Machine-to-Machine Technologies & Markets - Shift of Industries

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6 April 2014

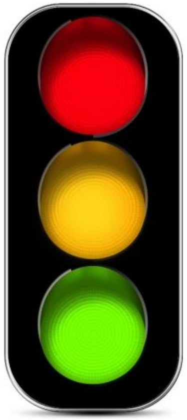
1

Introduction to M2M & IoT

Home IoT/M2M Applications

© NEST Inc (now Google)

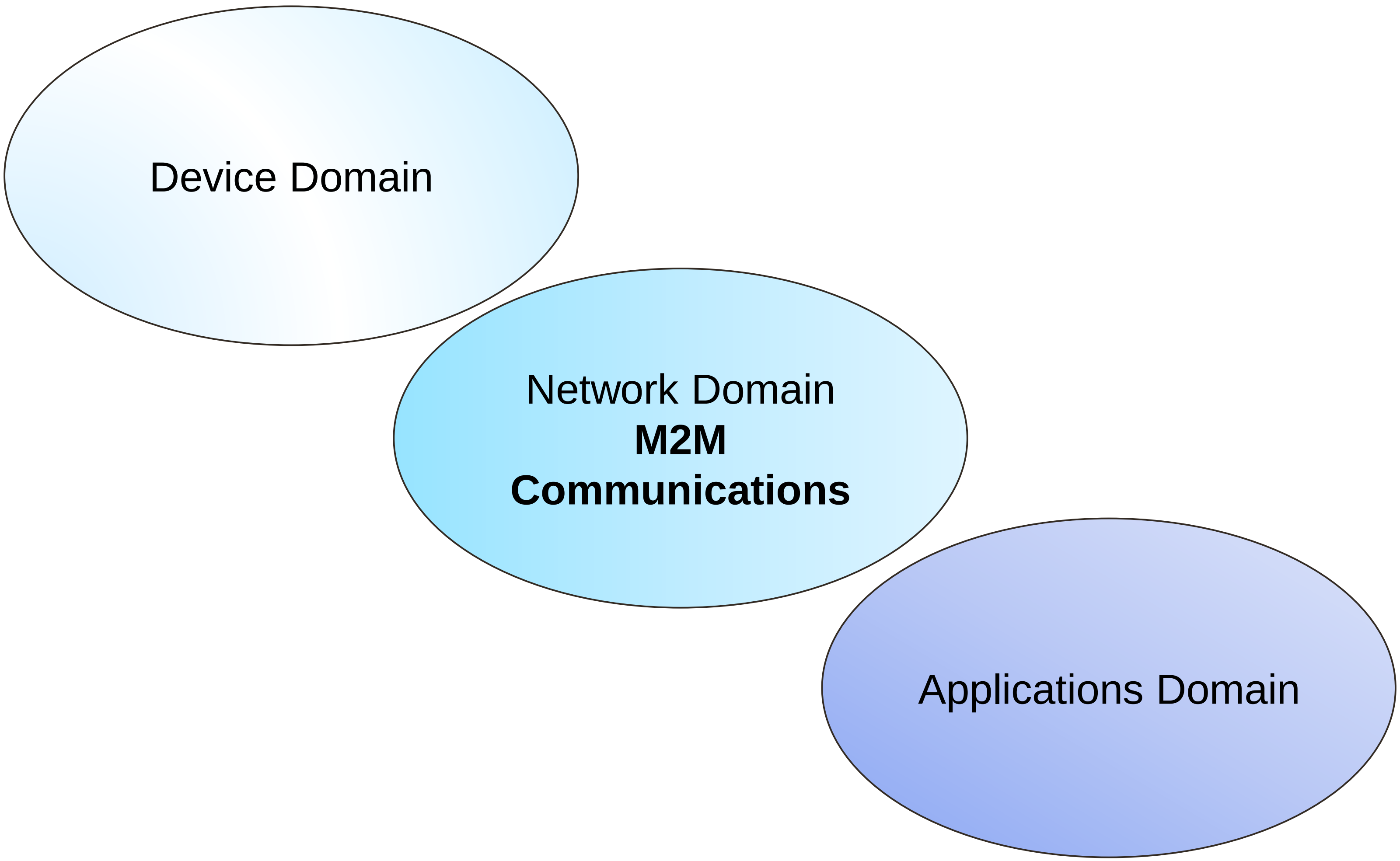
Smart Cities IoT/M2M Applications



Industrial IoT/M2M Applications

© Worldsensing

Technological Challenges



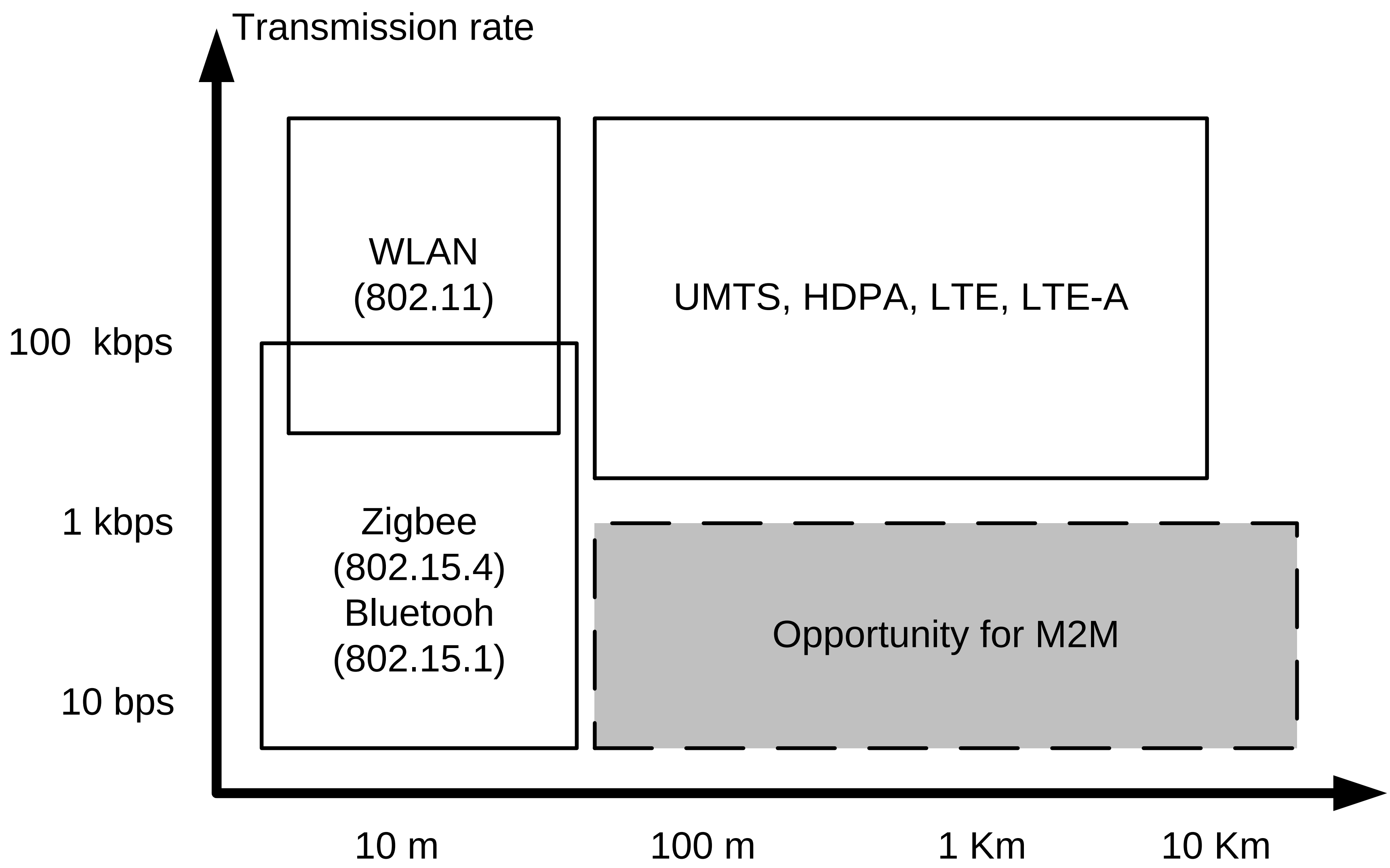
Overview of Tutorial

1. **Introduction to M2M and the IoT**
2. **M2M Technology Landscape**
3. **Cellular M2M Performance**
4. **Business Opportunities**
5. **Conclusions**

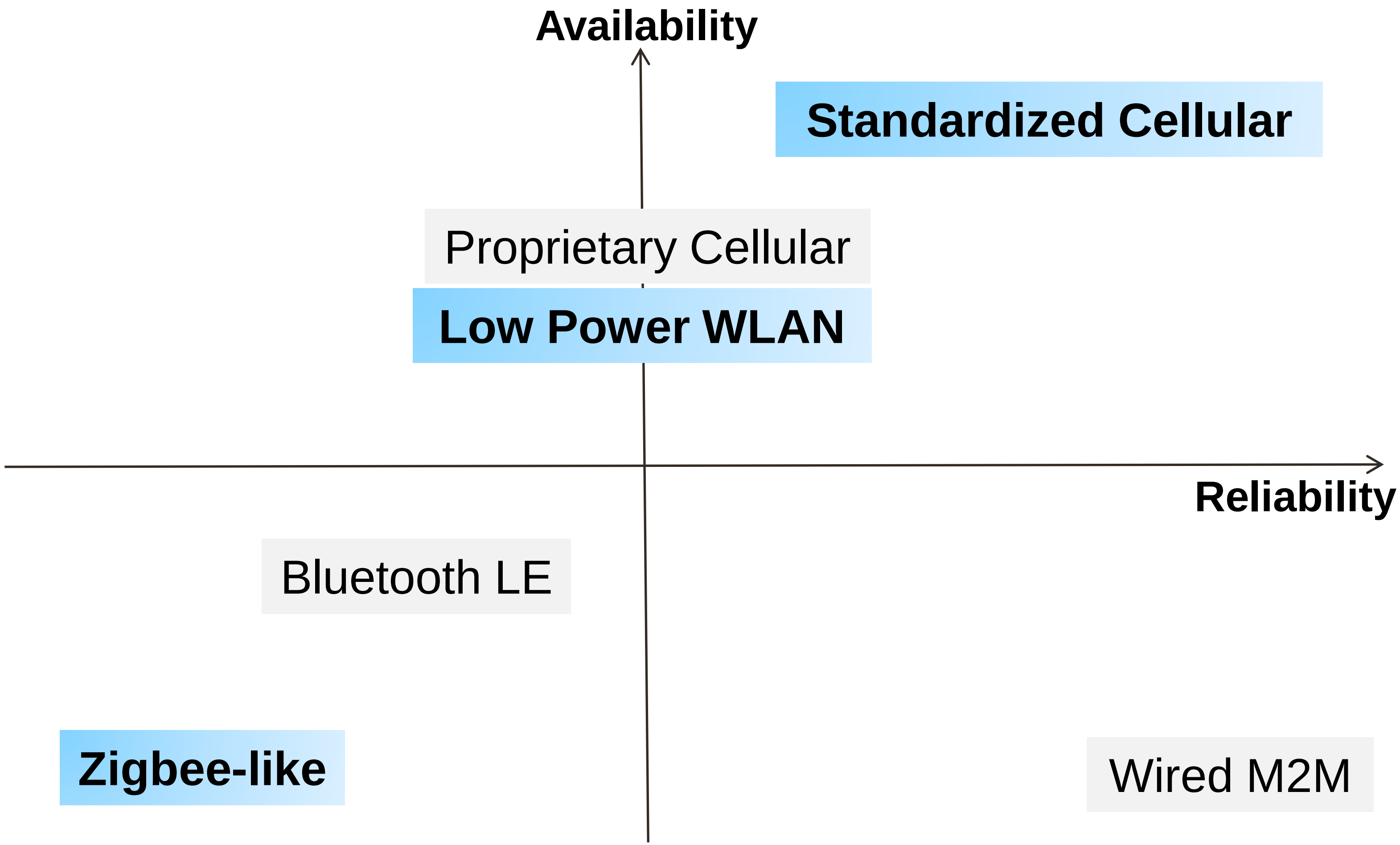
2

M2M Communications: The Access Network

A General View (Wireless)



M2M Prime Business Criteria



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

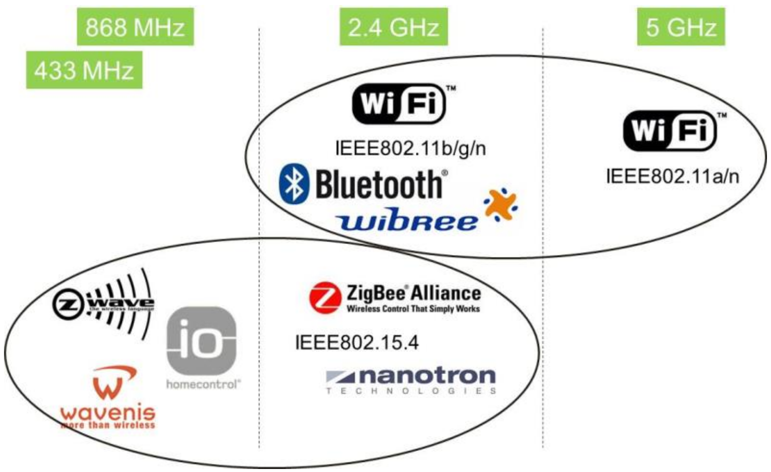
<table>
<tr><td></td><td colspan="3">**Capillary M2M**
M2M Area Neworks</td><td>**Cellular M2M**</td></tr>
<tr><td></td><td colspan="2">Zigbee-Like</td><td>Low Power Wifi</td><td>LTE/LTE-A MTC</td></tr>
<tr><td>Application</td><td colspan="2">IETF CORE</td><td>HTTP, etc.</td><td></td></tr>
<tr><td>Transport</td><td colspan="2">Lightweight TCP, UDP</td><td>TCP, UDP</td><td rowspan="3">LTE/LTE-A
Networking Layer</td></tr>
<tr><td rowspan="2">Networking</td><td colspan="2">IETF ROLL</td><td rowspan="2">IPv4, IPv6</td></tr>
<tr><td colspan="2">6LowPAN</td></tr>
<tr><td rowspan="2">MAC</td><td colspan="2">IETF 6TSCH</td><td rowspan="3">802.11g/ac/ad/ah</td><td rowspan="3">LTE/LTE-A
Link Layer</td></tr>
<tr><td>802.15.4
/e Industrial
Apps.</td><td rowspan="2">802.15.4
/f RFID</td></tr>
<tr><td>PHY</td><td>802.15.4-2006
/g Smart Grids
/k Low-Energy
Infrastructure
Monitoring</td></tr>
</table>

IETF (Application to Networking) · IEEE (MAC, PHY) · 3GPP (Transport to PHY)

2.1
Capillary Networks (Zigbee-like and LP-WIFI)

Problems of ZigBee-like Solutions

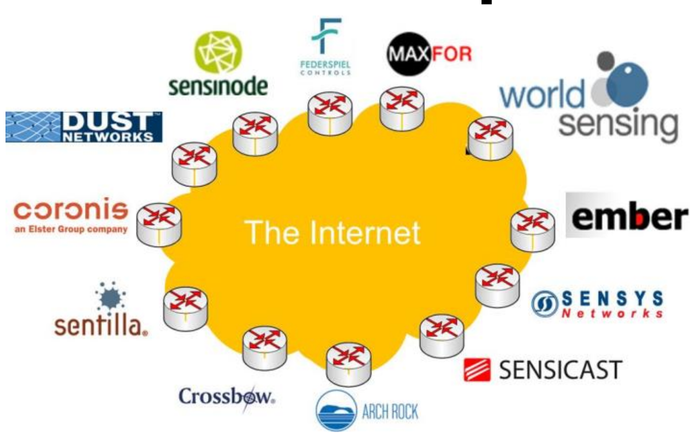
Interference in ISM



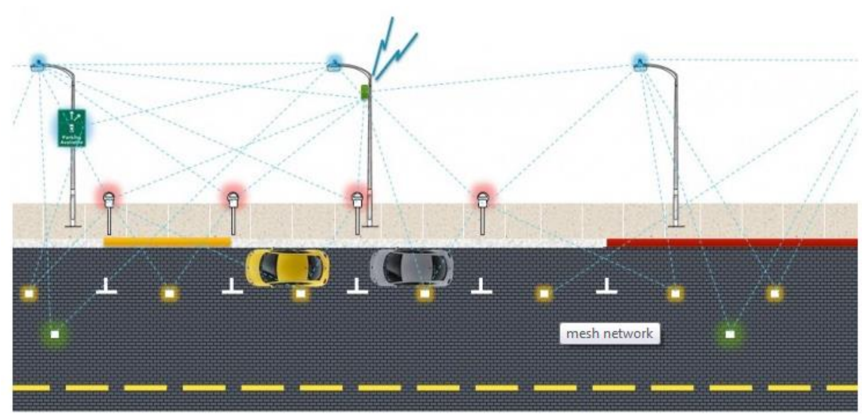
No Global Infrastructure

ZigBee Alliance
Wireless Control That Simply Works

Lack of Interoperability



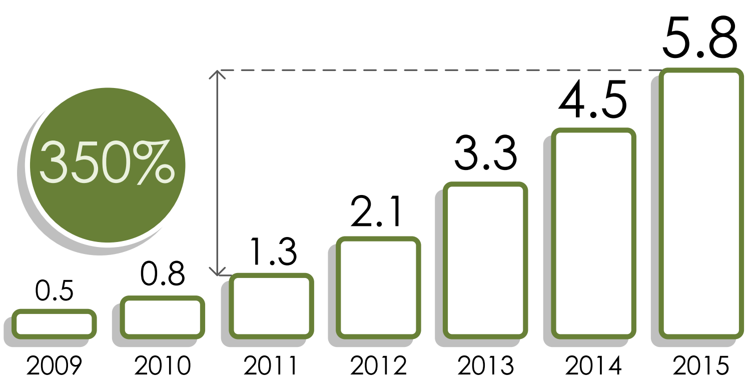
Higher Total Cost



Advantages of Low-Power WiFi

Ubiquitous Infrastructure

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



Source: Wireless Broadband Access (WBA), Informa, Nov. 2011

Vibrant Standard

300 members

Interference Management

NAV Medium
Reservation

Sound Security

LP-Wifi vs ZigBee Capillary M2M

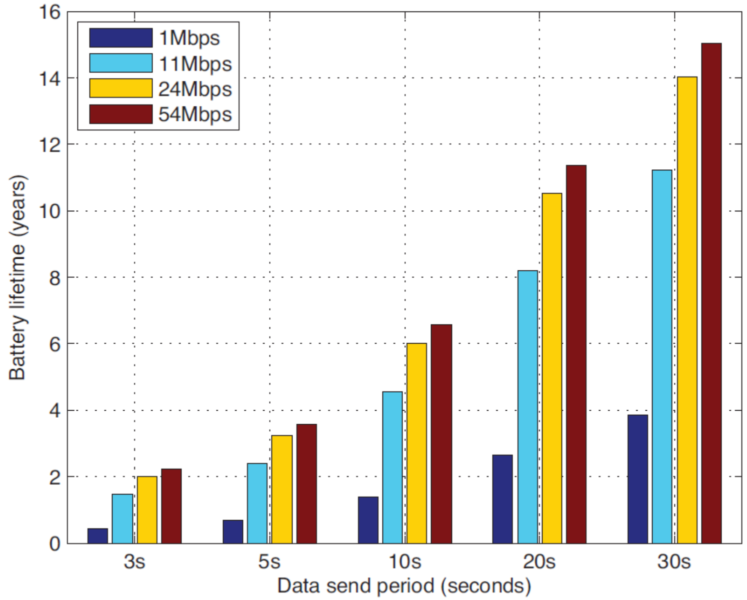
6LoWPAN vs. Low-power Wi-Fi at 54Mbps

	6LoWPAN		Low-power Wi-Fi	
Packet size	8 Bytes	1024 Bytes	8 Bytes	1024 Bytes
Time (ms)	6	23.61	11.3	16.58
Energy (mJ)	2.5	9.17	0.55	1.28

10x

"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]

- QUALCOMM
- GainSpan — Getting Connected with Wi-Fi
- SAMSUNG
- HUAWEI
- MARVELL
- intel
- LG Electronics
- MEDIATEK
- ETRI
- MOTOROLA MOBILITY
- BROADCOM

Low-Power Wifi Products [© Gainspan]

2.2

Low-Power Wide Area Networks (LPWA)

Advantages of LPWA M2M Networks

Large Coverage

Low Cost

Available Today

SigFox Wireless — REINVENT RADIO COMMUNICATION

SEMTECH

ONRAMP WIRELESS

neul

Operator Model

Current Eco-System

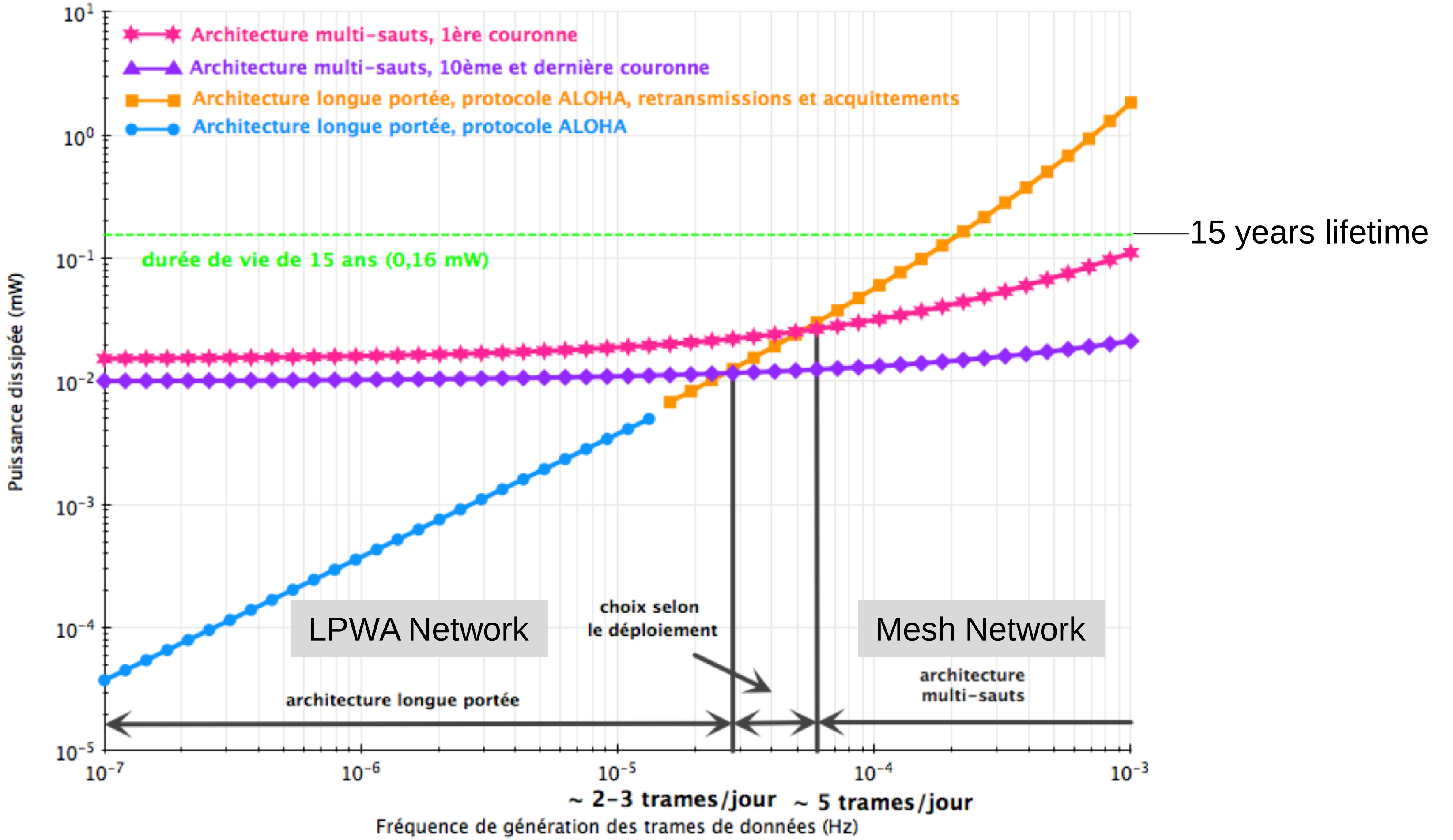
- **Sigfox** (market leader in Q1 2014):
  - technical: sub-GHz, UNB, very long range, one-way
  - business approach: operator, yearly license fee; Intel Ventures €10 million VC
- On-Ramp:
  - technical: 2.4GHz ISM band; “Random Phase Multiple Access”; 170dB link budget
  - business approach: equipment provider mainly; Managed Service SLA possible
- Cycleo (now Semtech):
  - technical: sub-GHz, CDMA-based, long range
  - business approach: equipment provider
- Neul:
  - technical: initially TVWS only; now shift into other bands too (notably licensed!)
  - business approach: originally only equipment; now SLA possible

Weightless Alliance

- Alliance-driven “standardization” of Neul-like technologies:
  - **Low cost**. Both of the hardware and the service, i.e. chipset costs need to be in the region $1-$2 and annual service charges less than $10 to make it worth embedding wireless technology.
  - **Excellent coverage**. To make applications such as smart metering viable there needs to be coverage of near 100% of all meters. With many meters deep within the home or even in basements this implies vastly better coverage than achieved with today’s cellular networks.
  - **Ultra low-power operations**. Many machines are not connected to the mains and so have to operate on batteries. Having to change the battery is at best an annoyance and at worst a significant expense. Battery life of ten years or more is essential.
  - **Secure and guaranteed message delivery**. While machines rarely need ultra-rapid transmission, they do need to be certain that messages have been received and that security of the system has not been compromised in any way.

Performance Comparison

© Orange, excerpt from PhD Thesis of Dr Quentin Lampin:



(a) $N = 100$ et $d = 10$

2.3
Cellular M2M Standards & Architectures

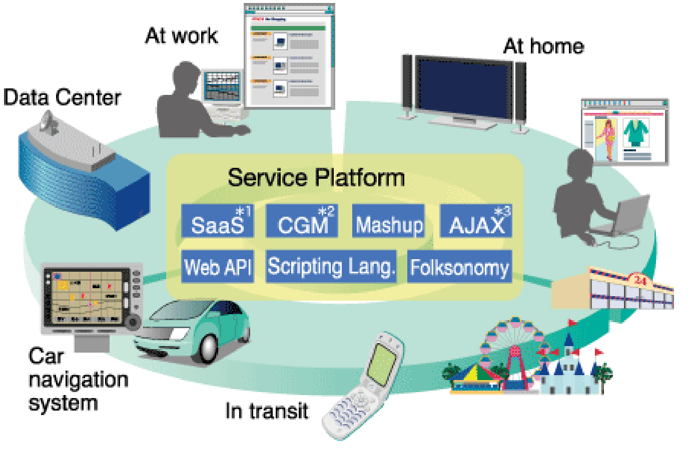
Advantages of Cellular M2M

Ubiquitous Coverage

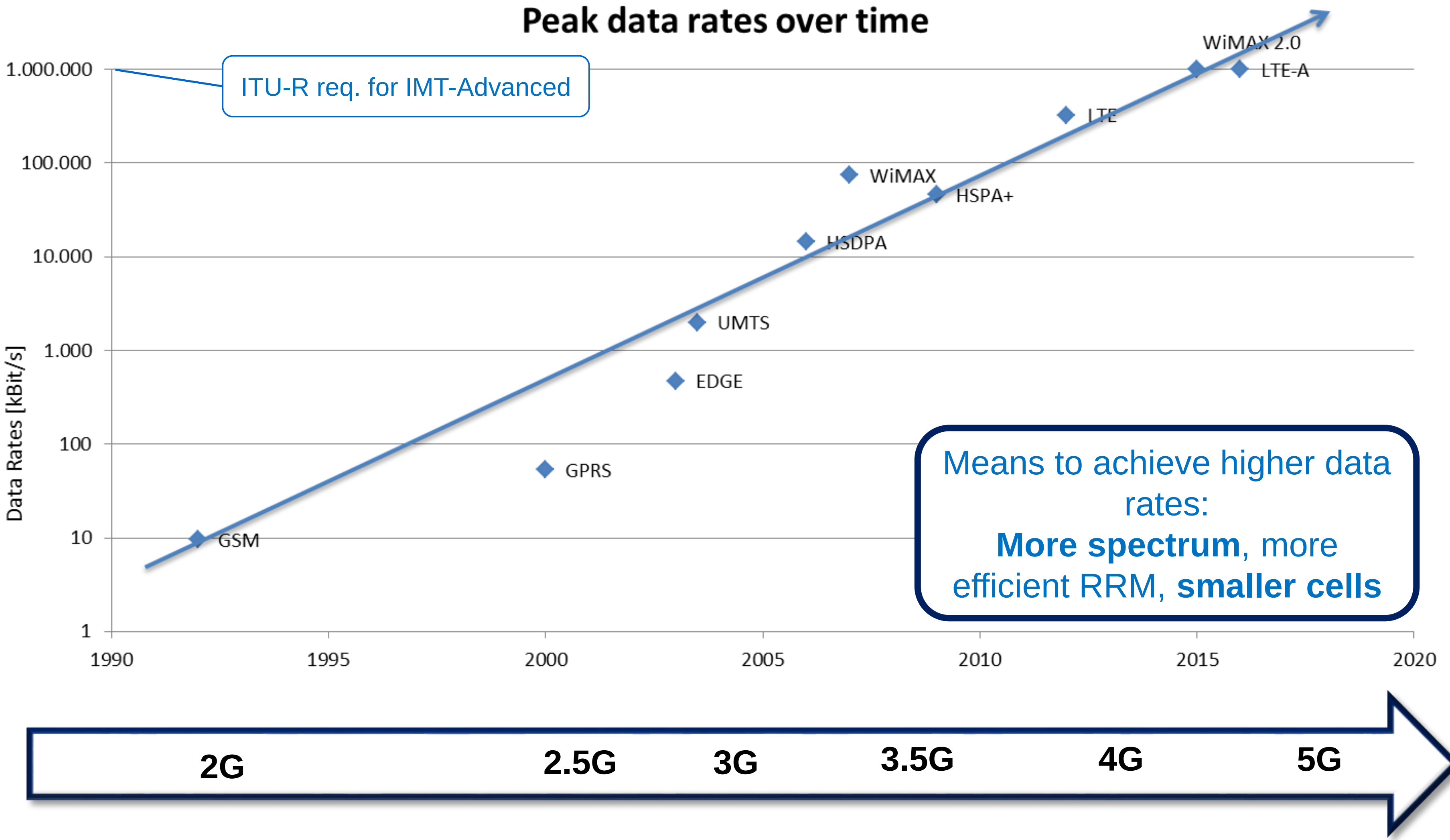
Mobility & Roaming

Interference Control

Service Platforms



However…



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***

2.3.1

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

Technology	Download (kbit/s)	Upload (kbit/s)	TDMA Timeslots allocated
CSD	9.6	9.6	1+1
HSCSD	28.8	14.4	2+1
HSCSD	43.2	14.4	3+1
GPRS	80.0	20.0 (Class 8 & 10 and CS-4)	4+1
GPRS	60.0	40.0 (Class 10 and CS-4)	3+2
EGPRS (EDGE)	236.8	59.2 (Class 8, 10 and MCS-9)	4+1
EGPRS (EDGE)	177.6	118.4 (Class 10 and MCS-9)	3+2

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.

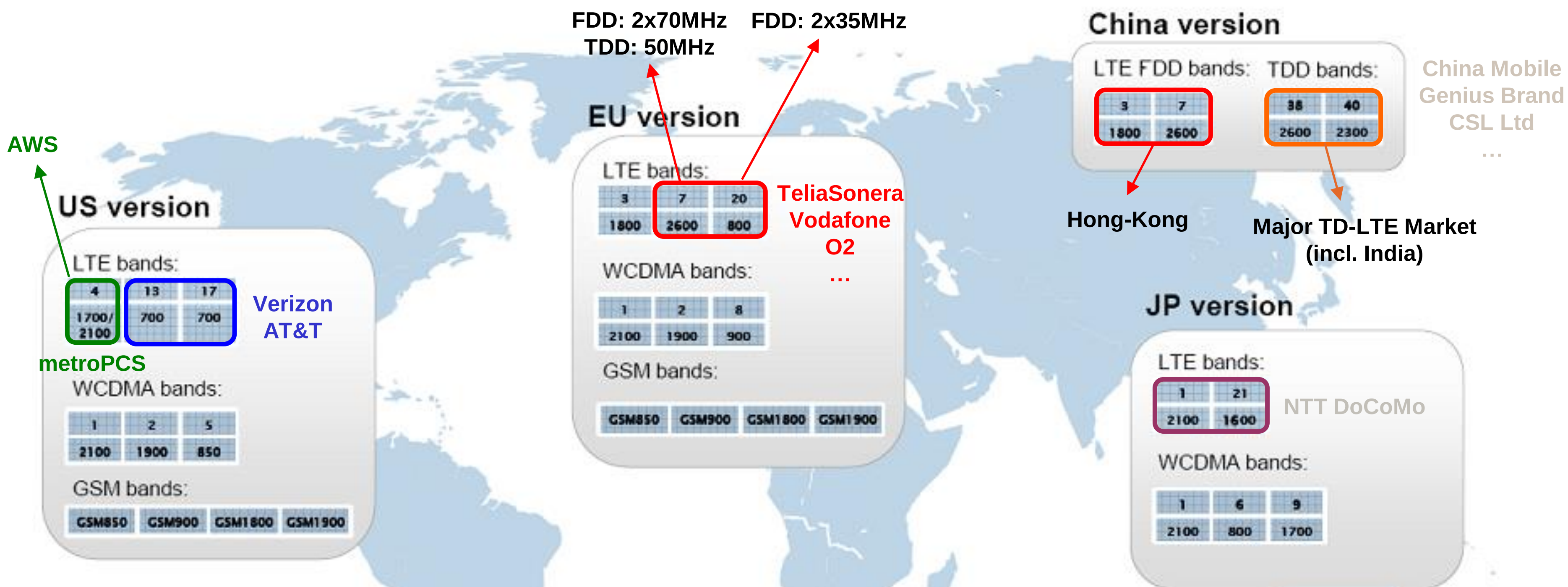
LTE & LTE-A

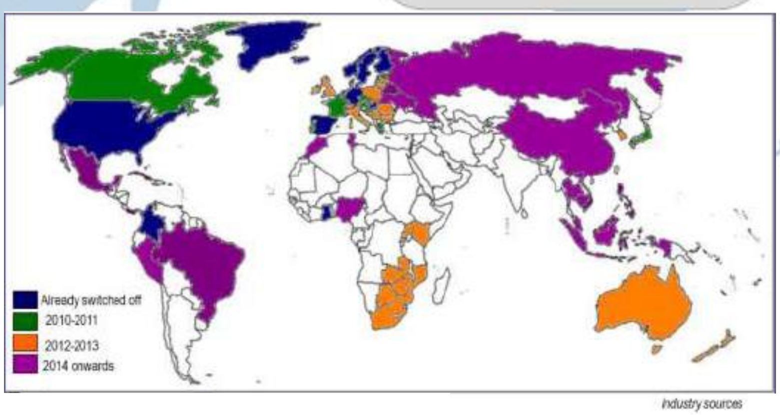
- **LTE (Release 8 and 9)**
  - OFDMA (downlink) + SC-FDMA (uplink)
    - Robust to multipath
    - Flexible spectrum allocation (adjusting number of subcarriers)
    - Efficient receiver implementations
    - Simple MIMO implementation in frequency domain → freq. diversity gain
  - Quicker RTT & throughput
  - 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.

Source: presentation by Thierry Lestable, Sagemcom, BEFEMTO Winter School, Barcelona, Feb. 2012.

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

2.3.2
Standardization Activities

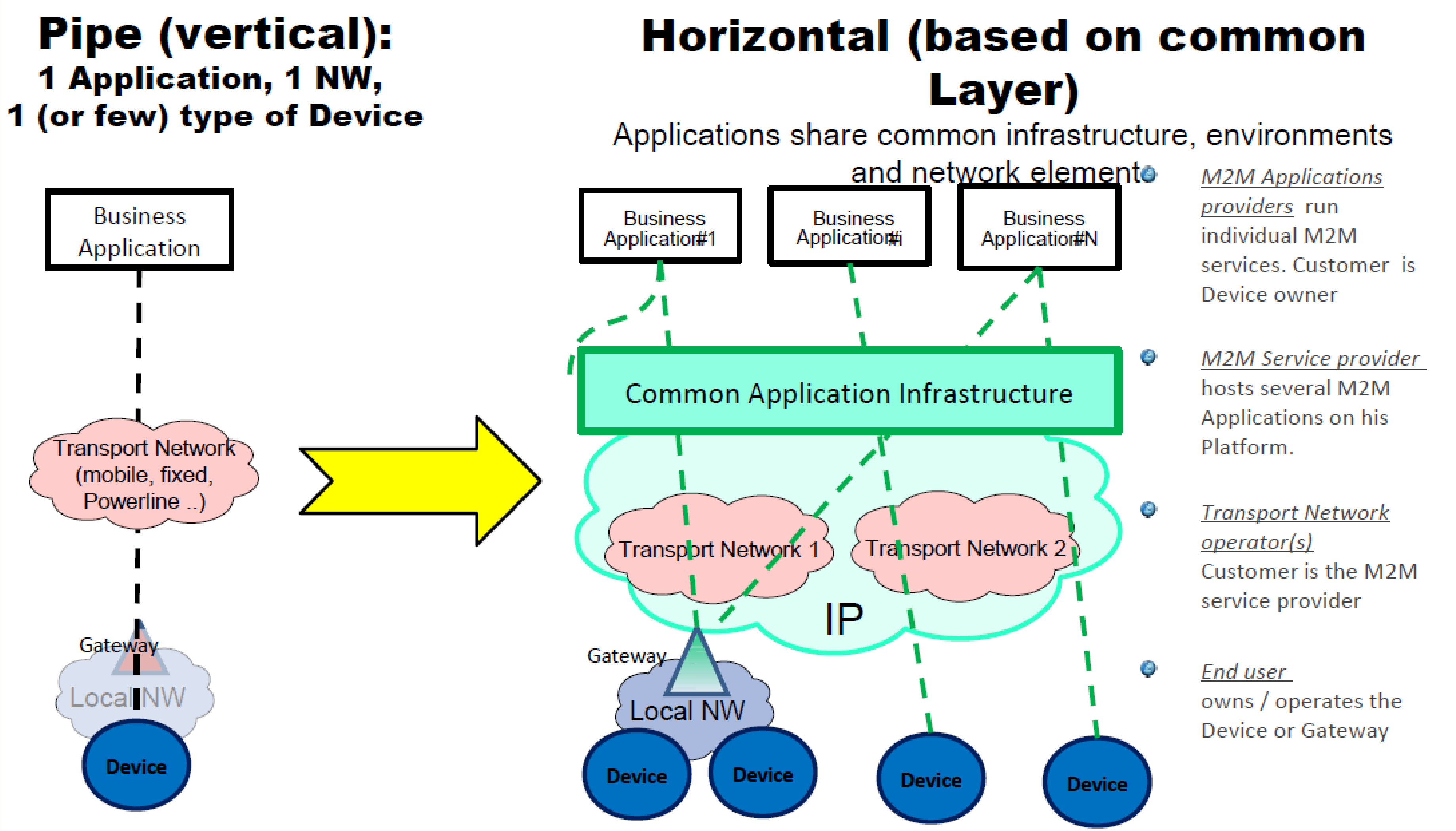
http://www.3gpp.org/ftp/Information/WORK_PLAN/Description_Releases/M2M_yyyymmdd.zip

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

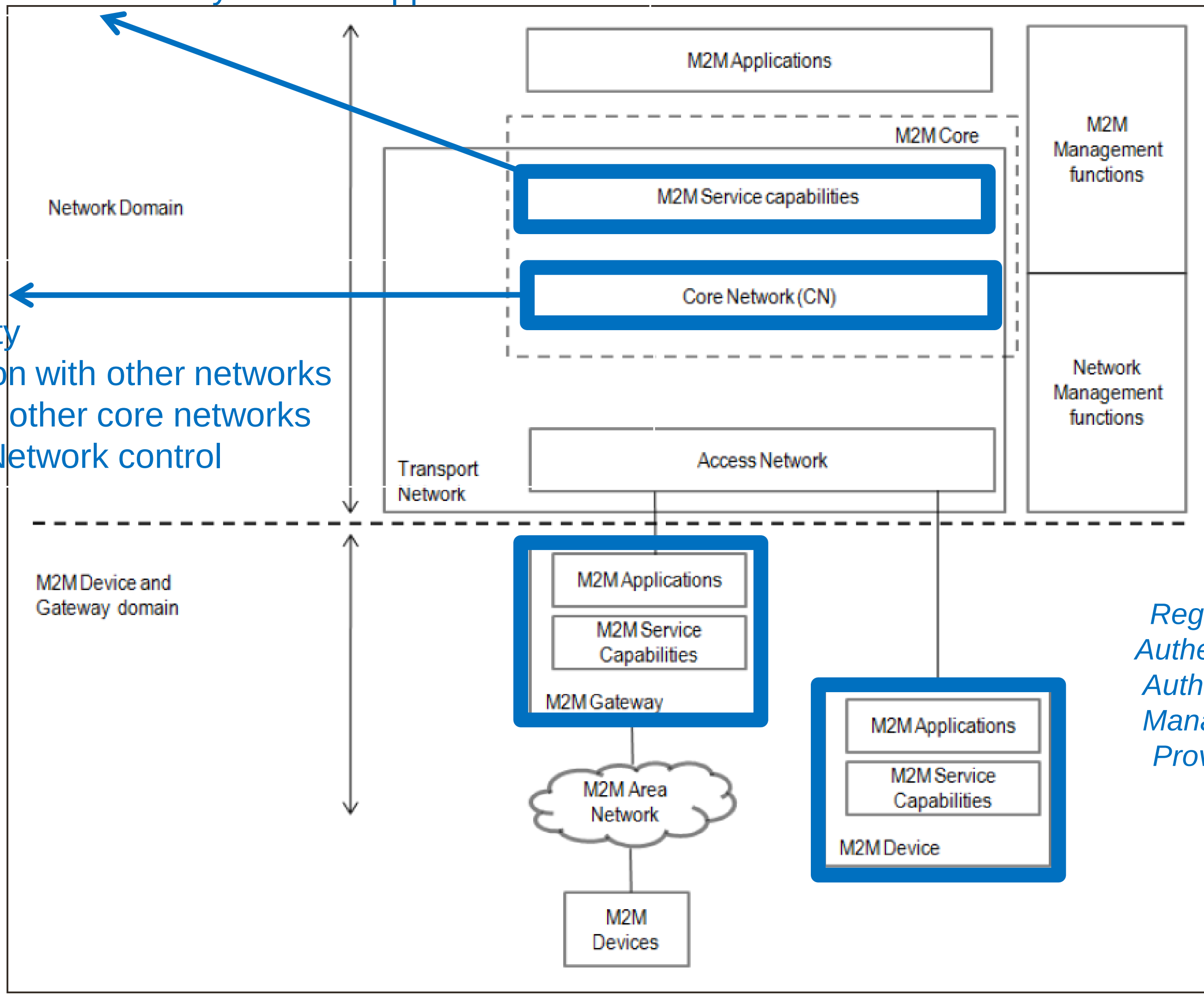


© ETSI

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

© ETSI

Creation of oneM2M Partnership project

China

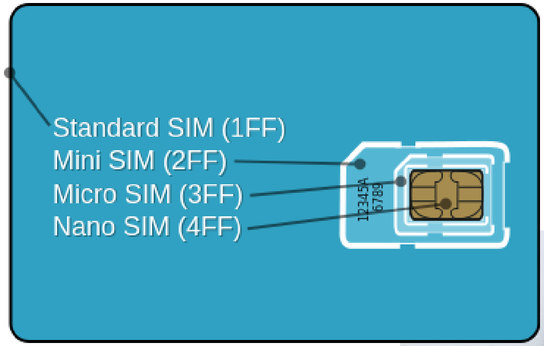
USA

Korea

Japan

ETSI Smart Card Platform (2000)

- **SIM: S**ubscriber **I**dentity **M**odule → 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
- 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.

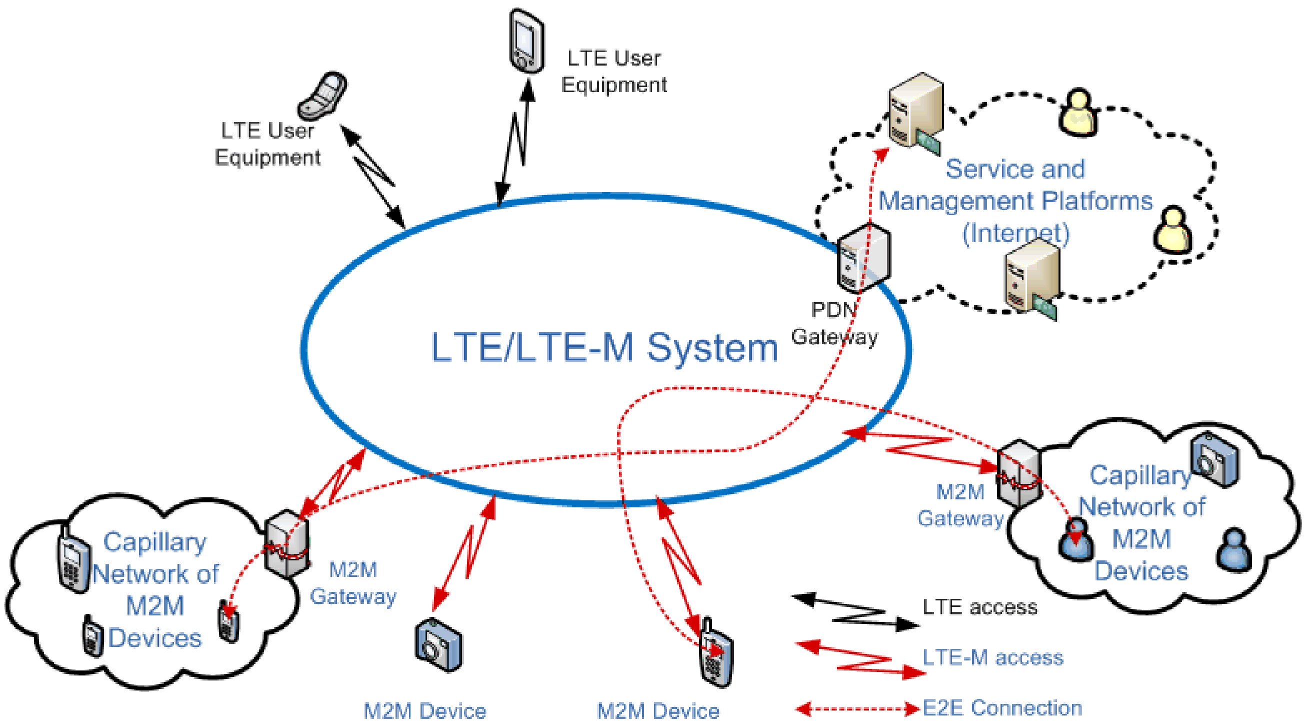
Tools

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
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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)*

Duration: *Sept. 2010 – Feb. 2013*
Funding scheme: *IP*
Total Cost: *€11m*
EC Contribution: *€7.4m*

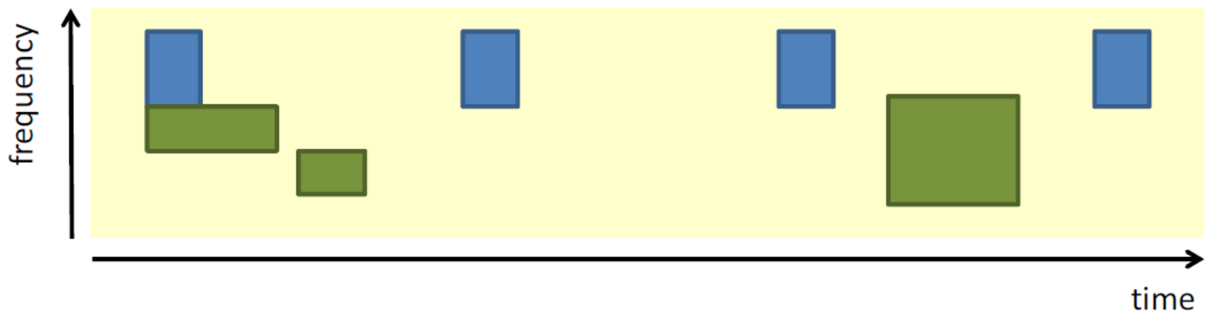
Contract Number: INFSO-ICT-258512

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)



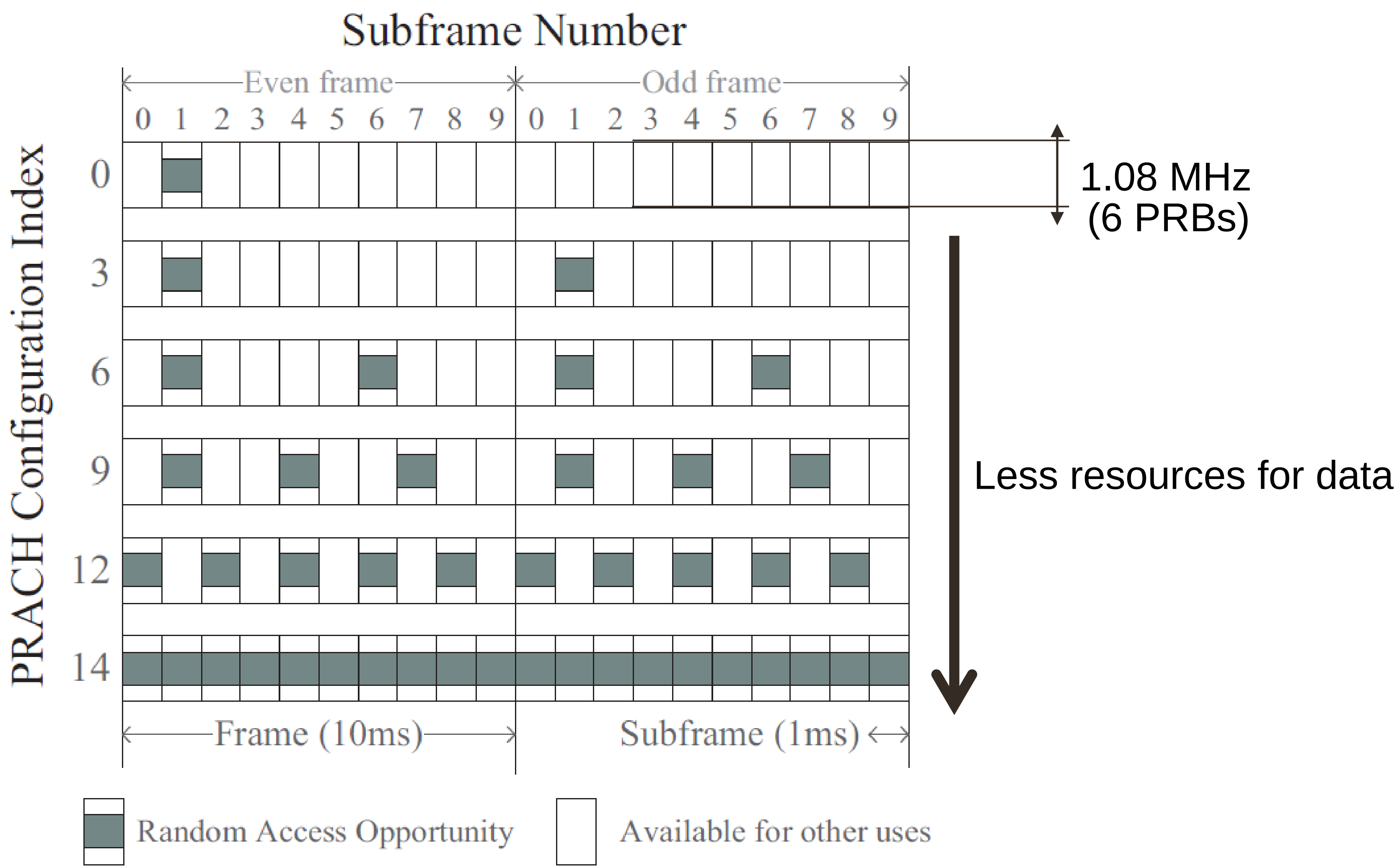
  - Discontinuous Reception (DRX): Duty Cycle
  - Use of RACH for small data transmission, adding CDMA for data collision recovery.

3.3

High Number of Devices: The access to the network

The Random Access Channel (RACH) of LTE

Examples of RACH Configuration



The Procedure

64 Orthogonal Preambles

Not all available for random access

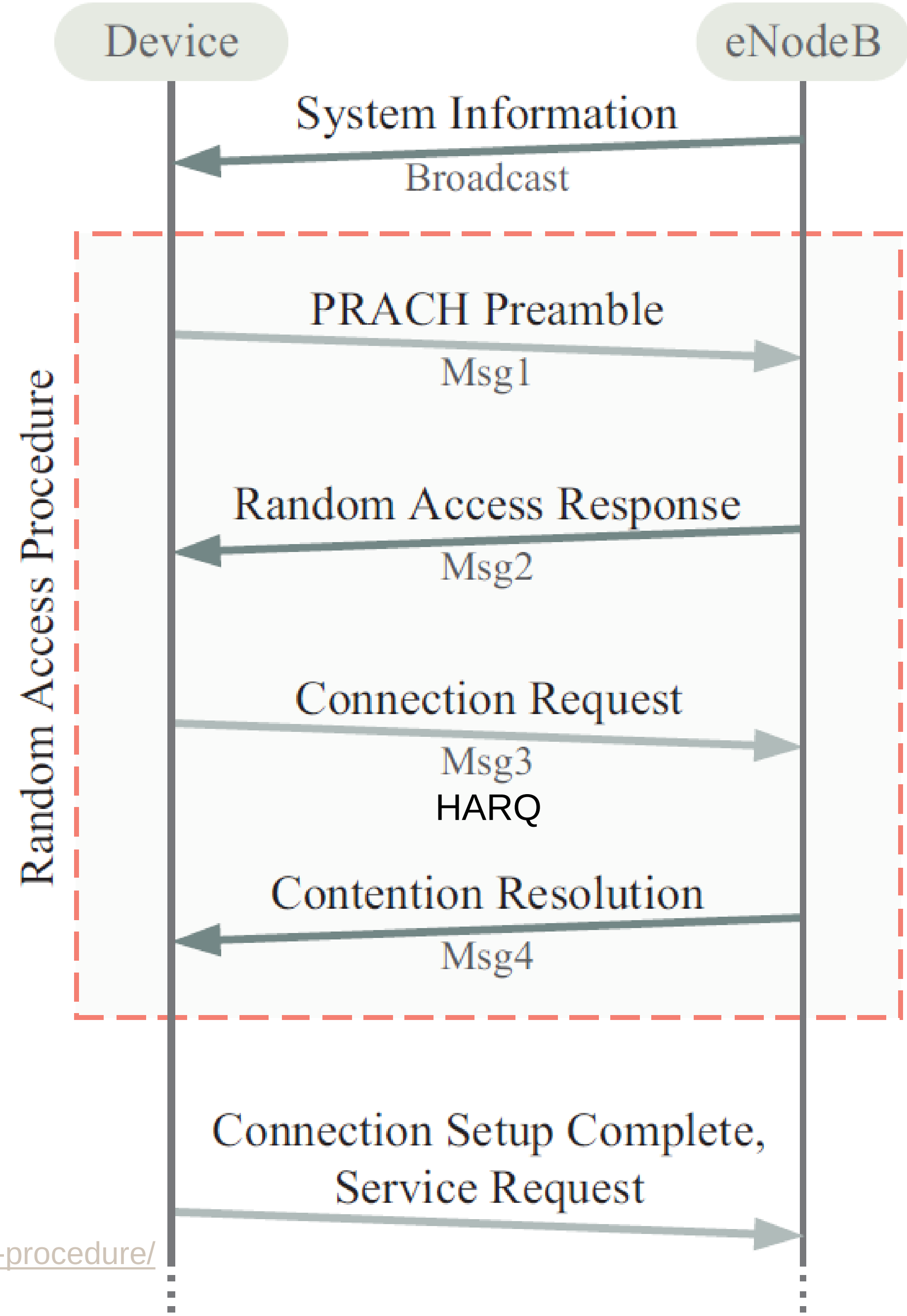
LIMITATIONS

Preamble transmission based on FS-ALOHA

Preamble Collisions

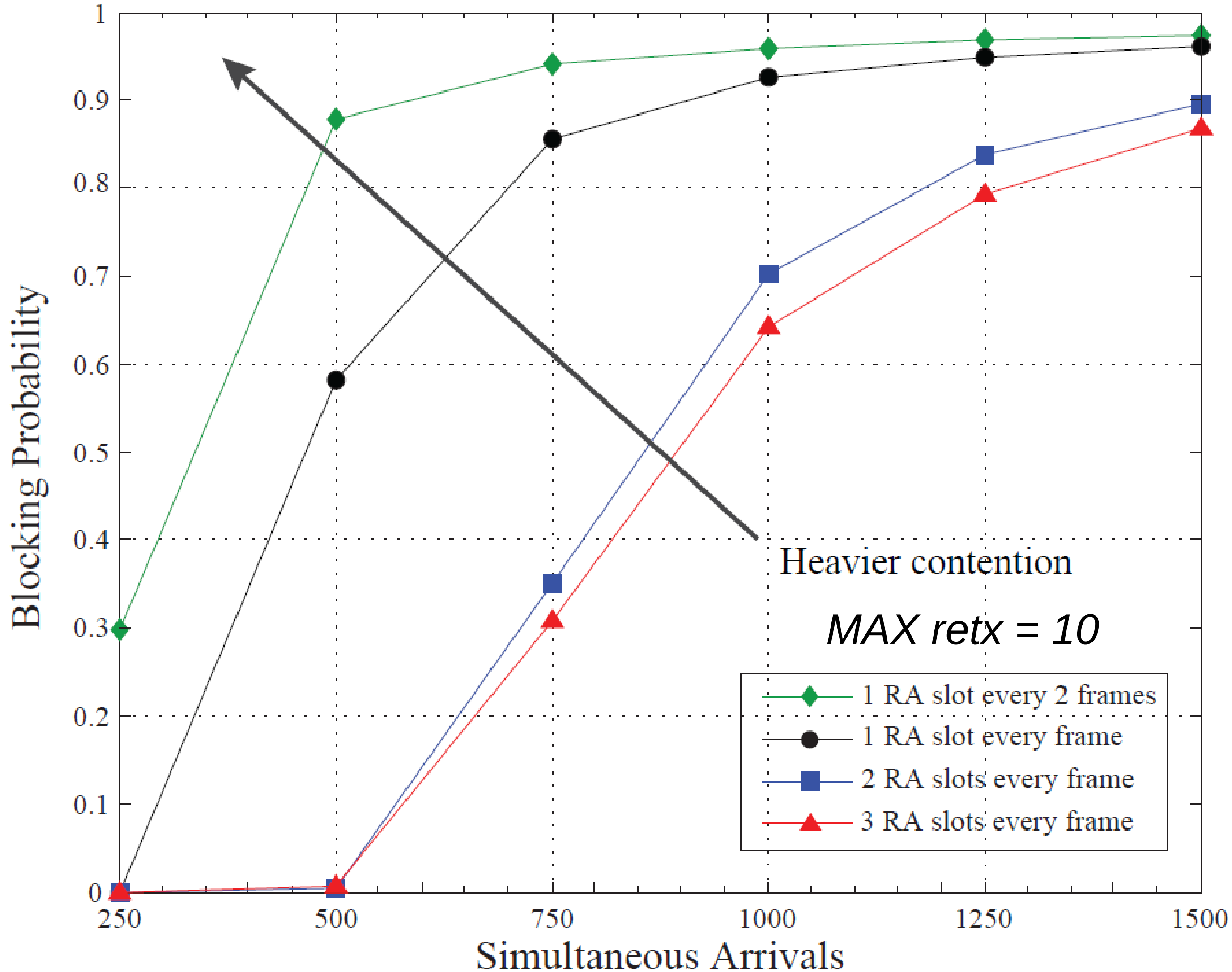
Collisions in Message 3

Lack of resources for Msg3

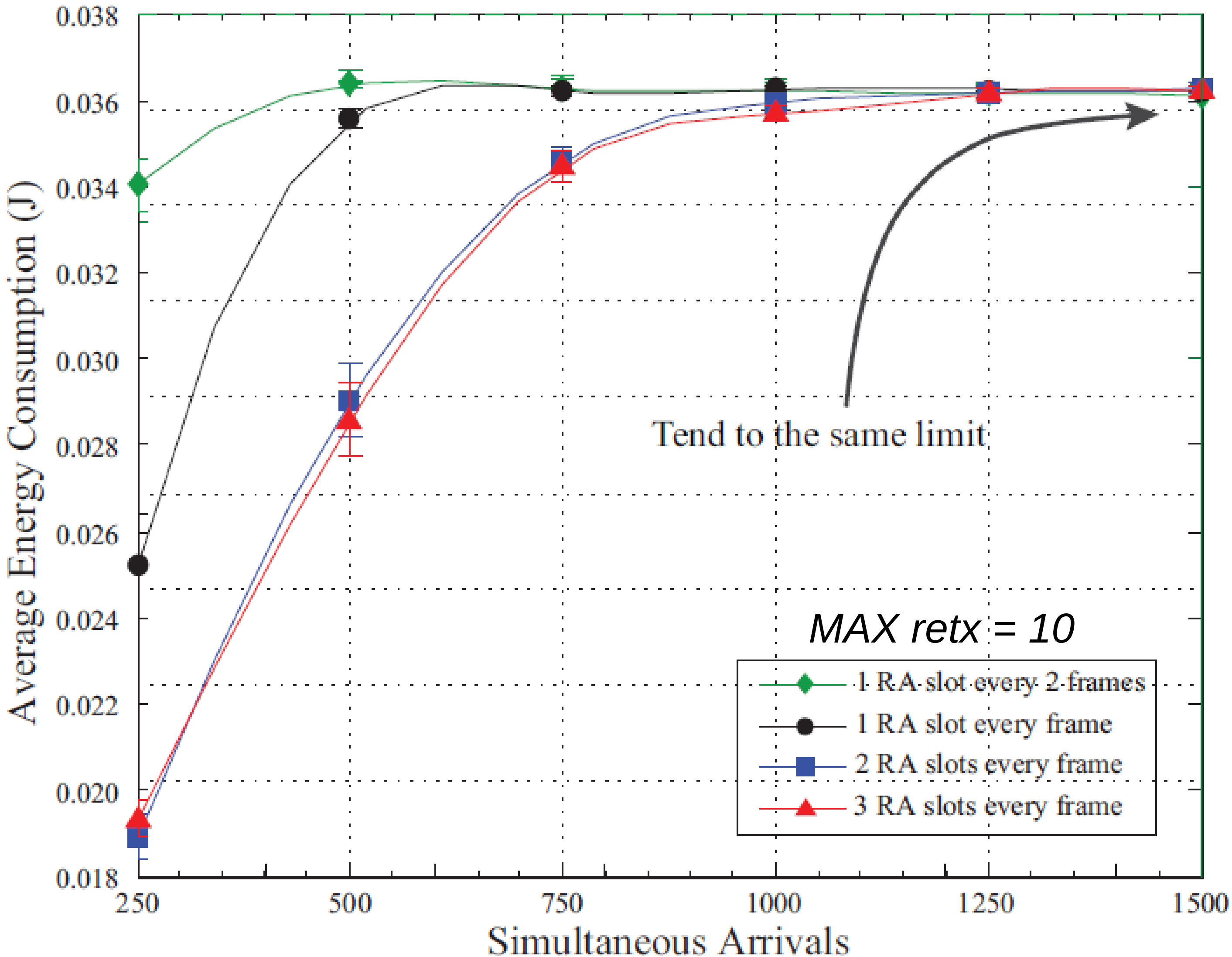


http://prezi.com/likwdk7dksmj/ns-3-lte-random-access-procedure/

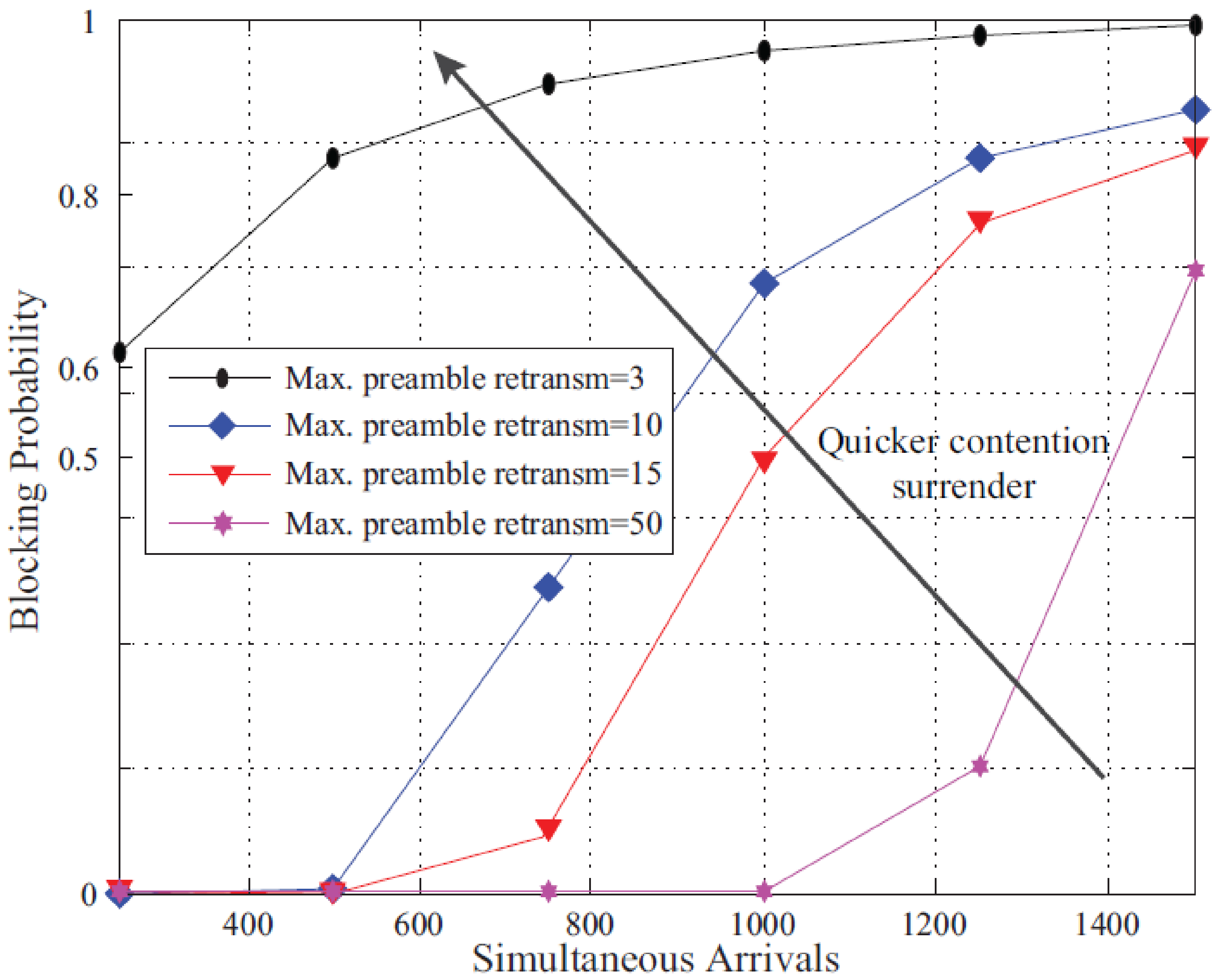
Blocking Probability: bulk arrival



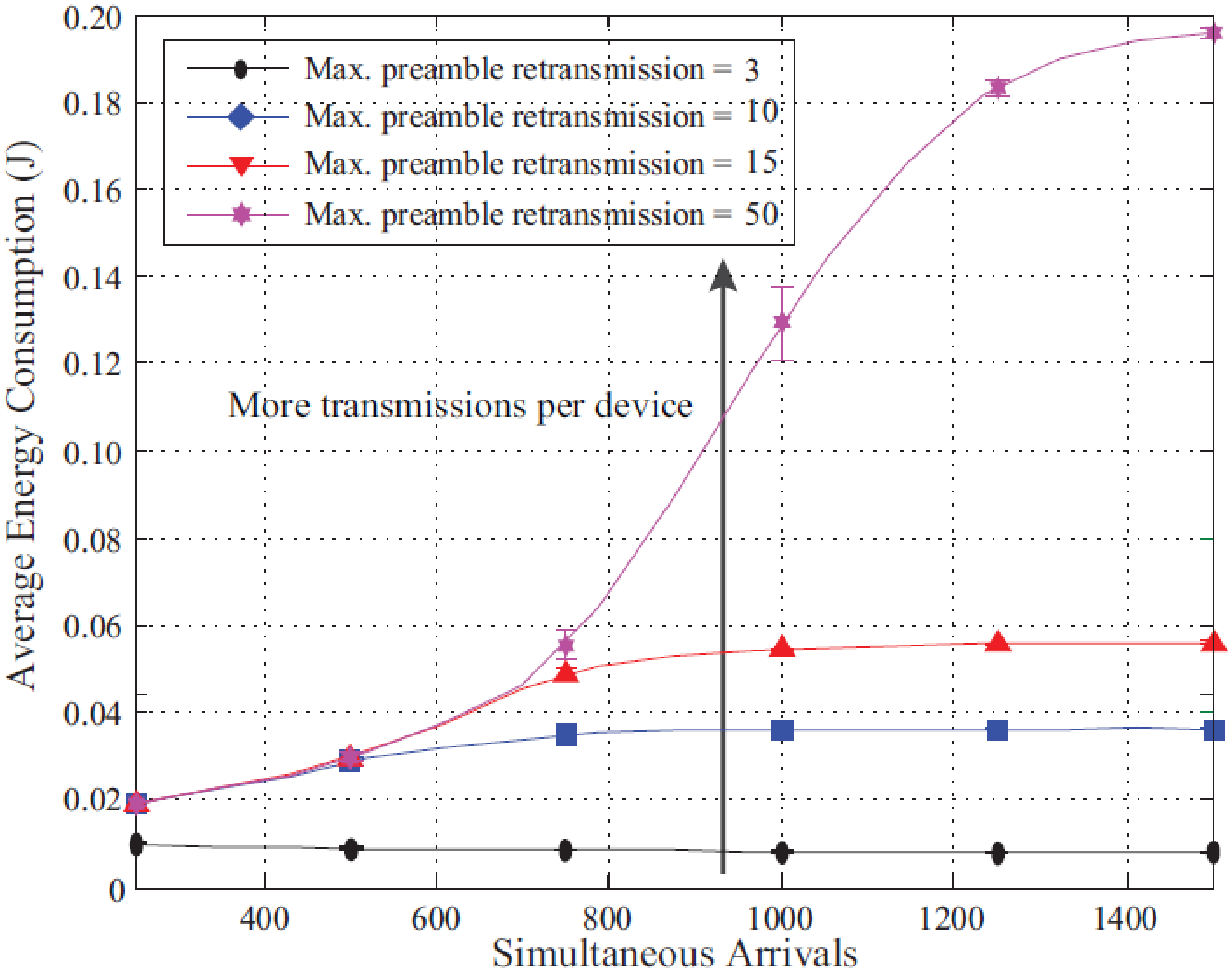
Energy Consumption: bulk arrival



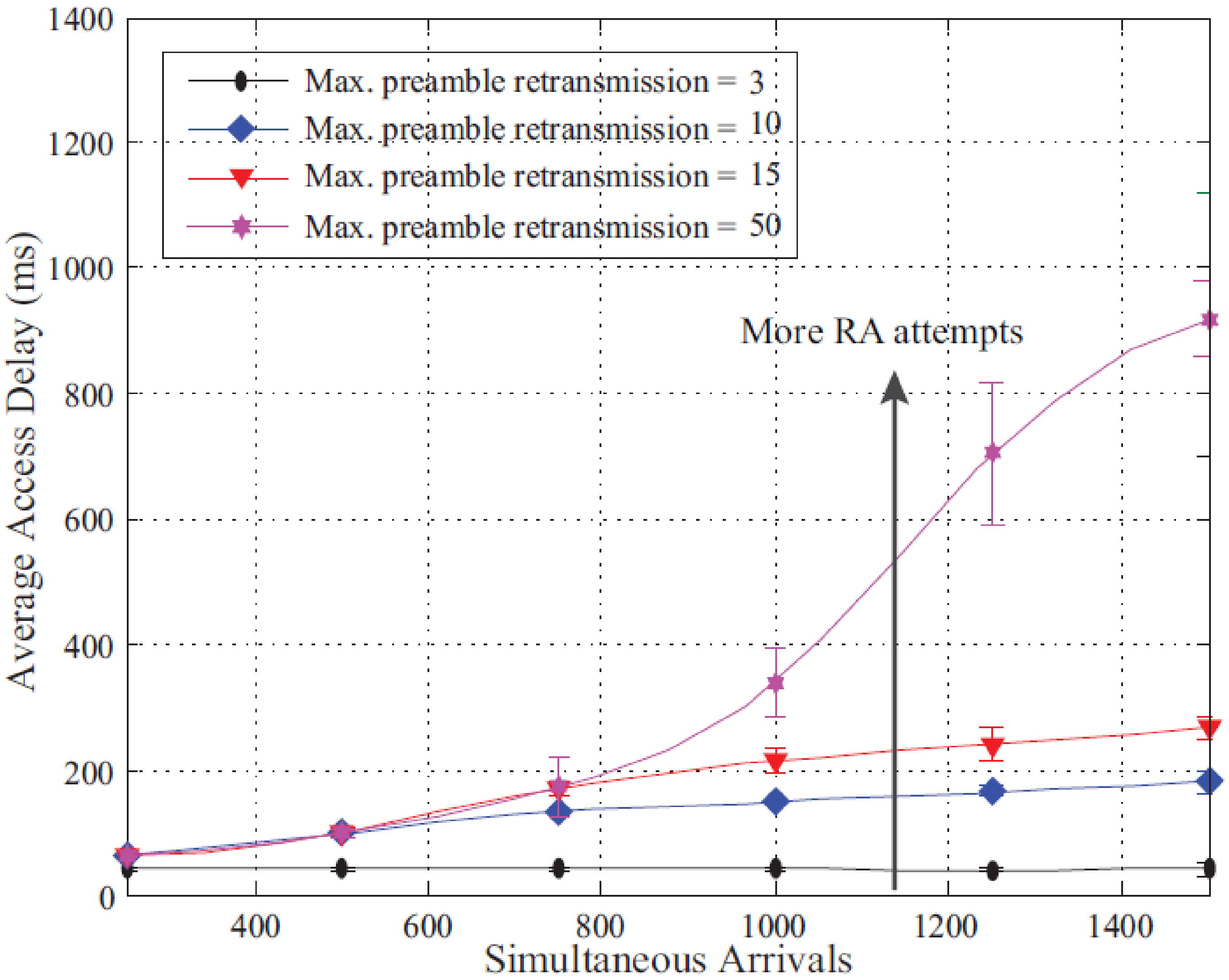
Blocking Probability: more retx



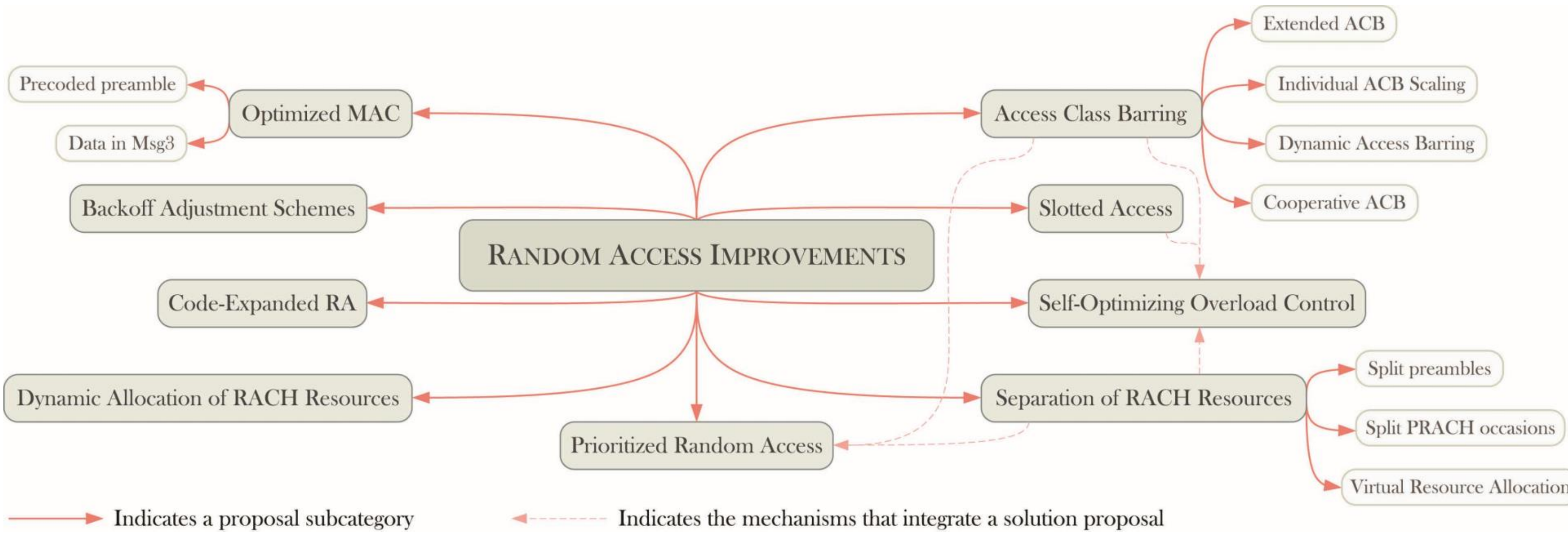
Energy Consumption: more retx



Delay: more retx



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

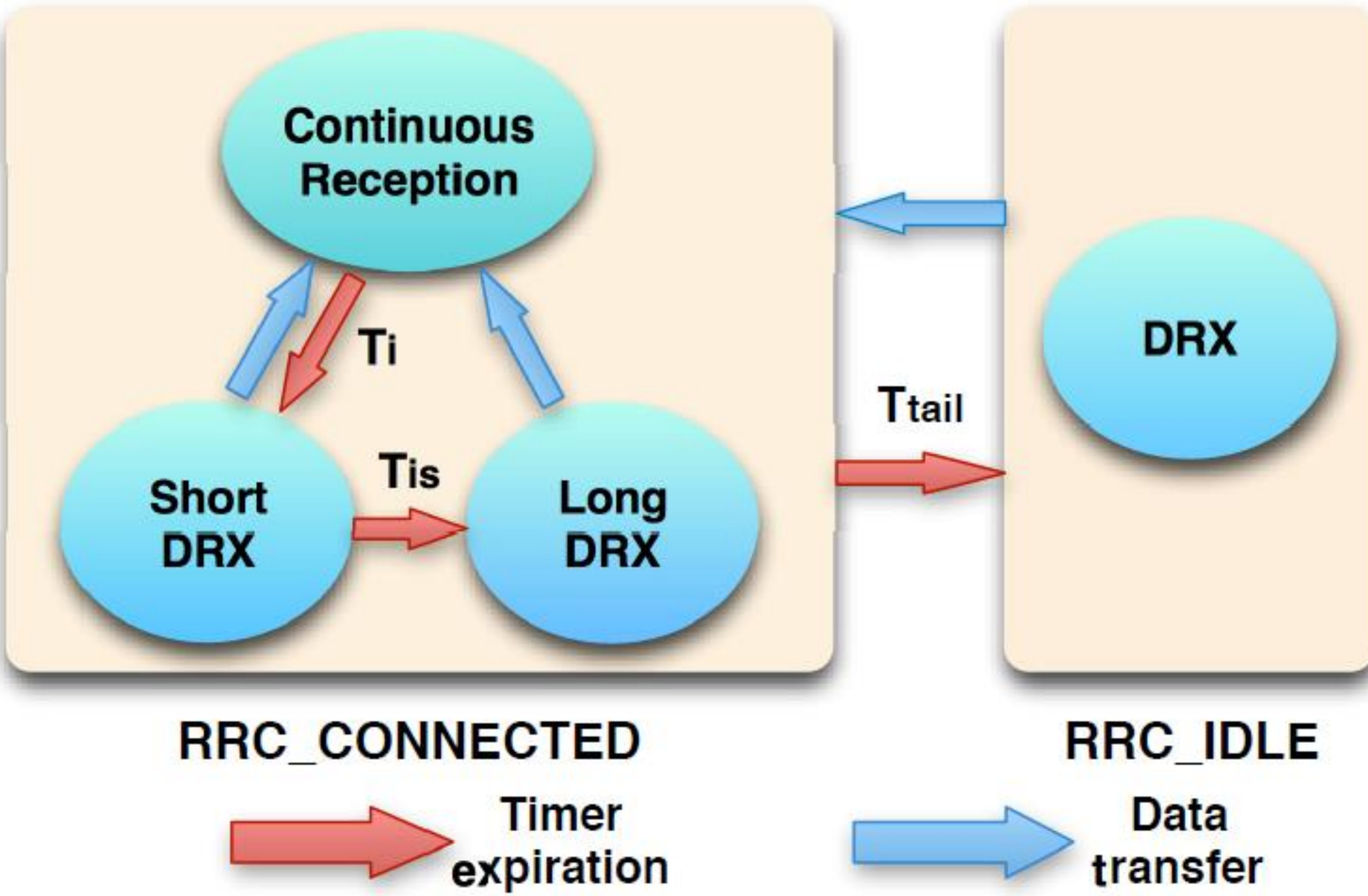
- Go away from ALOHA-type access
- Contention-Tree Algorithm (CTA)
- Distributed Queuing Random Access Protocol (DQRAP)
- Performance independent of number of users
- Simple operation with two logical queues
- One for transmission of successful access requests
- One to solve contention
- Downlink Control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

J. Alonso-Zárate, E. Kartsakli, A. Cateura, C. Verikoukis, and L. Alonso.
“A Near-Optimum Cross-Layered Distributed Queuing Protocol for Wireless LAN,”
IEEE Wireless Communication Magazine.
Special Issue on MAC protocols for WLAN, vol. 15, no. 1, pp. 48-55, February 2008.

3.4

Limitations of the RLC layer

RRC State Transitions



RRC Delays

- “A Close Examination of Performance and Power Characteristics of 4G LTE Networks,” by J. Huang, F. Qian, A. Gerber. MobiSYS’12.

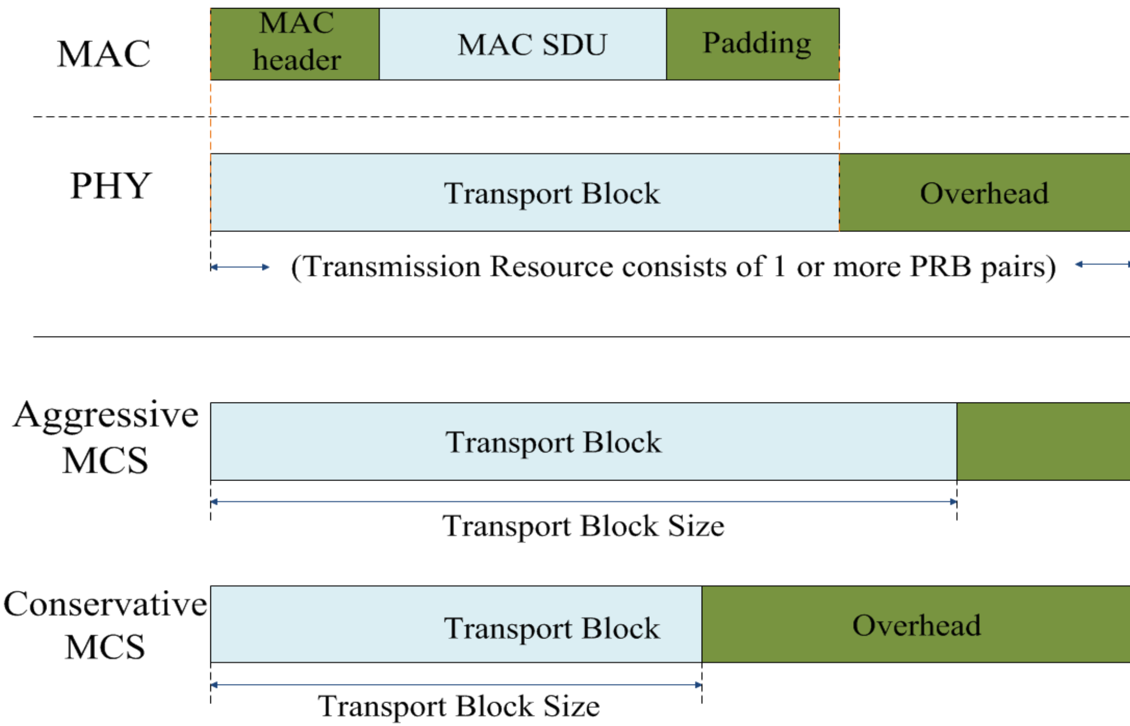
		Power* (mW)	Duration (ms)	Periodicity (ms)
screen	Screen off (base)	11.4±0.4	N/A	N/A
	Screen 100% on	847.2±2.7	N/A	N/A
LTE	LTE promotion	1210.7±85.6	T_{pro}: 260.1±15.8	N/A
	LTE Short DRX On RRC_CONNECTED	1680.2±15.7	T_{on}: 1.0±0.1	T_{ps}: 20.0±0.1
	LTE Long DRX On RRC_CONNECTED	1680.1±14.3	T_{on}: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

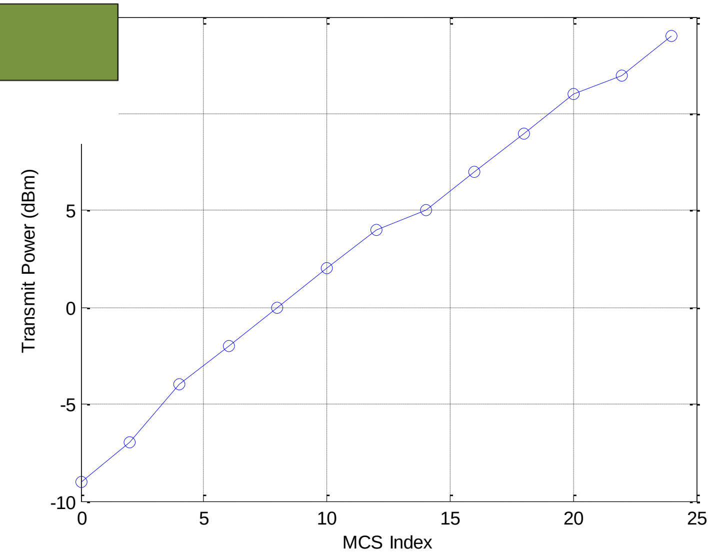
Table 3: LTE, 3G, and WiFi power model.

3.5
Optimizing LTE for Small Data Transmissions

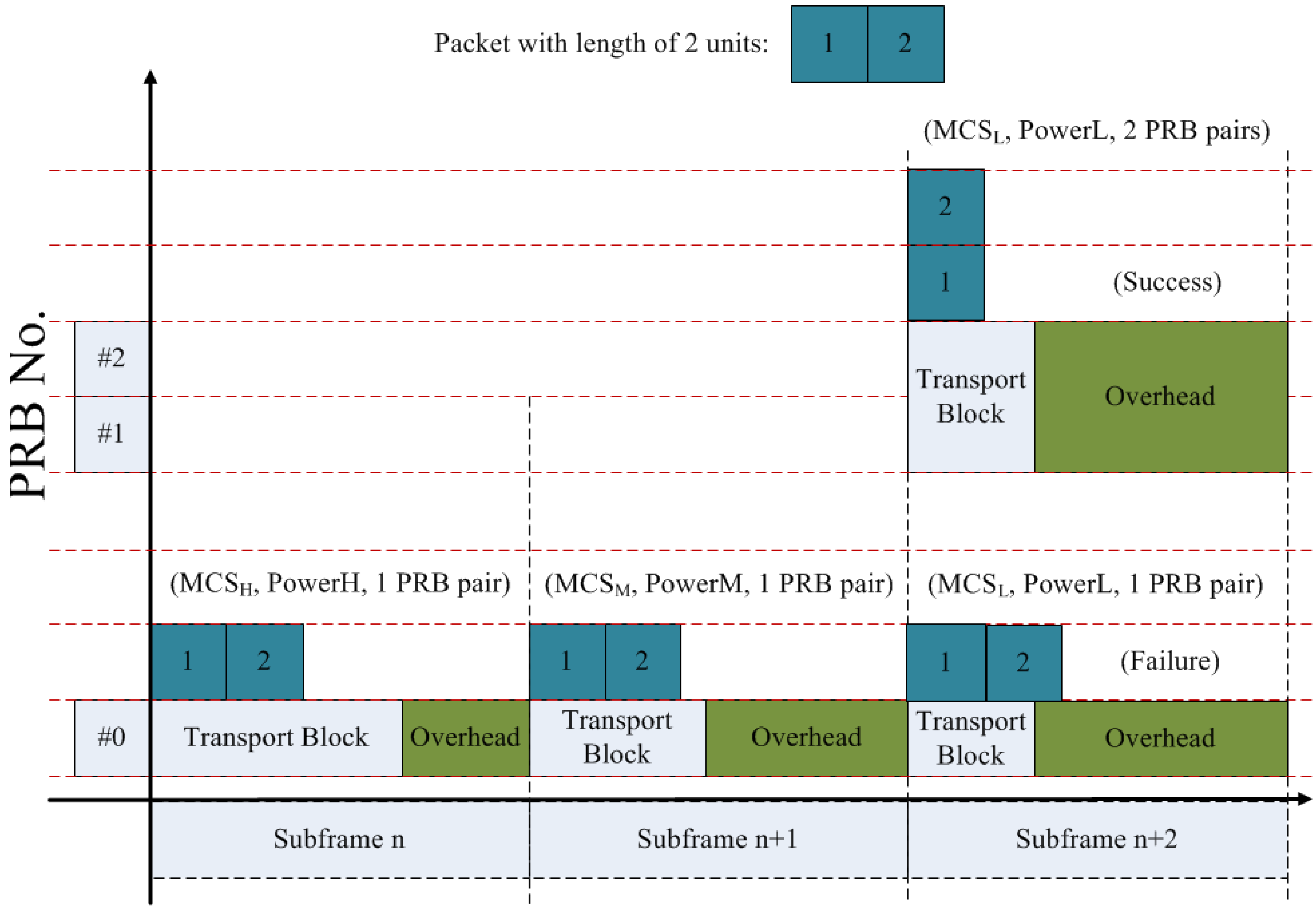
K. Wang, J. Alonso-Zarate, M. Dohler,
"Energy-Efficiency of LTE for Small Data Machine-to-Machine Communications,"
in proc. of the IEEE ICC 2013, Budapest, Hungary, June 2013.

Transport Block Size vs. MCS



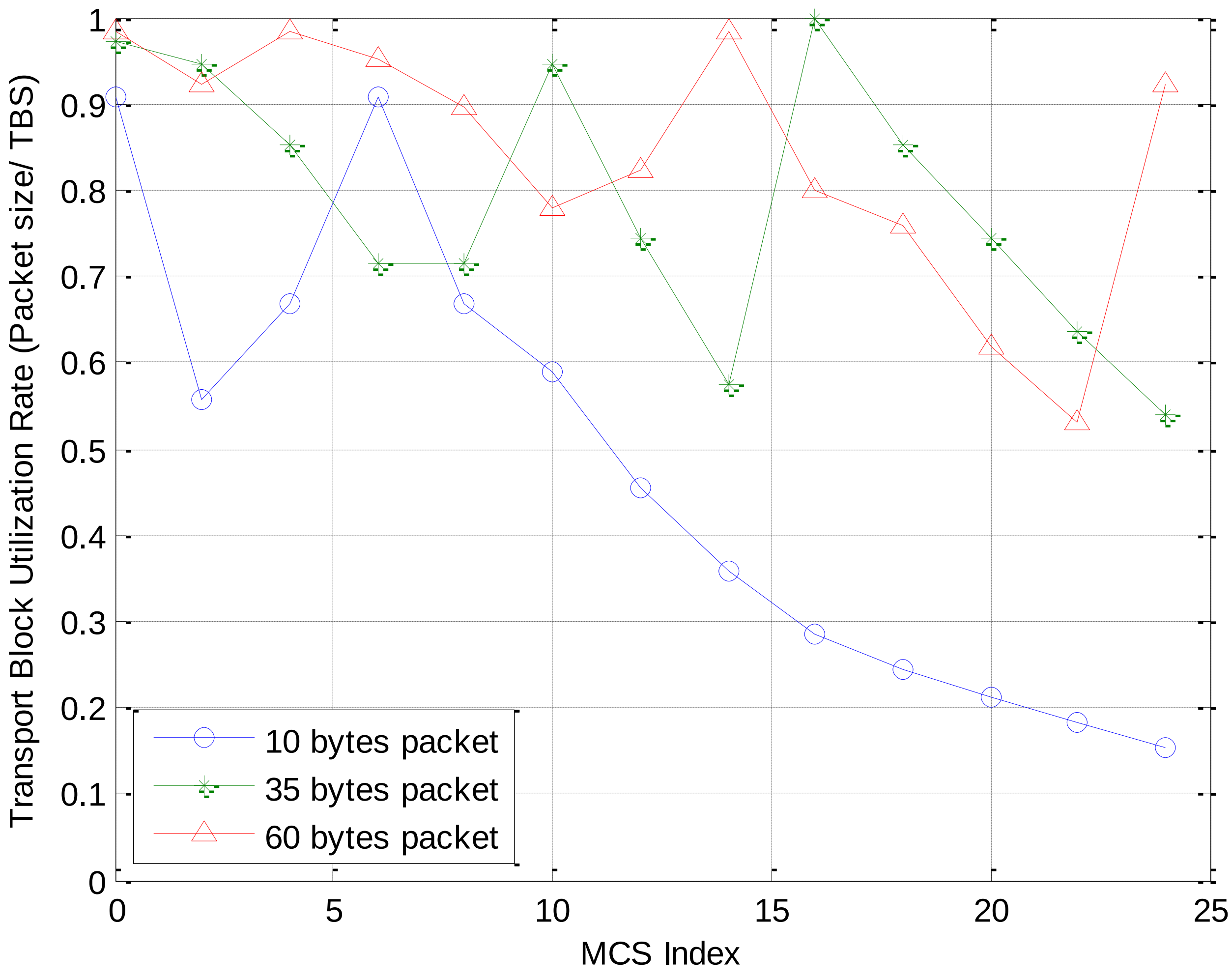


Example

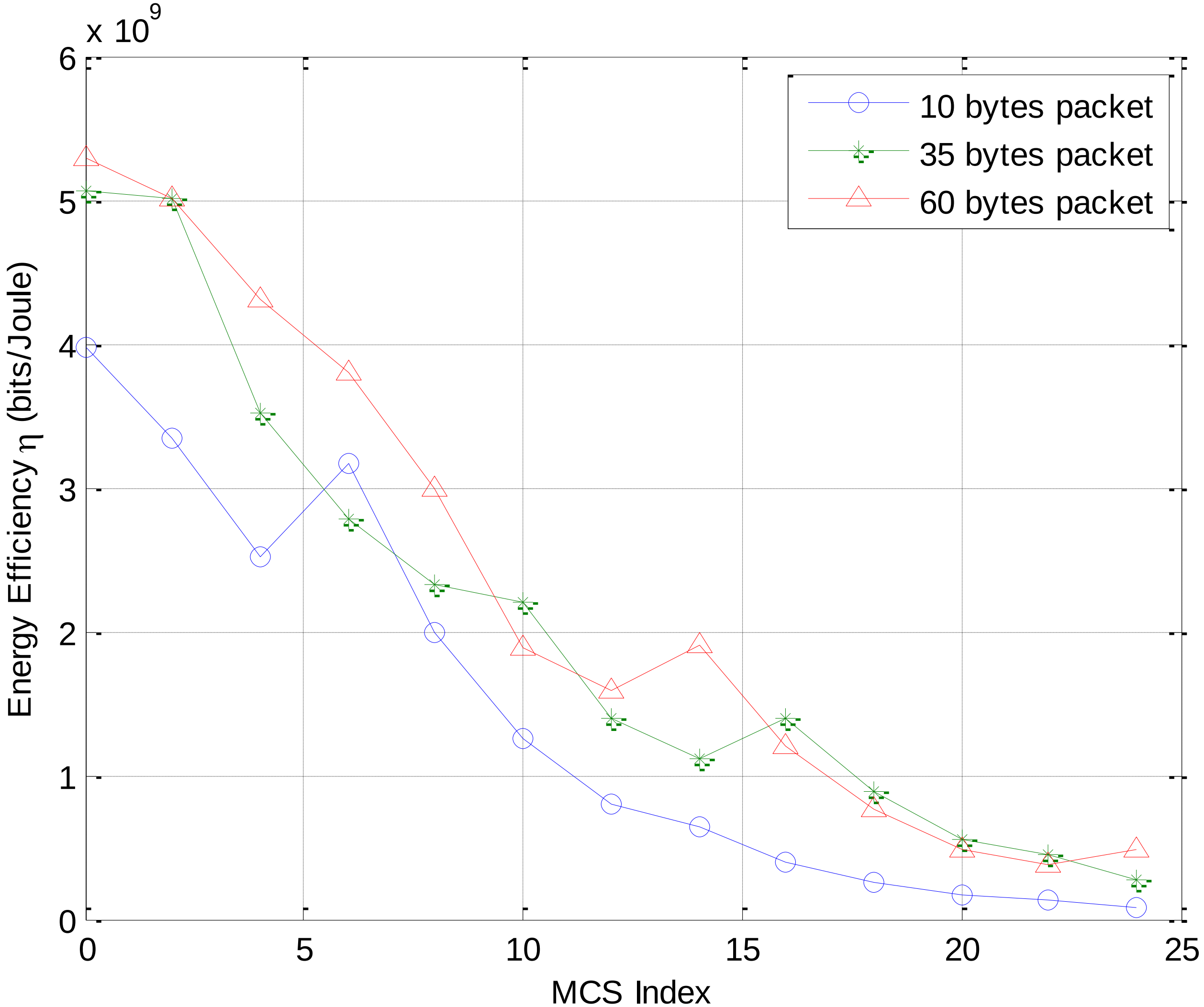


Packet with length of 2 units:
1
2
PRB No.
(MCS_L, PowerL, 2 PRB pairs)
(Success)
#2
#1
Transport Block
Overhead
(MCS_H, PowerH, 1 PRB pair)
(MCS_M, PowerM, 1 PRB pair)
(MCS_L, PowerL, 1 PRB pair)
(Failure)
#0
Transport Block
Overhead
Subframe n
Subframe n+1
Subframe n+2

The Optimal MCS



The Optimal MCS



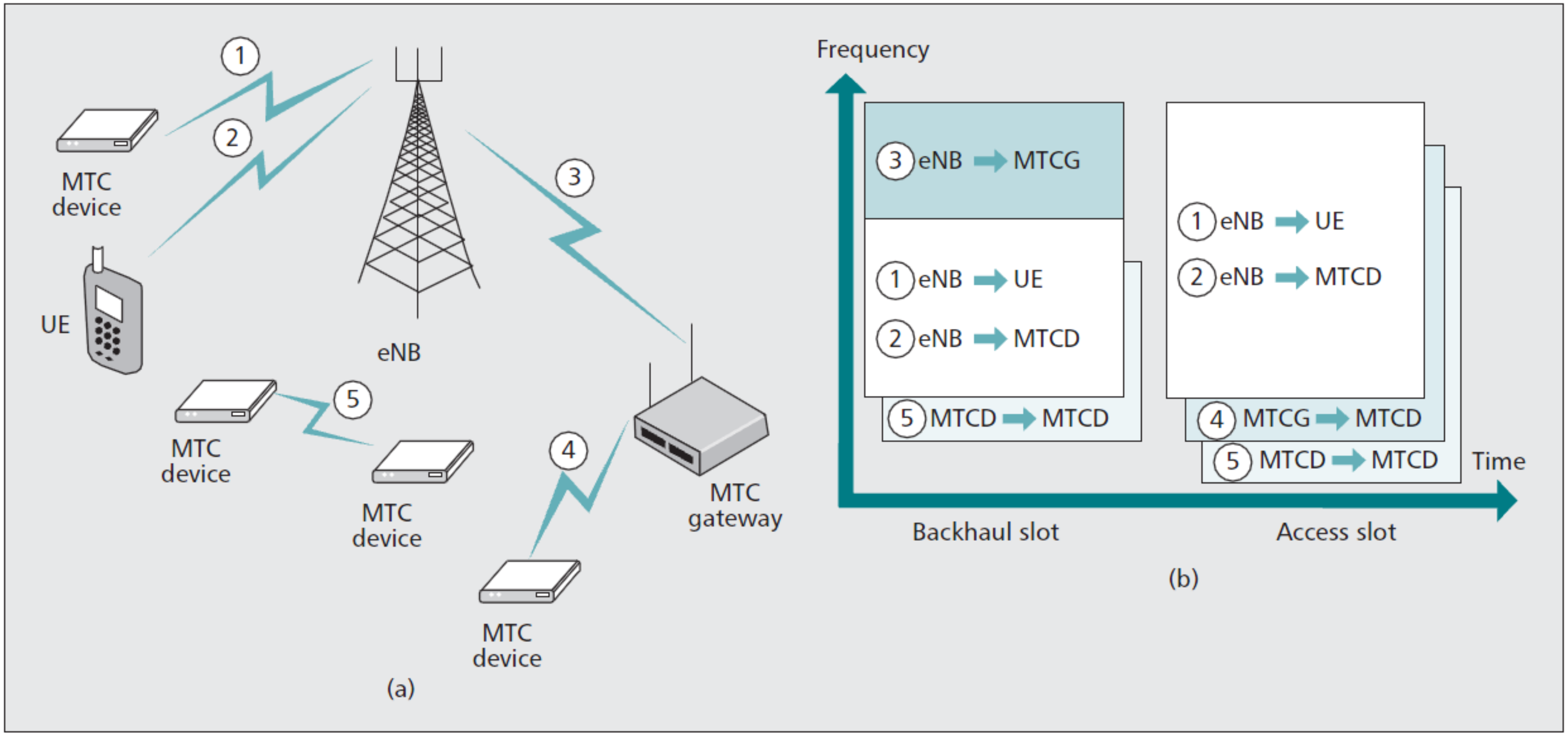
3.6

Coexistence of Machines and Humans

K. Zheng, S. Ou, J. Alonso-Zarate, M. Dohler, F. Liu, H. Zhu,
“Challenges of Massive Access in Highly-Dense LTEChallenges 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:



[© K. Zheng, F. Hu, W. Xiangy, Mischa Dohler, W. Wang, "Radio Resource Allocation in LTE-Advanced Cellular Networks with M2M Communications, " IEEE Communications Magazine, 2012]

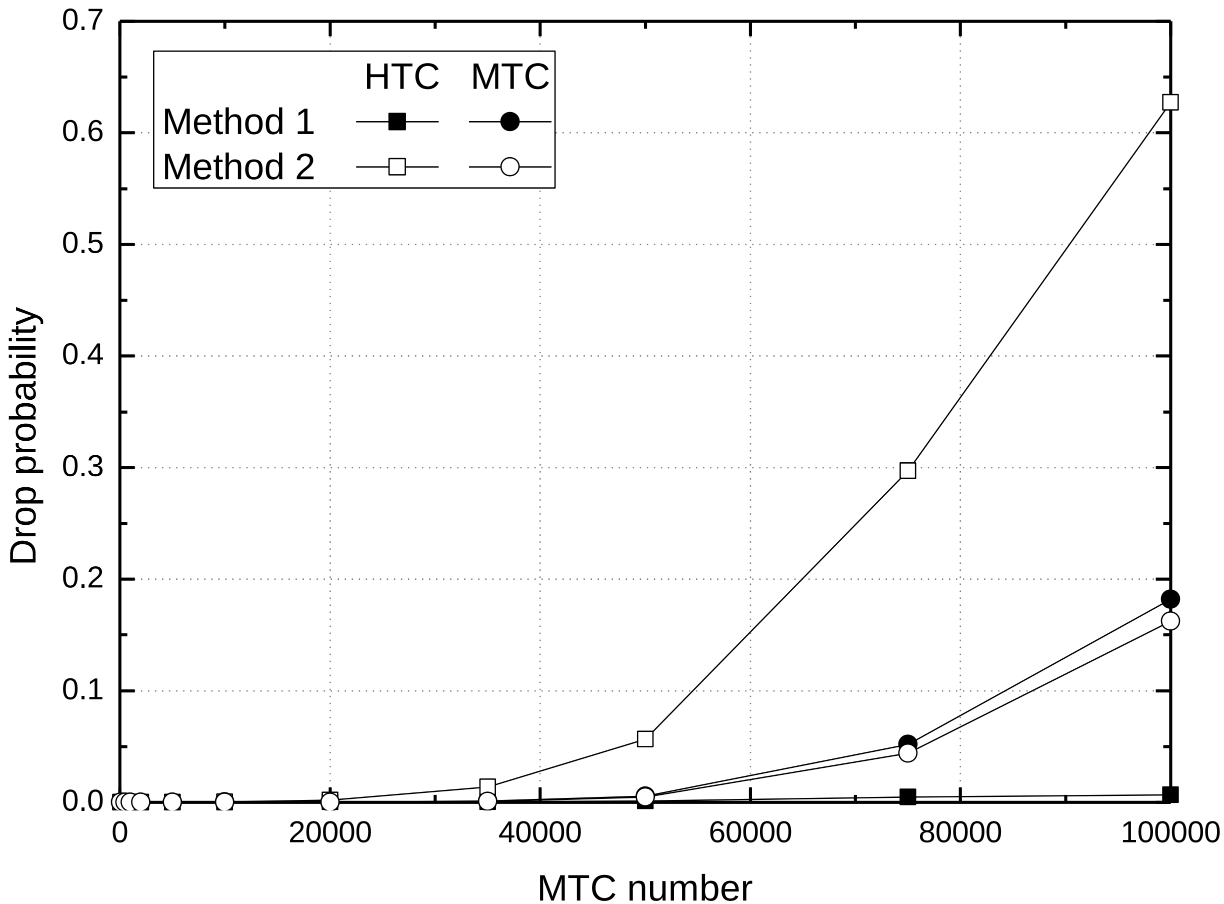
Impact of MTC onto HTC

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

Parameter	Value	
RACH Number	1	
RACH TTI	20ms	
	HTC	MTC
Number	100	100~100,000
Access Frequency Distribution	Poisson	Poisson
Access Frequency [average]	1min	5min/30min
Access Attempt Before Outage	100ms	1000ms

Impact of MTC onto HTC

- Dropping probabilities, duty cycle and delay for 30min access case:

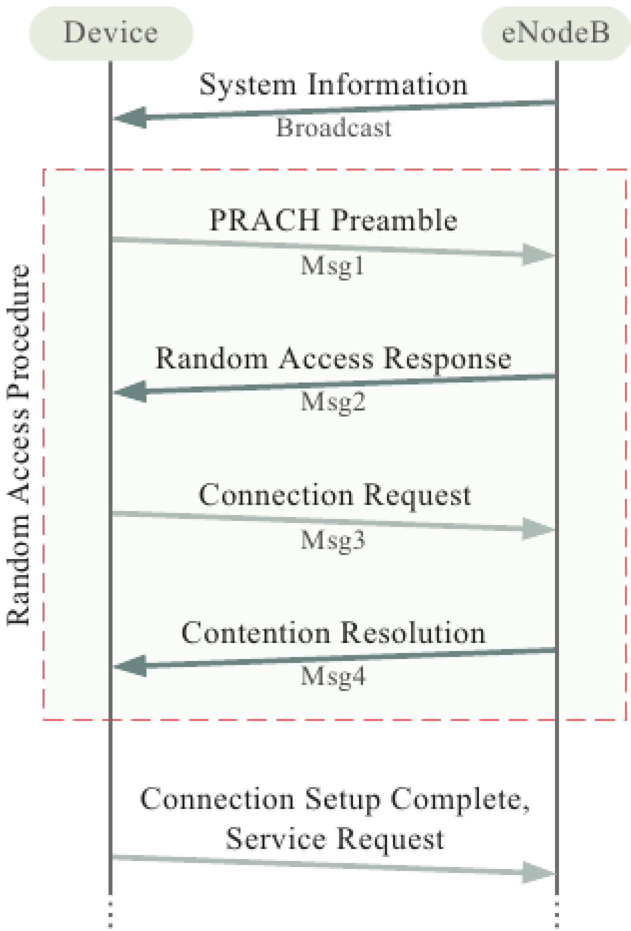


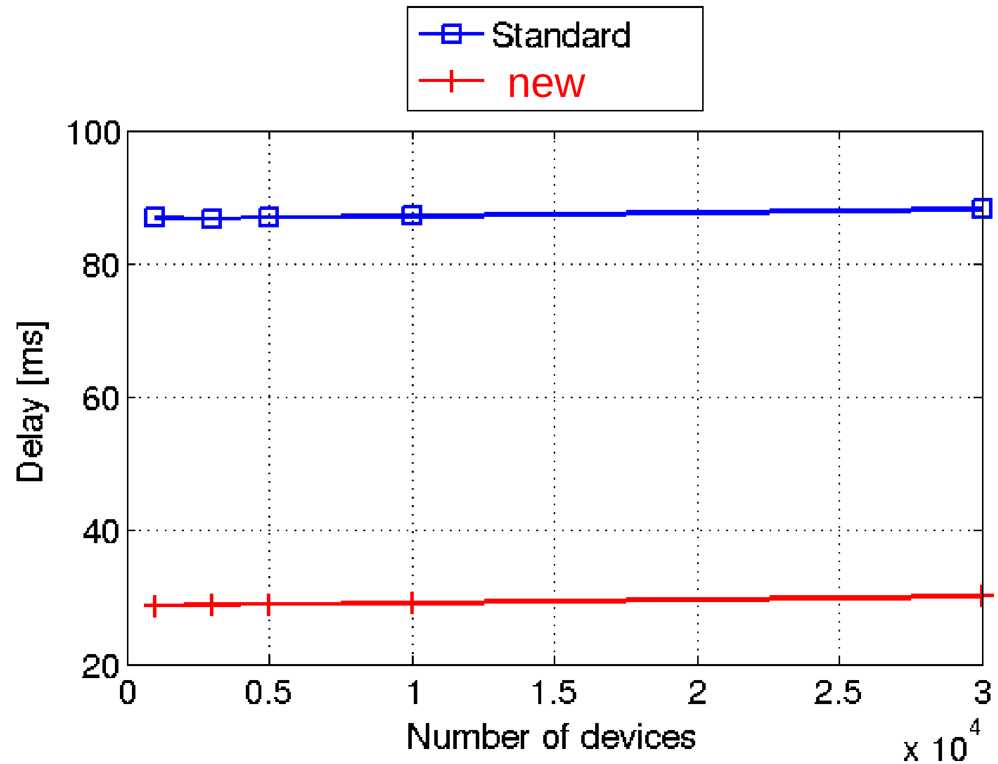
© Kan Zheng, Jesus Alonso-Zarate, and Mischa Dohler

3.7

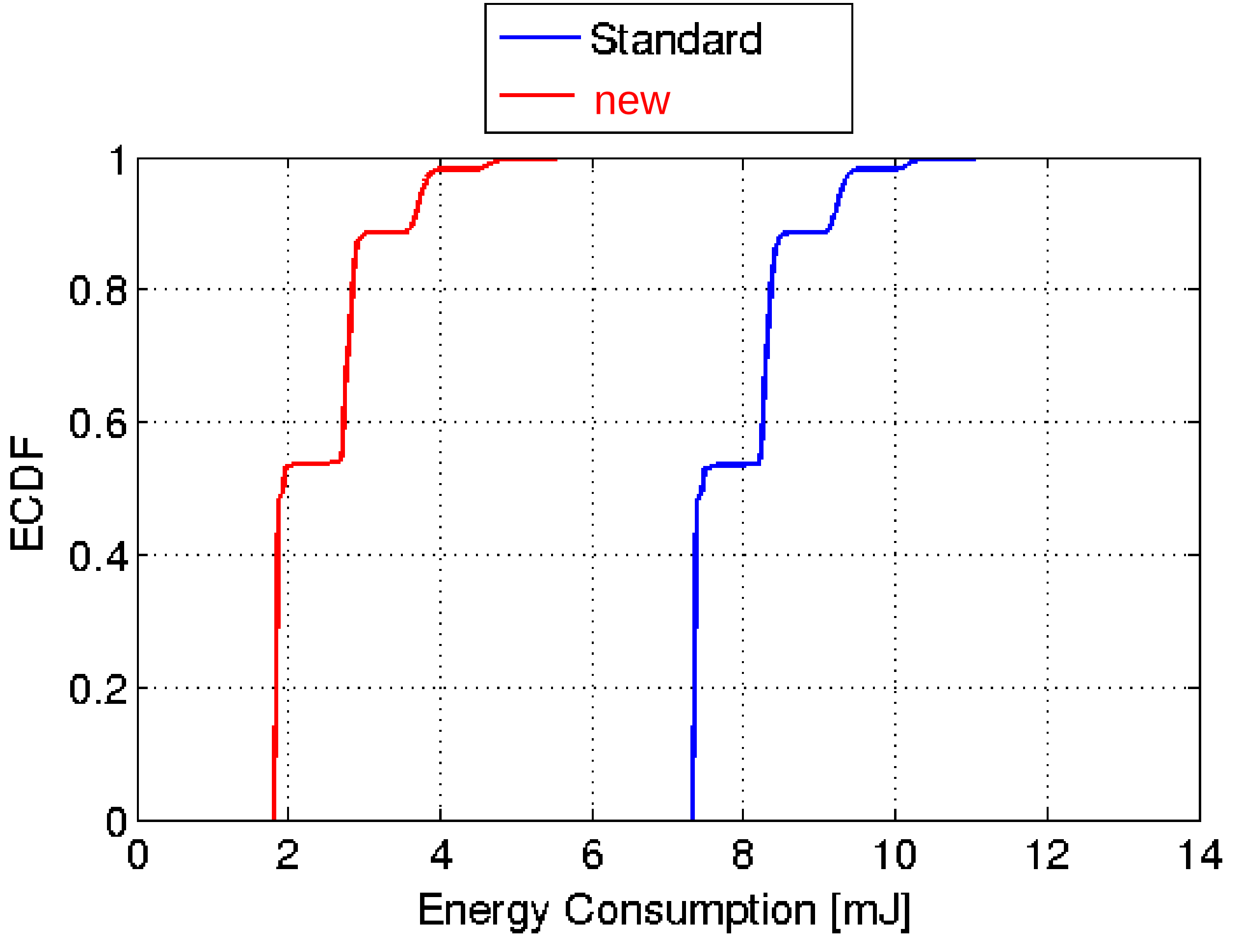
Reducing MTC Access Delay

Improving RACH Procedure





Improving RACH Procedure



© Massimo Condoluci, Mischa Dohler, Antonella Molinaro, Giuseppe Araniti

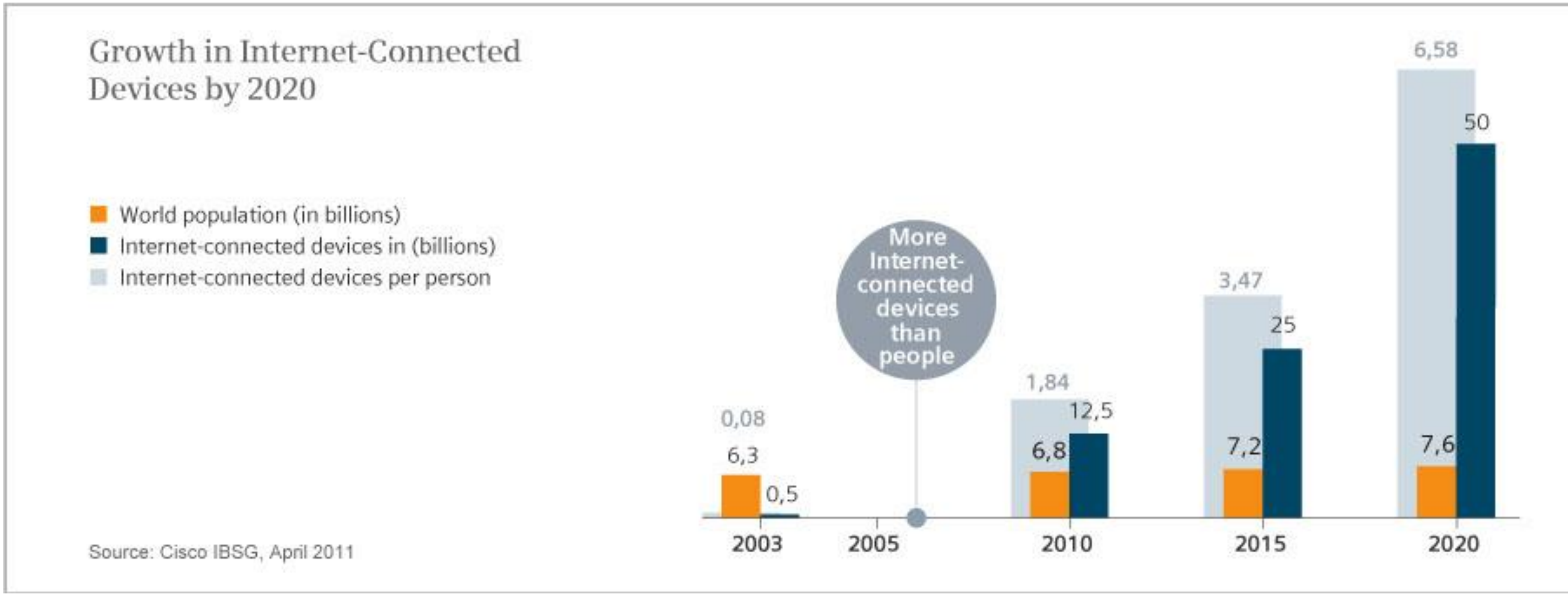
4

Business Opportunities

4.1

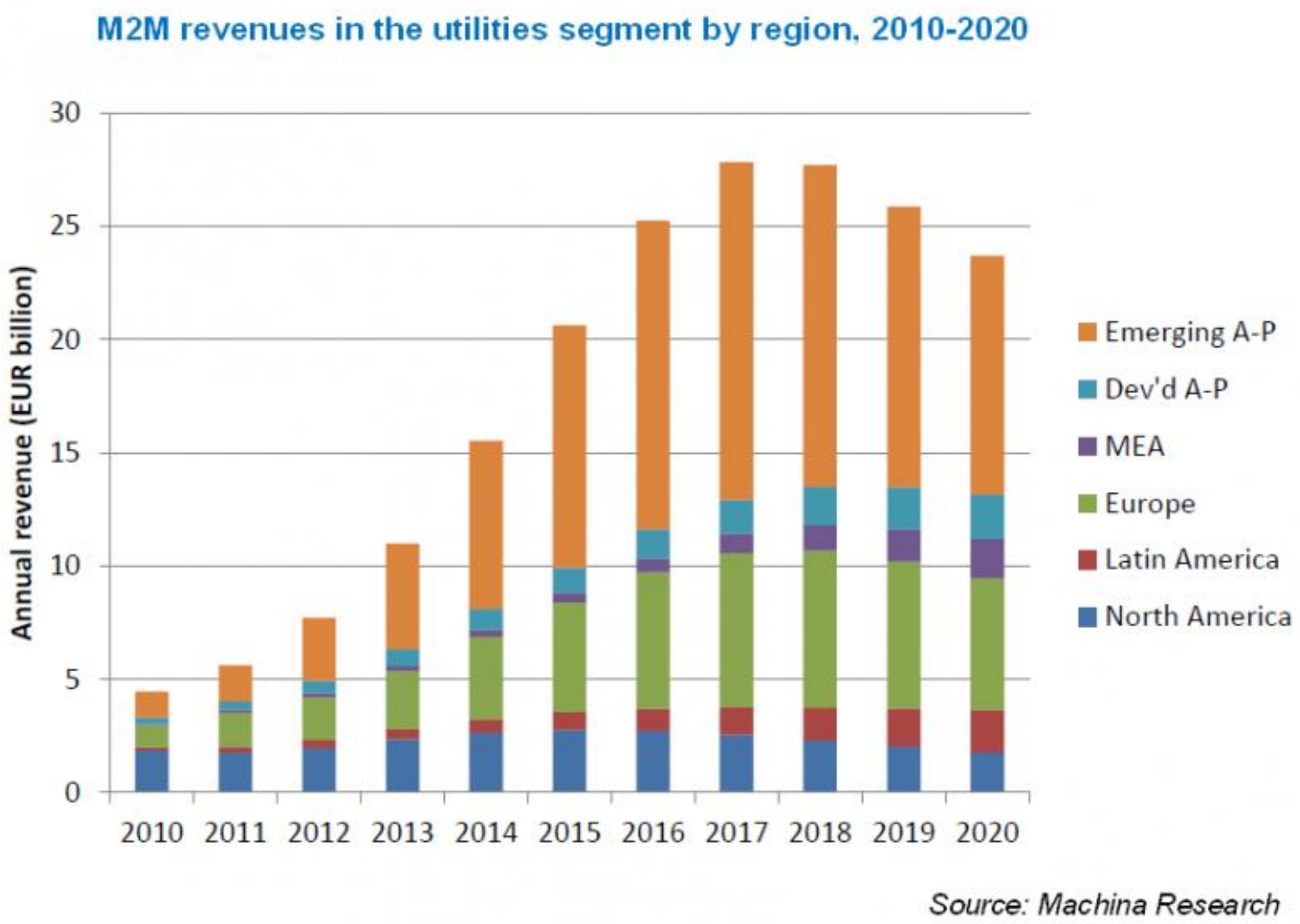
M2M Connectivity

Growing IoT-Enabled Devices



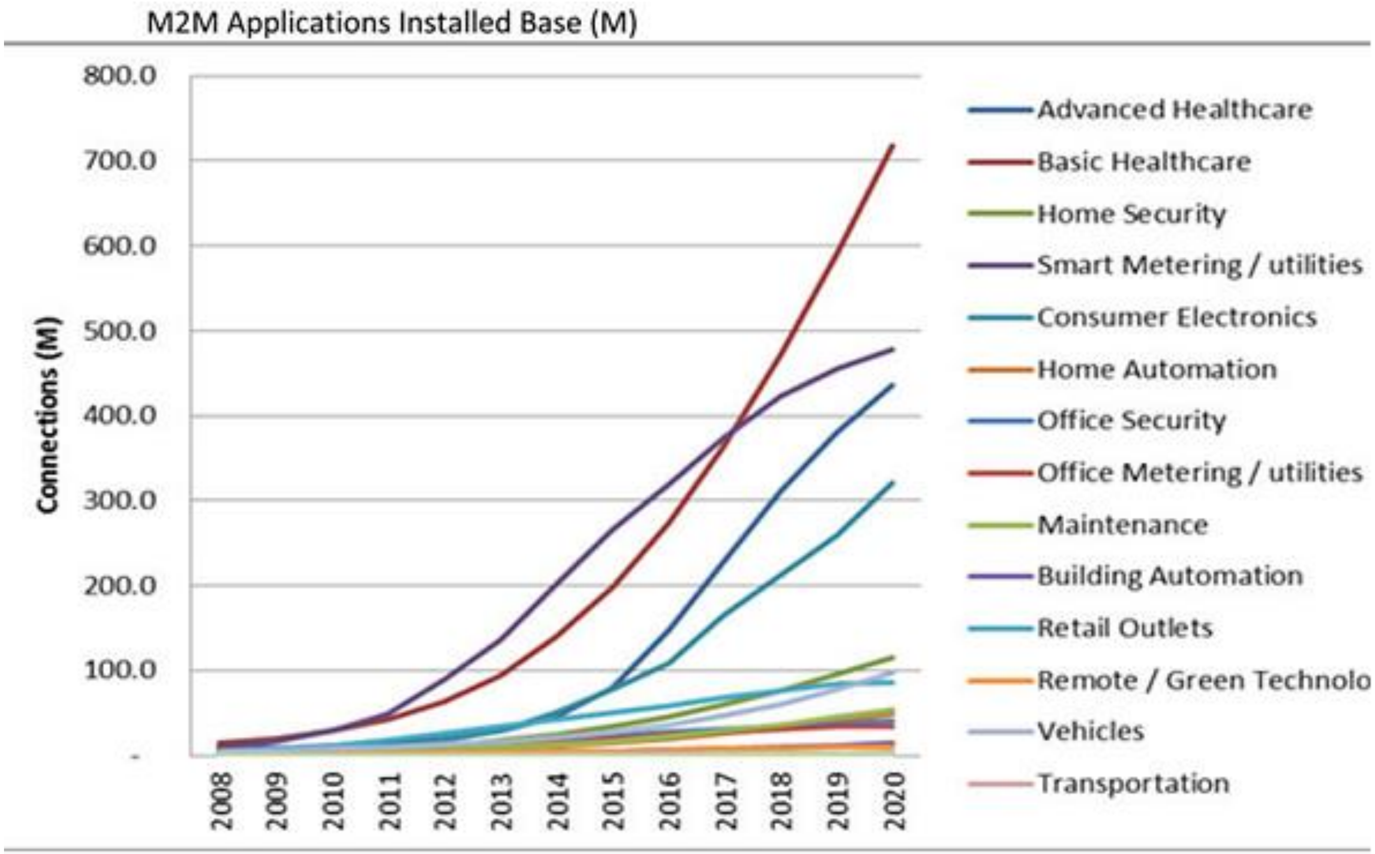
© CISCO, taken from http://ipcarrier.blogspot.co.uk/2013/10/internet-of-things-forecasts-vary-by.html

M2M by Markets



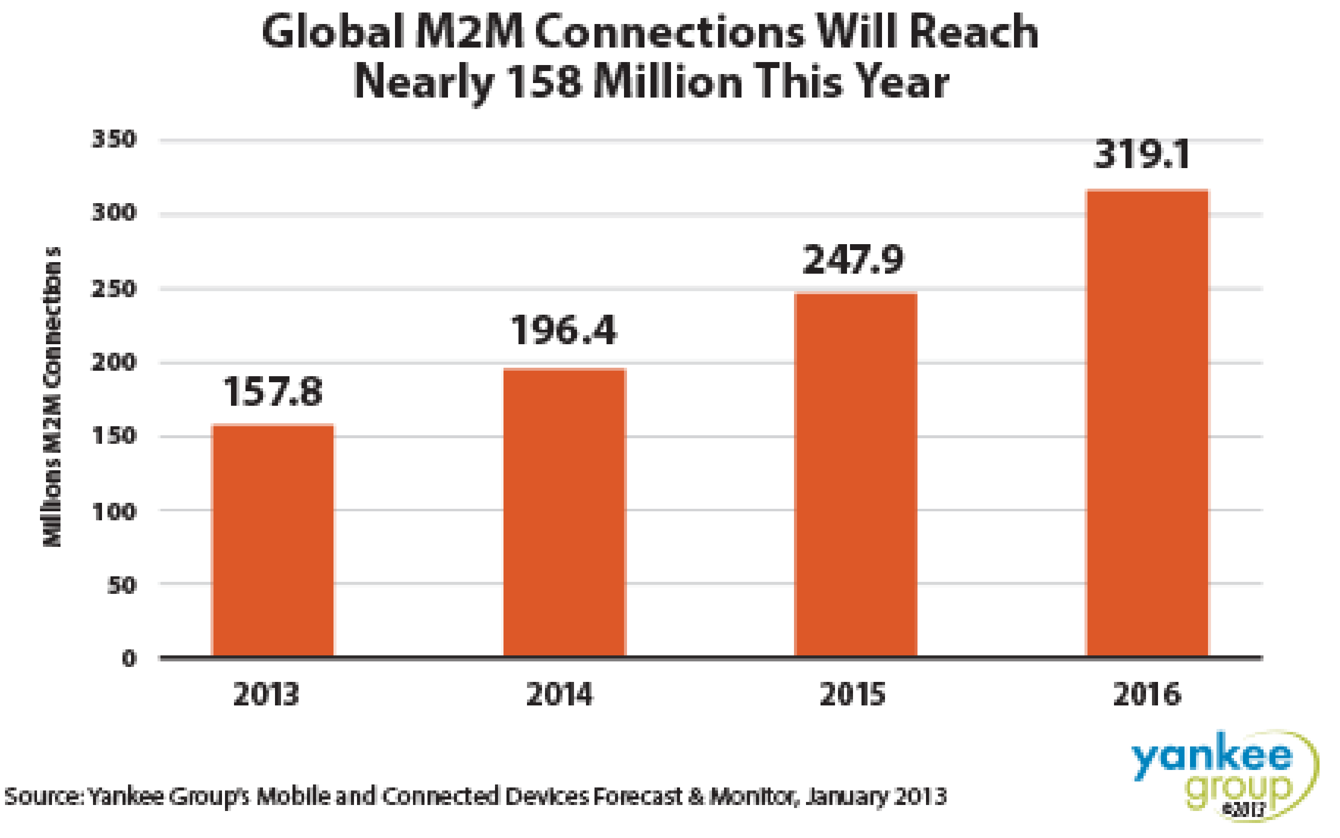
© Machina Research, taken from http://postscapes.com/companies/r/87-machina-research

M2M by Industrial Sector



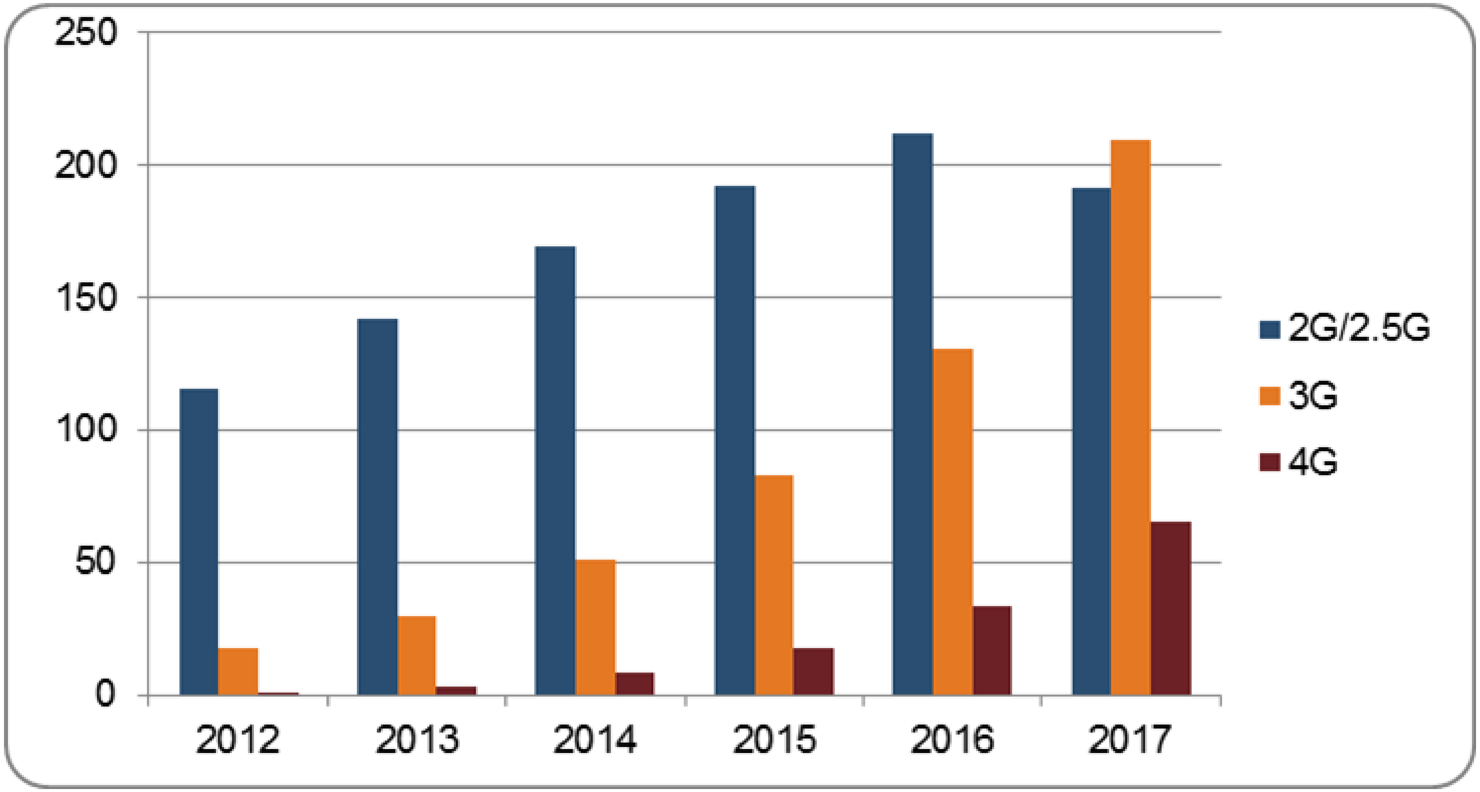
© Strategy Analytics M2M; taken from http://m2mworldnews.com/2013/07/19/41008-verizon-partner-program-highlights-increased-mobile-operator-focus-on-mhealth-solutions/

Cellular M2M Connectivity



© Yankee Group, taken from http://www.telecomlead.com/enterprise-communications/mwc-2014-deutsche-telekom-demo-m2m-solutions-smart-city-64712/

Composition of Cellular



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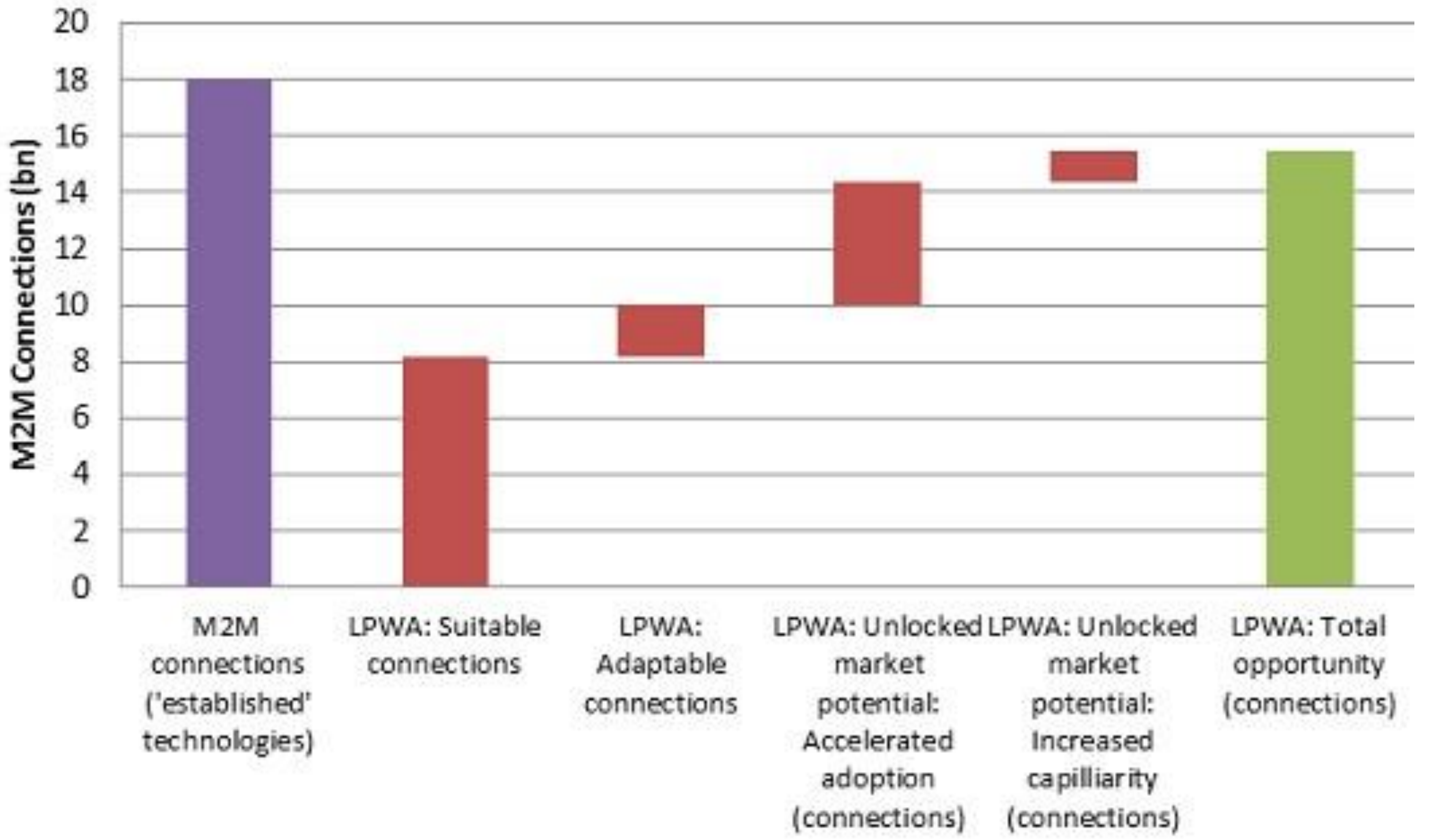
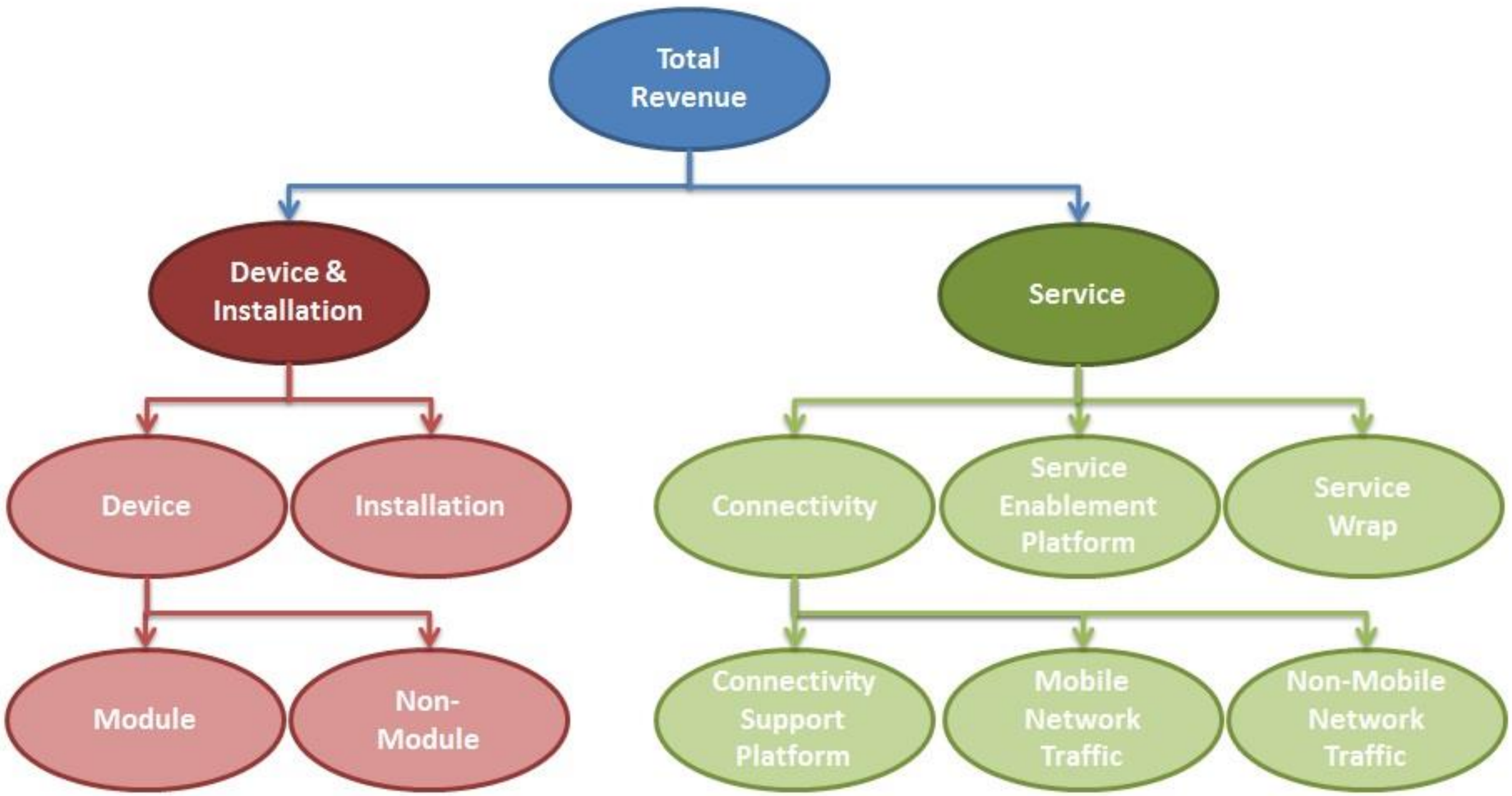
Low Power Wide Area Connectivity



© Machina Research, taken from http://www.fiercewireless.com/story/machina-research-how-low-power-wide-area-wireless-networks-may-transform-m2/2013-06-25

4.2
Revenue Opportunities

Revenue Forecast Metrics

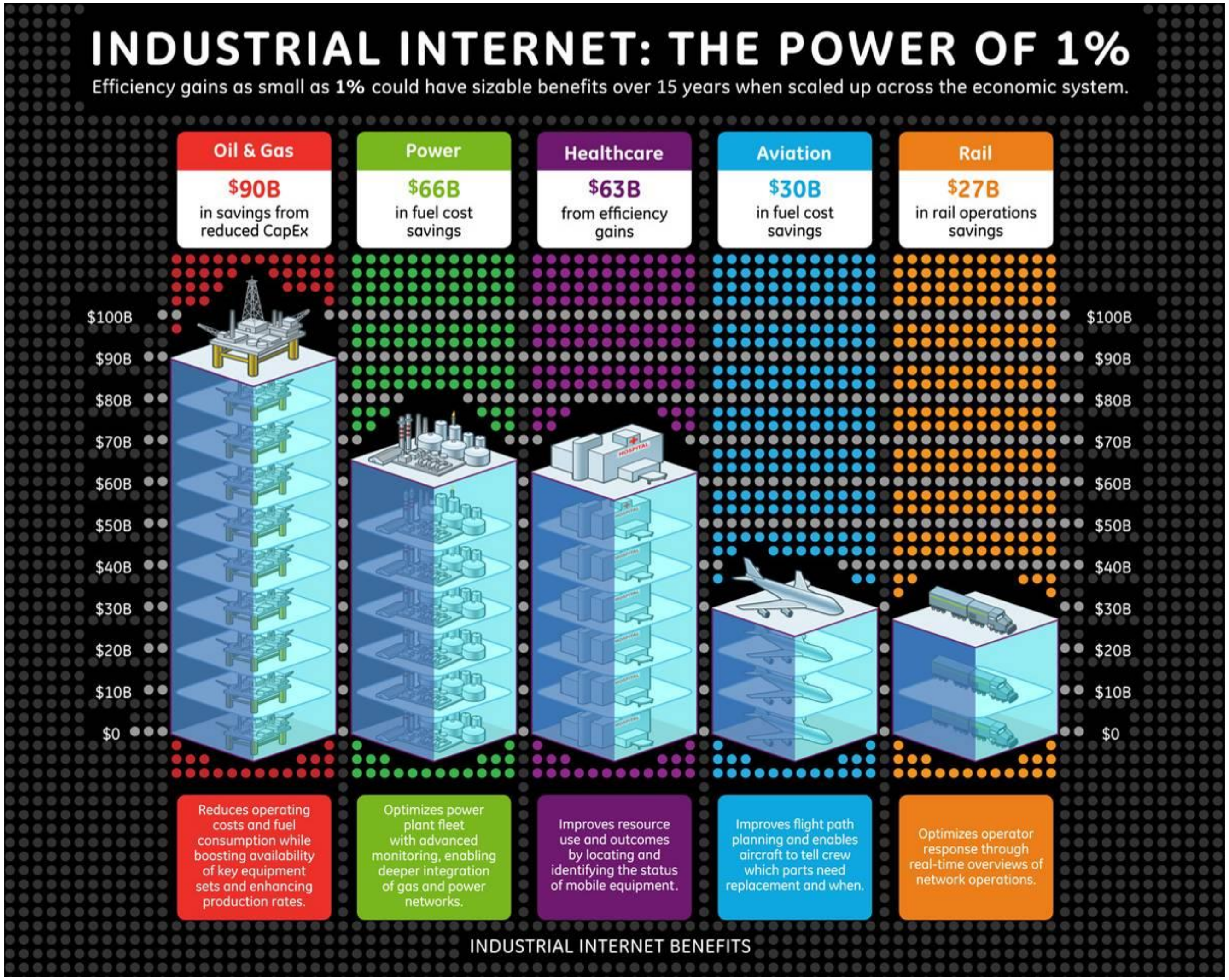


© Machina Research; taken from https://machinaresearch.com/what-we-do/about-the-forecast-database/

A growing $bn-Market

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

Enormous Gains in Industries

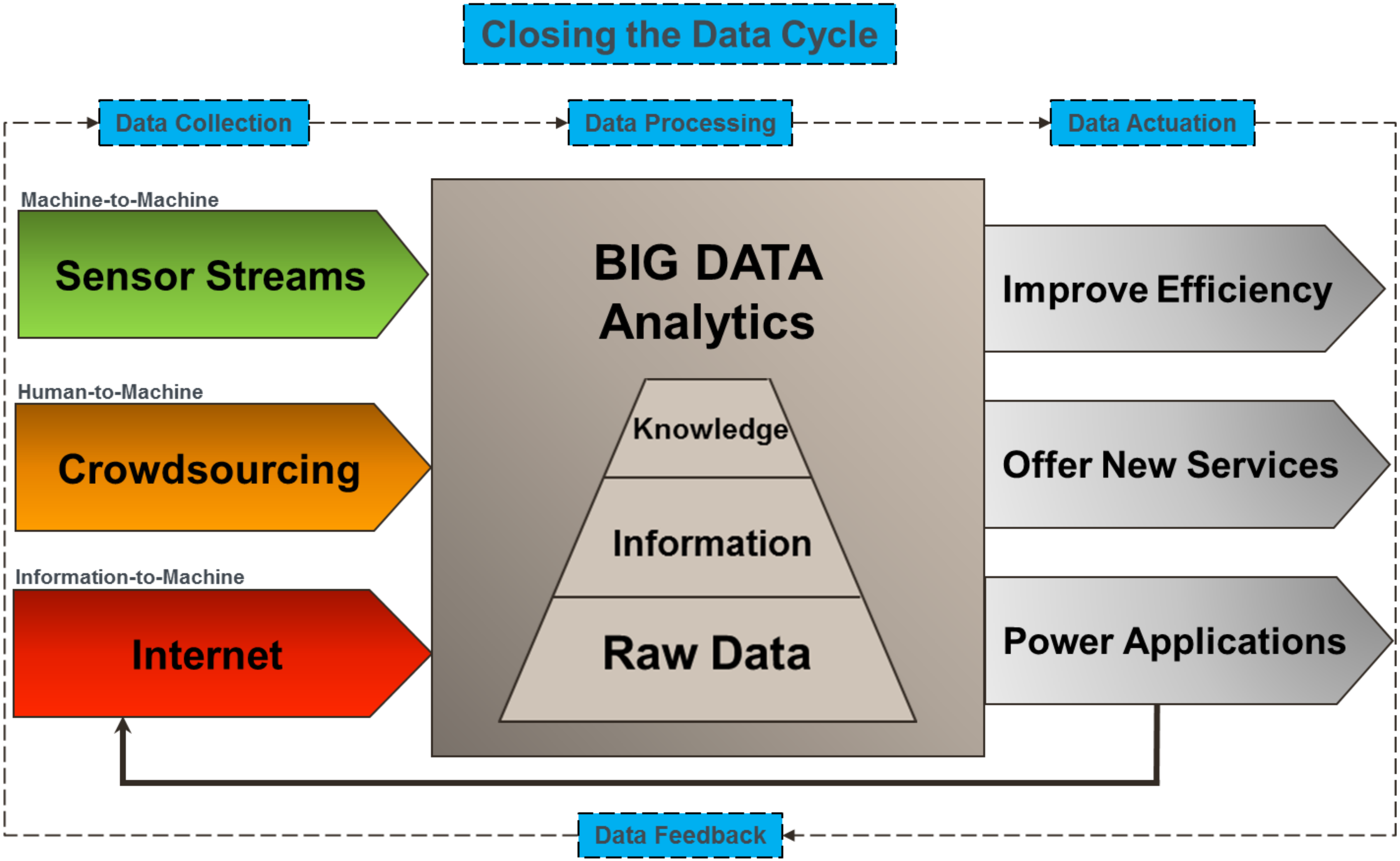


http://www.gereports.com/new_industrial_internet_service_technologies_from_ge_could_eliminate_150_billion_in_waste/

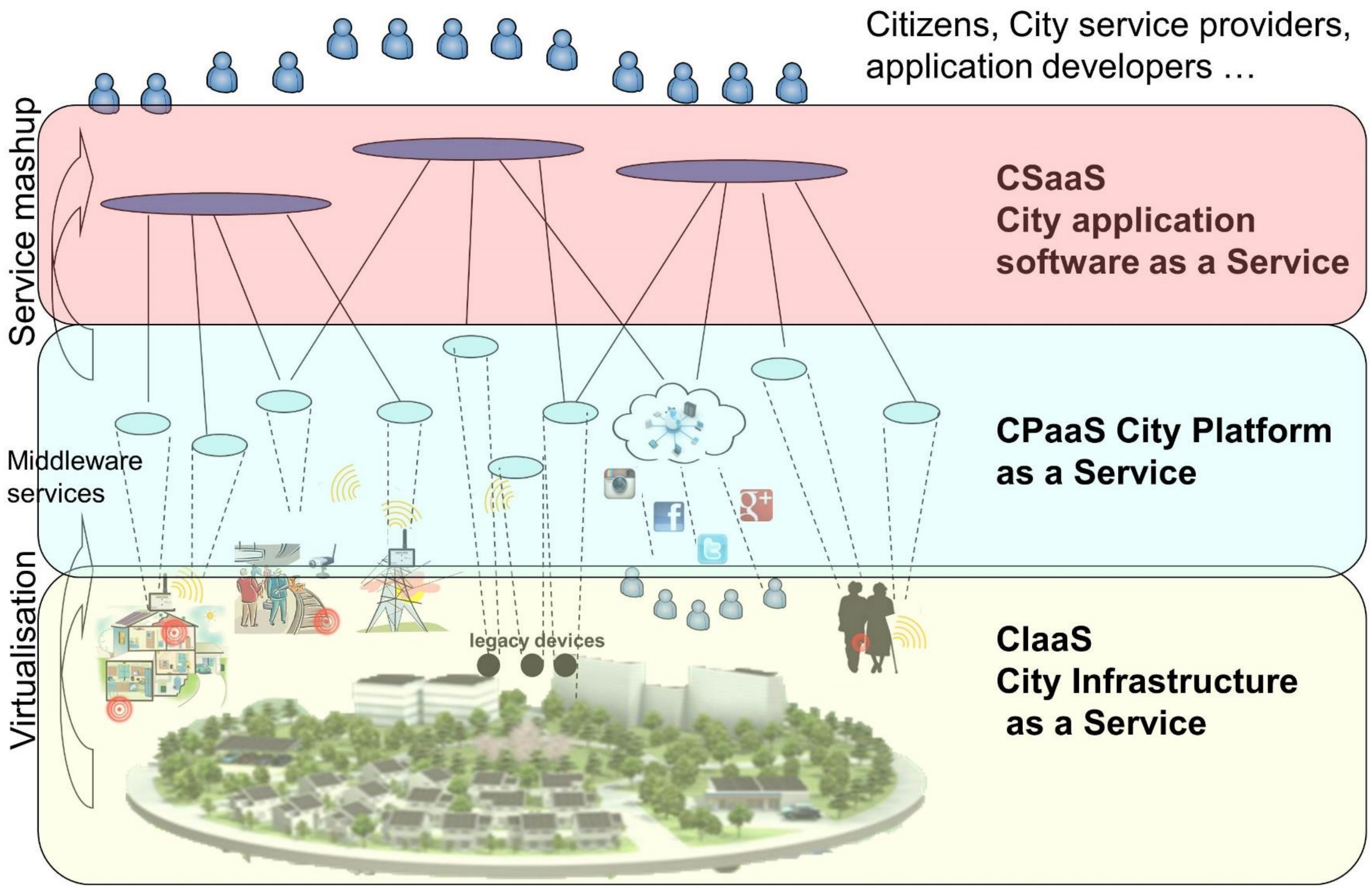
4.3

IoT, Big Data & The Cloud

Closing the Big Data Cycle



IoT/M2M in The Cloud



© http://clout-project.eu.

5
Conclusions

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

Source: http://www.claropartners.com/the-emerging-iot-business-landscape-insights-from-the-iot-world-forum-2/

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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