IoT : The Era of LPWAN is starting now

Jean-Paul Bardyn, Thierry Melly, Olivier Seller, Nicolas Sornin.
Wireless and Sensing Business Unit
Semtech

***Abstract*—This paper focusses on LPWAN segment of IoT, describing network constraints and comparing existing and upcoming solutions in unlicensed and licensed frequency bands.**

Keywords—IoT; LPWAN; UNB; NB-IoT; Spread Spectrum, LoRa.

I. INTRODUCTION

IoT (Internet of Things) is a hot topic which is keeping the internet community very active. There is no doubt about the market opportunity being tremendous. This is leading to a lot of marketing buzz, each player willing to position his technology or approach as being the best solution. For a new comer in this field, it is difficult to build a well-balanced thinking since data used to promote solutions sometimes appear to be incorrect or reports are biased. This paper is an attempt to provide an overview of the LPWAN (Low Power Wide Area Network) segment of the IoT in Europe, comparing main competing technologies and solutions on a rational basis.

II. LPWAN IN IOT

"IoT" term covers every object that can be connected to the Internet using any kind of radio link. The IoT landscape is broad containing objects with data rates from a few bps to Mbps. Ranges can also spread from less than a meter up to more than a kilometer. Wireless communication can operate into licensed bands or unlicensed bands. LPWAN is covering low-power long-range applications, meaning a range exceeding a few kilometers and data rates from 10bps up to a few kbps. Most of LPWAN applications will be new ones, LPWAN technologies connecting objects for which no practical connectivity solution existed.

A. Main characteristics of a LPWAN network

LPWAN will cover a wide scope of applications but there are common requirements that should guide the design of a LPWAN network.

- Ultra low-power operation of the object is a must to avoid costly battery change and even no battery at all is very welcome. The environmental impact of changing batteries on billion devices would be terrific. Coin cell batteries also have limited life if current peaks exceed 30-50mA, meaning that achieving the required range through high RF output power is to be excluded.
- Economic constraints are a strong driver. Deployments should be cheap for wide acceptance; this means low cost objects, no SIM card or equivalent, easy network installation and minimum maintenance. Hardware and software complexity of the objects have to stay very limited, meaning simple architectures and simple protocols. Expensive components in the Bill Of Material (BOM), like TCXO or SAW filters, should be avoided.
- The activity level may vary from application to application but to limit the power consumption, the network should not require the object to wake-up unless there is a need to send or receive data. This, in principle, would reject any kind of synchronized network or meshed network, making ALOHA [1] the preferred medium access method. A non-cellular star network configuration is usually chosen.
- Network infrastructure should be easy to deploy at nationwide level, with good overall coverage and possibility to move across countries. Adding infrastructure and adding a new object to the network should be simple tasks. The protocol should align to some kind of standard to maximize availability of objects and seamless connectivity. An efficient downlink is welcome to enable efficient network management through for instance Adaptive Data Rate (ADR) or Transmit Power Control (TPC).
- Data transfer between object and final data user should be fully secured. Network operator should not be able to get access to meaningful data. As part of security, RF link should also be robust against jamming.
- In most applications, it is a valuable adder if the object can be easily localized, preferably without power-consuming GPS.
- Objects are generally not moving or slow-moving but may be positioned in environments having fast moving channel characteristics, like being next to a road. Modulation should be robust to some possible fading.
- From an application perspective, objects will provide data that will be used to build a large variety of services, either directly or through complex data fusion and machine-learning processes.

B. LPWAN requires a full ecosystem

To operate properly, LPWAN requires objects, network infrastructure, protocols, network controllers, network servers, application servers and user interfaces. This can be offered as a full turnkey solution proposed by a single player (e.g. SigFox) or as multiple vendor offerings relying on intense cooperation between various companies offering services around a common open concept (like e.g. LoRaWAN™ pushed by the LoRa Alliance [2]). Drivers can be telecom operators whose main interest is to sell connectivity or enterprise solution providers focusing on delivering services. Open solutions like

978-1-5090-2972-3/15/$31.00 ©2016 IEEE

LoRaWAN™ can even support viral deployments and local private community networks.

C. *Licensed or unlicensed bands ?*

The mobile wireless players have great interest to develop new standards for LPWAN connectivity for expanding their market. 3GPP RAN is taking care of defining the next steps of the wireless broadband connectivity solutions into licensed bands. IoT is part of their thinking and the last release 13 includes preliminary definitions of LPWAN solutions mainly based on 4G-LTE extensions (e.g. LTE Cat-M and NB-LTE). Licensed bands are expensive for operators, in the order of several hundred thousand Euros per kHz bandwidth per country. LTE-based IoT objects will also follow the 4G approach using the concept of SIM cards (or e-SIM) for security, which will lead to a cost adder to every object. Deployments will progressively start in 2017-18, with some early announcements for end 2016. While providing LPWAN service as an extension to the 4G-LTE network, operators want their IoT deployments to be firmware update to their most recent network investments. Solutions will carry part of the complexity of the 4G-LTE software and hardware architecture, meaning inherently more complexity, cost and power than objects connected to a network operated in unlicensed bands. Geographical coverage of 4G networks is also generally limited to dense urban areas, leaving rural zones with little or even no coverage at all, meaning exclusion of services like smart farming or environmental control. But objects will benefit from a better Quality of Service (QoS) thanks to well-proven security scheme and guaranteed latency.

Many players tend to put these solutions in competition to LPWAN operated in unlicensed bands. In fact, the target markets are mostly different, operation in licensed bands being more valuable for selected professional services and unlicensed bands providing generally better coverage, lower power and lower cost, at the expense of a lower QoS and no guaranteed latency. Most telecom operators understood this complementarity and are taking advantage of the earlier time to market through existing LPWAN solutions in unlicensed bands.

D. *Location services: RSSI, TDOA or GPS*

Most of the applications (estimate is 30-70%) will require or benefit from some form of location capability. GPS offers a reliable solution for outdoor location at the expense of additional hardware and power consumption. Some LPWAN - assisted GPS solutions are coming which significantly reduce time to fix under cold start conditions, by pushing most of the calculation to the cloud, hence lowering power impact on the end-node.

Infrastructure-based location is possible using RSSI, knowing location of the network base stations. This is usually not precise enough and the best achievable accuracy is generally around 25% of the average distance between base stations.

Measurement of TDOA (Time Difference Of Arrival) between an end-node and multiple precisely synchronized base stations can be used to locate an object with reasonable accuracy, even penetrating buildings. The achievable accuracy is inversely proportional to channel bandwidth and cannot be applied to narrow band networks. A minimum of 100 kHz of bandwidth is needed to approach less than 50m intrinsic accuracy (excluding radio multipath effects). As a comparison, simple GPS receivers achieve a few meters accuracy with a signal bandwidth of 1MHz.

III. LPWAN SOLUTIONS IN UNLICENSED BANDS (EUROPE)

To compare the different solutions and understand some performance constraints, it is important to have a quick look at regulations on ISM bands which are used for LPWAN. We shall limit to Europe, i.e. ETSI rules, to simplify the comparison.

A. *Choice of unlicensed frequency band*

2.4GHz is an attractive band since regulations are mostly applicable for a worldwide deployment and the physical size or antenna is compatible with small objects. Players like Ingenu in USA made this choice. The main drawback of this band is the poor propagation. At 1km distance, Hata modeling shows a typical difference of 15dB in attenuation between 868MHz and 2.4GHz, the latter being also less efficient in penetrating inside buildings. The lower end of the spectrum offers possibility around 169MHz, not practical due to the antenna size. The 433 MHz range used in many consumer and automotive applications is limited to 10mW but is crowded. The best choice with wider acceptance across Europe is the 863-870MHz band (see [3] ERC/REC 70-03 recommendation for more details). In most of this band, power is limited to 25mW (or 14dBm) and a duty cycle of 0.1%. The 868-868.6MHz band benefits from an extension to a 1% duty cycle and the 869.4-869.65MHz from an extension to 500mW (or 27dBm) with 10% duty cycle. The latter is often used for downlinks (base station to object).

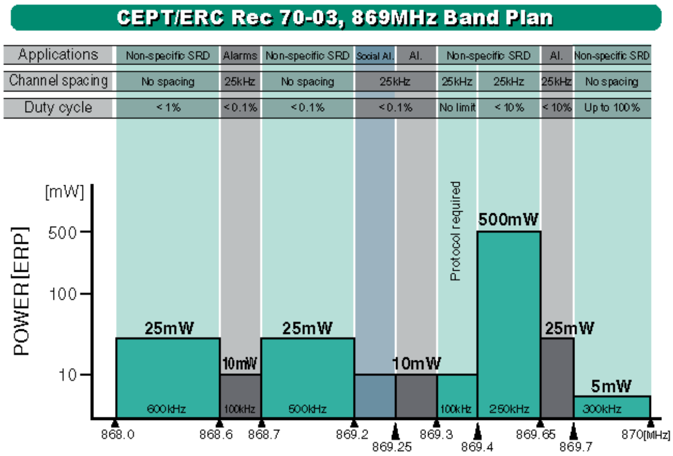

Fig.1. Unlicensed band in Europe in the 868-870MHz

B. *Typical budget links*

For the uplink (object to base station), objects are limited to 14dBm output power. To achieve the high budget link of around 160dB needed to reach a few kilometers range, network base stations are using high sensitivity receivers and are equipped with high gain antennas. Downlink benefits from the 869.4-869.65MHz high power high duty cycle band to compensate for the lower sensitivity and small antenna on the low power end point. It must be noted that network operation is usually highly asymmetrical. Most of the data flow is using uplink. Downlink is mainly used for network management and object control, even sometimes for Over-The-Air (OTA) firmware updates when bandwidth is high enough.

C. Ultra Narrowband (UNB) solution to long range

UNB solutions make use of narrow RF channels to provide higher sensitivity and long range at the expense of limited data rates – typically below a few hundred bps. The demodulated spectrum is much wider than individual transmissions, so that multiple uplinks can occur simultaneously. The advantage claimed is simplicity and low cost implementation of the object while the base station is carrying complexity to decode multiple narrow band channels simultaneously without knowing exactly the exact frequency of these channels. As any technology, UNB suffers from some limitations.

1) Uplink characteristics

For sake of simplicity, modulation used for each narrow band channel is usually Differential Binary Phase Shift Keying (D-BPSK) which permits easy demodulation while not being sensitive to absolute phase errors.

In a pure ALOHA communication channel, objects are sending only one message at a time, using a fixed frame length and uplink attempts are occurring randomly following a Poisson distribution. Under these conditions, and to limit collision rate to battery friendly levels, a single channel will only be able to handle 5 to 15% of the maximum achievable throughput (see [1]). For total of e.g. 200kHz receiving bandwidth on the base station, using 200Hz narrow band channels to meet 100bps data rate for uplinks, the total number of available independent channels should be one thousand. But this would require a frequency reference on the end node better than 25Hz/868MHz = 0.03ppm accuracy over long-term, which is not achievable for low-cost objects. Considering then possible collisions between uplink transmissions being randomly distributed in carrier frequency over the total receiving bandwidth, the pure ALOHA throughput will be further reduced. The reduction is essentially a factor of two compared to ALOHA, as 2 dimensions become available instead of 1 for collisions.

Such an UNB network is usually designed to operate with minimal number of base stations and maximum range capability for end points. That means that all objects will transmit at maximum power and the ranges for base stations will be adjusted to slightly overlap. Fixed points objects being at the limit of a base station range will always be received at low SINR. Objects closer to the base station will benefit from drastically larger SINR. Depending on the receiver adjacent channel rejection capability, end-node transmitted spectrum width and phase noise, base station may not be able to receive a frame with low SINR being 2000Hz apart from the higher SINR neighbor. Low SINR nodes can be considered as weak nodes since they always experience low SINR due to distance to base station, and only them experience this kind of collisions. This introduces further limits in the actual throughput of the network, because protecting weak nodes only consists in limiting the total number of nodes.

A typical payload in a UNB network is around 12 bytes which converts to around 25 bytes when added to necessary network management information. A typical frame duration is then around 2s. Any aggressive burst exceeding the duration of a bit (10ms) will impact frame integrity. CRC encoding is used to reject frames containing errors. Then packet needs to be resent, leading to lower network capacity. As for example, SigFox are resending frames three times to compensate for lost frames, leading to a total of 6s per payload frame. Objects are then allowed to send up to a maximum of 6 frames per hour to comply to the maximum 1% duty cycle on selected channel.

There are a lot of discussions about the extremely large capacity offered by an UNB network but these mostly use simplistic calculations to justify the approach. Only a statistical simulation taking into account random behavior of the objects, over time and frequency, including performance limitations of base station receivers, can give a realistic understanding of the actual capacity which may be significantly lower than rough estimations.

Another limitation of UNB network is QoS related to fading. Due to the inherent coherent demodulation of D-BPSK, receiver is sensitive to phase shift over the bit duration. Usually, most the IoT objects are either fixed or slow-moving, which should minimize the impact. For successful demodulation, an object should not change phase across the bit duration by more than $\pi/4$ over 10ms, due to Doppler effect. This leads to a maximum variation of speed of around 10km/h. In the presence of strong multipath, varying fading conditions due to a moving object or a quick change in the environment can lead to frame errors. As an example, an object residing close to a highway with fast moving reflectors beside (cars or trucks) may be difficult to reach even if it is fixed. A moving bicycle in urban environment could face similar limitations.

2) Downlink characteristics

Downlink benefits from the authorized higher output power and duty cycle and can also use antenna with larger gain. As a result and in order to maximize capacity, larger bandwidths and more traditional modulation schemes are used (e.g. SigFox using 600bps using GFSK). An object must be reachable on a precise demodulation frequency. In order to minimize power consumption, networks are designed to minimize listening time of objects, by opening a receive window immediately after transmit. The base station adjusts its frequency to the crystal of the object during receive and then uses this to send the downlink message at the right frequency. This introduces some requirement on short-term frequency stability of the object in the order of a few tenths of ppm over a few tens of seconds. This requires the use of Temperature Compensated Crystal Oscillators (TCXO), putting some cost and power consumption penalty on the object.

To close this chapter about UNB, it is interesting to roughly evaluate the battery lifetime of an object. Let’s consider a CR2032 lithium disposable battery which can deliver up to 150mAh at 3V if current peaks are under 50mA. Typical recent general purpose D-BPSK transceivers are using 10mA in receive mode and 30mA in transmitter mode at 14dBm output power. An object sending 6 messages per day using previous network scheme would last for approximately 1 year with a

CR2032 battery. This could be extended easily to 5 years by using an AAA size alkaline battery with proper power management.

D. Spread Spectrum – LoRa™ modulation

This section will illustrate the benefits and drawbacks of the Spread Spectrum modulation with focus on the LoRa™ modulation which is the most widely used Spread Spectrum technology for IoT in the sub-GHz band.

1) LoRa™ modulation basics [9]

Shannon-Hartley theorem indicates that an increase of the transmission channel bandwidth is a way to overcome a poor SNR. This is the basis of different spread spectrum techniques like Direct Sequence Spread Spectrum (DSSS) which multiplies the wanted data signal by a spreading code at much faster rate than the data signal, spreading the original data bandwidth over a larger resulting bandwidth. DSSS inherent complexity presents some implementation challenges when dealing with battery operated low cost receivers. LoRa™ modulation has been proposed to overcome these challenges using a proprietary implementation of the Chirp Spread Spectrum technique used for radar applications since the 1940's. This technique was chosen for its inherent robustness to channel degradation mechanisms like multipath fading, Doppler-effect, and in-band jamming interferers.

In LoRa™ modulation, the spreading of the spectrum is achieved by generating a chirp signal that continuously varies in frequency. The raw data rate (R_b) can be expressed as follows:

$$R_b = SF \times \frac{BW}{2^{SF}} \quad bits\ per\ second \qquad (1)$$

Where:

SF is the spreading factor (7 … 12)

BW is the modulation bandwidth (typ. 125 KHz).

LoRa™ also includes a variable error correction scheme that improves the robustness of the transmitted signal thanks to some redundancy. The nominal raw data rate is now modified as follows:

$$R_b = SF \times \frac{BW}{2^{SF}} \times \frac{4}{4+CR} \quad bits\ per\ second \qquad (2)$$

Where:

CR is the code rate (1 … 4).

TABLE I. LORA BIT RATE AND SENSITIVITY VS SF

Mode	Equivalent bit rate (kb/s)	Sensitivity (dBm)	Δ (dB)
FSK	1.2	-122	-
LoRa SF = 12	0.293	-137	+15
LoRa SF = 11	0.537	-134.5	+12.5
LoRa SF = 10	0.976	-132	+10
LoRa SF = 9	1757	-129	+7
LoRa SF = 8	3125	-126	+4
LoRa SF = 7	5468	-123	+1
LoRa SF = 6	9375	-118	-3

LoRa™ modulation is constant envelope for low power efficient transmitters. Thanks to coherent demodulation of spread symbols, LoRa™ modulation improves practical sensitivity by around 6dB to 10dB versus FSK for same bit rate. By using larger value for SF, bit rate decreases and sensitivity is becoming equivalent or even better than UNB using D-BPSK (e.g. -137dBm for LoRa™ at 300bps vs -136dBm for UNB at 100bps).

Spreading factors are orthogonal in the sense they appear as noise to others. Since all rates can be received with negative SINRs, a base station can receive simultaneously different messages using different SF in the same band. Due to the redundancy introduced by spread-spectrum modulation, the modulation is quite resilient to interference mechanism that appears as short duration bursts. LoRa™ shows 6dB sensitivity degradation when facing strong interfering bursts with durations of around one LoRa™ symbol period, up to 25% interference duty cycle.

Co-channel jamming is well supported with immunity usually higher than 20dB for other LoRa™ signals at different SF or GMSK / FSK signals in same channel.

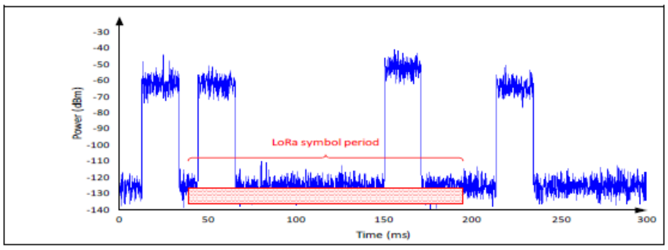

Fig.2. Effect of burst interferers on LoRa™ symbol

2) LoRa™ network operation

LoRa™ networks are operated using ALOHA in a star configuration. Thanks to the SF programmability, nodes closer to the base stations can be operated at higher data rate to save power thanks to shorter messages. Nodes far from the base stations will use maximum spreading factor to maximize their range. Network capacity can be adjusted by a good management of the objects, through ADR and TPC. Introducing new base stations reduces need for range and increases the network capacity if ADR is properly managed, which is not possible using UNB since data rate and range are fixed and collisions cannot be avoided. Network is truly bi-directional in essence and different network management possibilities can be offered (see hereunder about LoRaWAN™ classes).

LoRa™ networks are using much more bandwidth than UNB for transmitting low data rate and this could be considered as the main limitation. A SF=12 LoRaWAN™ compliant message containing 12 Bytes of payload with preamble and header will take approximately 1.5s. You can transmit simultaneously 2 messages at SF11, 4 messages at SF10, ... leading to 64 possible transmissions over 1.5s with optimum ADR. Compared to UNB, this can be a serious limitation. But as soon as you add base stations, the need for high SF is drastically reduced and the network capacity increases, offering better capacity than UNB networks in practical cases, while reducing power on the object thanks to shorter frames. In most of practical implementations, only SF7 to SF10 are used for reaching outdoor objects. SF11 and SF12 are there to reach deep indoor objects when needed.

The LoRa™ modulation does not need a good alignment between transmitter and receiver frequencies. A ± 30ppm frequency deviation can be tolerated, meaning a simple crystal can be used vs a TCXO for UNB. This lowers the cost and power consumption of the end point.

Chirp Spread-spectrum exhibits good immunity to multipath fading and Doppler effect meaning LoRa™ objects are still reachable when moving. In that case, these objects are mostly outdoor and smaller SF can be used for shorter communications.

3) LoRa™ Localization

Thanks to the large bandwidth and intrinsic synchronization of the LoRa™ modulation, location services can be offered using TDOA techniques. Base stations have to be synchronized (e.g. using GPS) and precise timestamps are calculated. A solver can then calculate position based on TDOA. Practical measurement on actual deployments are leading to an accuracy better than 40m in near line of sight rural environment, opening free location service for a number of applications in smart farming or environmental control. In urban environments, multipath is impacting performance and typical accuracies around 150m have been demonstrated. Diversity can be introduced (antenna, frequency, directionality,…) to improve performance.

4) LoRa Alliance

LoRa Alliance is an open, non-profit organization of members collaborating together to define an open global standard for secure and carrier-grade IoT LPWAN connectivity. LoRa™ is a proprietary modulation that is owned and patented by Semtech. LoRaWAN™ is the open protocol defined by the LoRa Alliance, based on the unique properties of the LoRa™ modulation.

The LoRa Alliance was founded at MWC 2015 and counts today more than 300 members, ranking it as the fastest growing wireless alliance ever. Members are representing the different layers of an IoT ecosystem from chipsets, modules, devices, gateways to network and application servers. The Alliance consists of different committees that cover strategy, technical development, marketing presence and certification programs.

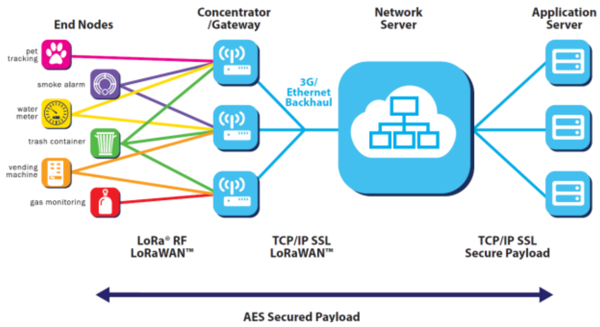

Fig.3. LoRa™ network architecture

New LoRaWAN™ deployments are being announced every month in Europe, Asia and USA. Big operators like Orange, ZTE (China) or TATA (India) have selected LoRa™ for IoT deployments. Other big companies like Cisco, IBM, Bosch, Schneider Electric, STM, Microchip, Foxconn and others have joined the LoRa Alliance, making the LoRaWAN™ become a worldwide de facto IoT standard for operation in unlicensed bands. Despite LoRa™ being a proprietary modulation of Semtech, LoRa™ chips can be supplied through different silicon providers, avoiding single source. Deployments are moving ahead since Q1 2016, putting time pressure on 3GPP for NB-IoT definition.

LoRaWAN™ specification defines the network architecture and the communication protocol. Three classes of devices are considered:

- Bi-directional end-devices (Class A): End-devices of Class A allow for bi-directional communications whereby each end-device's uplink transmission is followed by two short downlink receive windows. The transmission slot scheduled by the end-device is based on its own communication needs with a small variation based on a random time basis (ALOHA-type of protocol). This Class A operation is the lowest power end-device system for applications that only require downlink communication from the server shortly after the end-device has sent an uplink transmission. Downlink communications from the server at any other time will have to wait until the next scheduled uplink.
- Bi-directional end-devices with scheduled receive slots (Class B): In addition to the Class A random receive windows, Class B devices open extra receive windows at scheduled times. In order for the end-device to open its receive window at the scheduled time, it receives a time-synchronized beacon from the gateway. This allows the server to know when the end-device is listening.
- Bi-directional end-devices with maximal receive slots (Class C): End-devices of Class C have almost continuously open receive windows, only closed when transmitting.

LoRaWAN™ utilizes two layers of security: one for the network and one for the application. The network security ensures authenticity of the node in the network while the application layer of security ensures the network operator does not have access to the end user's application data. AES encryption is used with the key exchange utilizing an IEEE EUI64 identifier. This security scheme is sufficient for most IoT applications and surpasses existing security scheme used by UNB players.

IV. LPWAN SOLUTIONS IN LICENSED BANDS

A lot of effort is being done within 3GPP to address the IoT in licensed bands. In [5], the chairman of 3GPP RAN is describing the different standards covering IoT with particular focus on NB-IoT as being the low-end competing with LPWAN operated in unlicensed bands.

Three technologies are proposed to cover specific market segments. eMTC and NB-IoT are using eDRX (extended Discontinued Receiver Mode) features to avoid staying permanently in receive mode to decode the downlink data. Connected mode (C-eDRX) increases cycles up to 5.12 or 10.24 seconds. Idle mode (I-eDRX) can increase that time up to around 44 minutes for eMTC and 3 hours for NB-IoT. These extended DRX modes are the key to minimize power consumption.

A. eMTC (LTE Cat.M)

This standard can be deployed in any LTE spectrum. The cost is comparable to a GPRS/GSM device, providing a battery life of around 10 years on a 5Wh battery. Coverage is extended through a budget link around 156dBm. It can be deployed through a software update on existing LTE base stations. It is using narrow band with 1.40MHz bandwidth and provides a data rate of 1Mbps in both directions. Output power for objects is 20dBm. Uplink is using Single Carrier FDMA and downlink uses OFDMA 16 QAM with 15kHz tone spacing. Receiver on objects is much more complex than FSK or BPSK. eMTC objects require large capacity batteries than can sustain peak currents exceeding 150mA. Coin cells are excluded.

B. EC-GSM

This standard is operated in GSM band. Device is cheaper than eMTC. Coverage is close to eMTC with an option to extend range by increasing output power to 33dBm, at the expense of huge current consumption with direct impact on battery technology and lifetime. Standard supports GMSK between 350bps and 70kbps using 200kHz per channel. Higher bit rate is proposed using 8PSK to provide up to 240kbps.

C. NB-IoT

This standard is still under definition and seems best suited for low-power LPWAN. The transceiver architecture is simpler and upper layers of the protocol will be simplified to limit complexity and power dissipation. Budget link is targeted to 164dBm, close to LoRa or UNB networks. Bandwidth will be 180kHz. Downlink will use OFDMA with 15kHz tone spacing to achieve 250kbps. Uplink will use single tone with 15kHz or 3.75kHz tone spacing or multiple tone transmissions with 15kHz tone spacing. Output power is currently set to 23dBm which does not allow operation under coin lithium cells.

NB-IoT will support three modes of operation: stand-alone carrier to reuse GSM carrier frequencies, use of LTE guard bands or in-band LTE.

NB-IoT could offer location services based on TDOA.

D. Deployments and future evolution

NB-IoT being still under definition, deployments will be late compared to LPWAN solutions in unlicensed bands. 3GPP RAN is in a rush to speed-up the specification efforts. Nevertheless, NB-IoT positioning is better suited to applications requiring a good QoS at the expense of more complexity in the hardware and addition power consumption. Coin cells batteries won’t be useable.

V. CONCLUSIONS

Different solutions have been compared to address the requirements of objects dedicated to the LPWAN segment of IoT. Existing solutions in both unlicensed and licensed spectrums have been presented. From this analysis, it appears that there is room for every solution in the LPWAN space, each solution showing a list of pros and cons. Market segments will benefit from these differences. UNB is well suited for fixed objects, being very low-power and provides good capacity for outdoor coverage. LoRa™ offers a lot of flexibility in the network configuration, can support location services and mobile objects and shows better immunity to interferences and security. NB-IoT promises to be a good solution offering a good QoS for reasonable power while excluding coin cell batteries.

These technologies are in competition but are also very complementary. Longer term, if large ecosystems like the LoRa Alliance continue to develop, 3GPP won’t have other choice than enabling some of the unlicensed solutions to be included into their solution using third party trusted solution like WiFi and LTE are combined today. When this occurs, it would be good to benefit from both worlds which will require flexible radios. With most advanced manufacturing processes, future will open the path to new architectures offering multi-standard radio chips based on software defined modems in the end points. Advances in power management will also reduce need for batteries and enable more and more energy harvesting solutions.

ACKNOWLEGMENTS

The authors want to thank the LoRa Alliance for their support in providing information about the existing LPWAN solutions.

REFERENCES

[1] https://en.wikipedia.org/wiki/ALOHAnet

[2] https://www.lora-alliance.org/

[3] CEPT ECC, ERC Recommendation 70-03, May 2016.

[4] Dr. Ayman Elnashar, “Building IoT Networks for Smart City”, Forum on Internet of Things, Geneva Switzerland, Oct. 2015.

[5] Dino Flore, “3GPP Standards for the Internet-of-Thigs”, GSMA MIoT, Feb. 2016.

[6] Mobile Experts, “White Paper for the LoRa Alliance – where does LoRa fit in the Big Picture ?”, LoRa Alliance White Papers, 2015.

[7] Nokia Networks, “LTE-M – Optimizing LTE for the Internet of Things”, White Paper, 2015.

[8] Realwireless, “A comparison of UNB and Spread Spectrum Wireless Technologies as used in LPWA M2M Appliactions”, White Paper, 2015.

[9] Semtech, “LoRa Modualtion basics”, AN 1200.22, May 2015.