Connectivity Technologies and Interference Signal Analysis for IoT Service.
What is Internet of Things (IoT)?

Privacy traded......

Convenience gained

Connecting billions of devices to the internet

Cost Efficiency

Market Efficiency

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IoT Market Predictions

50B devices will be connected by 2020
- Cisco

>30B Connected devices by 2020
- ABI Research

95.5B connected devices by 2025
- HIS Technology
Vertical and Horizontal

Consumer

Connected homes

Connected cars

Wearables

Industrial

Connected cities

Healthcare

Transportation

Agriculture

Connected cars

Manufacturing

Energy

Wearables

Connected homes

Apps & Analytics

$262B

$18B

$17B

$31B

Compute & storage

Communication

Things

Gartner’s estimated 2020 IoT revenue

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Connecting Things to the Cloud

Cloud storage, intelligence and analytics

Cable/fiber

ADSL

Cellular

e.g. LTE

WiFiAP

WiFi

e.g. LTE

Ethernet

Satellite

e.g. Iridium

e.g. WiFi

e.g. LoRa

e.g. SIGFOX

Industrial, vehicle, maritime, aviation, gateways

WiFi

Consumer gateway

e.g. ISA100.11a

e.g. Wi-SUN

e.g. Telensa

WiFi

Thread, ZigBee, Z-Wave

Sensors and actuators

e.g. ISA100.11a

Bluetooth

NFC

Keysight
Measurement
Forum

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Page 5
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
Primary Market for the Internet of Things

A single wireless technology cannot accommodate the diverse needs of IoT markets.
Popular Frequency Use

### Usual called

<table>
<thead>
<tr>
<th>Frequency (MHz)</th>
<th>NFC/EMV</th>
<th>Wireless M-Bus</th>
<th>China WMRNET</th>
<th>LoRa</th>
<th>SIGFOX</th>
<th>Telensa</th>
<th>OnRamp</th>
<th>Wi-SUN</th>
<th>ZigBee</th>
<th>Thread</th>
<th>WirelessHART</th>
<th>ISA100.11a</th>
<th>Z-Wave</th>
<th>EnOcean</th>
<th>ANT+</th>
<th>Bluetooth</th>
<th>802.11a/b/g/n/ac</th>
<th>802.11ah</th>
<th>802.11p</th>
<th>802.11af</th>
<th>Positive Train Ctrl</th>
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<tbody>
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</table>

### Aliases

- ISO14443
- EN13757
- WMRNET I, II, III, IV
- 802.15.4k
- 802.15.4g/e/6loWPAN
- 802.15.4-2003, c, d
- 802.15.4-2003/6loWPAN
- 802.15.4e
- 802.15.4e/6loWPAN
- ITU G.9959
- ISO14543-3-10
- 802.15.1
- WiFi
- V2X
- White Space
- 802.15.4p
Agenda

– IoT/M2M Introduction and Market Situation

– IoT/M2M Key Enabling Wireless Technologies
  • IEEE 802 LAN/MAN Working Group
  • Wide area networks (LPWAN) and NB-IoT

– IoT Optimization and test challenges
  • Optimization
  • Interference & operating environment replication

– Summary
IEEE 802 LAN/MAN Working Group

IEEE 802 LAN/MAN Standards Committee

- 802.1 Higher Layer LAN Protocols Working Group
- 802.11 Wireless Local Area Network (WLAN) Working Group
- 802.15 Wireless Personal Area Network (WPAN) Working Group
- 802.16 Broadband wireless access

- TG1 WPAN/Bluetooth Task Group
- TG2 Coexistence Task Group
- TG3 WPAN High Rate Task Group
- TG4 WPAN Low Rate Task Group

- IEEE 802.15.1
  (BT standard is no longer maintained by IEEE, it is controlled by Bluetooth SIG)

- IEEE 802.15.4

Major IEEE 802 LAN/PAN standards used for IoT
Bluetooth® Standard Evolution

1999
- V1.0
  - Many problems
  - Difficult making products interoperable
- V1.2
  - Faster connection/discovery
  - Use AFH
  - Up to 721 kbps

2003
- V2.0 + EDR
  - Introduction of EDR
  - EDR Up to 2.1 Mbps

2004
- V2.1 + EDR
  - Alternate MAC/PHY
  - Unicast connectionless data
  - Enhanced power control
  - HS up to 24 Mbps
  - SSP, EIR
  - Power consumption optimization

2007
- V3.0 + HS
  - HS up to 24 Mbps

2009
- V4.0
  - Adoption of Bluetooth LE
  - LE up to 260 kbps
  - Including classic, LE and HS

2010
- V4.1
  - Coexist with 4G
  - Smart connectivity
  - Data transfer improvement

2013
- V4.2
  - For IoT (Support IPv6/6LoWPAN)
  - High privacy
  - Data throughput increase (10x packet capacity increase)

2014
- For dual-mode: LE + Legacy BT
- For single-mode: LE only

Two New Trademarks for Certified BT Devices

Bluetooth® is a registered trademark of Bluetooth SIG, Inc.
IoT Key Enabling Technologies

Bluetooth Smart – Powering IoT

Bluetooth Core 4.0/4.1/4.2 enables a world of sensors

- Bluetooth Low Energy (BLE) enables low cost sensors to send their data over the internet
  - Version 4.2 enables IPv6 to a BT device
- Very low duty cycle = low power consumption
- Ability to run for years (up to 5 years) on standard coin-cell batteries
- Target applications:
  - Health monitors such as heart rate monitor
  - Fitness devices, smart watches
  - Environmental sensing
  - Proximity applications and many others
Wireless Standards

IEEE 802 defines standards, does not define a certification process or test plans, that is done by the individual standards/working groups
802.15.4..... Something for Everyone

- Thread Group
- ZigBee
- Wi-SUN
- IPv6

Non-IP
Proprietary upper stack

- MiWi
- Wireless HART

802.15.4...... 2003 2006
UWB Active RFID MBAN TV WS China Medical Japan L-pwr

802.15.4 includes >60 non-interoperable PHY combinations

= A popular non-interoperable format
IEEE 802.15.4
Low Rate Wireless Personal Area Network (LoWPAN)

- Important standard for home networking, industrial control and building automation
- Deals with low data rate, long battery life (months or even years) and very low complexity
  - Data rates of 250 kbps, 40 kbps, and 20 kbps
- Specifies PHY and MAC layers for LoWPAN networks
  - Ex. ZigBee, THREAD, WirelessHART, ISA100.11a
- Upper layers for WPAN are not developed by IEEE 802.15 working group
  - Standards or working groups, such as ZigBee Alliance, implement upper layers to enable multi-vendor interoperable solutions
IoT Key Enabling Technologies

ZigBee

Low power, low data rate, mesh network

- Conceived in 1998, first standardized in 2003 and revised multiple times, latest in 2012 (ZigBee PRO)
- Based on IEEE 802.15.4 physical and MAC layers operating in sub-GHz and 2.4GHz frequency bands
- Transmission distances range from 10 to 100 meters - depending on power output and environmental characteristics

Target Applications:
IoT Key Enabling Technologies

THREAD

- Thread Group launched in July 2014

- Main competitor to ZigBee for home automation
  - Appliances, access control, climate control, lighting, energy management etc..

- Collection of existing IEEE and IETF standards:
  - IEEE 802.15.4-2006 PHY/MAC operating in 2.4 GHz
  - 6LoWPAN (IPv6) based protocol

- Requires only software update to run on existing IEEE 802.15.4 based silicon such as 2.4 GHz version of ZigBee

Ref: www.threadgroup.org
# IoT for Home Automation

## Technology Tradeoffs for Home Automation Application

<table>
<thead>
<tr>
<th>Technology</th>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
</table>
| Bluetooth  | - Low energy  
- Available on mobile devices  
(Already supported on iOS and Android)  
- IPv6 based | - Star network  
- Short range  
- New technology – not well established compared to ZigBee |
| WiFi       | - Well established standards  
- Available on mobile devices  
- Good range  
- IPv6 based | - Star network  
- Not low energy – new standard coming in 2016 (802.11ah) |
| ZigBee     | - Low energy  
- Well established standards  
- Mesh network  
- Good range | - Not IP based for home automation  
(ZigBee IP for Smart Energy 2.0 is IP based)  
- Not available on mobile phones/tablets |
| THREAD     | - Low energy  
- Mesh network  
- Good range  
- IPv6 based | - Not well established compared to ZigBee  
- Not available on mobile phones/tablets |
**IoT Key Enabling Technologies**

**Wi-SUN**

- IPv6 based Wireless Smart Utility Network (Wi-SUN) based on IEEE 802.15.4g
  - IEEE 802.15.4g, also known as the Smart Utility Networks (SUN), was approved by IEEE in March, 2012
- Initially Japan focused, now expanding globally (US, South East Asia, India, Europe)
- Target smart utility use cases:
  - Gas metering; demand/response; distribution automation
- PHY layer based on IEEE 802.15.4g but the specification will be categorized based on use cases
  - Frequency: 868 MHz (EU), 915 MHz (USA), 2.4 GHz ISM bands (worldwide)
- MAC may be based on or not based on 802.15.4. Application dependent.

---

**3 PHY formats supported:**
- MR-FSK: 2FSK and 4FSK
- MR-OFDM: available but not popular
- MR-O-QPSK: DSSS and multiplexed DSSS
IEEE 802.11 Standards Evolution

802.11-1997
2 Mbps, DSSS, FHSS

802.11b
11 Mbps, CCK, DSSS

802.11a
54 Mbps, OFDM, 5 GHz

802.11g
54 Mbps, OFDM, 2.4 GHz

802.11n
600 Mbps with 4x4 MIMO, 20/40 MHz BW, 2.4 or 5 GHz

802.11ac

802.11ad

802.11p
27 Mbps, 10 MHz BW, 5.9 GHz

Wireless Access for Vehicular Environment (WAVE/DSRC)

802.11ah
Up to 4 MHz (16 MHz optional) BW Below 1 GHz

Low power, low rate, long range applications

Wireless Gigabit (WiGig)

Very High Throughput, <6 GHz

Very High Throughput, 60 GHz

802.11af
TVWS

TV White Spaces

WAVE = Wireless Access for Vehicular Environment

DSRC = Dedicated Short-Range Communications

KEYSIGHT TECHNOLOGIES

Keysight Measurement Forum
IoT Enabling Technologies
IEEE 802.11ah – Middle 2016

– Optimized for IoT applications
– PHY/MAC – *trade-off of power, range, rate*
  - PHY based on 802.11ac with data rates > 100 kbps
  - Optimizations for highly robust links and low power consumption required for battery operated devices
  - Sub-1 GHz unlicensed bands
  - Range up to 1 km – beyond 2.4 and 5 GHz range due to improved propagation characteristics of sub-GHz radio waves

– Target use cases
  - Large scale low power sensor networks and smart meter
  - Video surveillance, wearable consumer electronics
  - Backhaul for aggregated sensor and meter data
  - Outdoor Wi-Fi for cellular traffic offloading
**IoT Enabling Technologies**

**IEEE 802.11ah Bandwidth and Data Rates**

- **11ah Bandwidth Modes**
  - 1 MHz
  - 2 MHz
  - 4 MHz
  - 8 MHz
  - 16 MHz

- **Extended range**
  - 150kbps – 4Mbps
  - 650kbps – 7.8Mbps
  - 1.35Mbps – 18Mbps
  - 2.9Mbps – 39Mbps
  - 5.8Mbps – 78Mbps
  - 6.5Mbps – 78Mbps

- **Minimum 11n/ac bandwidth**
  - 20 MHz

- **Mandatory & Globally Interoperable**
  - modes optimized for sensor networking

- **Optional higher data rate modes for extended range WLAN**

---

Keysight Technologies

Keysight Measurement Forum

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IoT Key Enabling Technologies

IEEE 802.11p

- Adds a vehicular communication system to IEEE 802.11 WLAN standard -> **Wireless Access in Vehicular Environment (WAVE)**
- Supports low latency, Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2X) communication
  - Vehicle broadcasts its position and velocity and receives broadcasts of neighboring road users
  - Uses channels of 10MHz bandwidth in the 5.9GHz band (5.850-5.925 GHz)
  - Developed based on 802.11a but targets for reliable connection
- Main uses:
  - Vehicle safety services
  - Commerce transactions via cars
  - Toll collection
  - Traffic management
- USA, Europe, China, Japan, Korean and Singapore are working towards hard /soft mandate or MOU for dedicated short range communication (DSRC) installation.
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

Blue: > billion units/year now
Red: emerging

WPAN: Bluetooth/LE, ANT+, MiWi
WHAN: NFC, EMV
WFAN: ISA100.11a (6LoWPAN), WirelessHART, Many others
WNAN: ZigBee, Z-Wave, Thread (6LoWPAN), EnOcean, Many others
WLAN: 802.11a/b/g/n/ac (WiFi), 802.11ah (WiFi HaLow 1km), 802.11p (V2X), 802.11af (white space)
WWAN: 3GPP LTE-MTC, eMTC/Cat M, LTE-V, 3GPP GSM, WCDMA, EC-GPRS, 3GPP2 Cdma2000, WiMAX
LPWAN: 3GPP NB-IoT, SigFOX, LoRa, Telensa, OnRamp/INGENU, Weightless P, Many others

Proximity (<1cm)
Cellular (licensed) (<100km)
LPWAN (un-licensed) (<100km)

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Low Power Wide Area (LPWA)

Range

<table>
<thead>
<tr>
<th>LPWA</th>
<th>LTE</th>
</tr>
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<tbody>
<tr>
<td>ZigBee Ant+ BT LE</td>
<td>WiFi</td>
</tr>
</tbody>
</table>

Data rate

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

Figure 1. LPWAN global module shipment forecast by application, 2014 - 2019

Coverage pools

- Social housing monitoring
- Street lighting
- Parking sensor
- Fire detection

Region coverage

- Trash collection
- Soil moisture
- Bike tracker
- Bag tracker
- Embedded asset status

Global coverage

- Pet tracker
- Capital asset inventory
- Usage statistics

Keysight Measurement Forum
Low Power Wide Area (LPWA)

Unlicensed niche rollouts

Funded multi-country multi-application rollouts

- **Low cost BS often cellular backhaul**
- **Telensa**
- **SIGFOX**
- **LoRa Alliance**
- **OnRamp Wireless**
- **INGENU**

Significant US, UK and Asia streetlight rollouts

- **US potential TBC**

- **WEIGHTLESS™ mwave**

- **Died, reincarnated, may not make it?**

Licensed Global

Preparing for 2017 LTE/GSM BS rollouts

GSM & LTE Software upgrade

3GPP Release 13:

Clean sheet:
- **NB-IoT** 180kHz BW
- Huawei (HiSilicon/Nuel), Qualcomm, Intel, MTK all working on silicon for 2016 release
- LTE and GSM base station software upgrade
- Deploy in re-farmed GSM spectrum, dedicated fragmented spectrum and LTE guard bands

LTE derivative
- **LTE Cat 0 (or 00?)** 1.4MHz BW
- Altair, Sequans, probably others working on silicon
- LTE base station software upgrade

GSM derivative
- **EC-GSM** 200kHz BW
- Ericsson promoting
- GSM base station software upgrade
Why is LPWAN attracting so much excitement?

Typical ARPU $ per month

Voice & Data Peta Bytes per month

- Voice
- Data
- Typical ARPU

Smartphone: 500MB/mo, $25/mo, $0.05/MB

Source: Ericsson, Strategy Analytics and other industry sources
It’s a money maker!

How much would you pay a month?

Car, cat, bike, livestock, capital equipment tracker?
Building, fire, trash-can alarm?
Meter reader, lighting control?

Smartphone
500MB/mo
$25/mo
$0.05/MB

Guess 1
100kB/mo
$1/mo
$10/MB

Guess 2
100kB/mo
$0.10/mo
$1/MB

Guess 3
100kB/mo
$10/mo
$100/MB

Revenue per MB

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IoT Key Enabling Technologies

LoRa™ (Long Range)

- LoRa is a Semtech technology for IoT
- Provides long range and low power wireless technology to connect low-cost, battery-operated sensors over long distances (10 miles range and > 10 years battery life)
- The LoRa Alliance was formed in February 2015. Release 1.0 of LoRaWAN specification was released to public on June 16, 2015
- **Applications**: smart city, sensor networks, industrial automation application

<table>
<thead>
<tr>
<th>Frequency (MHz) ISM Band</th>
<th>Bandwidth</th>
<th>Modulation Schemes</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>433 (Europe)</td>
<td>125 kHz &amp; 250 kHz</td>
<td><strong>LoRa</strong> (Chirp Spread Spectrum or CSS) GFSK</td>
<td>&gt;15 km (9 miles) in a suburban environment and up to 5 km (3 miles) in a dense urban environment</td>
</tr>
<tr>
<td>853-870 (Europe)</td>
<td>125 kHz &amp; 250 kHz</td>
<td><strong>LoRa</strong> (Chirp Spread Spectrum or CSS) GFSK</td>
<td></td>
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<tr>
<td>779-787 (China)</td>
<td>125 kHz &amp; 250 kHz</td>
<td><strong>LoRa</strong> (Chirp Spread Spectrum or CSS) GFSK</td>
<td></td>
</tr>
<tr>
<td>902-928 (North America)</td>
<td>125 kHz &amp; 500 kHz</td>
<td><strong>LoRa</strong> (Chirp Spread Spectrum or CSS)</td>
<td></td>
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</tbody>
</table>

*LoRa, Semtech’s proprietary modulation, is a spread spectrum modulation scheme that is derivative of Chirp Spread Spectrum modulation (CSS) and which trades data rate for sensitivity within a fixed channel bandwidth.*
**LoRaWAN**

*Products & Services*

For Carrier Grade Low Power
Wide Area Solutions

---

**Keysight**

*Radio Test equipment*

Keysight vector signal analyzers and generator enable designers and manufacturers to verify the receiver and transmitter performance of wireless devices.

Arbitrary waveforms based on model or capture data can be loaded and replayed at low signal levels to test receiver sensitivity.

Transmitter spectrum occupancy can be verified. Vector Signal Analyzers can verify modulation metrics for GMSK. The 89601B FMCW Radar option can visualize and provide metrics for chirp modulated signals.

Keysight Battery Drain Analysis tools enable developers to optimize software and hardware designs to extend battery lifetime.

---

**LoRaWAN™ Ready**

Yes

**Radio Regions**

- Europe 868 MHz
- USA 915 MHz
- Asia 470 MHz
- 433 MHz

**Focus Markets**

- Signal generation and analysis
- Battery drain analysis
- Tools for R&D and manufacturing test

---

**Company:** Keysight

**Country:** USA

**Type:** Test and Measurement tool provider

**Commercial Contact:** ian_reading@keysight.com

**Technical Contact:** ian_reading@keysight.com
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
Key 3GPP Release 13 updates

Clean sheet:
• NB-IoT 180kHz BW
• LTE and GSM base station software upgrade
• Trial service 2016, commercial service 2017

LTE derivative
• LTE Cat M 1.4MHz BW
• LTE base station software upgrade
• Commercial service 2017

GSM derivative
• EC-GSM (EC-GPRS) 200kHz BW
• GSM base station software upgrade
• Commercial service TBC
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

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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## 3GPP Cellular IoT Summary

<table>
<thead>
<tr>
<th></th>
<th>3GPP Rel 12</th>
<th>3GPP Rel 13</th>
<th>NB-IoT*</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MTC Cat 0</strong></td>
<td>3GPP Cell</td>
<td>3GPP Cell</td>
<td>Clean-slate</td>
</tr>
<tr>
<td><strong>eMTC Cat M</strong></td>
<td>3GPP Cell</td>
<td>3GPP Cell</td>
<td>Clean-slate</td>
</tr>
<tr>
<td><strong>EC-GPRS</strong></td>
<td>3GPP Cell</td>
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<td>Clean-slate</td>
</tr>
<tr>
<td><strong>NB-IoT</strong></td>
<td>3GPP Cell</td>
<td>3GPP Cell</td>
<td>Clean-slate</td>
</tr>
<tr>
<td><strong>Heritage</strong></td>
<td>LTE</td>
<td>LTE</td>
<td>GSM</td>
</tr>
<tr>
<td><strong>Bandwidth (downlink)</strong></td>
<td>20 MHz</td>
<td>1.4 MHz</td>
<td>200 kHz</td>
</tr>
<tr>
<td><strong>Bandwidth (uplink)</strong></td>
<td>20 MHz</td>
<td>1.4 MHz</td>
<td>200 kHz</td>
</tr>
<tr>
<td><strong>Multiple access (downlink)</strong></td>
<td>OFDMA</td>
<td>OFDMA</td>
<td>TDMA</td>
</tr>
<tr>
<td><strong>Multiple access (uplink)</strong></td>
<td>SC-FDMA</td>
<td>SC-FDMA</td>
<td>TDMA</td>
</tr>
<tr>
<td><strong>Modulation (downlink)</strong></td>
<td>QPSK, 16QAM, 6 4QAM</td>
<td>QPSK, 16QAM, 64 QAM</td>
<td>GMSK, optional 8PSK</td>
</tr>
<tr>
<td><strong>Modulation (uplink)</strong></td>
<td>QPSK, 16QAM</td>
<td>QPSK, 16QAM</td>
<td>GMSK, optional 8PSK</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>
</tr>
<tr>
<td><strong>Coverage (link budget)</strong></td>
<td>~141dB</td>
<td>~156dB</td>
<td>~164dB</td>
</tr>
<tr>
<td><strong>Mobility</strong></td>
<td>Full</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

Low power

Deep coverage

Low latency

Data rate

Density

Mobility

Enhanced mobile broadband

Ultra reliable low latency

Drones

Vehicles

VR & AR

Smartphones

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Local Interworking
Device discovery, publish, subscribe

Competing consortia

AllSeen Alliance (Qualcomm)
Open source
Qualcomm, Sharp, Sony, Cisco, Microsoft, LG…….

Open Interconnect Consortium (Intel)
Open source
Intel, Samsung, GE, Cisco, Broadcom, IBM….

Apple HomeKit

Google Weave

Time for coffee

Coffee's ready

Someone's at the door

Keysight Measurement Forum
“If Company A runs a fleet of trucks and Company B runs a fleet of container ships then their mutual customer, Company C, can use one application to track the cargo, regardless of the handler.”

OneM2M

- Formed July 24th 2012, Founding partners: ARIB, ATIS, CCSA, ETSI, TIA, TTA, TTC
- Reference architecture and conformance test regime for a common service layer for global interworking
- Focus is edge to cloud so good synergy with Allseen & OIC. Also looking at HomeKit interworking
- CoAP, MQTT, DTLS, OMA LWM2M
Agenda

- IoT/M2M Introduction and Market Situation
- IoT/M2M Key Enabling Wireless Technologies
  - IEEE 802 LAN/MAN Working Group
  - Wide area networks (LPWAN) and NB-IoT
- IoT Optimization and test challenges
  - Optimization
  - Interference & operating environment replication
- Summary
### Design optimization

**Smartphone**
- User powers off/on
- User recharges
- Unlimited software updates

**Critical IoT**
- Large integrated information and control systems
- Distributed sensors/actuators
- Onsite repair to reset and/or replace prematurely drained battery
- Battery constrains software updates

### Questions:
- How often do you need to power cycle your smartphone?
- Have you ever experienced an app or network problem that drained the battery?
- What was the cost to repair… power off/on or recharge the battery until software fixed?
- Large systems may only be as good as the weakest (IoT) element
- Repair can involve expensive onsite visit
### Design optimization

<table>
<thead>
<tr>
<th>Smartphone</th>
<th>Critical IoT</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Failure impact</strong></td>
<td></td>
</tr>
<tr>
<td>- User powers off/on</td>
<td>Large integrated information and control systems</td>
</tr>
<tr>
<td>- User recharges</td>
<td>Distributed sensors/actuators</td>
</tr>
<tr>
<td>- Unlimited software updates</td>
<td>-</td>
</tr>
<tr>
<td><strong>Repair</strong></td>
<td></td>
</tr>
<tr>
<td>- Onsite repair to reset and/or replace prematurely drained battery</td>
<td></td>
</tr>
<tr>
<td>- Battery constrains software updates</td>
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- Have you ever experienced an app or network problem that drained the battery?
- What was the cost to repair... power off/on or recharge the battery until software fixed?
- Large systems may only be as good as the weakest (IoT) element
- Repair can involve expensive onsite visit
Design optimization

Software stability

Hardware reliability

Max data rate

Low cost

Low power

Time to market

IoT

Low power

IoT

Low cost

Time to market

Hardware reliability

Max data rate

Low power

IoT

Low cost

Time to market

Software stability

Hardware reliability

Max data rate

Low cost

Time to market

Software stability

Hardware reliability

Max data rate

Low cost

Time to market

Software stability

Hardware reliability

Max data rate

Low cost

Time to market

Software stability

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Hardware reliability

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Low cost

Time to market

Software stability

Hardware reliability

Max data rate

Low cost

Time to market

Software stability

Hardware reliability

Max data rate

Low cost

Time to market
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
  - 3rd 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

Radio frequency design

UXM RF Meas'

UXM built-in app server

Stability/longevity

Test Automation Platform (TAP)

Acceptance/production

T4000S RCT/RRM operator RF

Anite protocol and operator test

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## Power consumption analysis

### Table: Seamless Range Changes

<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% + 100 nA)</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>

- [Image: Device under test](image1)
- [Image: Golden device](image2)
- [Image: Charge / Energy](image3)
- [Image: N6705B with Source Measurement Unit](image4)

**Activity**

- BLE Advertisement: 3.65 ms
- Like 28 bits

**Golden device**

**Device under test**

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Probing for insight

**Device under test**

- **N6705B with Source Measurement Unit**
- **Infiniium S-Series oscilloscopes**
- **89601B VSA Software**
- **N9010B EXA Signal Analyzer, Multi-touch, 10 Hz to 44 GHz**
- **N2820A 3 MHz/50uA High Sensitivity AC/DC Current Probe**
- **U5855A TrueIR Thermal Imager**
- **N6705B with Source Measurement Unit**
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

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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Vector Signal Analysis and Generation

**Signal Analysis**
- 89600 VSA Software

**X-Series Application**
- X-Series Analysers e.g. MXA
- Modular e.g. VXT

**Signal Generation**
- InfiniiVision Oscilloscopes
- X-Series Generators e.g. MXG
- Integrated Test sets e.g. EXM & EXF

**Signal Studio & Waveform Creator**
- Modular e.g. VXT
Test Challenges (Interference)

Some Common Test Challenges for IoT

Sensor Networks – Up to 8,000 devices (sensors) may connect to a single AP
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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Modelling tools

R&D

- Modelling
- PHY/RF
- L2/L3
- Apps
- Integration

VSA/VSG

Pre-standard NB-IoT simulation and signal analysis
Test Instrument Used for Drone Testing

- Power Analyzer
- Scope
- Network Analyzer
- Signal Analyzer
- Logic Analyzer
- DMM
- Power Supply
- HH Meter
- Signal Generator

Diagram:
- Flight Control System
- Main Controller for Flight Control
- Chargeable Battery 1
- Chargeable Battery 2
- Power Management Unit (PMU 1)
- Power Management Unit (PMU 2)
- Ground Controller
- Transmit Unit
- GPS/GNSS
- Switch
- Remote Main Controller
- Wireless Video Tx Module (on ground)
- Mobile equipment (APP & Ground Station)
- CAN or Dedicated BUS
- Video Recording Module
- HDMI-HD/AV Module
- Pan-Tilt
- Independent IMU
- Rudder/Pan-Tilt/Video System
- 5G/2.4G/SubG
- Wireless Video Rx Module (on ground)
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Q and A Session