GREEN NETWORK TECHNOLOGIES FOR MTC IN 5G

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Introduction to M2M & IoT
Internet of Things is all about…

- Things (Useful)
- People
- Connectivity
- Interoperability
- Energy Efficiency
- Big Data
- Added Value
- Business
- Privacy and Security
- Well-Being
The traditional use of M2M…

http://www.gereports.com/new_industrial_internet_service_technologies_from_ge_could_eliminate_150_billion_in_waste/
Applying the concept to cities…
And finally...hitting the consumer

**Smart Home**

*Heat your home efficiently*
Smart thermostats like the Nest use sensors, real-time weather forecasts, and the actual activity in your home during the day to reduce your monthly energy usage by up to 30%, keeping you more comfortable, and offering to save you money on your utility bills. // Visit

*Make sure the oven is off*
Smart outlets like the Wemo allow you to instantly turn on and off any plugged in device from across the world or just your living room. Save money and conserve energy over time by eliminating standby power, measure and record the power usage of any device, and increase its operating lifespan through more efficient use and scheduling. // Visit

*Light your home in new ways*
Web-enabled lights like the Philips Hue can be used as an ambient data displays (I know not when my bus is 5 minutes away). These multi-functional lights can also help you to reduce electricity use (automatically turn off the lights when no one is in a room) or help to secure your home while you are away by turning your lights on and off. // Visit

*Avoid disasters*
Using a device like the Ninja Block and its range of add-on sensors you can track a water pipe has burst in your basement, if there is motion inside your home while you are away, and have it automatically send you a notification by email or text message when it happens. // Visit

*Track down those lost keys*
You can easily track down those lost keys or cell phone in your house using Bluetooth and other wireless technology devices like the Cobra Tag. // Visit

*Keep your plants alive*
Whether taking care of a small hydroponic system or a large backyard lawn, systems like HarvestCruck with their suite of sensors and web connectivity help save you time and resources by keeping plants fed based on their actual growing needs and conditions while automating much of the labor processes. // Visit

© http://postscapes.com/internet-of-things-examples/

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M2M Platforms for the IoT

Machine-to-Machine

Sensor Streams
(Real Time)

Human-to-Machine

Crowdsourcing

Information-to-Machine

Internet
(Open Data)

BIG DATA
Analytics

DATA
INFO
KNW
W

Improves Efficiency
Offer New Services
Applications
Technological Challenges

- Device Domain
- Network Domain
  - M2M Communications
- Applications Domain
M2M Communications: The Access Network
A General View (Wireless)

Transmission rate: (Delay! Energy! Reliability! … !)

- **WLAN (802.11)**
  - 100 kbps

- **Zigbee (802.15.4)**
  - 1 kbps

- **Bluetooth (802.15.1)**
  - 10 bps

- **UMTS, HSPA, LTE, LTE-A**
  - 100 m, 1 km, 10 km

**Opportunity for M2M**

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M2M Prime Business Criteria

Availability

Reliability

Availability = coverage, roaming, mobility, critical mass in rollout, etc.

Reliability = resilience to interference, throughput guarantees, low outages, etc.

(Total Cost of Ownership = CAPEX, OPEX.)
# Standardized M2M Protocol Stack

<table>
<thead>
<tr>
<th>Capillary M2M</th>
<th>Cellular M2M</th>
</tr>
</thead>
<tbody>
<tr>
<td>M2M Area Networks</td>
<td>LTE/LTE-A MTC</td>
</tr>
<tr>
<td>Zigbee-Like</td>
<td>Low Power Wifi</td>
</tr>
</tbody>
</table>

## Application
- IETF CORE
- HTTP, etc.

## Transport
- Lightweight TCP, UDP
- TCP, UDP

## Networking
- IETF ROLL
- IPv4, IPv6
- 6LowPAN
- LTE/LTE-A Networking Layer

## MAC
- 802.15.4
  - /e Industrial Apps.
- 802.15.4-2006
  - /f RFID
- 802.11g/ac/ad/ah
- LTE/LTE-A Link Layer

## PHY
- 802.15.4-2006
  - /g Smart Grids
  - /k Low-Energy Infrastructure Monitoring
- 802.11g/ac/ad/ah
- LTE/LTE-A Link Layer

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2.1

Capillary Networks (Zigbee-like and LP-WIFI)
Problems of ZigBee-like Solutions

Interference in ISM
- 868 MHz
- 433 MHz
- 2.4 GHz
- 5 GHz

No Global Infrastructure
- ZigBee Alliance

Lack of Interoperability

Higher Total Cost

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Advantages of Low-Power WiFi

Ubiquitous Infrastructure

Interference Management

Vibrant Standard

Sound Security

Number of Wi-Fi Public Hotspots in the World (in million), 2009-2015

LP-Wifi vs ZigBee Capillary M2M

6LoWPAN vs. Low-power Wi-Fi at 54Mbps

<table>
<thead>
<tr>
<th>Packet size</th>
<th>6LoWPAN</th>
<th>Low-power Wi-Fi</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 Bytes</td>
<td>6</td>
<td>11.3</td>
</tr>
<tr>
<td>1024 Bytes</td>
<td>23.61</td>
<td>16.58</td>
</tr>
<tr>
<td>8 Bytes</td>
<td>2.5</td>
<td>0.55</td>
</tr>
<tr>
<td>1024 Bytes</td>
<td>9.17</td>
<td>1.28</td>
</tr>
</tbody>
</table>

“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.”

© IEEE, from “Feasibility of Wi-Fi Enabled Sensors for Internet of Things,” by Serbulent Tozlu (2011)
Low-Power Wifi Eco-System [examples]
2.2
Cellular M2M Standards & Architectures
Advantages of Cellular M2M

Ubiquitous Coverage

Mobility & Roaming

Interference Control

Service Platforms
However…

Means to achieve higher data rates:

More spectrum, more efficient RRM, smaller cells

Source: NEC – Andreas Maeder, Feb 2012
Key Technical Novelties

- Cellular Networks have been designed for humans!

- Accommodation of M2M requires paradigm shift:
  - There will be a lot of M2M nodes
  - 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!
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 bits of information from time to time
- Low Average Revenue Per User (ARPU)
- Fragmentation and complexity of applications
- Lack of standardization (so far)
- Competition from other (emerging) technologies
  - Low Power Wide Area (LPWA) Technologies
Advantages of LPWA M2M Networks

Large Coverage

Low Cost

Available Today

Operator Model

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M2M in Current Cellular Networks

How suitable are current technologies for M2M?
GSM – PHY and MAC Layers

**PHY Layer**
- Carrier Frequency: 900 MHz, 1.8 GHz, and others.
- Simple Power Management:
  - 8 power classes; min 20 mW = 13 dBm
  - (2dB power control steps)
- Modulation with Constant envelope (good for PA)
- PHY Data Rates: 9.6 Kbps
- Low Complexity

**MAC Layer**
- Duplexing: FDD
- FDMA/TDMA + ALOHA-based access

**Traffic Type:** Voice, Data, 160 7-bit SMS.
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>
UMTS – PHY and MAC Layers

- **PHY Layer**
  - Carrier Frequency: 2Ghz, and others.
  - Instantaneous Power Management
  - CDMA Modulation: Variable envelope
  - PHY Data Rates: >100 kbit/s packet switched
  - Medium Complexity

- **MAC Layer**
  - Duplexing: FDD
  - FDMA/CDMA (256 codes) + ALOHA-based access

- **Traffic type**: conversational, streaming, interactive, background.
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 (Releases 10-11-12): LTE + new features + M2M support
- DL: 1Gbps, UL: 500 Mbps.
Key Limitations of LTE & LTE-A

Refarming and extensions are still to come…

Fragmentation & Harmonization of Spectrum is a critical problem!

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
- High mobility support

Source: IP-FP7-258512 EXALTED D3.1
LTE is moving…

Study Item for low-cost, enhanced coverage, for MTC recommends:
- Single receive antenna for MTC devices
- Reduced peak data rate of 1Mbps
- Reduced bandwidth with baseband data channel of 1.4MHz
- Coverage Enhancement of 15dB
- Further cost-reduction available with half-duplex

Source: Vodafone
2.2.2
Standardization Activities

http://www.3gpp.org/ftp/Information/WORK_PLAN/Description_Releases/M2M_yyyymmdd.zip
Standards for Cellular M2M

Industry has become more active in standardizing M2M:
- Because of the market demand
- Essential for long term development of technology
- For interoperability of networks
- Ability to “roam” M2M services over international frontiers

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)
ETSI: Inverting the pipes

Pipe (vertical):
1 Application, 1 NW, 1 (or few) type of Device

Horizontal (based on common Layer)
Applications share common infrastructure, environments and network elements

© ETSI

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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

Registration,
Authentication,
Authorization,
Management,
Provisioning
Creation of oneM2M Partnership project
ETSI Smart Card Platform (2000)

- **SIM**: Subscriber Identity Module → more 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)
- Data of the SIM:
  - ICCID: identifier
  - IMSI
  - Authentication key
  - Location Area Identity
  - User data: Contacts and SMS
- Embedded SIMs for M2M
3GPP: M2M Features

- A feature is a system optimization possibility
- Different requirements → 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
3

Specific M2M Architectures & Performance
3.1 Tools to Play Around with M2M/IoT
Tools

- Math
- Computer-based Simulators (MATLAB, Ns-3 Simulator)
  - Cellular (LENA simulator)
  - Capillary Networks (Zigbee-Like, WiFi, etc.)
- Testbeds
  - Arduino, WizziMotes, PanStamps, Raspberry Pi, OpenMAC, WARP, Digi Xbee Modules, etc.
- Free M2M Platforms in the Cloud
  - Xybely, Thingspeak, etc.
Tools
3.2

A Possible M2M Architecture

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

Expanding LTE for Devices

At A Glance: EXALTED
Expanding LTE for Devices

Project Coordinator
Djelal Raouf
Sagemcom SAS
Tel: +33 (0)1 57 61 20 08
Fax: +33 (0)1 57 61 39 09
Email: djelal.raouf@sagemcom.com
Project website: www.ict-exalted.eu

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
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)
  - Discontinuous Reception (DRX): Duty Cycle
  - Use of RACH for small data transmission, adding CDMA for data collision recovery.
3.3

High Number of Devices: The access to the network

*The Random Access Channel (RACH) of LTE*

A. Laya, L. Alonso, J. Alonso-Zarate

*“Is the Random Access Channel of LTE and LTE-A Suitable for M2M Communications? A Survey of Alternatives”*

IEEE Tutorials and Survey Communications Magazine

Special Issue on Machine-to-Machine Communications.

Publication Date: January 2014.
Examples of RACH Configuration

Subframe Number

Even frame

Odd frame

0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9

1.08 MHz
(6 PRBs)

PRACH Configuration Index

0 3 6 9 12 14

Less resources for data!

Random Access Opportunity
Available for other uses

Frame (10ms) Subframe (1ms)

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The Procedure

64 Orthogonal Preambles
Not all available for random access

LIMITATIONS
Preamble transmission based on FS-ALOHA
Preamble Collisions
Collisions in Message 3
Lack of resources for Msg3

http://prezi.com/likwdk7dksmj/ns-3-lte-random-access-procedure/
Blocking Probability: bulk arrival

Heavier contention

$MAX\ retx = 10$

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

Simultaneous Arrivals
Energy Consumption: bulk arrival

MAX retx = 10

Tend to the same limit
Blocking Probability: more retx
Energy Consumption: more retx

More transmissions per device

Average Energy Consumption (J) vs. Simultaneous Arrivals

- Max. preamble retransmission = 3
- Max. preamble retransmission = 10
- Max. preamble retransmission = 15
- Max. preamble retransmission = 50
Delay: more retx

More RA attempts
RACH Improvements

A. Laya, L. Alonso, J. Alonso-Zarate
“Is the Random Access Channel of LTE and LTE-A Suitable for M2M Communications? A Survey of Alternatives”
IEEE Tutorials and Survey Communications Magazine
Special Issue on Machine-to-Machine Communications.
Publication Date: January 2014.
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

IEEE Wireless Communication Magazine.
3.4 Limitations of the RLC layer
RRC State Transitions
RRC Delays


<table>
<thead>
<tr>
<th></th>
<th>Power* (mW)</th>
<th>Duration (ms)</th>
<th>Periodicity (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Screen off (base)</td>
<td>11.4±0.4</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Screen 100% on</td>
<td>847.2±2.7</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>LTE promotion</td>
<td>1210.7±85.6</td>
<td>260.1±15.8</td>
<td>N/A</td>
</tr>
<tr>
<td>LTE Short DRX On RRC_CONNECTED</td>
<td>1680.2±15.7</td>
<td>1.0±0.1</td>
<td>20.0±0.1</td>
</tr>
<tr>
<td>LTE Long DRX On RRC_CONNECTED</td>
<td>1680.1±14.3</td>
<td>1.0±0.1</td>
<td>40.1±0.1</td>
</tr>
<tr>
<td>LTE tail base</td>
<td>1060.0±3.3</td>
<td>11576.0±26.1</td>
<td>N/A</td>
</tr>
<tr>
<td>LTE DRX On RRC_IDLE</td>
<td>594.3±8.7</td>
<td>43.2±1.5</td>
<td>1280.2±7.1</td>
</tr>
<tr>
<td>3G promotion</td>
<td>659.4±40.4</td>
<td>582.1±79.5</td>
<td>N/A</td>
</tr>
<tr>
<td>3G DCH tail base</td>
<td>803.9±5.9</td>
<td>8088.2±149.6</td>
<td>N/A</td>
</tr>
<tr>
<td>3G FACH tail base</td>
<td>601.3±6.4</td>
<td>824.2±148.1</td>
<td>N/A</td>
</tr>
<tr>
<td>3G DRX (idle)</td>
<td>374.2±13.7</td>
<td>55.4±1.5</td>
<td>5112.4±37.7</td>
</tr>
<tr>
<td>WiFi promotion</td>
<td>124.4±2.6</td>
<td>79.1±15.1</td>
<td>N/A</td>
</tr>
<tr>
<td>WiFi tail base</td>
<td>119.3±2.5</td>
<td>238.1±9.2</td>
<td>N/A</td>
</tr>
<tr>
<td>WiFi beacon (idle)</td>
<td>77.2±1.1</td>
<td>7.6±0.1</td>
<td>308.2±1.0</td>
</tr>
</tbody>
</table>

Table 3: LTE, 3G, and WiFi power model.
3.5
Optimizing LTE for Small Data Transmissions

K. Wang, J. Alonso-Zarate, M. Dohler,
“Energy-Efficiency of LTE for Small Data Machine-to-Machine Communications,”
Transport Block Size vs. MCS

MAC

MAC header
MAC SDU
Padding

PHY

Transport Block
Overhead

(Transmission Resource consists of 1 or more PRB pairs)

Aggressive
MCS

Transport Block Size

Conservative
MCS

Transport Block Size

Graph showing the relationship between Transport Block Size and MCS Index with Transmit Power (dBm) as a variable.
Example

Packet with length of 2 units:  

(MCS_L, PowerL, 2 PRB pairs)

(MCS_H, PowerH, 1 PRB pair)  
(MCS_M, PowerM, 1 PRB pair)  
(MCS_L, PowerL, 1 PRB pair)

(Subframe n)  
(Subframe n+1)  
(Subframe n+2)
The Optimal MCS
The Optimal MCS

Energy Efficiency $\eta$ (bits/Joule)

MCS Index

- 10 bytes packet
- 35 bytes packet
- 60 bytes packet
The Optimal MCS
3.6
Coexistence of Machines and Humans

“Challenges of Massive Access in Highly-Dense LTE-Advanced Networks with Machine-to-Machine Communications,”
in press, IEEE Wireless Communications Magazine,
Special Issue on Research & Standards: Leading the Evolution of Telecom Network Architectures
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></td>
</tr>
<tr>
<td>HTC</td>
<td>MTC</td>
</tr>
<tr>
<td>Number</td>
<td>100</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>
</tbody>
</table>

[© Kan Zheng and Mischa Dohler, under development]
Impact of MTC onto HTC

- Dropping probabilities, duty cycle and delay for 30min access case:
Business Opportunities
A growing $bn-Market

By 2022, M2M will be a USD 1.2 trillion opportunity

- Total M2M revenue will grow from USD200 billion in 2011 to USD1.2 trillion in 2022, a CAGR of 18%
- Total revenue includes:
  - device costs where connectivity is integral to the device
  - module costs where devices can optionally have connectivity enabled
  - monthly subscription, connectivity and traffic fees

© Machina Research; taken from http://blog.dayaciptamandiri.com/2013_01_06_archive.html
Revenue Forecast Metrics

© Machina Research; taken from https://machinaresearch.com/what-we-do/about-the-forecast-database/
Conclusions
The IoT World Forum, October 2013

- The IoT is nascent, and its value needs to be defined
- 90% of the business is comprised of start-ups
  - No single company will build the IoT
  - Major companies will need to find ways to engage with and enable these builders.
- Industrial internet + consumers-facing opportunities.
- Consumers will be a source of innovation in the IoT.
  - Arduino, Raspberry Pi, Thingsquare, Libelium’s Cooking Hacks, Smart Citizen Kit, TheThings.io, Electric Imp to Telefonica’s recently announced Thinking Things, and Intel’s Galileo, among others.
- The IoT will not rest on one killer app, but on openness and interoperability

Final Take-Away Message

Henry Ford

“If I had asked people what they wanted, they would have said… A FASTER HORSE!”
THANKS!

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