Machine-to-Machine in Smart Grids & Smart Cities
Technologies, Standards, and Applications

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Furthermore, these slides are not endorsed ETSI but are simply based on the work currently underway in ETSI M2M.

Thank you for your understanding!
Machines Do What Humans Don’t

<table>
<thead>
<tr>
<th>Repetitive (Boring) Jobs</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>(Time) Critical Jobs</th>
</tr>
</thead>
<tbody>
<tr>
<td>© <a href="http://balancedlifeskills.com/home/tag/teen-stress">http://balancedlifeskills.com/home/tag/teen-stress</a></td>
</tr>
</tbody>
</table>
M2M Is All About Helping Humans


© CNN “When Machines Talk To Each Other”;
M2M Is All About Real-Time “Big” Data

http://www.zdnet.com/big-data-all-you-need-to-know-1339335818/

http://strata.oreilly.com/2012/01/what-is-big-data.html

http://tinyurl.com/bro8y8u

http://tinyurl.com/duy2ncs
M2M Is All About Opportunities

http://www.gereports.com/new_industrial_internet_service_technologies_from_ge_could_eliminate_150_billion_in_waste/
Upstream Data Flow

Instrumented + Interconnected + Intelligence = Smarter Data

embedded computing + network computing + cloud computing = reliable real-time & statistical data

LOW POWER NETWORK

sensor (efficiency) network (reliability) gateway (availability)

BIG DATA HANDLING

cloud (ubiquitous) data (scalable) storage (availability)
Downstream Data Flow

Intelligent Data + Front-Ends + Panels = Real-Time News

business intelligence + corporate view + crowd view = unprecedented client experience

AppSrv
Analytics
Data Storage
WOCS
OLAP

application (secure) processing (intelligent) interface (scalable)

BIG DATA INTELLIGENCE

computer (ubiquitous) mobile (reachable) infrastructure (reliable)

VISUAL FRONT-ENDS

© Worldsensing

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Data Mashup Platforms

Real-Time + Crowdsourced + Open Data = Smart Applications

- Machine-to-Machine
- Sensor Streams
- Human-to-Machine
- Crowdsourcing
- Information-to-Machine
- Internet

"Big Data" Analytics

- Improve Efficiency
- Offer New Services
- Power Applications
Machine-to-Machine (M2M) means no human intervention whilst devices are communicating end-to-end.

This assumes some fundamental M2M system characteristics:
- support of a huge amount of nodes, sending small data each
- mission-critical data provision
- autonomous operation
- self-organization
- power efficiency
- reliability
- etc, etc
# Overview of Tutorial

## 1. Overview of M2M
1. A Quick Introduction
2. ROI, Markets & Cellular Market Shares
3. M2M in Smart Cities
4. M2M in Smart Grids

## 2. Capillary M2M
1. Quick Intro to Capillary M2M
2. IEEE-Pertinent M2M Standards
3. IETF-Pertinent M2M Standards
4. Low-Power Wifi for M2M

## 3. Cellular M2M
1. Introduction to Cellular M2M
2. M2M in Current Cellular Networks
3. M2M Cellular Standardization Activities
4. Specific M2M Architectures and Performance

## 4. Concluding Observations
1. Challenges for the future
2. Some Predictions for M2M
Overview of M2M
1.1
A Quick Introduction
Quick Intro

- **Machine – To – Machine:**
  - device (water meter) which is monitored by means of sensor [in “uplink”]
  - device (valve) which is instructed to actuate [in “downlink”]
  - keywords: physical sensors and actuators; cost

- **Machine – To – Machine:**
  - network which facilitates end-to-end connectivity between machines
  - composed of radio, access network, gateway, core network, backend server
  - keywords: hardware; protocols; end-to-end delay and reliability; cost

- **Machine – To – Machine:**
  - device (computer) which extracts, processes (and displays) gathered information
  - device (computer) which automatically controls and instructs other machines
  - keywords: middleware, software, application; cost
M2M End-to-End Network

- **Access Network** – connecting the sensors & actuators:
  - “wired” (cable, xDSL, optical, etc.)
  - wireless “capillary”/short-range (WLAN, ZigBee, IEEE 802.15.4x, etc.)
  - wireless cellular (GSM, GPRS, EDGE, 3G, LTE-M, WiMAX, etc.)

- **Gateway** – connecting access and backhaul/core networks:
  - network address translation
  - packet (de)fragmentation; etc.

- **Backhaul/Core/Internet Network** – connecting to computer system:
  - IPv6-enabled Internet
M2M Access Networks [1/2]

- Connecting your smart meters through 4 example access methods:

  - **CAPILLARY - WIRED**
    - Mediterranean Water Company (MWC) A/C
    - xDSL

  - **CAPILLARY - CELLULAR**
    - Cellular VAS: AT & T GATEWAY

  - **CELLULAR**
    - GATEWAY
M2M Access Networks [2/2]

- **Wired Solution** – dedicated cabling between sensor - gateway:
  - pros: very, very *reliable*; very high rates, little delay, secure
  - cons: very *expensive to roll out, vandalism, not scalable*, *no mobility*

- **Wireless Capillary Solution** – shared short-range link/network:
  - pros: *cheap* to roll out, generally scalable, *low power*
  - cons: short range, *multi-hop not a solution*, low rates, weaker security, *interference, lack of universal infrastructure/coverage*

- **Wireless Cellular Solution** – dedicated cellular link:
  - pros: *excellent coverage*, mobility, *roaming*, generally secure, infrastructure
  - cons: *expensive operate*, not cheap to maintain, *not power efficient*, delays
## Timeline of M2M

**Origin of term “Machine-to-Machine”:**

<table>
<thead>
<tr>
<th></th>
<th>past</th>
<th>presence</th>
<th>near future</th>
<th>far future</th>
</tr>
</thead>
<tbody>
<tr>
<td>WIRED</td>
<td>SCADA, &gt;1980</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CELLULAR</td>
<td>Maingate, 1998 (also Ericsson)</td>
<td>Nokia M2M, 2002</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CAPILLARY</td>
<td>WSN, &gt;1990</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HYBRID</td>
<td>Coronis, 2002</td>
<td></td>
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</tbody>
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Novelty of Wireless M2M [1/2]

- WiFi WLAN
  - Short Range Communications e.g. Zigbee
  - 10^{11} nodes

- Mobile networks e.g. LTE
  - 10^8 users

New major opportunity: Many M2M users Low overhead
Novelty of Wireless M2M [2/2]

Billions of subscribers, trillions of objects
Seamlessly connected and fully integrated

Presented by Interdigital: Globecom’11 – IWM2M, Houston
1.2
ROI, Markets & Cellular Market Shares
ROI #1 – Real-Time Instrumentation
ROI #2 – “Big Data” Value

factorial growth!
The Promise of Wireless

ROI #3 – Savings of Wireless M2M

$\text{wired cost}$

\text{installation, connection, commissioning}

$\text{cellular M2M}$

$\text{capillary M2M}$

$\text{90\%?}$
Popular M2M Markets

Building Automation

Smart City

Telemetry

Smart Grids

Industrial Automation
Growing Cellular M2M Market

Worldwide Cellular M2M Module Shipments
by Air Interface (ABI Research, Q3 2009)

Cellular M2M modules shipments forecast
(worldwide, Berg Insight, Q3 2009)

LTE modules deliveries by Application (ABI Research forecast in Q3 2009 for 2014)
1.3 M2M in Smart Cities
Situation Today

- From the *humanity* point of view:
  - we are now more than 7bn people on the planet
  - 1 out of 2 is living in cities today; impact onto people’s health is enormous
    - 80% in Europe
  - e.g. 2 Million people are estimated to die annually due to pollution

- From the *political* point of view:
  - politicians have hence become very susceptible to this topic
  - politicians are eyeing ICT technologies as a possible remedy

- From the *market* point of view:
  - >$100bn per year in 2020 with >$20bn annual spending on Smart Cities

- From the *technology* point of view:
  - technology players are hence trying to enter this market (IBM, Cisco, HP, Oracle)
Smart City Rollout Phases

PHASE 1: Revenue and Useful

PHASE 2: Useful to Public

PHASE 3: the rest

- 2010
- 2015
- 2020

Efficient Townhall

Efficient City

Smart City
Smart City Rollout Phase Examples

**PHASE 1: Revenue and Useful:**
- Smart Parking
- Smart Street Lightening
- Smart Litter Bins

**PHASE 2: Useful to Public:**
- Smart Traffic Flow
- Pollution Monitoring

**PHASE 3: the rest:**
- AR (gaming), etc
Smart City Stakeholders (abstraction)
Smart City Technology Platform

Internet
Crowdsourcing
Sensor Streams

Smart City Operating System

Improve Efficiency
Offer New Services
Power Applications
Wireless M2M Technologies

Low Cost

Low Energy

Low Env. Footprint

Machine-To-Machine (M2M) Smart City Technologies

Capillary M2M

Cellular M2M
Yesterday’s M2M Smart City Vision

- Weather sensors with mobile connectivity
- Surveillance cameras with 3G connectivity
- Connected wearable health monitor
- Connected smart energy meters in houses
- 3G connectivity in cars
- Wireless sensory networks
- E-book readers, connected sports devices, digital picture frames...

© Northstream

Today’s M2M Smart City Reality

- Smart Parking
- Traffic Flow
- Travel Time
- Smart Bins
- Critical Infrastr.
- Historic Sites

Smart City Control Platform

Proven Technologies With Solid Deployment Track-Record Today!
Example: Moscow Smart Parking
Example: Barcelona Harbor

- **Problem**: Monitoring beams settlement. 200 biaxial inclinometers. 72 Km of cable. Expensive logistics.

- **Solution**: Loadsensing.com radio nodes and gateway deliver data 24/7 into the Internet and to the company’s control centre. Installed in few hours.

- **Benefits**: monitoring cost greatly reduced; reduction of installation costs. Safety significantly increased: 24/7 connectivity and alert capabilities.
1.4

M2M in Smart Grids
Smart Grid Vision

- **Historical Smart Grid Developments:**
  - EU initiated the smart grid project in 2003 (almost 10 years back!)
  - Electric Power Research Institute, USA, around 2003
  - US DOE (Dept. of Energy) had a Grid 2030 project, around 2003
  - National Institute of Standards and Technology (NIST) is responsible as of 2007

- **Mission of ICT in Smart Grids:**
  - enable energy efficiency distribution and usage
  - keep bills at both ends low
  - minimize greenhouse gas emissions
  - automatically detect problems and route power around localized outages
  - accommodate all types and volumes of energy, including alternative
  - make the energy system more resilient to all types of failures
Reduce Waste & Dependency ...
... with Smart Grids

1. Local Energy Production
2. Bi-Directional Energy Flow
3. Real-Time Instrumentation
Future Energy Landscape
Microgrids Play Central Role

G- Instalación fotovoltaica de 25 kWp

G- Grupo electrógeno diesel 55 kVA

G- Aerogenerador 20 kW tipo full-converter

A- Banco de baterías plomo ácido de gel, 50 kW x 2 horas
M2M Plays Central Role
Smart Grid Comms Standards

- Challenge to develop standards: connecting two worlds!

- Most relevant standard:
  - IEEE P2030 Smart Grid Interoperability of Energy Technology and Information Technology Operation with the Electric Power System (EPS), End-Use Applications, and Loads

- Power System Control and Monitoring:
  - IEEE C37.239™-2010 - IEEE Standard for Common Format for Event Data Exchange (COMFEDE) for Power Systems

IEEE P2030 Interoperability Concept

Systems Approach
Interconnection & Interfaces
Technical Standards
Advanced Technologies
Systems Integration

Transmission System
Bulk Power
Substations
Distribution System

Communications and Information Technology
Information Flow, Data Management, Monitor & Control

Source: IEEE Standards Association

ETSI M2M Smart Grid “Architecture”
M441 Among CEN/CENELEC/ETSI

[Diagram showing the integration of various systems and standards, including Home automation, CENELEC TC 205, CEN TC 294, HAN/LAN, M2M gateway, ETSI interface for M2M communications, CENELEC TC 13, Non-electricity meters (Water, Heat, Gas), and Electricity meters.]
Today’s M2M Smart Grid Reality

[© EDP Portugal and FP7 STREP WSAN4CIP]
2

Capillary M2M
2.1 Quick Intro to Capillary M2M
## History of WSN → M2M

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>1967</td>
<td>REMBASS Remotely Monitored Battlefield Sensor System</td>
</tr>
<tr>
<td>1978</td>
<td>Distributed Sensor Networks for Aircraft Detection Lincoln Labs - Lacoss</td>
</tr>
<tr>
<td>1993-1996</td>
<td>DARPA ISAT studies - many WSN ideas and applications discussed. Deborah Estrin leads one of the studies.</td>
</tr>
<tr>
<td>1997</td>
<td>Smart Dust proposal written - UCB, Kris Pister</td>
</tr>
<tr>
<td>1998</td>
<td>Seth Hollar makes wireless mouse collars</td>
</tr>
<tr>
<td>1999</td>
<td>Endeavour project proposed by Randy Katz, David Culler PicoRadio project started by Jan Rabaey</td>
</tr>
<tr>
<td>2000</td>
<td>Crossbow begins selling &quot;Berkeley motes&quot;</td>
</tr>
<tr>
<td>2001</td>
<td>Multiple demos proving viability</td>
</tr>
<tr>
<td>2002</td>
<td>Dust, Ember, Millennial, Sensicast founded</td>
</tr>
<tr>
<td>2003</td>
<td>IEEE 802.15.4 standard published Moteiv (now Sentilla) founded</td>
</tr>
<tr>
<td>2004</td>
<td>Zigbee 1.0 standard ratified TSMP 1.1 shipping</td>
</tr>
<tr>
<td>2005</td>
<td>Arch Rock founded</td>
</tr>
<tr>
<td>2006</td>
<td>Zigbee 2006 standard ratified 802.15.4-2006 standard ratified</td>
</tr>
<tr>
<td>2007</td>
<td>Wireless HART standard ratified RFC4944 published</td>
</tr>
<tr>
<td>2008-2009</td>
<td>IETF workgroup Routing Over Low-power Lossy links (ROLL) created IEEE 802.15.4e work group created</td>
</tr>
<tr>
<td>2010</td>
<td>IEEE 802.15.4e’s MAC protocol ratified IETF 6LoWPAN’s RFC4944 updated IETF ROLL’s RPL routing protocol ratified</td>
</tr>
</tbody>
</table>
Characteristics of Capillary M2M

■ What is “Capillary M2M”:
  ■ mostly embedded design, low power, low cost design
  ■ short-range communication systems
  ■ power consumption is major headache (go harvesting?) - need to live for decades

■ What it is not:
  ■ cellular system (cellular connectivity only possible via gateway)
  ■ “academic” wireless sensor networks (since not guaranteeing universal connectivity)

■ Conclusion:
  ■ Whilst many insights from academic research on WSNs can be used, the capillary M2M will be dominated by industry-driven standardized low-power solutions.
Barriers in Capillary M2M

- Reliability
- Standards
- Ease of use
- Power consumption
- Development cycles
- Node size

*source: OnWorld, 2005*
Design of Capillary M2M

- Each node typically consists of these basic elements:
  - sensor
  - radio chip
  - microcontroller
  - energy supply

- These nodes should be:
  - low – cost
  - low – complexity
  - low – size
  - low – energy
  - robust
Off-The-Shelf Hardware – Today?
Hardware Differs Significantly

<table>
<thead>
<tr>
<th>vendor</th>
<th>name</th>
<th>sensitivity</th>
<th>current Tx @ 0dBm</th>
<th>current Rx</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atmel</td>
<td>AT86RF231</td>
<td>-101dBm</td>
<td>14.0mA</td>
<td>12.3mA</td>
</tr>
<tr>
<td>Dust Networks</td>
<td>DN6000</td>
<td>-91dBm</td>
<td>4.4mA</td>
<td>3.5mA</td>
</tr>
<tr>
<td>Ember</td>
<td>EM357</td>
<td>-100dBm</td>
<td>27.5mA</td>
<td>25.0mA</td>
</tr>
<tr>
<td>Freescale</td>
<td>MC13233</td>
<td>-94dBm</td>
<td>26.6mA</td>
<td>34.2mA</td>
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<tr>
<td>Microchip</td>
<td>MRF24J40</td>
<td>-95dBm</td>
<td>23.0mA</td>
<td>19.0mA</td>
</tr>
<tr>
<td>NXP/Jennic</td>
<td>JN5148</td>
<td>-95dBm</td>
<td>15.0mA (1.8dBm)</td>
<td>17.5mA</td>
</tr>
<tr>
<td>Texas Instruments</td>
<td>CC2520</td>
<td>-98dBm</td>
<td>25.8mA</td>
<td>18.8mA</td>
</tr>
</tbody>
</table>
Experimentation – Surprise, Surprise!

http://people.csail.mit.edu/jamesm/

http://senseandsensitivity.rd.francetelecom.com/
Important Practical Challenges

- **External Interference:**
  - often neglected in protocol design
  - however, interference has major impact on link reliability
  - Use of saturated ISM bands → WLANs

- **Wireless Channel Unreliability:**
  - MAC and routing protocols were often channel agnostic
  - however, wireless channel yields great uncertainties due to eg fading

- **Lack of Standards:**
  - lack of standards causes inoperability between devices
  - this hinders scalability and true uptake of M2M technologies
Challenge #1: External Interference

![Graph showing frequency bands for different standards: IEEE802.11 (Wi-Fi), IEEE802.15.1 (Bluetooth), and IEEE802.15.4 (ZigBee).]
Challenge #1: External Interference

Typical Tx power
- IEEE802.11-2007: 100mW
- IEEE802.15.4-2006: 1mW

2.4 GHz PHY

Channels 11-26

5 MHz

2.4 GHz

2.4835 GHz
Challenge #1: External Interference

IEEE802.11b/g/n
IEEE802.11a/n
IEEE802.15.4
Challenge #1: External Interference

- 45 motes*
- 50x50m office environment
- 12 million packets exchanged, equally over all 16 channels

*data collected by Jorge Ortiz and David Culler, UCB
Publicly available at wsn.eecs.berkeley.edu
Challenge #2: Multipath Fading
Challenge #2: Multipath Fading

0% reliability

Channel Frequency Band #11

100% reliability

Channel Frequency Band #12
Challenge #3: Standards

The Internet
Challenge #3: Standards
Challenge #3: Standards

- Standards Developing Organization bodies can be
  - international (e.g. ITU-T, ISO, IEEE),
  - regional (e.g. ANSI, ETSI), or
  - national (e.g. CCSA)

- Standardization efforts pertinent to capillary M2M are:
  - **IEEE** (physical and link layer protocols)
  - **IETF** (network and transport protocols)
  - **ISA** (regulation for control systems, *not dealt with*)
  - **ETSI** (complete M2M solutions) → in fixed and cellular part
  - **oneM2M** (globalized M2M solution)
## Challenge #3: Standards

<table>
<thead>
<tr>
<th></th>
<th>Zigbee-like</th>
<th>Low-Power Wifi</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Application</strong></td>
<td>IETF CORE</td>
<td>HTTP, etc</td>
</tr>
<tr>
<td><strong>Transport</strong></td>
<td>(Lightweight TCP), UDP</td>
<td>TCP, UDP, etc</td>
</tr>
<tr>
<td><strong>Networking</strong></td>
<td>IETF ROLL (routing)</td>
<td>IPv4/6, etc</td>
</tr>
<tr>
<td></td>
<td>IETF 6LoWPAN (adapt.)</td>
<td></td>
</tr>
<tr>
<td><strong>MAC</strong></td>
<td>IEEE 802.15.4e</td>
<td></td>
</tr>
<tr>
<td><strong>PHY</strong></td>
<td>IEEE 802.15.4-2006</td>
<td>IEEE 802.11</td>
</tr>
</tbody>
</table>
2.2

IEEE-Pertinent Capillary M2M Standards
IEEE – Embedded Standards

- The IEEE usually standardizes:
  - PHY layer of the transmitter
  - MAC protocol rules

- The following IEEE standards are applicable to M2M:
  - IEEE 802.15.1 (technology used e.g. by Bluetooth)
  - IEEE 802.15.4 (technology used e.g. by ZigBee and IETF 6LowPan)
  - IEEE 802.11 (technology used by WiFi)

- Some facts and comments:
  - ultra-low power (ULP) IEEE 802.15.1 (Bluetooth) is competing … but to be seen
  - IEEE 802.15.4 was dormant and only with .15.4e seems to become viable
  - low power IEEE 802.11 solutions are becoming reality (origins with Ozmo Devices)
IEEE 802.15.4e – Overview

■ Standards history:
  ■ 2006: TSCH approach emerges in the proprietary *Time Synchronized Mesh Protocol* (TSMP) of Dust Networks
  ■ 2008/2009: TSMP is standardized in ISA100.11a and WirelessHART
  ■ 2011: 802.15.4e Sponsor Ballot opened on 27 July 2011 and closed on 28 August with 96% of votes being affirmative

■ Aim of amendment:
  ■ define a MAC amendment to the existing standard 802.15.4-2006
  ■ to better support industrial markets

■ 3 different MACs for 3 different types of applications:
  ■ LL: Low Latency
  ■ CM: Commercial Application
  ■ PA: *Process Automation*
Slotframe structure = sequence of repeated time slots:

- time slot can be used by one/multiple devices (dedicated/shared link) or empty
- multiple slotframes with different lengths can operate at the same time
- SlotframeCycle: every new slotframe instance in time
- Slotframe size: # slots in a slotframe
Link = (time slot, channel offset) → CHANNEL HOPPING

Dedicated link assigned to:
- dedicated link: 1 node for Tx; 1 or more for Rx
- shared link: 1 or more for Tx

Prime aim to help:
- channel impairments
- system capacity

The two links from B to A are dedicated
D and C share a link for transmitting to A
D use a dedicated link for transmitting to E and F
PA - Channel Hopping

![Graph showing received signal power over frequency]

- **fb.11** to **fb.26**

**Frequency (GHz)**

- **2.400** to **2.480**

**Received Signal Power (dBm)**

- **-25** to **-65**

Interference indicated between **2.430** and **2.450** GHz.

**Device A**

**Device B**
PA - Slotted Structure

- A super-frame repeats over time
  - Number of slots in a superframe is tunable
  - Each cell can be assigned to a pair of motes, in a given direction

<table>
<thead>
<tr>
<th>APPL</th>
<th>COAP</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRAN</td>
<td>UDP</td>
</tr>
<tr>
<td>NET</td>
<td>RPL</td>
</tr>
<tr>
<td>adaptation</td>
<td>6LoWPAN</td>
</tr>
<tr>
<td>MAC</td>
<td>IEEE802.15.4e</td>
</tr>
<tr>
<td>PHY</td>
<td>IEEE802.15.4</td>
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</table>
PA - Slotted Structure

- Cells are assigned according to application requirements
PA - Trade-Off [1/3]

- Cells are assigned according to application requirements
- Tunable trade-off between
  - packets/second
  - …and energy consumption

16 channel offsets

e.g. 33 time slots (330ms)
PA - Trade-Off [2/3]

- Cells are assigned according to application requirements
- Tunable trade-off between
  - packets/second
  - Latency

...and energy consumption

16 channel offsets

e.g. 33 time slots (330ms)
PA - Trade-Off [3/3]

- Cells are assigned according to application requirements
- Tunable trade-off between
  - packets/second
  - Latency
  - Robustness

...and energy consumption

![Diagram showing channel offsets]

- e.g. 33 time slots (330ms)
PA - Slot Structure

2.120ms

< 4.256ms

0.800ms

0.400ms

9.976ms

2ms

2.400ms

= transmitter on

= receiver on

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PA - Energy Consumption

Type of slot | Transmitter | Receiver
---|---|---
< = transmitter on | = receiver on

<table>
<thead>
<tr>
<th>2.120ms</th>
<th>&lt; 4.256ms</th>
<th>0.800ms</th>
<th>0.400ms</th>
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<tbody>
<tr>
<td>T2</td>
<td>T3</td>
<td>T4</td>
<td></td>
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</table>

<table>
<thead>
<tr>
<th>Start of timeslot</th>
<th>2ms</th>
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<tr>
<th>9.976ms</th>
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<tr>
<th>2.400ms</th>
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<thead>
<tr>
<th>End Of timeslot</th>
</tr>
</thead>
</table>
PA - Synchronization

Clocks drift
(10ppm typical)

Periodic realignment
(within a clock tick)

Resynchronization every 100s needed
(every 30s in practice)
PA – Lifetime

■ Assumptions
  ■ 2400mAh (AA battery)
  ■ 14mA when radio on (AT86RF231)

■ If my radio is on all the time
  ■ 171 hours of time budget (7 days of lifetime)

■ If I only want to keep synchronization (theoretical lower limit)
  ■ 7.656ms from a time budget of 171 hours → I can resync. 80x10^6 times
  ■ 76 years of lifetime (» battery shelf-life)

■ A duty cycle of 1% → 2 years of lifetime
PA – Lifetime

- Looking at node D
  - “normal” case
    - 1 reception, 1 transmission (15ms) every 3.3 seconds
    - .45% duty cycle → 4 years lifetime

- 16 channel offsets
- e.g. 330 time slots (3.3s)
PA – Lifetime

- Looking at node D
  - “normal” case
  - Triple data rate
    - 3 receptions, 3 transmissions (45ms) every 3.3 seconds
    - 1.36% duty cycle → 17 months lifetime
IEEE 802.15.4e does **not** specify how such schedule is built:

- **centralized approach**: good for static networks
- **distributed approach**: suitable for mobile networks with many gateways

**Traffic Aware Scheduling Algorithm (TASA):**

![Diagram of TASA](image)

(a) $DCF(k)$ set selection based on local and global queue level.

(b) Coloring $I(k)$.

**Figure.** Matching and Coloring phases of TASA scheme  [M.R. Palattella, N. Accettura, M. Dohler, L.A. Grieco, G. Boggia, “Traffic Aware Scheduling Algorithm for the Emerging IEEE 802.15.4e Standard”, submitted to ACM Transaction on Sensor Networks.]
PA – Network Schedule

2.3
IETF-Pertinent Capillary M2M Standards
IETF – Overview

- Internet Engineering Task Force:
  - not approved by the US government; composed of individuals, not companies

- General scope of IETF:
  - above the wire/link and below the application
  - however, layers are getting fuzzy (MAC & APL influence routing) → challenge
  - Example IEEE 802.15.4e: multi-hop is challenging layer 2 (schedule) and routing.
  - Traditional IETF protocols are not suitable for embedded networks
  - Solution → design new protocols taking into account layer-2 protocols (IEEE)

- Same people → IETF developments pertinent to Capillary M2M:
  - 6LoWPAN (IPv6 over Low power WPAN)
  - ROLL (Routing Over Low power and Lossy networks)
  - CORE (Constrained RESTful Environments)
Every host on the Internet has a unique Internet Protocol (IP) address
  - A packet with an IP header is routed to its destination over the Internet

IP is the narrow waist of the Internet
  - “If you speak IP, you are on the Internet”

Evolution of the Internet Protocol
  - IPv4 (1981) is currently used
    - 32-bit addresses
    - “third-party toolbox”: ARP, DHCP
  - IPv6 (1998) is being deployed
    - “toolbox” integrated
    - 128-bit addresses
IETF 6LoWPAN

- IPv6 for very low power embedded devices using IEEE 802.15.4
- 6LoWPAN has the following key properties:
  - packet fragmentation (1260 byte IPv6 frames -> 127 byte 802.15.4 frames)
  - header compression with up to 80% compression rate
  - provision of neighborhood discovery protocol
  - direct end-to-end Internet integration (but no routing)
IETF 6LoWPAN

- Typical architecture
IETF ROLL – Status

- IETF WG “Routing Over Low power and Lossy networks”
  - Design a routing protocol for Wireless Mesh Network
  - Final stage of standardization

- Since LLNs are application specific, 4 scenarios are dealt with:
  - home applications: draft-brandt-roll-home-routing-reqs
  - industrial applications: draft-pister-roll-indus-routing-reqs
  - urban applications: draft-dohler-roll-urban-routing-reqs
  - vehicular applications: draft-wakikawa-roll-invehicle-reqs
IETF ROLL – Overview

- Gradient-Based & Distance Vector Routing Protocol:
  - Topology organized as a Direct Acyclic Graph (DAG, i.e., a gradient)
  - Destination Oriented DAG (DODAG) is built per sink or LBR (Local Border Router)
    - redundant paths from each leaf to the DODAG root are included
    - nodes acquire a “rank” based on the distance to the sink
    - messages follow the gradient of ranks

- Separation of packet processing and forwarding (RPL core functionalities) from the routing optimization (Objective Function and Routing Metrics/Constraints)

[© Maria Rita, UL presentation, 2012]
1. Each node heartbeats its rank
   • Initially 0 for the Sink
   • Initially 255 (max value) for others

2. Nodes evaluate the Expected Transmission Cost (ETX) to their neighbors
   • In our case $10 \times (1/\text{packet delivery ratio})$
   • Perfect link: cost=10
   • Link with 50% loss: cost=20

3. Nodes update their rank as \( \text{min}(\text{rank neighbor} + \text{link cost}) \) over all neighbors
   • The chosen neighbor is preferred routing parent

4. Continuous updating process

- **Objective Functions (OFs):**
  - translate key metrics and constraints into a rank
  - allow the selection of a DODAG to join
  - parent selection at a node could be triggered in response to several events

- **Metrics and Constraints:**
  - node energy, hop count, throughput, latency, link reliability and encryption
  - possibility to timely adapt the topology to changing network conditions
  - need to keep under control the adaptation rate of routing metrics in order to avoid path instabilities
Transport layer is responsible of providing end-to-end reliability over IP-based networks.

Why TCP (Transmission Control Protocol) is not (so) suitable?
- reacts badly to e.g. wireless packet loss
- support for unicast communications only
- 3-way handshake TCP connection not suitable for very short transactions

The User Datagram Protocol (UDP) (RFC 768)
- datagram oriented protocol (i.e., asynchronous)
- used to deliver short messages over IP
- unreliable, connectionless protocol
- can be used with broadcast and multicast
- to be integrated with retransmission control mechanisms at application layer

Light-weight TCP → seems to work thanks to stability of lower layers
IETF CORE – COAP

- 2008: The IETF Constrained RESTful Environments (CORE) working group defines the Constrained Application Protocol (CoAP)
  - It translates to “HTTP (HyperText Transfer Protocol) for integration with the web, meeting specialized LLNs requirements: multicast support, very low overhead, and simplicity for constrained environments.”

- Main features addressed by CoAP:
  - Constrained web protocol specialized to M2M requirements
  - Simplification of messaging
  - Based on UDP transport with application layer reliable unicast and best-effort multicast support
  - Asynchronous message exchanges
  - Low header overhead and parsing complexity
2.4
Low Power WiFi – The Next IoT Revolution?
Advantages of Low-Power WiFi

Ubiquitous Infrastructure

2bn Wifi Devices

Vibrant Standard

IEEE 802.11

300 members

Interference Management

NAV Medium Reservation

Sound Security

WPA2/PSK/TLS/SSL

© 2012 M. Dohler, D. Boswarthick, J. Alonso-Zarate
Required changes from broadband to low-power WiFi (IEEE 802.11):

- device must be **highly integrated** to shorten connections; all circuitry should ideally be incorporated on a single die
- flexible and **rapid power management**, including both fast-response states with reduced power consumption, and quick wake-up times
- **power-efficient connection maintenance and remote device management** to ensure minimal drain on the energy resources of the device

http://www.gainspan.com/docs2/Low_Power_Wi-Fi_for_Smart_IP_Objects_WP_cmp.pdf
## Optimizing Broadband for Low-Power

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Conventional Wi-Fi</th>
<th>Low-Power Wi-Fi</th>
<th>units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power consumption</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standby / Idle</td>
<td>NA*</td>
<td>&lt;4</td>
<td>μW</td>
</tr>
<tr>
<td>Processor + clock sleep</td>
<td>13</td>
<td>0.2</td>
<td>mW</td>
</tr>
<tr>
<td>Data processing</td>
<td>115</td>
<td>56</td>
<td>mW</td>
</tr>
<tr>
<td>Receive sensitivity, 1 Mbps</td>
<td>-91</td>
<td>-91</td>
<td>dBm</td>
</tr>
<tr>
<td>Time to wake from Standby</td>
<td>NA*</td>
<td>10</td>
<td>ms</td>
</tr>
<tr>
<td>Time to wake from processor+clock sleep</td>
<td>75</td>
<td>5</td>
<td>ms</td>
</tr>
</tbody>
</table>

*Not applicable: comparable state does not exist.

http://www.gainspan.com/docs2/Low_Power_Wi-Fi_for_Smart_IP_Objects_WP_cmp.pdf
IEEE 802.11ah use cases target low rate, long range applications (metering, sensors, automation).

Battery operated devices should limit the power consumption by:
- limiting the packet transmissions
- limiting the awake/receive time (for low transit power devices, RX power consumption may be comparable with TX power consumption)

Listening for beacons/traffic information maps (TIM) frames consumes power:
- clock drift during long sleep requires an early wake up before Beacon/TIM (5min doze time, 20ppm -> node should wake up to 12ms before the Target Beacon Transmission Time (TBTT))
- reception of beacon/TIM may require several milliseconds
Low-Power Wifi Eco-System [examples]
Low-Power Wifi Products [© Gainspan]
“Low-power Wi-Fi provides a significant improvement over typical Wi-Fi on both latency and energy consumption counts.”

“LP-Wifi consumes approx the same as 6LoWPAN for small packets but is much better for large packets.”
3

Cellular M2M
Cellular M2M: Outline

- 3.1 Introduction to Cellular M2M

- 3.2 M2M in Current Cellular Systems
  - 3.2.1 GSM family: GSM, GPRS, EDGE
  - 3.2.2 3GPP family: UMTS, LTE, LTE-A
  - 3.2.3 B3G: LTE & LTE-A

- 3.3 Cellular M2M: Standardization Activities and Challenges
  - 3.3.1 Overview of Standardization in Cellular Communications
  - 3.3.2 M2M Activities in ETSI
  - 3.3.3 M2M Activities in 3GPP

- 3.4 Specific M2M Architectures & Performance
3.1 Introduction to Cellular M2M
3.1.1 Fundamentals of Cellular Systems
Data Traffic Evolution - PAST

AT&T traffic evolution

Source: AT&T
Data Traffic Evolution - FUTURE

Total mobile traffic (EB per year)

Yearly traffic in EB

Source: IDATE

Exabyte = $10^{18}$
Cellular Evolution

**Peak data rates over time**

- **ITU-R req. for IMT-Advanced**

- **Means to achieve higher data rates:**
  - More spectrum
  - More efficient RRM
  - Smaller cells

Source: NEC – Andreas Maeder, Feb 2012
3GPP Release 11 (LTE-A) – Timeline

What’s next? Release 11
- Green Activities / Energy Efficiency: ICT 2% of global emissions (telecom 0.5%)
- Standardization for M2M applications


Tentative Freeze Dates:
- Stage 1 freeze (*no further additional functions added*) date: September 2011
- Stage 2 freeze date: March 2012
- Stage 3 freeze target: September 2012
- RAN ASN.1 freeze target: 3 months after Stage 3 Freeze.
- equivalent CT formal interface specification freeze: 3 months after Stage 3 Freeze

→ More info at: http://www.3gpp.org/ftp/Information/WORK_PLAN/Description_Releases/
3.1.2 Motivating Cellular for M2M Applications
Advantages of Cellular M2M

Ubiquitous Coverage

Mobility & Roaming

Interference Control

Service Platforms
Why cellular in M2M?

A Simple Motivation: Initiatives

According to GSMA, 49 worldwide operators launched LTE deployments by January 2012, and 285 have committed to do either deployments of trials.

Global Initiatives: ETSI, GSMA, TIA TR-50 Smart Device Communications


Network Connectivity/Services: AT&T Inc., KORE Telematics, KPN, Numerex Corp., Orange SA, Rogers Business Solutions, Sprint, TIM (Brasil), Telcel

System Integrators: Accenture Ltd., Atos Origin, IBM, inCode

Sim Cards: Gemalto, Giesecke & Devrient, Oberthur, Sagem Orga
Reality

THE advantage of cellular M2M:
- Ethernet/WiFi/etc only provides local coverage
- Users already familiar with and proven infrastructure
- Easier configuration: suitable for short-term deployments
- Cellular networks provide today ubiquitous coverage & global connectivity
- Mobility and High-Speed Data Transmission
- ... and, above all, interference can be managed
Opportunities for Mobile Operators

- Cellular’s past and **current involvements** in M2M:
  - so far, indirect (albeit pivotal) role in M2M applications
  - just a transport support, a pipe for data from the sensor to the application server
  - M2M applications run on proprietary platforms

- Cellular’s **future potential** in M2M:
  - M2M is attracting Mobile Network Operators (MNOs) to become active players
  - technical solutions, standardization, business models, services, etc, etc
  - capitalize on the data content rather than on the data pipe
Challenges for Mobile Operators

- Lack of M2M experience
  - mobile operators are experts in human-to-human (H2H)
  - M2M is a new market and a *mental shift* is required

- High operational costs
  - the network has to be dimensioned for a number of devices that just transmit few information from time to time

- Low *Average Revenue Per User* (ARPU)

- Fragmentation and complexity of applications

- Lack of *standardization* (so far)

- Competition from other technologies
Technical Novelties of Cellular M2M

■ Current cellular systems are designed for human-to-human (H2H):
  ■ we are not too many users, in the end
  ■ we tolerate delay/jitter, even for voice connections
  ■ we like to download a lot, mainly high-bandwidth data
  ■ we don’t mind to recharge our mobiles on a daily basis (!!!)
  ■ we raise alert when mobile is compromised or stolen

■ Accommodation of M2M requires paradigm shift:
  ■ there will be a lot of M2M nodes, i.e. by orders of magnitude more than humans
  ■ more and more applications are delay-intolerant, mainly control
  ■ there will be little traffic per node, and mainly in the uplink
  ■ nodes need to run autonomously for a long time
  ■ automated security & trust mechanisms

■ … and all this without jeopardizing current cellular services!
3.2 M2M in Current Cellular Networks

*How suitable are current technologies for M2M?*
3.2.1

GSM Family: GSM (2G), GPRS (2.5G) & EDGE (3G)
GSM – PHY Layer

- **Carrier Frequency:**
  - 900 MHz, 1.8 GHz, and others
  - the lower, the better

- **Power Management:**
  - 8 power classes; min 20 mW = 13 dBm
  - (2dB power control steps)
  - can be easily handled

- **Modulation:**
  - GMSK \(\rightarrow\) constant envelope
  - good for M2M PA

- **PHY Data Rates:**
  - 9.6 kbit/s per user
  - too low for many app

- **Complexity:**
  - fairly low as of 2010
  - generally, good candidate
GSM – MAC Layer

**Duplexing:**
- FDD

**Multiple Access:**
- FDMA (124 bands) / TDMA (8 slots) for data
- Aloha-type for association

TDD would be better

Can be easily handled

Channel Separation = 45 MHz

Uplink

Downlink

Channel 0

Channel 1

Channel 124

200 KHz

25 MHz
GSM – Traffic Types

- **Voice:**
  - bounded delay, main traffic
  - no application in M2M

- **SMS:**
  - 160 7-bit characters
  - best effort over control channel
  - # of SMS bounded (ca. 10/minute)
  - $20/Mbyte (video = $0.017/Mbyte)
  - useful for device wake-up, data backup, configuration, remote diagnosis, etc.

- **Data:**
  - circuit switched data, 9.6Kbps
  - often not sufficient
Beyond GSM – GPRS & EDGE

**GPRS** = GSM + …
- … more time slots for users +
- … adaptive coding schemes

**EDGE** = GPRS + …
- … 8PSK modulation scheme

<table>
<thead>
<tr>
<th>Technology</th>
<th>Download (kbit/s)</th>
<th>Upload (kbit/s)</th>
<th>TDMA Timeslots allocated</th>
</tr>
</thead>
<tbody>
<tr>
<td>CSD</td>
<td>9.6</td>
<td>9.6</td>
<td>1+1</td>
</tr>
<tr>
<td>HSCSD</td>
<td>28.8</td>
<td>14.4</td>
<td>2+1</td>
</tr>
<tr>
<td>HSCSD</td>
<td>43.2</td>
<td>14.4</td>
<td>3+1</td>
</tr>
<tr>
<td>GPRS</td>
<td>80.0</td>
<td>20.0 (Class 8 &amp; 10 and CS-4)</td>
<td>4+1</td>
</tr>
<tr>
<td>GPRS</td>
<td>60.0</td>
<td>40.0 (Class 10 and CS-4)</td>
<td>3+2</td>
</tr>
<tr>
<td>EGPRS (EDGE)</td>
<td>236.8</td>
<td>59.2 (Class 8, 10 and MCS-9)</td>
<td>4+1</td>
</tr>
<tr>
<td>EGPRS (EDGE)</td>
<td>177.6</td>
<td>118.4 (Class 10 and MCS-9)</td>
<td>3+2</td>
</tr>
</tbody>
</table>
3.2.2

3GPP Family: UMTS (3G), HSxPA
UMTS – PHY Layer

- **Carrier Frequency:**
  - around 2 GHz, and others
  - losses problematic

- **Power Management:**
  - fast power control is must
  - (1dB power control steps)
  - big challenge

- **Modulation:**
  - CDMA → envelope depends on code
  - difficult for M2M PA

- **PHY Data Rates:**
  - >100 kbit/s packet switched
  - sufficient for most app.

- **Complexity:**
  - medium as of 2010
  - basic 3G configuration okay
UMTS – MAC Layer

- **Duplexing:**
  - FDD

- **Multiple Access:**
  - FDMA (1-3 bands) / CDMA (4-256 codes) for data
  - Aloha-type for association

TDD would be better

could be handled but limited number of codes
UMTS – Traffic Types

- **Conversational Class:**
  - voice, video telephony, gaming

- **Streaming Class:**
  - multimedia, video on demand, webcast

- **Interactive Class:**
  - web browsing, network gaming, etc

- **Background Class:**
  - email, SMS, downloading, etc

- **M2M Class?**
  - small data bundles, mission-critical

Little application in M2M

Little application in M2M

Of use in control appl.

Of use in wide range of M2M
3.2.3
B3G: LTE (3.9G) & LTE-A (4G)
LTE & LTE-A

- **LTE (Release 8 and 9)**
  - OFDMA (downlink) + SC-FDMA (uplink)
    - Robust to multipath
    - Flexible spectrum allocation (adjusting number of subcarriers)
    - Efficient receiver implementations
    - Simple MIMO implementation in frequency domain → freq. diversity gain
  - Quicker RTT & throughput
  - Both TDD and FDD duplexing modes
  - Variable bandwidth (1.4 to 20MHz)
  - Spectral Efficiency (x3)
  - Simplified Architecture → lower CAPEX and OPEX
  - More User Capacity (x10)

- **LTE-A (Release 10): LTE + M2M support + more sexy features**
  - DL: 1Gbps, UL: 500 Mbps.
Key Limitations of LTE & LTE-A

- Not efficient for small data transmission
- Scheduled Radio access → random access and more flexibility
- Device cost issues
  - Scalable bandwidth
  - Data rate (overdesigned UE categories)
  - Transmit power (max. 23dBm)
  - Half Duplex operation (simpler device)
  - RF chains with 2 antennas
  - Signal processing accuracy
- Overload issues → big number of devices
- Low mobility support
- Paging of M2M devices
- Addressing schemes

Source: IP-FP7-258512 EXALTED D3.1
Key Limitations of LTE & LTE-A

Refarming and extensions are still to come...

Fragmentation & Harmonization of Spectrum is a critical problem!

Four reasons to believe in LTE M2M


- Four reasons, even when capacity is not required:
  1) *Longevity* (long-term deployment of infrastructure)
  2) *Potentially Lower Service Costs* (compared to 2G or 3G)
  3) *Scalability* (IPv6)
  4) *Superior performance* (for demanding M2M applications)
3.3
M2M Cellular Standardization Activities

http://www.3gpp.org/ftp/Information/WORK_PLAN/Description_Releases/M2M_20120621.zip
3.3.1 Overview of M2M Standardization
Standards for M2M

- Industry has become more active in standardizing M2M:
  - Because of the market demand
  - Multitude of technical solutions result in slow development of M2M market
  - Cost-effective solutions
  - Essential for long term development of technology
  - For interoperability of networks
  - Ability to “roam” M2M services over international frontiers
  - Reduced complexity

- Due to potentially heavy use of M2M devices and thus high loads onto networks, interest from:
  - ETSI TC M2M and recently oneM2M Partnership Project
  - 3GPP (GSM, EDGE GPRS, UMTS, HSPA, LTE)
  - IEEE 802.16 (WiMAX)

- The starting point is to have popular M2M applications identified and then refine scenarios in each application to identify the areas needing standards.
Example: EC Mandates

- **European Commission Mandate 411**
  - **March 2009:** to build standards for European smart meters, *(electricity / water / heat / gas)* allowing interoperability and Consumer actual consumption awareness. *Reaching completion with a final set of standards expected Q1 2013*

- **European Commission Mandate 490**
  - **March 2011:** to build standards for European Smart Grids. Entering Phase 2, with issues identified for Security and privacy of sensitive data. ICT standards have been included in the list of referenced standards.
3.3.2

M2M Activities in ETSI

*European Telecommunication Standards Union*
ETSI: TC M2M

- 2009: Technical Committee (TC) created for M2M service level standards
- Mission: develop standards, identify gaps, and re-use existing standards
- Very collaborative (e.g., with 3GPP, BBF, OMA, industry fora, etc.)
- Participants: (2009 figures)

![Pie chart showing the distribution of participants: Manufacturers 59%, Network Operators 26%, Research Body Public 5%, Research Body Private 3%, Users 3%, Administration 2%, University 2%, and others at 5%]
ETSI: TC M2M Simplified Vision

- M2M Horizontal Service Platform
- Standards re-use
- Multi – Application
- End to End
- Technology Agnostic
- M2M Service Capabilities

© ETSI
ETSI: TC M2M

- Mission: develop standards for M2M
  - Different solutions based on different technologies and standards can be interoperable
ETSI: TC M2M Deliverables (R2)

Use Cases [Stage 0]

- **TR 102 691** Smart Metering
- **TR 102 732** eHealth
- **TR 102 857** Connected Consumer
- **TR 102 898** Automotive
- **TR 102 897** City automation

Stage 1

- **TS 102 689** M2M Service Requirements

Stage 2

- **TS 102 690** M2M Functional Architecture

Stage 3

- **TS 102 921** M2M Comms; mla, dla, mld interfaces

Published (P)

Drafts available at: http://docbox.etsi.org/M2M/Open/

© 2012 M. Dohler, D. Boswarthick, J. Alonso-Zarate
ETSI: TC M2M Simplified Architecture
ETSI: TC M2M Simplified Architecture
ETSI: Functional Architecture

Service Capabilities shared by different applications

Core Network:
- IP Connectivity
- Interconnection with other networks
- Roaming with other core networks
- Service and Network control
ETSI: TC M2M Milestones

- September 2010: 1st Workshop on M2M Communications
- 26-27 October 2011: 2nd Workshop on M2M. Agora, Sophia Antipolis
  - Present the M2M Release 1 Specifications
  - Future requirements for M2M standardization
  - Feedback from early M2M solutions
- Published first release of M2M Standards in 20th February 2012
  - M2M Release 2 Specifications and new use cases
  - 12 demos onsite for early implementation of M2M standards (health / energy / security application)
- More info at: http://portal.etsi.org/m2m
Creation of oneM2M Partnership project
ETSI Smart Card Platform (2000)

- **SIM**: Subscriber Identity Module → for than 4B in circulation
- Evolution to UICC (Universal Integrated Circuit Card) → CPU, RAM, ROM, EEPROM, I/O.
- June 2012, 4th Form Factor (nano-SIM, from Apple)
- Technical Specs → TS 102 221 v11.0.0 (2012-06)
  - [http://www.etsi.org/deliver/etsi_ts/102200_102299/102221/11.00.00_60/ts_102221v110000p.pdf](http://www.etsi.org/deliver/etsi_ts/102200_102299/102221/11.00.00_60/ts_102221v110000p.pdf)

- ETSI defines **UICC** specifications for particular use in M2M
- Embedded UICC → eUICC
- M2M poses new requirements
  - Size, Shape, Environmental Conditions, Vibrations, …
  - Secure Remote Access and Change of Subscription
Example: GEMALTO

- A Machine Identity Module (MIM) range for industrial environment:

- **M2M_{plug} 85:**
  - standard SIM card format
  - ideal for replacement of classic SIM in existing modems
  - suitable for environments up to 85°C

- **M2M_{plug} 105:**
  - standard SIM card format but made with a more robust material
  - ideal for replacement of classic SIM in existing modems
  - resistant to harsh environments

- **FullM2M Quad:**
  - miniaturized standardized format (TS 102.671)
  - invulnerable to theft
  - semiconductor packaging (SMD) resistant to high temperature (105°C), shocks, vibrations and humidity
3.3.3
M2M Activities in 3GPP
About 3GPP

- Created in December 1998: The 3rd Generation Partnership Project (3GPP) unites [Six] telecommunications standards bodies, known as “Organizational Partners” and provides their members with a stable environment to produce the highly successful Reports and Specifications that define 3GPP technologies.
3GPP: Organization

Project Co-ordination Group (PCG)

**TSG GERAN**
- GSM EDGE
- Radio Access Network
- GERAN WG1
  - Radio Aspects
- GERAN WG2
  - Protocol Aspects
- GERAN WG3
  - Terminal Testing

**Maintenance/development of GSM/GPRS/EDGE RAN**

**TSG RAN**
- Radio Access Network
- RAN WG1
  - Radio Layer 1 spec
- RAN WG2
  - Radio Layer 2 spec
  - Radio Layer 3 RR spec
- RAN WG3
  - lub spec, lur spec, lu spec
  - UTRAN O&M requirements
- RAN WG4
  - Radio Performance
  - Protocol aspects
- RAN WG5
  - Mobile Terminal Conformance Testing

**Maintenance/development of UMTS/HSPA/LTE RAN**

**TSG SA**
- Service & Systems Aspects
- SA WG1
  - Services
- SA WG2
  - Architecture
- SA WG3
  - Security
- SA WG4
  - Codec
- SA WG5
  - Telecom Management

**System architecture, service capabilities, codecs (inc. EPC)**

**TSG CT**
- Core Network & Terminals
- CT WG1
  - MM/CC/SM (Iu)
- CT WG3
  - Interworking with external networks
- CT WG4
  - MAP/GTP/BCH/SS
- CT WG6
  - Smart Card Application Aspects

**CN interfaces, protocols, interworking, IMS, terminals, SIM**
Working Procedure

- Project Coordination Groups
- Technical Specification Groups (TSGs)
- Working Groups WG launch *Work Items (WI)*

These WIs, generate Technical Requirements (TR) and Technical Specifications (TS) (called Releases) that can be transposed to relevant Standardization Bodies in three stages, following the ITU:

- Stage 1: Service description from user point of view
- Stage 2: Logical analysis, breaking the problem into functional elements and the information flows amongst them
- Stage 3: Detailed protocol specifications

In addition, documents XX.8XX are internal reports used for the development of releases.
Relevant Documentation

- April 2007 → Release 7, first doc. with requirements for M2M

- **Technical Specification 22.368**: “Service Requirements for MTC”.
  - September 2012: now R12 document

- **Technical Report 23.888**: “System Improvements for MTC”
  - September 2012: still R11, but likely to spill over to R12

- **Others**: low cost provision of UEs, security, remote management, support for MTC in GERAN and UTRAN, etc.
TS 22.368: Service Requirements for Machine-Type Communications (MTC).

- Focus only on *cellular segment* (GSM, UMTS, and LTE, …)
- Identify and specify
  - General requirements for MTC.
  - Network improvements required for MTC.
  - MTC requirements for these service aspects where network improvements are needed for MTC.
Machine Type Communications

- MTC are different to current mobile network communications:
  - Different Market Scenarios
  - Data communications
  - Lower costs and efforts
  - Potentially large number of devices (avoid congestion)
  - Little traffic per terminal
  - No human interaction (reconfiguration, security, etc.)
  - Need for security (*communications* vs. *manipulation*)
  - Energy *efficiency* (discontinuous reception modes)
Communications: Scenario 1

- Many terminals to one or more servers
  - Most of the applications today
  - Server operated by the network operator
Communications: Scenario 2

- Many terminals to one or more servers
  - Most of the applications today
  - Server operated by the network operator
  - Server not controlled by the network operator
Communications: Scenario 3

- **NOT CONSIDERED** in the ongoing release
  - *(future releases → research opportunity).*
Features in M2M

- A **feature** is a system optimization possibility
- Different requirements $\rightarrow$ different optimizations
- Offered on a *per subscription* basis:
  
  - Low Mobility
  - Time Controlled
  - Time Tolerant
  - Small Data Transmissions
  - Mobile originated only
  - Infrequent Mobile Terminated
  - MTC Monitoring
  - Priority Alarm Message (PAM)
  - Secure Connection
  - Location Specific Trigger
  - Infrequent transmission
  - Group Based features
    - Policing
    - Addressing
Specific Service Requirements [1/3]

■ Low Mobility
  • Reduce frequency of mobility signaling
  • Reduce reporting frequency

■ Time Controlled
  • Combination of allowed and Forbidden periods
  • Transmission of data during allowed time periods
  • Avoid signaling out of these periods
  • Allow transmission during forbidden periods subject to special charges and without priority.

■ Time Tolerant
  • Applications that can delay transmissions
  • Useful to avoid the overloading of the network: restrict access to delay tolerant MTCs during congestion periods
Specific Service Requirements [2/3]

- Small data transmissions
- Mobile originated only or infrequent mobile terminated
  - Reduction of management control signaling

- MTC Monitoring
  - Detect unexpected behavior, movement or loss of connectivity, change of location, failure in communications, etc.
  - Subscriber should decide which events can be detected by server
  - In case of event: notify the server or limit services provided by device

- Priority Alarm (maximum priority among features)
  - Case of theft or tampering, lack of connectivity, roaming not allowed, etc.
  - Maximum priority for alarm traffic

- Secure Connection
  - Even in the case of a roaming device, secure connection shall be available
  - The network shall enable the broadcast to a specific group of devices
Specific Service Requirements [3/3]

- **Location specific trigger**
  - Location information stored by the operator
  - Reduction of mobility control signaling

- **Infrequent transmission**
  - The network shall allocate resources only when needed
  - Apply duty cycling regarding connectivity (attach/detach)

- **Group based policing and addressing**
  - System optimized to *handle GROUPS*
  - The system shall be able to apply combined QoS policy for a group of devices
  - Limit transmission rate (UL and DL) for a group of devices
  - Broadcast and Multicast to a specific group of devices
Some Use Cases [1/4]

- Addressing from a centralized entity.
  - Meter reading
  - Addressing with private IPv4 becomes crucial

- Theft/Vandalism/Tampering Use case
  - No human presence
  - System cannot prevent it, but it can detect it
  - Example: detection of movement of a stationary device

- Time Controlled applications
  - Transmission time is not important
  - Reduction of costs using valley hours for transmission → low fares

- Radio Network Congestion
  - Mass access to the network by many devices
  - Example: railway bridge monitoring upon train circulation
Some Use Cases [2/4]

- Core Network Congestion Use Case: limit the rate for a group
- Signaling Network Congestion Use Case: spread access peaks

- National Holidays
- Power cut-off
- …
Some Use Cases [3/4]

- **Access Control with Billing Plan**

Machine type module

- USIM
- Ubiquitous plan
- Notification of IMEISV (machine type module)
- Accepted

SGSN

GGSN

Others

- USIM
- Ubiquitous plan
- Notification of IMEISV (handset or cart type)
- Denied
Some Use Cases [4/4]

- End-to-end Security for Roaming
TR 23.888: System Improvements for MTC

- Architectural enhancements to support a large number of MTC
- Architectural enhancements to fulfill MTC requirements
- Combination of solutions (not all combinations possible)
3GPP MTC Non-Roaming Architect.

3GPP MTC Architecture

Outside scope of 3GPP
System Improvements (there are 62)

- **Addressing:**
  - Static “host name” in addition to IMSI at EPS level.

- **Small data transmission and Device Triggering:**
  - use of SMS to transfer data
  - Trigger non-attached devices (listen to broadcast)
    - Exploit MTC user information to locate MTC device

- **Low Mobility** (reduce paging information):
  - Add low-mobility profile to subscription (HLR/HSS)

- **Network access Control** (avoid congestion)
  - Granted and forbidden periods in HLR/HSS subscription.
  - Class distinction: high/low priority MTC (use of HSS)
  - Random triggering during granted periods (downlink)
  - Random connection response (uplink)
  - Rejection of connection requests based on request types
3.4
Specific M2M Architectures & Performance
3.4.1
A Possible M2M Architecture

EXALTED is an FP7 funded IP Project (#258512)
ICT EXALTED

Expanding LTE for Devices

At A Glance: EXALTED

Expanding LTE for Devices

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Partners: Vodafone Group Services Limited (UK), Vodafone Group Services GmbH (DE), Gemalto (FR), Ericsson d.o.o. Serbia (RS), Alcatel-Lucent (DE), Telekom Srbija (RS), Commissariat à l’énergie atomique et aux energies alternatives (FR), TST Sistemas S.A. (ES), University of Surrey (UK), Centre Tecnològic de Telecomunicacions de Catalunya (ES), TUD Vodafone Chair (DE), University of Piraeus Research Center (GR), Vidavo SA (GR)

Funding scheme: IP
Total Cost: €11m
EC Contribution: €7.4m

Contract Number: INFSO-ICT-258512
EXALTED Architecture Overview
EXALTED Architecture
# EXALTED: LTE-M

<table>
<thead>
<tr>
<th>3GPP terminology</th>
<th>ETSI terminology</th>
<th>Equivalent EXALTED terminology</th>
</tr>
</thead>
<tbody>
<tr>
<td>MTC Server</td>
<td>M2M Service capabilities (SC)</td>
<td>M2M Server</td>
</tr>
<tr>
<td>MTC Application (UE)</td>
<td>M2M Application (Device)</td>
<td>M2M Application (Device)</td>
</tr>
<tr>
<td></td>
<td>M2M Application (M2M Gateway)</td>
<td>M2M Application (M2M Gateway)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>M2M Application (CH)</td>
</tr>
<tr>
<td>MTC User</td>
<td>M2M Device</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Core Network (CN)</td>
<td>LTE-M Device</td>
</tr>
<tr>
<td></td>
<td>Access Network</td>
<td>Non-LTE-M Device</td>
</tr>
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<td></td>
<td></td>
<td>EPC</td>
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<tr>
<td></td>
<td>eNB</td>
<td>LTE-M Access Network</td>
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<tr>
<td>Relay Node (RN)</td>
<td></td>
<td>eNB</td>
</tr>
<tr>
<td></td>
<td>M2M Gateway</td>
<td>LTE-M Relay</td>
</tr>
<tr>
<td></td>
<td>M2M Area Network</td>
<td>M2M Capillary Network</td>
</tr>
</tbody>
</table>

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LTE-M User Plane Protocol Stack
LTE-M User Plane Protocol Stack
LTE-M Control Plane Protocol Stack
Some Specific EXALTED Solutions

- LTE-M: Backwards compatible solution
- PHY Layer
  - Use of TDD
  - Generalized FDM for Uplink (beyond SC-FDMA)
  - Use of LDPC Codes instead of Turbo Codes
- Low-Complexity MIMO
- Cooperative Relaying
Some Specific EXALTED Solutions

- Higher Layers:
  - Optimal scheduling with energy-harvesting
  - Scheduling for heterogeneous traffic (event-driven or periodic)

- RACH: Addition of CDMA encoding to preamble transmission to enable collision recovery.
  - Use of RACH for small data transmission.
Some Specific EXALTED Solutions

- Discontinuous Reception (DRX): Duty Cycle
  - Maximum: 2560 subframes = 2.56 seconds
  - Paging flag factor
  - Paging done every flag factor x DRX cycle.
  - Include this information at the HSS (*Home Subscriber Server*)
  - Same approach can be used for signaling reception.
3.4.2 Small Data Transmissions
In the **time** domain, radio resources are organized into:

- frames, subframes, and slots.

Minimum scheduling resource unit: Physical Resource-Block (PRB) pair:

- In time, 2 consecutive PRBs within one subframe.
LTE Adaptive Modulation and Coding

- Selection of Modulation and Coding Scheme (MCS).
- Data transmission rate adjusted to trade **bit rate** and **robustness**.
- Available **Modulation** schemes:
  - QPSK (2 bits info per symbol), 16QAM (4 bits), 64QAM (6 bits).
- Channel **Coding**: rate 1/3 Turbo coding + Rate matching.
- The AMC leads to the concept of Transport Block Size (TBS).
LTE Transport Block (Size)

MAC

- MAC header
- MAC SDU
- Padding

PHY

- Transport Block
- Overhead

(Transmission Resource consists of 1 or more PRB pairs)

Aggressive MCS

- Transport Block

Transport Block Size

Conservative MCS

- Transport Block
- Overhead

Transport Block Size

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LTE Uplink Power Control (UPC)

\[ P_{\text{PUSCH}} = \min\{P_{\text{MAX}}, P_0 + \alpha \cdot PL_{\text{DL}} + 10 \log_{10} (M) + \Delta_{\text{MCS}} + \sigma \} \]

- \( P_{\text{MAX}} \) is the max. allowed Tx. power.
- \( P_0 \) is the target Rx. power.
- \( PL_{\text{DL}} \) is the downlink path loss estimated by the UEs.
- \( \alpha \) is a compensation coefficient.
- \( M \) is the number of PRBs.
- \( \Delta_{\text{MCS}} \) is the MCS power offset.
- \( \sigma \) is the explicit Transmit Power Control (TPC) command.
1 PRB pair consists of up to:
12 (subcarriers) × 7 (symbols in one slot) × 2 (slots in one subframe) = 168 symbols

Control overhead for PUSCH in PRB pair:
12 <subcarrier> × (2<demodulation reference> + 1<Sounding reference>) = 36 symbols
or
12 <subcarrier> × (2<demodulation reference> + 0<Sounding reference>) = 24 symbols

Basic resource unit consists of up to:
168 – 36 = 132 symbols
or
168 – 24 = 144 symbols

132 × 2 = 264 bits (QPSK)
132 × 4 = 528 bits (16QAM)
132 × 6 = 792 bits (64QAM)
or
144 × 2 = 288 bits (QPSK)
144 × 4 = 576 bits (16QAM)
144 × 6 = 864 bits (64QAM)
Measuring LTE for M2M

- **CRC per transport block**
  - a 24 bit-CRC is added to each transport block.

- **Code-block segmentation and CRC insertion**
  - for transport blocks larger than 6144 bits, code-block segmentation will be applied and a per-code-block CRC insertion will be added to each code block.

- **Channel coding**
  - rate 1/3 Turbo coding is used.

- **Rate matching**
  - select the exact bits of code to be transmitted.

---

Transport block size table (defined in 3GPP TS 36.213)

<table>
<thead>
<tr>
<th>(I_{TBS})</th>
<th>(N_{PRB})</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>16 32 56 88</td>
</tr>
<tr>
<td>1</td>
<td>24 56 88 144</td>
</tr>
<tr>
<td>2</td>
<td>32 72 144 176</td>
</tr>
<tr>
<td>3</td>
<td>40 104 176 208</td>
</tr>
<tr>
<td>4</td>
<td>56 120 208 256</td>
</tr>
<tr>
<td>5</td>
<td>72 144 224 328</td>
</tr>
<tr>
<td>6</td>
<td>328 176 256 392</td>
</tr>
<tr>
<td>7</td>
<td>104 224 328 472</td>
</tr>
<tr>
<td>8</td>
<td>120 256 392 536</td>
</tr>
<tr>
<td>9</td>
<td>136 296 456 616</td>
</tr>
<tr>
<td>10</td>
<td>144 328 504 680</td>
</tr>
<tr>
<td>11</td>
<td>176 376 584 776</td>
</tr>
<tr>
<td>12</td>
<td>208 440 680 904</td>
</tr>
<tr>
<td>13</td>
<td>224 488 744 1000</td>
</tr>
<tr>
<td>14</td>
<td>256 552 840 1128</td>
</tr>
<tr>
<td>15</td>
<td>280 600 904 1224</td>
</tr>
<tr>
<td>16</td>
<td>328 632 968 1288</td>
</tr>
<tr>
<td>17</td>
<td>336 696 1064 1416</td>
</tr>
<tr>
<td>18</td>
<td>376 776 1160 1544</td>
</tr>
<tr>
<td>19</td>
<td>408 840 1288 1736</td>
</tr>
<tr>
<td>20</td>
<td>440 904 1384 1864</td>
</tr>
<tr>
<td>21</td>
<td>488 1000 1480 1992</td>
</tr>
<tr>
<td>22</td>
<td>520 1064 1608 2152</td>
</tr>
<tr>
<td>23</td>
<td>552 1128 1736 2280</td>
</tr>
<tr>
<td>24</td>
<td>584 1192 1800 2408</td>
</tr>
<tr>
<td>25</td>
<td>616 1256 1864 2536</td>
</tr>
<tr>
<td>26</td>
<td>712 1480 2216 2984</td>
</tr>
</tbody>
</table>

\(I_{TBS}\) is the TBS index which is determined by MCS index.

How many bits in one resource unit?

Modulation and Coding Scheme is selected according to the channel states.

One resource unit can take up to 712 bits.
A Simple Energy-Efficiency Analysis

\[ \eta = \frac{L}{E_T} = \frac{L}{P \cdot N \cdot T} \]

\( \eta \): the energy efficiency.
L: the total amount of successfully transmitted payload bits.
\( E_T \): the total energy consumed by the transmitter.
P: the transmit power per PRB pair.
N: the number of PRB pairs used for the transmission.
T: the transmission time, equals the TTI (1ms).

Observations:
1) The lower N and P, the better.
2) Value of N depends on TBS and amount of M2M data
3) TBS depends on MCS, which depends on channel quality (only, so far)
4) Channel quality depends on 1) \textbf{Tx power}, 2) \textbf{distance}, and environment.
Key idea: maximize the utilization of the TB and decrease the transmit power by decreasing the MCS level.

\[
Power_H = Power_H \cdot \Delta_{MCS}(MCS_M, MCS_H),
\]
\[
Power_L = Power_M \cdot \Delta_{MCS}(MCS_L, MCS_M),
\]

because
\[
E_M < E_H
\]

only if
\[
Power_L \cdot 2 < Power_M \cdot 1
\]
Optimal Selection of the MCS

When the number of PRB pairs is fixed to $N$, the optimal MCS is:

$$MCS_N^* = \arg \max_{MCS} \left( \frac{L}{TBS(MCS, N)} \right),$$

$$s.t. L \leq TBS(MCS, N)$$

Reasons:

- If $N$ and $T$ are fixed, $P$ is the only parameter that affects the energy.
- The value of $P$ decreases as the MCS level decreases according to $\Delta MCS$.
- Optimal TBS $\rightarrow$ minimum enough to transmit a data packet of length $L$. 
Optimal Selection of the MCS

When the number of PRB pairs is **NOT** fixed, the optimal MCS is:

\[ MCS^* = \arg \min_{MCS_N^*}(\Delta_{MCS}(MCS_N^*) \cdot N), \]

**Key idea**: select the transmission scheme with the smallest total transmit power, because:

\[ P_{\text{total}} = P_{\text{basic}} \cdot \Delta_{MCS} \cdot N, \]

---

**Algorithm 1** MCS selection.

1: for each PRB pair number \( n = [1, N] \) do
2: calculate the \( MCS_N^* \)
3: end for
4: select the \( MCS^* \) from all \( MCS_N^* \)
5: return \( MCS^* \).
Optimal Selection of the MCS

![Graph showing the optimal selection of the Modulation and Coding Scheme (MCS) for different packet sizes. The graph plots the number of allocated PRB pairs against the MCS index, with three lines representing 10 bytes packet, 35 bytes packet, and 60 bytes packet, respectively.](image-url)
Optimal Selection of the MCS

![Graph showing the relationship between MCS index and transport block utilization rate (Packet size/ TBS) with energy efficiency (η bits/Joule) for different packet sizes (10 bytes, 35 bytes, 60 bytes).]
Conclusions

- Energy Efficiency of LTE for M2M with small data transmissions is low.

- Selection of optimal MCS for small size packet can help improve the energy efficiency.

- Alternatively, convenient location and power planning for machine devices *without dynamic power control* function can help optimize the energy-efficiency of the network.
3.4.3 High Number of Devices: The access to the network
LTE Random Access Channel (RACH)

- **UE** sends a random preamble (up to 64 available)
- eNodeB sends response to Preamble
  - Assigns T-RNTI to UE
  - Initial uplink resource grant (for Msg3)
  - An optional “Backoff indicator”
- Contention Resolution
- **UE** sends request using T-RNTI
- **RRC Connection Request**
  - **Msg3**
- **RRC Contention Setup**
  - **Msg4**
- **Connection Setup Complete, Service Request**

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RACH Configuration Index
Simulations in ns-3

- LTE FDD Mode.
- Number of devices: from 250 to 4000 devices
- Physical RACH Configuration Indexes:
  3, 6, 9 and 12 (1, 2, 3 and 4 opportunities per frame)

<table>
<thead>
<tr>
<th>TABLE III</th>
<th>SIMULATION PARAMETERS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameter</td>
<td>Simulated Values</td>
</tr>
<tr>
<td>PRACH Configuration Index</td>
<td>0, 3, 6, 9</td>
</tr>
<tr>
<td>Number of Available Preambles</td>
<td>60</td>
</tr>
<tr>
<td>preambleTransMax</td>
<td>3, 10, 15, 50</td>
</tr>
<tr>
<td>RAR Window Size</td>
<td>5 Subframes</td>
</tr>
<tr>
<td>Contention Resolution Timer</td>
<td>48 Subframes</td>
</tr>
<tr>
<td>Backoff Indicator</td>
<td>20ms</td>
</tr>
</tbody>
</table>

a See Fig. 2 for the number of access resources per frame.
b Refer to 3GPP TS 36.321 [10] for all the possible values.
c Refer to 3GPP TS 36.331 [11] for all the possible values.
Results: Delay

More resources per frame

Access Delay (ms)

Simultaneous Arrivals

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Results: Energy

Tend to the same limit

- 1 RA slot every 2 frames
- 1 RA slot every frame
- 2 RA slots every frame
- 3 RA slots every frame

Energy Consumption (J)
Simultaneous Arrivals

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Results: Retransmissions
Results: Blocking Probability

The graph shows the blocking probability as a function of simultaneous arrivals for different scenarios:
- **1 RA slot every 2 frames** (green diamonds)
- **1 RA slot every frame** (black circles)
- **2 RA slots every frame** (blue squares)
- **3 RA slots every frame** (red triangles)

As the number of simultaneous arrivals increases, the blocking probability also increases. The graph illustrates that with more RA slots per frame, the blocking probability decreases, indicating better network performance under heavier contention conditions.
RACH Improvements

**Random Access Improvements**

- Precoded preamble
- Data in Msg3
- Optimal MAC
- Backoff Adjustment Schemes
- Code-Expanded RA
- Dynamic Allocation of RACH Resources
- Prioritized Random Access
- Access Class Bearing
- Slotted Access
- Self-Optimizing Overload Control
- Separation of RACH Resources
- Extended ACB
- Individual ACB Scaling
- Dynamic Access Barring
- Cooperative ACB
- Split preambles
- Split PRACH occasions
- Virtual Resource Allocation

*Indicates a proposal subcategory*

*Indicates the mechanisms that integrate a solution proposal*
Distributed Queuing as a Solution

- Go away from ALOHA-type access
- Contention-Tree Algorithm (CTA)
- Distributed Queuing Random Access Protocol (DQRAP)
- Performance independent of number of users
- Simple operation with two logical queues
- One for transmission of successful access requests
- One to solve contention
- Downlink Control Channel of LTE ideal for implementation
3.4.4 Coexistence of Machines and Humans
LTE-A RRM with HTC & MTC

- High-level architecture with 3 different types of controlling MTC:

[Image of diagram showing MTC server, MTC user, and various network elements connected through control and data channels]

LTE-A RRM with HTC & MTC

- Radio resource partitioning between HTC and MTC:

Impact of MTC onto HTC

- System assumptions:
  - Method 1: HTC is prioritized all the time
  - Method 2: MTC is prioritized all the time

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>RACH Number</td>
<td>1</td>
</tr>
<tr>
<td>RACH TTI</td>
<td>20ms</td>
</tr>
<tr>
<td>Number</td>
<td>HTC 100</td>
</tr>
<tr>
<td>MTC</td>
<td>100~100,000</td>
</tr>
<tr>
<td>Access Frequency Distribution</td>
<td>Poisson</td>
</tr>
<tr>
<td>Access Frequency [average]</td>
<td>1min</td>
</tr>
<tr>
<td>Access Attempt Before Outage</td>
<td>100ms</td>
</tr>
<tr>
<td></td>
<td>1000ms</td>
</tr>
</tbody>
</table>
Impact of MTC onto HTC

- Dropping probabilities, duty cycle and delay for 30min access case:
3.4.5
The LENA Project – M2M in NS3
Tools for Research

Simulation

- Fast & cheap prototyping
- Scalable and repeatable experiments
- Abstract models, sometimes far from reality
- Hard to bring the design to product stage

Testbed

- Realistic evaluation
- Easier to bring the design to product stage
- Expensive and time consuming
- Poor scalability and reproducibility

Can we get the best of both?
The LENA project
LTE/EPC Network Simulator

- CTTC is working with Ubiquisys (UK) on the development of LENA, a simulation platform for LTE/EPC
- RAN and simplified EPC
- **Objective**: allow LTE femto/macro cell vendors to design and test SONs algorithms before deployment
The LENA project: LTE/EPC Network Simulator

- **Product-oriented:**
  - Designed around the Small Cell Forum MAC Scheduler API Specification
  - Allows testing real code in simulation
  - Accurate model of the LTE/EPC protocol stack
  - Specific Channel and PHY layer models for LTE macro and small cells

- **Open source:**
  - Development open to the community
  - Makes model more trustable
  - Free and open source licensing (GPLv2)
  - Fosters early adoption and contributions
The LENA project:
LTE/EPC Network Simulator

Possible target applications for LENA include:

- DL & UL Scheduler design
- Radio Resource Management Algorithm design
- Inter-cell interference coordination
- Heterogeneous networks (HetNets)
- Joint Radio and Backhaul Network Management
- End-to-end QoE evaluation
- Multi-RAT networks
- Cognitive LTE systems
- **M2M design**
Concluding Remarks
Elements Already Available ...

- **Access Network** – connecting the sensors & actuators:
  - “wired” (cable, xDSL, optical, etc.)
  - wireless cellular (GSM, GPRS, EDGE, 3G, LTE-M, WiMAX, etc.)
  - wireless capillary (WLAN, Bluetooth, ZigBee, IEEE 802.15.4x, etc.)

- **Gateway** – connecting access and core networks:
  - network address translation
  - packet (de)fragmentation; etc.

- **Core/Backend Network** – connecting the computer system:
  - IPv6-enabled Internet
... But Need To Be Optimized [1/3]

### Example Delays:

<table>
<thead>
<tr>
<th></th>
<th>Ethernet (LAN)</th>
<th>Wifi (WLAN)</th>
<th>Cellular (WAN)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Connection Delay</strong></td>
<td>normal: &lt;0.2s</td>
<td>normal: &lt;0.08s</td>
<td>normal: 2-5s</td>
</tr>
<tr>
<td></td>
<td>max.: 5-10s is failure</td>
<td>max.: &gt;.08s is failure</td>
<td>max.: must wait 30-60s before declaring failure</td>
</tr>
<tr>
<td><strong>Response Delay</strong></td>
<td>normal: &lt;0.2s</td>
<td>normal: &lt;10ms</td>
<td>normal: 1-3s</td>
</tr>
<tr>
<td></td>
<td>max.: 1-2s is failure</td>
<td>max.: around 1s</td>
<td>max.: must wait 30s before declaring failure</td>
</tr>
<tr>
<td><strong>Idle TCP Sockets</strong></td>
<td>TCP socket can sit idle indefinitely; limited by</td>
<td>theoretically indefinite; however, it might be</td>
<td>varies, but many cellular systems interfere with</td>
</tr>
<tr>
<td></td>
<td>application protocol only</td>
<td>limited by practical disconnection timeouts set</td>
<td>idle TCP sockets</td>
</tr>
<tr>
<td></td>
<td></td>
<td>in commercial APs</td>
<td></td>
</tr>
<tr>
<td><strong>UDP Reliability</strong></td>
<td>for modern 100Mbps Ethernet, UDP/IP is very</td>
<td>heavily depends on channel but can be made very</td>
<td>due to unreliable channel, loss of UDP is the</td>
</tr>
<tr>
<td></td>
<td>reliable</td>
<td>high if retries at MAC are used</td>
<td>norm</td>
</tr>
<tr>
<td><strong>Costs to Communicate</strong></td>
<td>only cost of generating network messages impacts</td>
<td>home/enterprise only energy (&gt;Ethernet) ; hot-spots</td>
<td>typically charge max rate per month; every</td>
</tr>
<tr>
<td></td>
<td>other devices</td>
<td>charge per minute</td>
<td>message potentially costs</td>
</tr>
</tbody>
</table>

[Digi White Paper & Marc Portolés]
... But Need To Be Optimized [2/3]

### Example Power Consumption:

<table>
<thead>
<tr>
<th>Technology</th>
<th>Mobility</th>
<th>Data transfer performance</th>
<th>Energy consumption/ battery life</th>
<th>Quality of Service</th>
<th>Cross-Layer Design Penetration</th>
</tr>
</thead>
<tbody>
<tr>
<td>2G (GSM)</td>
<td>Seamless global roaming</td>
<td>Physical rate: 9.6 – 57.6 Kb/s</td>
<td>Spectrum efficiency: 0.52 bit/s/Hz</td>
<td>Days (High) (dedicated channels, voice over data priority)</td>
<td>High</td>
</tr>
<tr>
<td>3G (UMTS)</td>
<td></td>
<td>384 Kb/s (mobile) 2Mb/s (stationary)</td>
<td>Up to 2.3 bit/s/Hz</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3G LTE</td>
<td></td>
<td>100 Mb/s</td>
<td>5 bit/s/Hz</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fixed WiMAX (802.16-2004)</td>
<td>Fixed</td>
<td>10 Mb/s (max up to 70 Mb/s)</td>
<td>3.75 bit/s/Hz</td>
<td>n/a (Normal (4 traffic classes, but not supported for network wide connections))</td>
<td>Medium</td>
</tr>
<tr>
<td>Mobile WiMAX (802.16e-2005)</td>
<td>Pedestrian Mobility</td>
<td>2-3 Mb/s (max up to 15 Mb/s)</td>
<td>2 bit/s/Hz</td>
<td>Hours</td>
<td>Low (802.11e if employed)</td>
</tr>
<tr>
<td>802.11b</td>
<td>Nomadic subnet roaming</td>
<td>11 Mbps</td>
<td>0.56</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>802.11a/g</td>
<td></td>
<td>54 Mbps</td>
<td>2.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>802.11n</td>
<td></td>
<td>260 Mbps</td>
<td>7.22</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bluetooth (2.0)</td>
<td>Fixed</td>
<td>Up to 2.1 Mb/s</td>
<td>2 bit/s/Hz</td>
<td>Hours</td>
<td>High (dedicated channels)</td>
</tr>
<tr>
<td>UWB</td>
<td></td>
<td>675 Mb/s</td>
<td>1.35 bit/s/Hz</td>
<td></td>
<td>Low</td>
</tr>
</tbody>
</table>

... But Need To Be Optimized [3/3]

- Example Cost:
  - Assuming today’s hardware, servicing and other fees, the costs for offering a smart parking service over 10 years in Barcelona would be:
Open Challenges of Wireless M2M

Challenges for “capillary” community:
- reliability: despite license-exempt bands
- range: multihop/mesh seems a must
- delays: minimize end-to-end delay (due to multihop)
- standards: interoperability is a major issue – even today!
- infrastructure: provision, servicing and maintenance of GW

Challenges for cellular community:
- nodes: management of huge amounts sending small packets
- rates: fairly low and rather uplink from small packets
- power: highly efficient (must run for years)
- delays: quick ramp-up after sleep
- application: don’t disturb existing ones
Challenge for M2M: Interface Humans

- Human Computer Interface (HCI) will be key to many M2M applications and services:

© http://www.blogcdn.com/www.moviefone.co.uk/media/2010/06/tomcruise-minorityreport20.jpg

© Reactable
Specific Cellular Challenges [1/2]

- Design for huge number of devices
- Reduction of control signaling
- Optimization for low data transmissions
- Cost reduction: e.g. remove previous RATs (GSM)
- Congestion control algorithms at RAN and Core Network
- Load distribution/balancing
- Security, e.g., denial of service
- Traffic Models
Specific Cellular Challenges [2/2]

- Ultra Low Power Operation: e.g., Ultra-Low Duty Cycling
- Quick association after deep sleep
- Efficient MAC protocols
- Scheduling mechanisms for handling M2M and H2H traffic
- Device-to-Device Communications
- Device Management techniques
- Cognitive and Cooperative (network coding included) techniques
- Interference Management for joint M2M & H2H communications
- and many more…
10 Predictions for M2M by Machina

- Machina Research’s Directors have gazed into their crystal balls:
  - 1. A clear top tier of operator alliances will emerge: Today Vodafone sets the benchmark; other operators are looking to extend their footprint through alliances and affiliations; most prominent is emerging Deutsche Telekom/ FT-Orange/ TeliaSonera/ Everything Everywhere alliance; Telefonica has also established some interesting agreements with Etisalat and China Unicom; The most interesting things to watch is what Telefonica and AT&T do during 2012.
  - 2. Satellite operators and Systems Integrators will join global M2M alliances.
  - 3. Android @home products will hit the marketplace.
  - 4. 2G will become accepted as a long term technology option: It is clear that the M2M world is, at best, grudging in its acceptance of 3G. M2M revenues are typically low, margins are thin, and the cost premium of 3G chipsets and modules over 2G is significant.
  - 5. Some M2M platforms that currently partner with communications service providers (CSPs) may begin to look like competitors to CSPs: Generic M2M platforms will naturally seek to provide an ever more comprehensive service to their CSP partners. The more capabilities such platforms develop, the easier it will be for them to compete for end-user revenues directly.
Machina Research’s Directors have gazed into their crystal balls:

- **6. Huawei will launch an M2M platform:** This would be a tactical move to drive sales volumes of devices, rather than a long term strategic play.

- **7. There will be further restructuring in the module/chipset market:** The traditional M2M module vendors (Cinterion, Telit, Sierra Wireless and SimCom) will face continuing pressure on margins and there will be further consolidation.

- **8. MNOs will position themselves to take advantage of the growth in connected consumer electronics (CE) devices:** Connected consumer electronics, such as cameras and portable games consoles, will remain the biggest category of M2M connected devices, accounting for 35% of the global total in 2020.

- **9. True standardisation proves harder than expected:** 2012 has already seen initiatives around open standards from the ITU and a grouping of the major standards development organisations with the ‘One M2M’ initiative. M2M is fragmented, with numerous different technologies and several existing industry-specific sets of standards and a diverse range of companies, with different requirements.

- **10. The mobile industry will agree on a definition of M2M!**
Machine-to-Machine Predictions

Prediction #1: The capillary embodiment of M2M, Zigbee, will never reach critical mass due to lack of already deployed infrastructure; however, low-power Wifi will scale very quickly.

Prediction #2: With some exceptions, operators will miss out again on the opportunity to become a true service provider, i.e. capitalize on the data content rather than on the data pipe.

Prediction #3: Integrators of integrators & data analytics companies, such as IBM, Oracle, SAP, will capitalize on the true value of M2M; and thus make it an expensive “circle” to be in.

Prediction #4: Uptake of M2M technologies will be much slower than anticipated since marginal business for very large corporations but too-long sales cycles for innovative startups.
THANKS

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CTTC [www.cttc.es]

Research, prototypes, commercialization:

> 200 papers per year!

6 cutting-edge R&D areas:

Major branch in Hong Kong!!!
Transactions on Emerging Technologies

<table>
<thead>
<tr>
<th>Year of submission</th>
<th>Average Days to first decision</th>
<th>Average Days to final decision</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009</td>
<td>158</td>
<td>243</td>
</tr>
<tr>
<td>2010</td>
<td>207</td>
<td>245</td>
</tr>
<tr>
<td>2011</td>
<td>61</td>
<td>83</td>
</tr>
</tbody>
</table>

Acceptance Rate

Yearly acceptance rates from 2007 to 2011.

European Transactions on Telecommunications

Impact Factors

- 2006: 0.434
- 2007: 0.321
- 2008: 0.372
- 2009: 0.453
- 2010: 0.448