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

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

Blue: > billion units/year now
Red: emerging

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Low Power Wide Area (LPWA)

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

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

Range

LPWA

LTE

ZigBee

Ant+

BT LE

WiFi

Data rate

Social housing monitoring

Street lighting

Parking sensor

Fire detection

Trash collection

Pet tracker

Bike tracker

Capital asset Meter

Soil moisture

Bag tracker

Embedded asset status

Coverage pools

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

### Coverage pools

**Social housing monitoring**

**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

Parking sensor

Fire detection

Soil moisture

Bag tracker

Embedded asset status

Capital asset Meter

**Keysight in IoT**

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IoT Key Enabling Technologies

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

Also: Axsemi, Freescale, Analog Devices, etc...

Keysight in IoT
S800 2015
## Wide area networks

### Technology Trade-offs

<table>
<thead>
<tr>
<th>Technology</th>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
</table>
| SIGFOX     | • Long range  
             • *Long battery life (up to 20 years)*  
             • Low cost | • 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       | • Long range  
             • *Long battery life (>10 years)*  
             • Low cost  
             • Uses cellular network as backhaul | • New standard  
             • Unlicensed band - interference  
             • Very low data rate – can only be used for IoT |
| 3GPP        | • Well established standards  
             • Long range  
             • High data rate  
             • Very wide coverage  
             • Licensed band (except LTE-U) | • Not optimized for IoT  
             • *Battery life*  
             • Cost |
LPWAN & the Internet of Things

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**WPAN:** Wireless Personal Area Network
**WHAN:** Wireless Home Area
**WFAN:** Wireless Field (or Factory) Area
**WLAN:** Wireless Local Area
**WNAN:** Wireless Neighbourhood Area
**WWAN:** Wireless Wide Area
**LPWAN:** Low Power Wide Area Network
GTI 2.0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)

GTI 2.0 (2016年~)

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
### 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

### 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

### 3GPP Release 13 Cellular IoT timelines

<table>
<thead>
<tr>
<th>2015</th>
<th>2016</th>
<th>2017</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3GPP spec dev</td>
<td>Conformance testing</td>
</tr>
<tr>
<td></td>
<td>3GPP test case development</td>
<td>Field trials</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Commercial service</td>
</tr>
</tbody>
</table>

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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

180kHz from 12x15kHz subcarriers (OFDMA downlink)

Central control 6PRB

NB-IoT LTE guard band

NB-IoT in 200kHz GSM spectrum no guard

NB-IoT in 200kHz GSM spectrum with guard

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Cat M
3GPP R13

Cat M
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

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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>
<thead>
<tr>
<th></th>
<th>3GPP Rel 12</th>
<th>eMTC Cat M*</th>
<th>3GPP Rel 13</th>
<th>EC-GPRS</th>
<th>NB-IoT*</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Heritage</strong></td>
<td>LTE</td>
<td>LTE</td>
<td>GSM</td>
<td>Clean-slate</td>
<td></td>
</tr>
<tr>
<td><strong>Bandwidth (downlink)</strong></td>
<td>20 MHz</td>
<td>1.4 MHz</td>
<td>200 kHz</td>
<td>180kHz (12 by 15kHz)</td>
<td></td>
</tr>
<tr>
<td><strong>Bandwidth (uplink)</strong></td>
<td>20 MHz</td>
<td>1.4 MHz</td>
<td>200 kHz</td>
<td>Single-tone (180kHz by 3.75kHz or 15kHz) or multi-tone (180kHz by 15kHz)</td>
<td></td>
</tr>
<tr>
<td><strong>Multiple access (downlink)</strong></td>
<td>OFDMA</td>
<td>OFDMA</td>
<td>TDMA</td>
<td>OFDMA</td>
<td></td>
</tr>
<tr>
<td><strong>Multiple access (uplink)</strong></td>
<td>SC-FDMA</td>
<td>SC-FDMA</td>
<td>TDMA</td>
<td>Single-tone FDMA or multi-tone SC-FDMA</td>
<td></td>
</tr>
<tr>
<td><strong>Modulation (downlink)</strong></td>
<td>QPSK, 16QAM, 64QAM</td>
<td>QPSK, 16QAM, 64QAM</td>
<td>GMSK, optional 8PSK</td>
<td>BPSK, QPSK, optional 16QAM</td>
<td></td>
</tr>
<tr>
<td><strong>Modulation (uplink)</strong></td>
<td>QPSK, 16QAM</td>
<td>QPSK, 16QAM</td>
<td>GMSK, optional 8PSK</td>
<td>TBC π/4-QPSK, rotated π/2-BPSK, 8PSK optional 16QAM</td>
<td></td>
</tr>
<tr>
<td><strong>Peak data rate</strong></td>
<td>1 Mbps</td>
<td>1 Mbps</td>
<td>10 kbps to 240kbps TBC</td>
<td>DL up to 250kbps TBC, UL single tone up to 20 to 64kbps TBC, UL multi-tone up to 250kbps TBC</td>
<td></td>
</tr>
<tr>
<td><strong>Coverage (link budget)</strong></td>
<td>~141dB</td>
<td>~156dB</td>
<td>~164dB</td>
<td>~164dB</td>
<td></td>
</tr>
<tr>
<td><strong>Mobility</strong></td>
<td>Full</td>
<td>Full</td>
<td>Full</td>
<td>Nomadic</td>
<td></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.

- Low power
- Deep coverage
- Low latency
- Data rate
- Density
- Mobility

Massive machine type communications

Ultra reliable low latency

Enhanced mobile broadband

- Drones
- Vehicles
- VR & AR
- Smartphones

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### 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>
</tr>
</thead>
<tbody>
<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>Multi-vendor</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>
</tr>
</tbody>
</table>
LPWAN & the Internet of Things

Agenda

I. IoT and LPWAN

II. 3GPP Cat M & NB-IoT

III. Test Challenge & Solution
IoT Verification Challenges

**Power consumption**
- Lifetime SLA, software update drain
- Operator settings, IoT protocol selection
- Unhandled software and network exceptions

**Radio frequency design**
- Achieving deep in-building coverage
- 3\textsuperscript{rd} party enclosure/antenna effects
- Multi-radio interference/inter-mod

**Stability/longevity**
- Long time between re-boot, unattended recovery
- Authentication, security, secure boot
- Remote software update

**Acceptance/production**
- Certification & regulation test e.g. GCF/PTCRB
- Operator acceptance, interop lab and field test
- System integrator acceptance
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)
- T4000S RCT/RRM operator RF

Acceptance/production

- Anite protocol and operator test
- EXM high volume mfg

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Power consumption analysis

<table>
<thead>
<tr>
<th>Range</th>
<th>Measurement Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 A</td>
<td>±(0.03% + 250 μA)</td>
</tr>
<tr>
<td>100 mA</td>
<td>±(0.025% + 10 μA)</td>
</tr>
<tr>
<td>1 mA</td>
<td>±(0.025% + 100 nA)</td>
</tr>
<tr>
<td>10 μA</td>
<td>±(0.025% + 8 nA)</td>
</tr>
</tbody>
</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
- U5855A TrueIR Thermal Imager
- N2820A 3 MHz/50uA High Sensitivity AC/DC Current Probe
- Infiniium S-Series oscilloscopes
- N6705B with Source Measurement Unit
- Device under test

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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)
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

**Signal Studio & waveform creator**

**89601B Flexible VSA**

**X-series measurement applications**

**Replay and edit captured waveforms**

**89601B Flexible VSA**

**M9420A VXT PXIe Vector Transceiver**

**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
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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R&D
- Modelling
- PHY/RF
- L2/L3
- Apps
- Integration

Design validation
- RF performance
- Throughput
- Battery Drain
- Stress
- Regression

Compliance
- OTA
- Lab IOT
- Operator
- GCF/PTCRB
- Regulations

Manufacturing
- IC
- Module
- Product
- Sample
- Debug

Deployment
- Spectrum clearance
- Installation
- Optimization
- Repair
- Operations

Modelling tools
- A9000 protocol conformance test
- i3070 test systems

A9000 protocol conformance test

i3070 test systems

Anite

Propsim channel emulator

FieldFox

Network Analyzers

VSA/VSG

UXM Wireless Test Set

Source measurement units

RF & RRM conformance

EXM Wireless Test Set

Oscilloscopes

Spectrum regulation and network optimization tools

LPWAN & the Internet of Things
Thank You !!!
Questions and Answers