Low Power Wide Area Networks, NB-IoT and the Internet of Things

Sep 2016

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Keysight Technologies
LPWAN & the Internet of Things

Agenda

I. IoT and LPWAN
II. 3GPP Cat M & NB-IoT
III. Test Challenge & Solution
IoT Market Predictions

>30B Connected devices by 2020
ABI Research

50B devices will be connected by 2020
Cisco

95.5B connected devices by 2025
IHS Technology

“90% of all Samsung’s products will be IoT devices by 2017, and 100% by 2020”
BK Yoon Samsung Electronics
President and CEO
Low Power Wide Area (LPWA)

Typical applications
- **Street lighting** (Telensa widely deployed)
- **Parking** space occupancy sensors
- **Burglar alarm** back-up (cellular jammers widely available)
- **Social housing** use cases (e.g. smoke alarm and energy credit policing SIGFOX in UK)
- **Pet tracking**
- **Garbage collection** bin fill level for pick up route optimization (LoRa)
- **Agricultural sensors** Forest fire detection

Coverage pools ➤ Region coverage ➤ Global coverage

- **Street lighting**
- **Social housing monitoring**
- **Fire detection**
- **Parking sensor**
- **Garbage collection**
- **Pet tracker**
- **Soil moisture**
- **Bike tracker**
- **Bag tracker**
- **Capital asset Meter**
- **Embedded asset status**

Narrow band + Robust modulation =
- 20dB better link budget than cellular
- 10 year battery life, Very low data rates
SIGFOX

- SIGFOX is a startup in France building a low cost network dedicated for IoT.
- Uses unlicensed spectrum – mostly sub-GHz band and patented ultra narrow band (UNB) communication
  - **Ultra low throughput** - ~100 bps
    - Device send 0 and 140 messages/day, each message is up to 12 bytes
  - **Low power**: Up to 20 years of battery life
  - **Long range** – up to 30 miles in rural area and 2-6 miles in urban area
- Devices require a SIGFOX modem and SIGFOX network
- Target applications: smart meter, pet tracking, smoke detector, agriculture etc…
- Networks deployed in France, Netherlands, Russia and Spain; Launching 902 MHz network in San Francisco
LoRa Alliance

- **LoRa**: Long Range M2M communications used for applications like IoT, using very low power levels. LoRa Alliance is an open, non-profit association.

- **Members** of the LoRa Alliance include Actility, Cisco, Eolane, IBM, Kerlink, IMST, MultiTech, Sagemcom, Semtech, and Microchip Technology.

- **Frequency bands**: sub-1GHz ISM bands:
  - 868 MHz for Europe
  - 915 MHz for North America
  - 433 MHz band for Asia

- **Key Features**
  - **Low Cost**: simple modulation
  - **Low power**: Long of ten yrs
  - **Long range**: ~15 - 20 km
Sub-GHz Chipset Ecosystem

- Mercury
- Embit
- Cisco
- Telit ME50 868
- Appcon
- Libelium
- Microchip
- Telena
- Telit LE51
- Telit ME51
- TI CC1120 + CC1125
- Silicon Labs Si44xx
- One vendor
- multi-vendor

- ZigBee
- CoAP/MQTT/DTLS
- UDP
- 6LoWPAN
- 802.15.4 2003/6
- 802.15.4e
- 802.15.4g

- ZigBeeNAN
- WiSUN
- WM-Bus
- WMRNET
- LoRa
- Telensa

- Z-Wave
- 802.15.4
- 802.15.6

- AT86RF212B
- SX1272/6
- TI CC1120 + CC1125

- Sigma Designs
- ATMEL
- SEMTECH
- Texas Instruments
- Sigma Labs

Also: Axsemi, Freescale, Analog Devices, etc...
Wide area networks
Technology Trade-offs

**SIGFOX**

**Pros:**
- Long range
- Long battery life (up to 20 years)
- Low cost

**Cons:**
- New standard
- Unlicensed band - interference
- Can’t run on existing cellular network – needs a dedicated SIGFOX network
- Very low data rate - can only be used for IoT

**LoRa Alliance**

**Pros:**
- Long range
- Long battery life (>10 years)
- Low cost
- Uses cellular network as backhaul

**Cons:**
- New standard
- Unlicensed band - interference
- Very low data rate – can only be used for IoT

**3GPP**

**Pros:**
- Well established standards
- Long rage
- High data rate
- Very wide coverage
- Licensed band (except LTE-U)

**Cons:**
- Not optimized for IoT
- Battery life
- Cost
LPWAN & the Internet of Things

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I. IoT and LPWAN

II. 3GPP Cat M & NB-IoT

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IoT Radios

WPAN: Wireless Personal Area Network
WHAN: Wireless Home Area
WFAN: Wireless Field (or Factory) Area
WNAN: Wireless Neighbourhood Area
WLAN: Wireless Local Area
WWAN: Wireless Wide Area
LPWAN: Low Power Wide Area Network

Proximity

WPAN

Cellular (licensed)

WHAN

<10cm

<5km

<100km

WFAN

WNAN

WLAN

WWAN

LPWAN (licensed)

LPWAN (un-licensed)

Terms not precise

Many others

NFC
EMV

3GPP NB-IoT

3GPP LTE-MTC, eMTC/Cat M, LTE-V
3GPP GSM, WCDMA, EC-GPRS
3GPP2 Cdma2000, WiMAX

802.11a/b/g/n/ac (WiFi)
802.11ah (WiFi HaLow 1km)
802.11p (V2X)
802.11af (white space)

Wi-SUN (6LoWPAN)
ZigBee NAN (6LoWPAN)
Wireless M-bus

Many others

ISA100.11a (6LoWPAN)
WirelessHART
Many others

ZigBee
Z-Wave
Thread (6LoWPAN)
EnOcean

Many others

802.11a/b/g/n/ac (WiFi)
802.11ah (WiFi HaLow 1km)
802.11p (V2X)
802.11af (white space)

Wi-SUN (6LoWPAN)
ZigBee NAN (6LoWPAN)
Wireless M-bus

Many others

SIGFOX
LoRa
Telensa
OnRamp/INGENU
Weightless P

Many others

Blue: > billion units/year now
Red: emerging

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啟航 加速推動LTE應用服務與擴大
LTE-A Pro發展資源為其重要的工作目標

**GTI 1.0** (2011年~2015年)

- Booming Global Development of 4G TD-LTE
  - 76 Commercial Networks
  - 4.7 Mil. Subscribers
  - 1.4 Mil. Base Stations
  - 26 Converged Networks
  - 2650+ Terminals

**GTI 2.0** (2016年~)

- A1s
- N2
- A2
- VoLTE
- RCS
- 推動 TDD 4G Plus技術過渡到5G世代
- 推動NB-IoT於2017年實現商用化

資料來源：DIGITIMES・2016/3
LTE MTC (Machine-Type Communications)

Features

- **Power saving:**
  - Enhanced Power Save Mode (PSM): More efficiently turn on/off modem; optimized for scheduled applications
  - Extended Discontinuous Reception (DRX): Longer sleep cycles optimized for delay-tolerant
  - Connectionless Random Access Channel (RACH)
  - Less frequent Tracking Area Updates (TAUs) and measurements

- **Reduces device cost:**
  - Narrowband (~1 MHz)
  - Reduced Data Rate (<2 Mbps)
  - Single receive antenna
  - Half Duplex Operation

Data refer from Qualcomm
3GPP Release 13 Cellular IoT timelines

GERAN Objectives
- 164dB link budget (GPRS +20dB)
- 40 devices per home (~50k/cell)
- >160bps at range limit
- 10 second latency
- 10 year life with 5Wh ~AA battery

eMTC Cat M:
- Machine Type Communication
- 1.4MHz Bandwidth LTE derivative
- Software update to LTE infrastructure
- 1Mbps, full mobility, 156dB link, 10 year batt

NB-IoT:
- Narrowband IoT
- 200 (180kHz) Clean sheet format
- Software update to LTE or GSM infrastructure
- <~250kbps, nomadic, 164dB, 10 year batt

EC-GPRS
- Extended coverage GPRS
- 200kHz GSM/EDGE
- Repetitions to get to 164dB link budget
- EC-PDTCH and EC-PACCH, ~52 min DRX
- Software update to GSM infrastructure

GERAN
- LTE Cat 0------------ LTE Cat 00
- NB-LTE
- eMTC Cat M
- NB-IoT
- EC-GPRS

3GPP Rel 13
- March-June 2016

2015  2016  2017

GSMA Mobile IoT initiative backed by 21 MNOs:
AT&T, Bell Mobility, Bermuda Digital Comm, China Telecom, China Unicom, China Mobile, Deutsche Telekom, Etisalat, KDDI, KT, Mobistar, NTT DoCoMo, Orange, Singtel, Softbank, Taiwan Mobile, Telecom Italia, Telefonica, Telenor, Telstra, Verizon, Vodafone

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**Cat M and NB-IoT**

**Deployment options**

- **Typical 5MHz LTE**: 5MHz with 25 x 180kHz
- **Cat M**: 1.4MHz with 6 x 180kHz
- **NB-IoT**: 200kHz from 1 x 180kHz

- **Central control 6PRB**: 25x180kHz = 4.5MHz
- **Cat M in-band with LTE**: 6x 180kHz = 1.08MHz
- **NB-IoT in-band with LTE**: 25x180kHz = 4.5MHz
- **NB-IoT LTE guard band**: 180kHz from 12x15kHz subcarriers (OFDMA downlink)
- **NB-IoT in 200kHz GSM spectrum no guard**
- **NB-IoT in 200kHz GSM spectrum with guard**

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Cat M

3GPP R13

1.4MHz from 6 x 180kHz

Close to standard LTE including full mobility

~ 15dB Coverage enhancements over standard LTE
• Frequency hopping
• PSD (Power Spectral Density) boosting
• TTI bundling or repetition (redundant transmission)
• Multi-subframe channel estimation

Power and complexity savings
• Fewer supported transmission modes
• Reduced max Tx power (20dBm power class)
• Reduced measurement reports
• PSM (R12 Power Saving Mode) & eDRX (R13 extended Discontinuous Reception)
• C-eDRX (Connected mode eDRX 5.12 and 10.24 second cycles)
• I-eDRX (Idle mode eDRX ~44 minute cycles)

Deployable in any 6PRB group e.g. of a 20MHz channel
• New M-PDCCH similar to EPDCCH (Physical Dedicated Control Channel)
• UE uses 6 central PRBs for synchronization & PRACH then re-tunes to another 6PRB frequency range for follow-on control messages
• No support for PDCCH, PCFICH, PHICH
Clean-sheet design though leverages significantly from LTE Cat M but with nomadic mobility only
- Coverage enhancements (~23dB improvement over standard LTE)
- Downlink leveraged from 1 LTE PRB
- Uplink: LTE-like 15kHz subcarrier multi-tone SC-FDMA, single tone 15kHz FDMA or 3.75kHz FDMA
- R13 standardization focussing on FDD, TDD could be added later

Power and complexity savings
- RLC-Transparent Mode and simplified RLC-Ack’ Mode only (TBC no RLC-Unack’ Mode)
- Downlink TBCC (tail biting convolutional code) – easier to decode than LTE turbo-codes
- Half-duplex only
- Control plane (CP) data transmission (inside RRC/NAS messages) as a lower overhead alternative to full DRB IP user plane (UP) data transmission
- C-eDRX (Connected mode eDRX 5.12 and 10.24 second cycles)
- I-eDRX (Idle mode eDRX ~3 hour cycles)

New NB channels

**Downlink:**
- **NPBCH** (physical broadcast channel)
- **NPDSCH** (physical downlink shared channel)
- **NPDCCH** (physical downlink control channel),
- **NRS** (Narrowband Reference Signal)
- **NPSS/SSS** (primary and secondary synchronization channels)

**Uplink:**
- **NPUSCH** (Narrowband Physical Uplink Shared CHannel),
- **NPRACH** (Narrowband Physical Random Access CHannel),
- **DMRS** (demodulation reference signal)
### 3GPP Cellular IoT summary

<table>
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<tr>
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<th>3GPP Rel 12</th>
<th>3GPP Rel 13</th>
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<td></td>
<td>MTC Cat 0</td>
<td>eMTC Cat M*</td>
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<tr>
<td><strong>Heritage</strong></td>
<td>LTE</td>
<td>LTE</td>
</tr>
<tr>
<td><strong>Bandwidth (downlink)</strong></td>
<td>20 MHz</td>
<td>1.4 MHz</td>
</tr>
<tr>
<td><strong>Bandwidth (uplink)</strong></td>
<td>20 MHz</td>
<td>1.4 MHz</td>
</tr>
<tr>
<td><strong>Multiple access (downlink)</strong></td>
<td>OFDMA</td>
<td>OFDMA</td>
</tr>
<tr>
<td><strong>Multiple access (uplink)</strong></td>
<td>SC-FDMA</td>
<td>SC-FDMA</td>
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<td><strong>Modulation (downlink)</strong></td>
<td>QPSK, 16QAM, 64QAM</td>
<td>QPSK, 16QAM, 64QAM</td>
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<tr>
<td><strong>Modulation (uplink)</strong></td>
<td>QPSK, 16QAM</td>
<td>QPSK, 16QAM</td>
</tr>
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<td><strong>Peak data rate</strong></td>
<td>1 Mbps</td>
<td>1 Mbps</td>
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<tr>
<td><strong>Coverage (link budget)</strong></td>
<td>~141dB</td>
<td>~156dB</td>
</tr>
<tr>
<td><strong>Mobility</strong></td>
<td>Full</td>
<td>Full</td>
</tr>
</tbody>
</table>

Note: * Cat M also currently referred to as Cat M1, NB-IoT also referred to as Cat M2. Details for NB-IoT are subject to change as 3GPP drafting continues.
NB-IoT 5G context

NB-IoT is a pre-5G technology likely to be developed into 5G massive MTC.
# Licensed and unlicensed examples

<table>
<thead>
<tr>
<th></th>
<th>SIGFOX</th>
<th>LoRaWAN</th>
<th>NB-IoT</th>
<th>Cat M</th>
<th>EC-GPRS</th>
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<tr>
<td><strong>Link budget</strong></td>
<td>~162dB</td>
<td>~157dB</td>
<td>~164dB</td>
<td>~156dB</td>
<td>~164dB</td>
</tr>
<tr>
<td><strong>Battery life</strong></td>
<td>&gt;10 years</td>
<td>&gt;10 years</td>
<td>&gt;10 years</td>
<td>&gt;10 years</td>
<td>&gt;10 years</td>
</tr>
<tr>
<td><strong>Spectrum</strong></td>
<td>un &amp; lightly-license bands e.g. 868, 915 MHz</td>
<td>un &amp; lightly-license bands e.g. 169, 433, 470, 868, 915 MHz</td>
<td>GSM &amp; LTE Licensed bands</td>
<td>LTE Licensed bands</td>
<td>GSM Licensed bands</td>
</tr>
<tr>
<td><strong>Rates and modulation</strong></td>
<td>Uplink: 100bps BPSK 100Hz BW Downlink: 500bps GFSK 600Hz BW</td>
<td>GFSK, CSS (Chirp Spread Spectrum) ~0.3 to 50kbps 125kHz BW</td>
<td>Up to ~250kbps Uplink π/4-QPSK, rotated π/2 BPSK, 8PSK, opt 16QAM Downlink BSK-16QAM 180kHz BW</td>
<td>1Mbps QPSK, 16 or 64QAM 1.4MHz BW</td>
<td>~10 to ~240kbps GMSK, opt 8PSK, 200kHz BW</td>
</tr>
<tr>
<td><strong>Silicon</strong></td>
<td>Multi-vendor</td>
<td>Semtech (2nd vendor announced)</td>
<td>Multi-vendor</td>
<td>Multi-vendor</td>
<td>TBC</td>
</tr>
<tr>
<td><strong>Protocol</strong></td>
<td>SIGFOX</td>
<td>Semtech (2nd vendor announced)</td>
<td>3GPP Multi-vendor</td>
<td>3GPP Multi-vendor</td>
<td>3GPP Multi-vendor</td>
</tr>
<tr>
<td><strong>Certification</strong></td>
<td>SIGFOX</td>
<td>LoRa Alliance</td>
<td>GCF/PTCRB TBC</td>
<td>GCF/PTCRB TBC</td>
<td>GCF/PTCRB TBC</td>
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LPWAN & the Internet of Things

Agenda

I. IoT and LPWAN
II. 3GPP Cat M & NB-IoT
III. Test Challenge & Solution
## IoT Verification Challenges

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<th>Challenges</th>
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<td><strong>Power consumption</strong></td>
<td>Lifetime SLA, software update drain</td>
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<tr>
<td></td>
<td>Operator settings, IoT protocol selection</td>
</tr>
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<td></td>
<td>Unhandled software and network exceptions</td>
</tr>
<tr>
<td><strong>Radio frequency design</strong></td>
<td>Achieving deep in-building coverage</td>
</tr>
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<td></td>
<td>3rd party enclosure/antenna effects</td>
</tr>
<tr>
<td></td>
<td>Multi-radio interference/inter-mod</td>
</tr>
<tr>
<td><strong>Stability/longevity</strong></td>
<td>Long time between re-boot, unattended recovery</td>
</tr>
<tr>
<td></td>
<td>Authentication, security, secure boot</td>
</tr>
<tr>
<td></td>
<td>Remote software update</td>
</tr>
<tr>
<td><strong>Acceptance/production</strong></td>
<td>Certification &amp; regulation test e.g. GCF/PTCRB</td>
</tr>
<tr>
<td></td>
<td>Operator acceptance, interop lab and field test</td>
</tr>
<tr>
<td></td>
<td>System integrator acceptance</td>
</tr>
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</table>

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Example applications

Power consumption
- UXM message editor
- Source Measurement Unit

Radio frequency design
- UXM RF Meas'
- GP RF test tools
- Antenna test systems

Stability/longevity
- UXM built-in app server
- Test Automation Platform (TAP)

Acceptance/production
- T4000S RCT/RRM operator RF
- EXM high volume mfg
- Anite protocol and operator test
## Power consumption analysis

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<th>Range</th>
<th>Measurement Accuracy</th>
<th>Activity</th>
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<tr>
<td>3 A</td>
<td>±(0.03% + 250 nA)</td>
<td>Idle</td>
</tr>
<tr>
<td>100 mA</td>
<td>±(0.025% + 10 nA)</td>
<td>Sleep</td>
</tr>
<tr>
<td>1 mA</td>
<td>±(0.025% + 100 nA)</td>
<td>Sleep</td>
</tr>
<tr>
<td>10 μA</td>
<td>±(0.025% + 8 nA)</td>
<td>Sleep</td>
</tr>
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</table>

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Power consumption analysis
CX3300 Current Waveform Analyzer

Current waveform through Current Measurement Terminal

Vdd

Device under test

nRF51DK
Probing for insight

89601B VSA Software

N9010B EXA Signal Analyzer, Multi-touch, 10 Hz to 44 GHz

N2820A 3 MHz/50μA High Sensitivity AC/DC Current Probe

U5855A TrueIR Thermal Imager

Infiniium S-Series oscilloscopes

N6705B with Source Measurement Unit

Device under test
Base station and network emulation

**Keysight UXM Wireless Test Set**
- 300MHz to 6GHz Multi-format base station emulation
- Built-in server PC to host cloud & remote end-point apps
- End to end IP connection to internet
- IMS support
- Tx and Rx measurements
- Built-in channel emulator (fader)

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RF Design verification

M9420A VXT PXIe Vector Transceiver
- 60MHz to 6GHz
- 160MHz channel bandwidth

Complement with:
- Vector Network analysers
- Microwave sources and analyzers
- Power supplies
- Software, fixtures, systems, services

89601B Flexible VSA
X-series measurement applications

M9420A VXT PXIe Vector Transceiver

Replay and edit captured waveforms

Device under test

Broadest format coverage
- LTE-A, GSM, WCDMA, cdma2000
- eMTC Cat M and NB-IoT TBC
- GNSS
- 802.11a/b/g/n/ac/p/j/ah/af
- 802.15.4 (Zigbee, Thread/ 6LoWPAN)
- Bluetooth/BLE, Z-Wave, ANT+
- Wireless M-Bus, LoRa, SIGFOX & many others

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Production ramp

E6640A EXM Wireless Test Set
- High speed sequencer
- Overlap/parallel Ping-Pong and pipelined testing
- Scalable and upgradeable from 1 to 4 TRX
- Port switching, robust N-connectors
- Broadest format coverage with arb files and X-Apps
- Systems, software, consulting and services
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**Network Analyzers**
- SystemVue
- Advanced Design System Visualizer

**Anite**
- Propsim channel emulator

**FieldFox**
- i3070 test systems

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<th>A9000 protocol conformance test</th>
<th>i3070 test systems</th>
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**Modelling tools**
- VSA/VSG
- UXM Wireless Test Set
- Source measurement units

**RF & RRM conformance**
- Thermal test
- EXM Wireless Test Set
- Oscilloscopes

**Spectrum regulation and network optimization tools**
- Anite

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**Source measurement units**
- Keysight Technologies
Thank You !!!
Questions and Answers