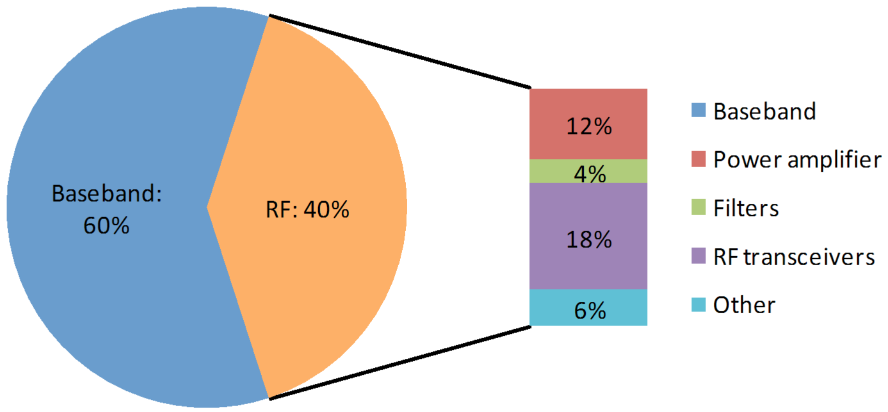

Figure 5: Cost structure for IoT devices.

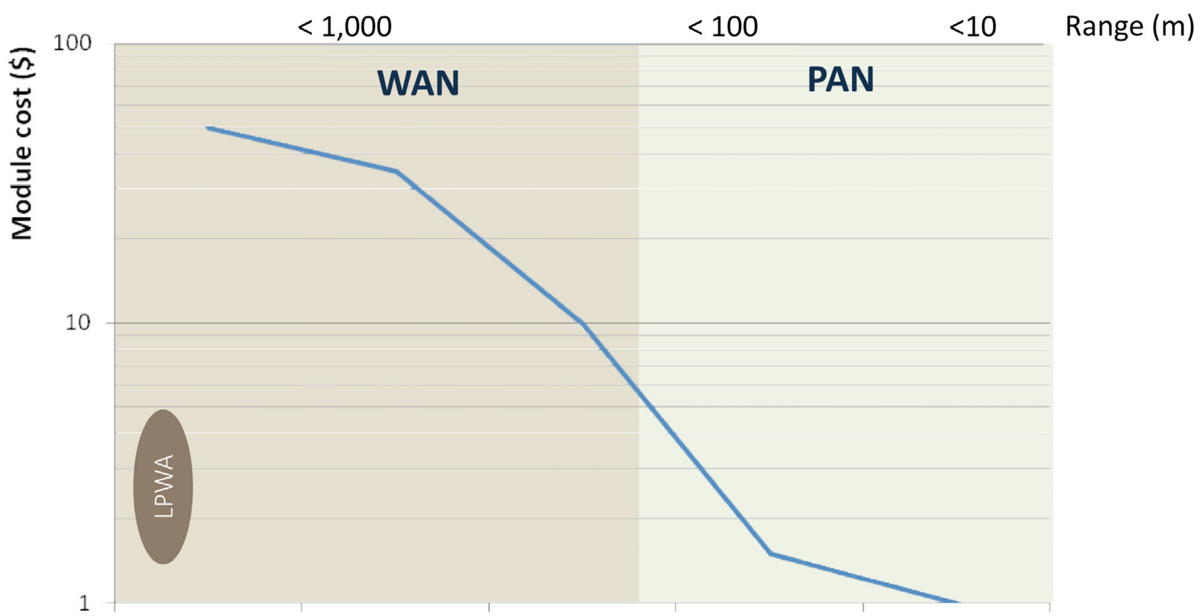

Figure 6: Device cost in IoT applications.

Mobile network operators rely on an existing framework for providing service while LPWA challenge this framework with new operational and business models. While legacy systems provide an advantage in the short term, they fail to meet long-term objectives. This is where the opportunity for LPWA lies provided it can prove a positive business case and sufficient operating performance. MNOs that would have the capability to deploy LTE-M will need to carefully weigh their options as their cost structure may exceed the threshold required to enable some IoT applications, especially ones based on very low and intermittent data rates. On the other hand, LPWA operators would need to ensure that the business model and cost of service will lead to profitability.

Table 2 Comparative assessment of wide-area IoT technologies.

	Advantage	**Disadvantage**
LTE-M evolution	• Existing ecosystem of operators • Ability to leverage existing LTE network operation processes and framework for core network (upgrade still be required) • Licensed spectrum • Higher throughput performance • Reliability and service level agreements • Established infrastructure	• High cost base (capex & opex) • Short range • High power consumption (in relationship to narrowband technologies)
Narrowband technologies / LPWA	• Designed for IoT device connectivity requirements: - High system gain for long range and fewer sites - Efficient medium access control layer - Efficient power management for long field operation on batteries • Business models and pricing schemes aligned with IoT business case requirements • Low cost of devices and service • Scalability to support high number of devices	• Nascent and evolving ecosystem • Fragmentation: many technologies vying for prominence • Spectrum: license-exempt spectrum raises questions on reliability of service • Unproven: LPWA has few deployments today. Scalability, business model, and many other factors remain to be validated

6 Concluding Remarks

Wide-area IoT connectivity is on the cusp of a major shakeup that will unfold in the next few years. The shortcomings of today's cellular technologies are evident with the limited proliferation of wide-area IoT and the potential opportunities that new technologies can unleash. IoT services are fundamentally different from consumer broadband services. Yet, the wireless industry has primarily worked at retrofitting existing network and service models designed for consumer broadband to running M2M/IoT networks with limited success to date. Narrowband or LPWA technologies are designed from the ground up to cater to low-power, low-data rate, and longevity in the field. They are also designed for high scale and long range to enable a better business case in comparison with existing cellular technologies. LPWA powered by new core/backend technologies provide a new way for delivering services that is better optimized to the application requirements. However, cellular technologies have key strength in an established and vibrant ecosystem, licensed spectrum, and an infrastructure on which to build and evolve which the LPWA ecosystem is working to create. Cellular technologies are advancing to support device communications along their own roadmap. These trends are creating interesting dynamics as the boundaries for collaboration and competition are being defined with high stakes to decide the winners for a market valued in the trillions of dollars.

7 Acronyms

2G	Second generation
3G	Third generation
3GPP	Third Generation Partnership Project
4G	Fourth generation
AAA	Authentication, Authorization, and Accounting
BPSK	Binary phase shift keying
Cat	Category
CSS	Chirp spread spectrum
C-UNB	Cooperative Ultra Narrowband
D-BPSK	Differential binary phase shift keying
D-QPSK	Differential quadrature phase shift keying
DRX	Extended discontinuous reception
eUICC	embedded Universal Integrated Circuit Card
FDD	Frequency division duplex
GERAN	GSM EDGE radio access network
GFSK	Gaussian frequency shift keying
GMSK	Gaussian minimum shift keying
GSM	Global System for Mobiles
IoT	Internet of Things
ISM	Industrial Scientific Medical
IWF	Interworking function
LAPI	Low access priority indicator
LoRa	Long Range
LPWA	Low power wide area
LTE	Long Term Evolution
LTE-M	LTE Machine
M2M	Machine to machine
MAC	Medium access control
MNO	Mobile network operator
MSISDN	Mobile Station Integrated Services Digital Network
NB-OFDMA	Narrow-band OFDMA
OFDMA	Orthogonal frequency division multiple access
PDU	Packet data unit
PSM	Enhanced power saving mode
QAM	Quadrature amplitude modulation
QPSK	Quadrature phase shift keying
Rel	Release
Rx	Receiver
SC-FDMA	Single carrier frequency division multiple access
TAU	Reduced tracking area updates
TDOA	Time Difference of Arrival

8 The Xona Partners Team

Xona Partners (Xona) is a boutique advisory services firm specialized in technology, media and telecommunications. Xona was founded in 2012 by a team of seasoned technologists and startup founders, managing directors in global ventures, and investment advisors. Drawing on its founders' cross functional expertise, Xona offers a unique multi-disciplinary integrative technology and investment advisory service to private equity and venture funds, technology corporations, as well as regulators and public sector organizations. We help our clients in pre-investment due diligence, post investment life-cycle management, and strategic technology management to develop new sources of revenue. The firm operates out of four regional hubs which include San Francisco, Paris, Dubai, and Singapore.

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