M2M in Smart Grid & Smart Cities

Technologies, Standards, and Applications

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Machine-to-Machine Vision(s)

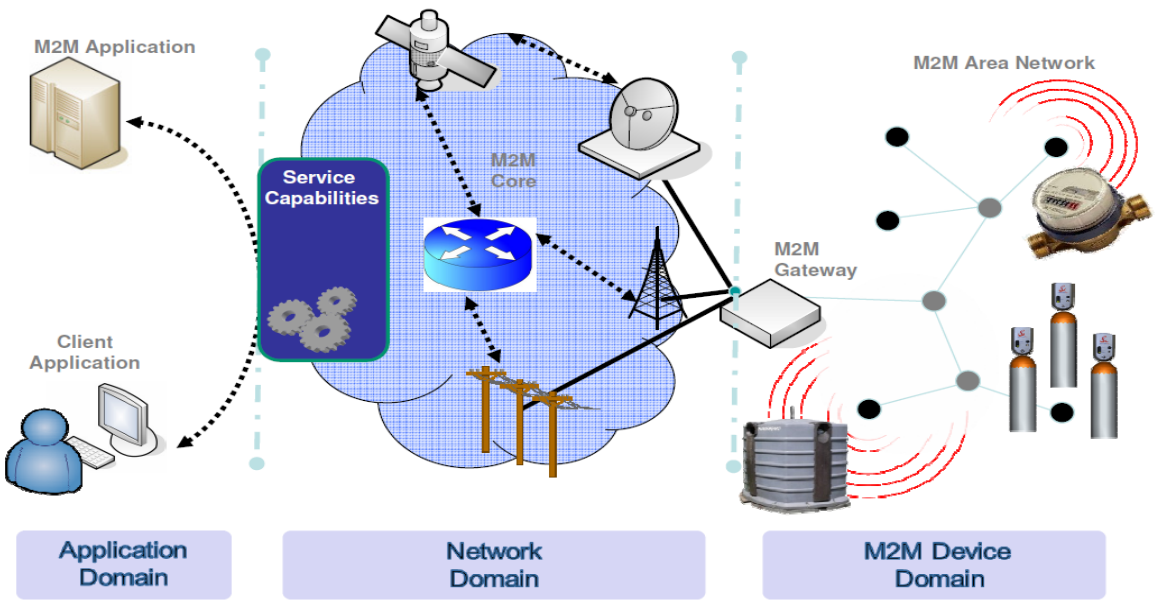
- Different Visions of M2M:
  - WWRF [2007-10]: **7 Trillion** devices by 2017
  - Market Study [2009]: **50 Billion** devices by 2010
  - ABI Research [2010]: **225 Million** cellular M2M by 2014

- Numbers differ significantly, with WWRF prediction implying:
  - ... 7,000,000,000,000 (7 Trillion) devices by 2017 ...
  - ... are powered by (in average) AA battery of approx 15kJ ...
  - ... this requires 100,000,000,000,000,000 (100 Quadrillion) Joules ...

- Sanity Check:
  - 1GW nuclear power plant needs to run for more than 3 years to sustain this
  - 1000 devices per person in average at any time
  - **It is important to get this vision and these numbers right!**

Machine-to-Machine Definition

- **Machine-to-Machine (M2M) means no human intervention whilst devices are communicating end-to-end.**
- This leads to some core M2M system characteristics:
  - support of a huge amount of nodes
  - seamless domain inter-operability
  - **autonomous operation**
  - **self-organization**
  - **power efficiency**
  - **reliability**
  - etc, etc



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Overview of Tutorial

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2. Academic WSN Research
3. Proprietary M2M Solutions
4. Standardization Efforts Pertinent to M2M

3. Cellular M2M

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2. M2M in Current Cellular Networks
3. M2M Cellular Standardization Activities
4. Cellular M2M Business

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1

Overview of M2M

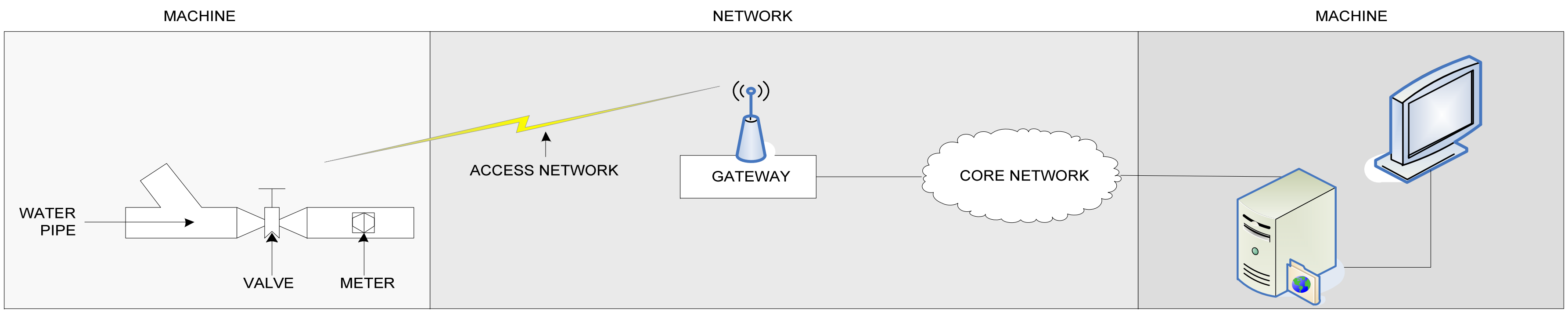
1.1
A Quick Introduction

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

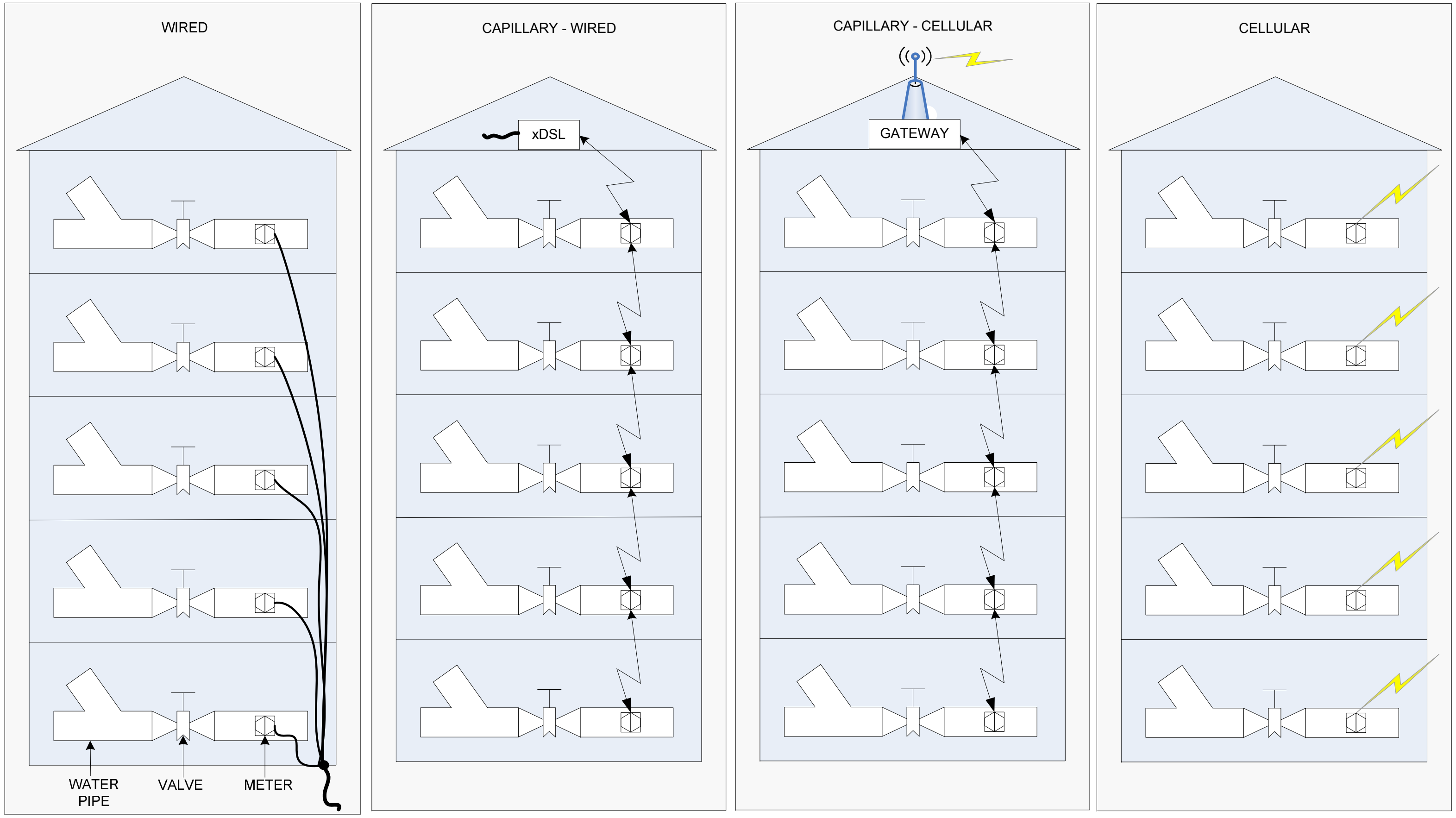
M2M End-to-End Network

- **Access Network** – connecting the sensors & actuators:
  - “wired” (cable, xDSL, optical, etc.)
  - wireless cellular (GSM, GPRS, EDGE, 3G, LTE-M, WiMAX, etc.)
  - wireless “capillary”/short-range (WLAN, ZigBee, IEEE 802.15.4x, etc.)
- **Gateway** – connecting access and backhaul/core networks:
  - network address translation
  - packet (de)fragmentation; etc.
- **Core/Backend/Internet Network** – connecting to computer system:
  - IPv6-enabled Internet



M2M Access Networks [1/2]

- Connecting your smart meters through 4 example access methods:

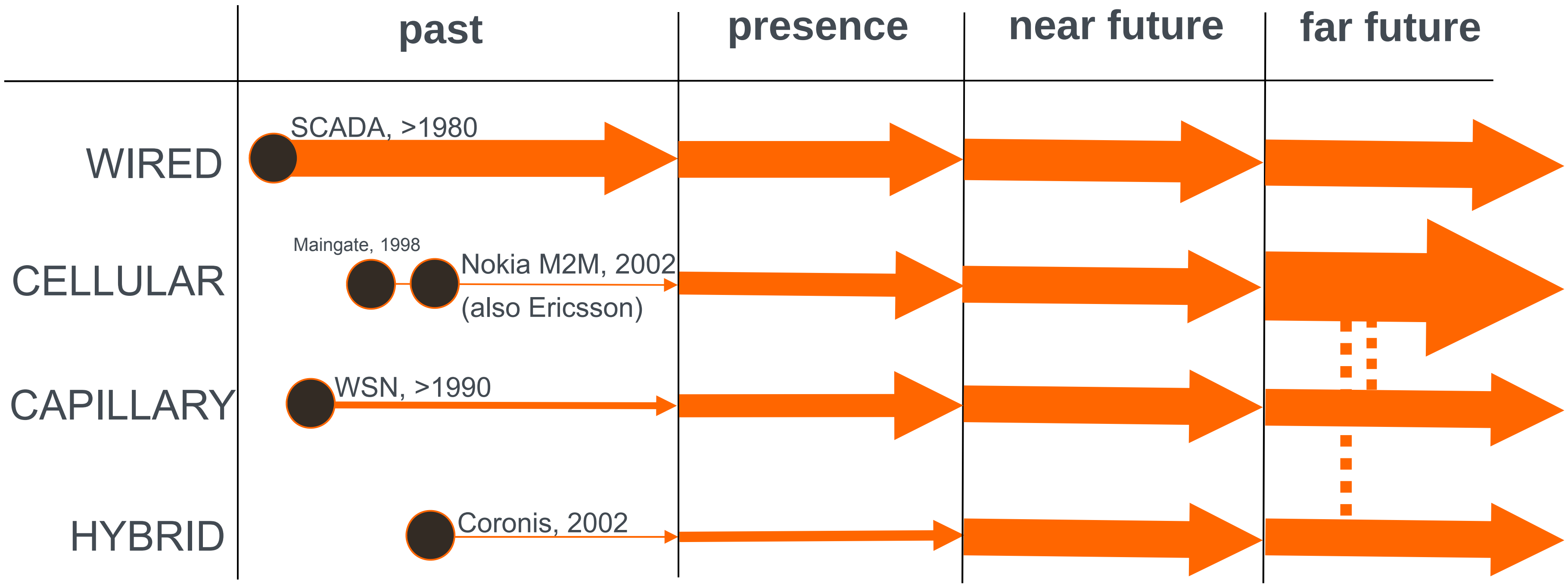


M2M Access Networks [2/2]

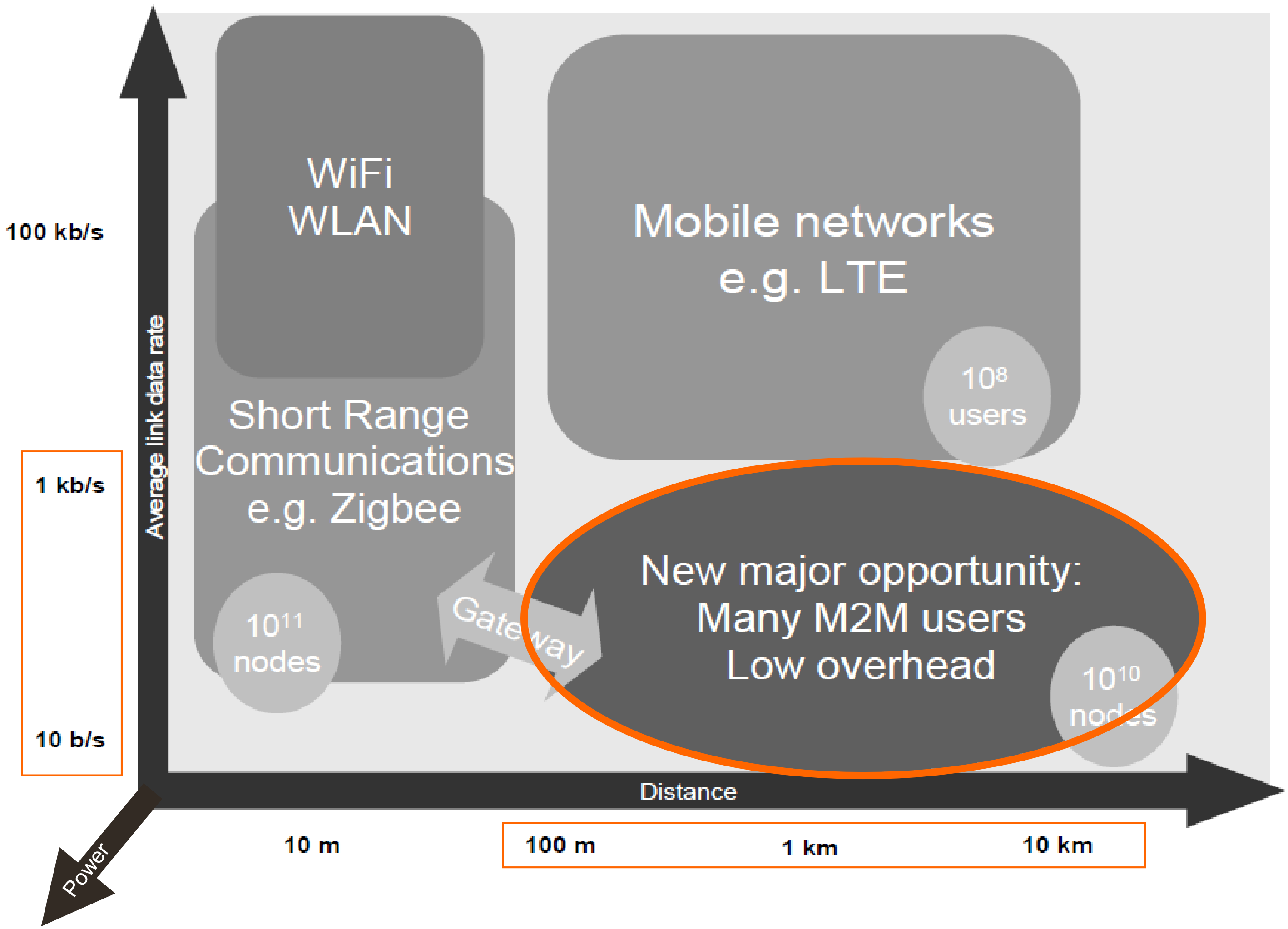
- **Wired Solution** – dedicated cabling between sensor - gateway:
  - pros: very, very reliable; very high rates, little delay, secure, cheap to maintain
  - cons: very expensive to roll out, not scalable
- **Wireless Cellular Solution** – dedicated cellular link:
  - pros: excellent coverage, mobility, roaming, generally secure
  - cons: expensive rollout, not cheap to maintain, not power efficient, delays
- **Wireless Capillary Solution** – shared short-range link/network:
  - pros: cheap to roll out, generally scalable, low power
  - cons: not cheap to maintain, poor range, low rates, weaker security, large delays
- **(Wireless) Hybrid Solution** – short-range until cellular aggregator:
  - pros: best tradeoff between price, range, rate, power, etc.
  - cons: not a homogenous and everything-fits-all solution

Timeline of M2M

- **Origin** of term "Machine-to-Machine":
  - Nokia M2M Platform Family [2002] = Nokia M2M Gateway software + Nokia 31 GSM Connectivity Terminal + Nokia M2M Application Develop. Kit (ADK)



Novelty of Wireless M2M



Challenge of Wireless M2M Today

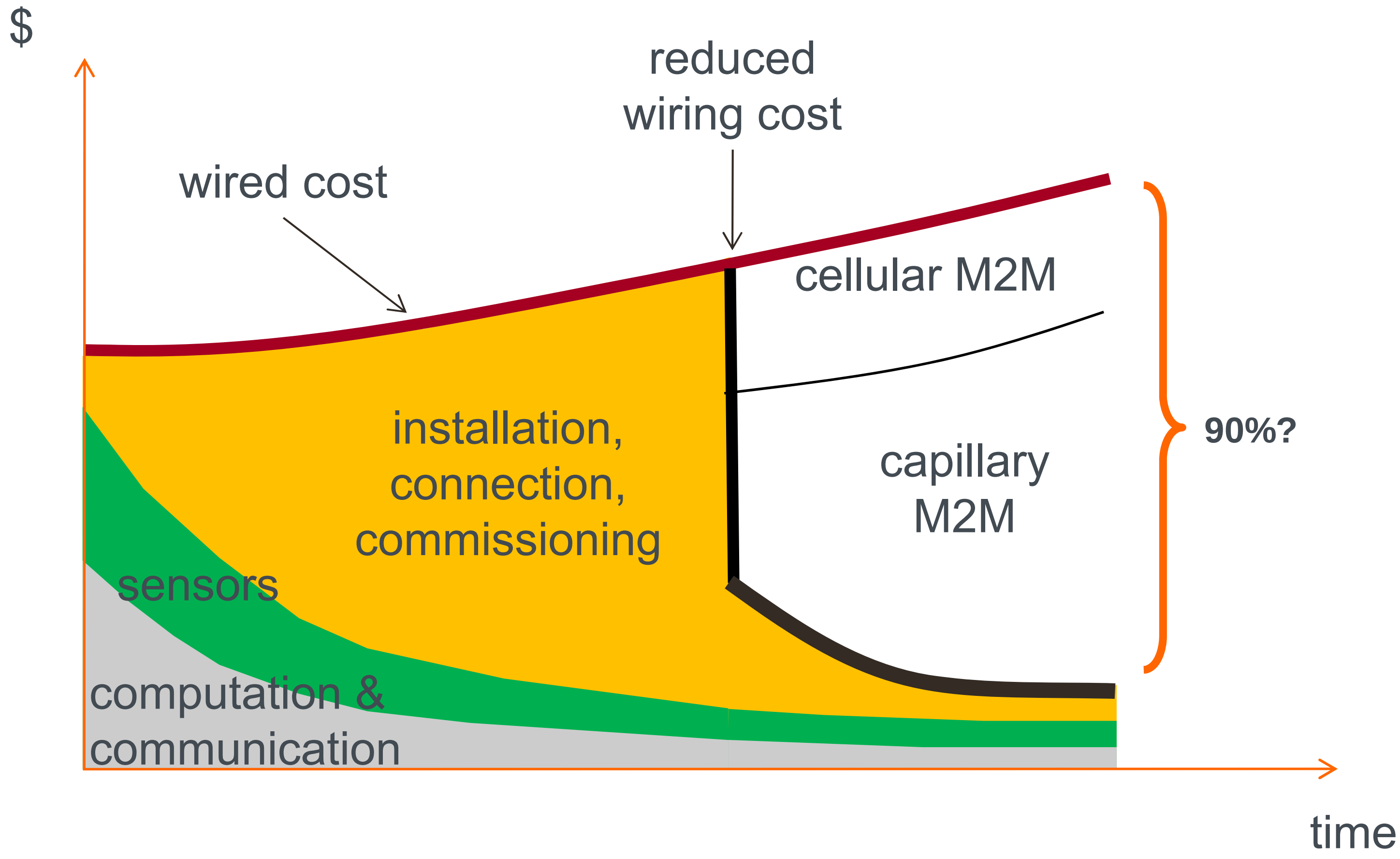
- Challenges for **capillary** community:
  - **reliability:** despite license-exempt bands
  - **range:** multihop/mesh is a must
  - **delays**: minimize end-to-end delay (due to multihop)
  - **security**: suitable security over multiple hops
  - **standards**: lack of standardization across layers

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

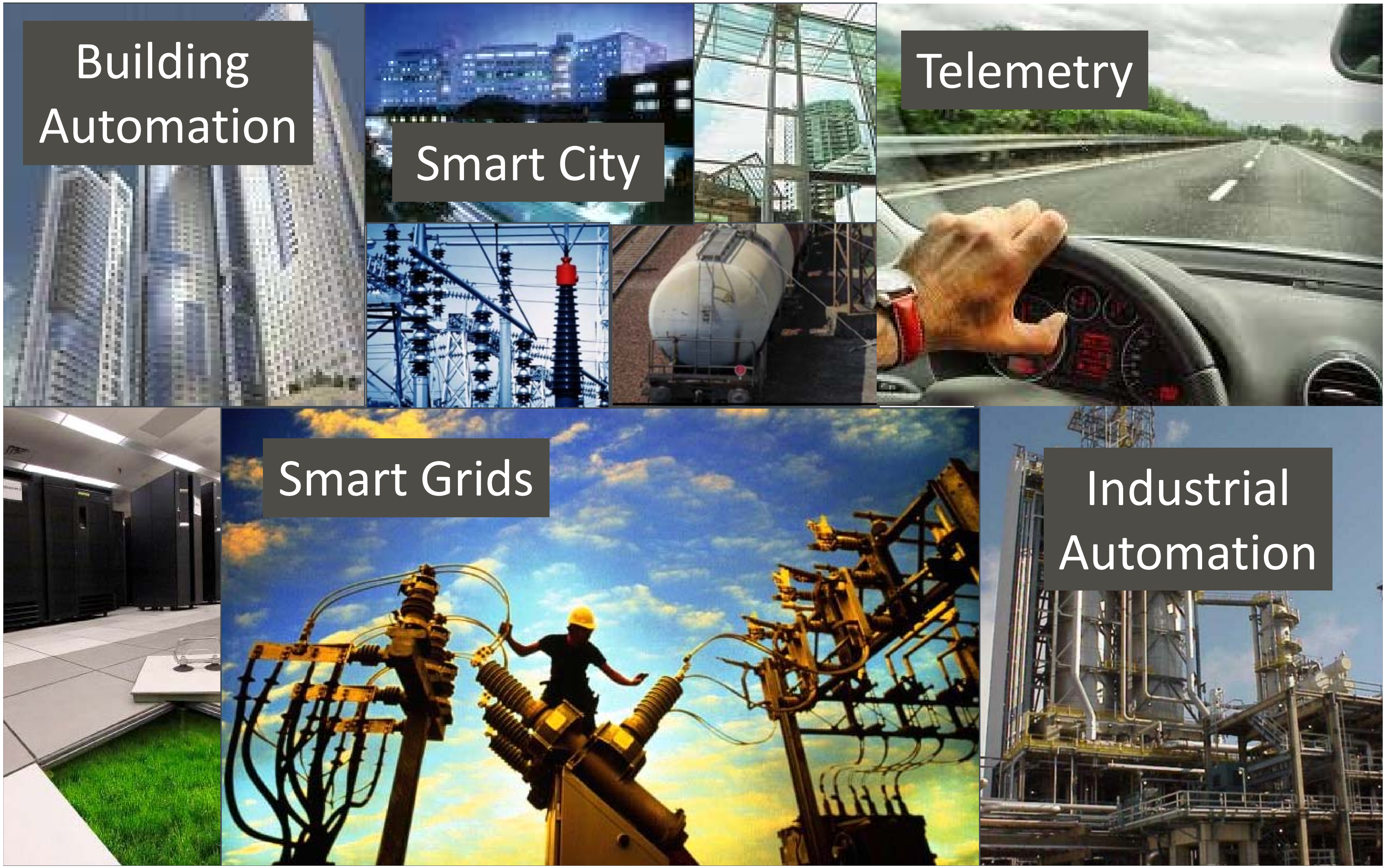
- Is this possible?

1.2
ROI, Markets & Cellular Market Shares

ROI - Cost of Wireless M2M



Popular M2M Markets



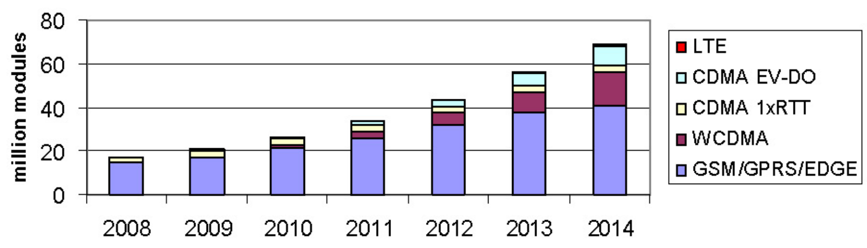
Growing Cellular M2M Market

© B. Tournier, Sagemcom, EXALTED Kick-off Meeting, Barcelona, 14 Sept 2010

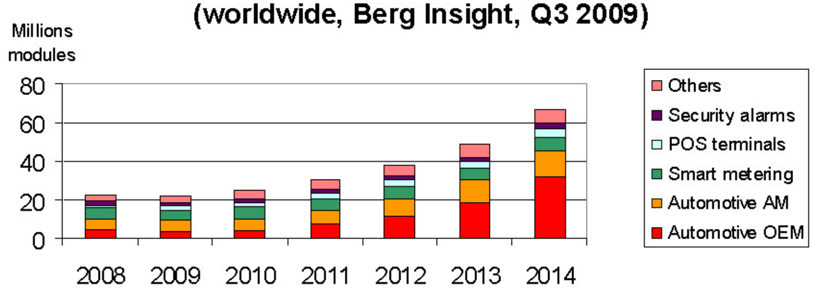
- Predictions on M2M LTE:
  - minor market until 2014
  - 2.5% (1.7M) of total M2M market
  - LTE module = twice 3G cost

- Predictions on Automotive:
  - primary market on M2M cellular
  - unique (short-term) market for M2M LTE

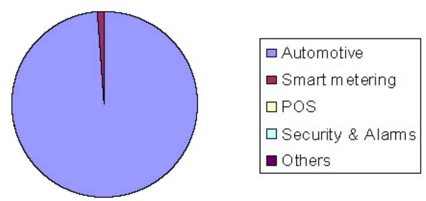
Worldwide Cellular M2M Module Shipments by Air Interface (ABI Research, Q3 2009)



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

- 2011 will be remembered for:
  - running out of addressing space → a few months ago we run out of IPv4 addresses
  - running out of living space → as of a few days ago, we are 7bn people

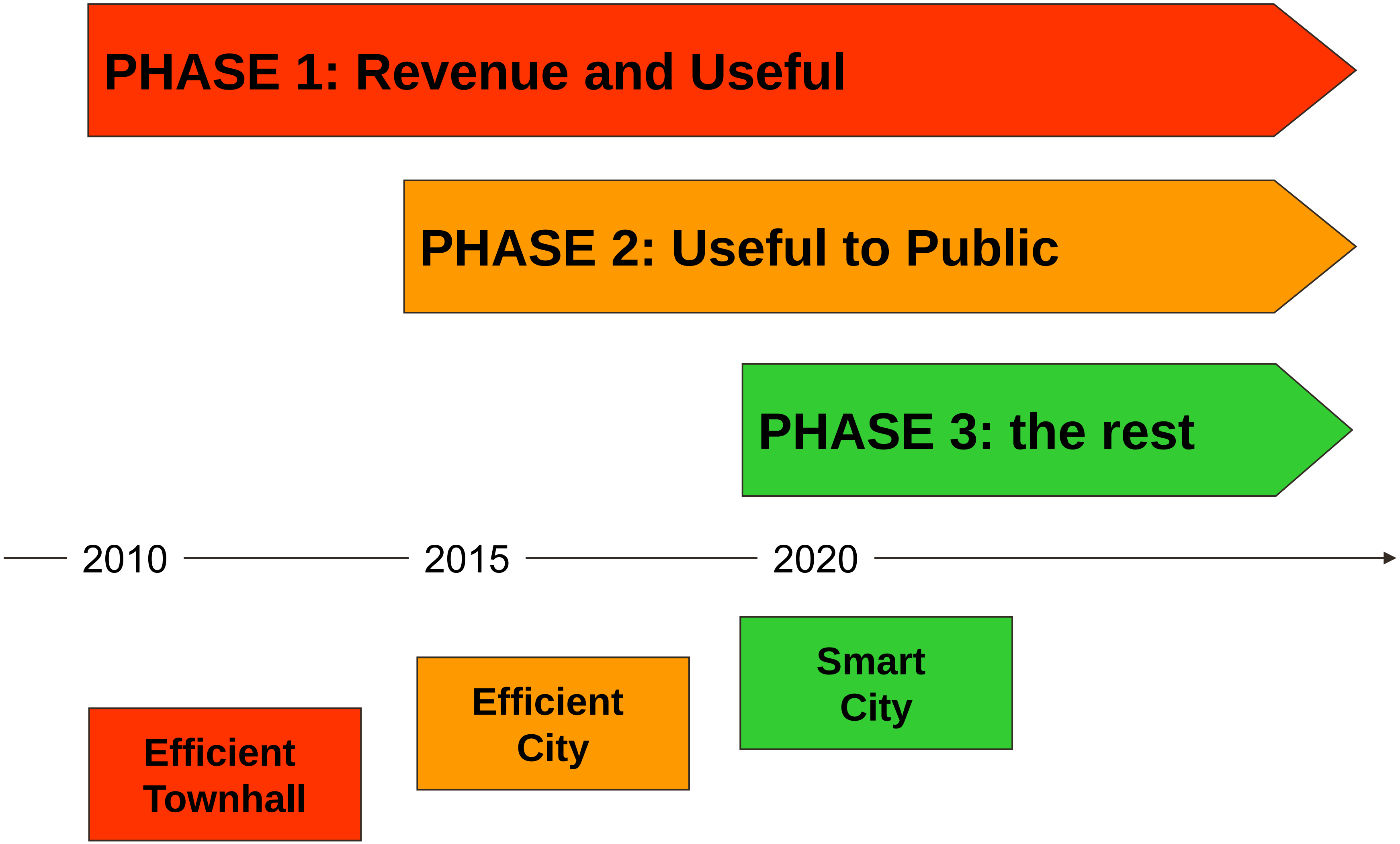
- Humanity point of view:
  - 1 out of 2 is living in cities today; impact onto people's health is enormous
  - e.g. 2 Million people are estimated to die annually due to pollution

- Political point of view:
  - politicians have hence become very susceptible to this topic
  - politicians are eyeing ICT technologies as a possible remedy → "smart syndrome"

- Market point of view:
  - >$100bn per year in 2020 with >$20bn annual spendings

- Technology point of view:
  - technology players are hence trying to enter this market (IBM, Cisco, HP, Oracle)

Smart City Rollout Phases



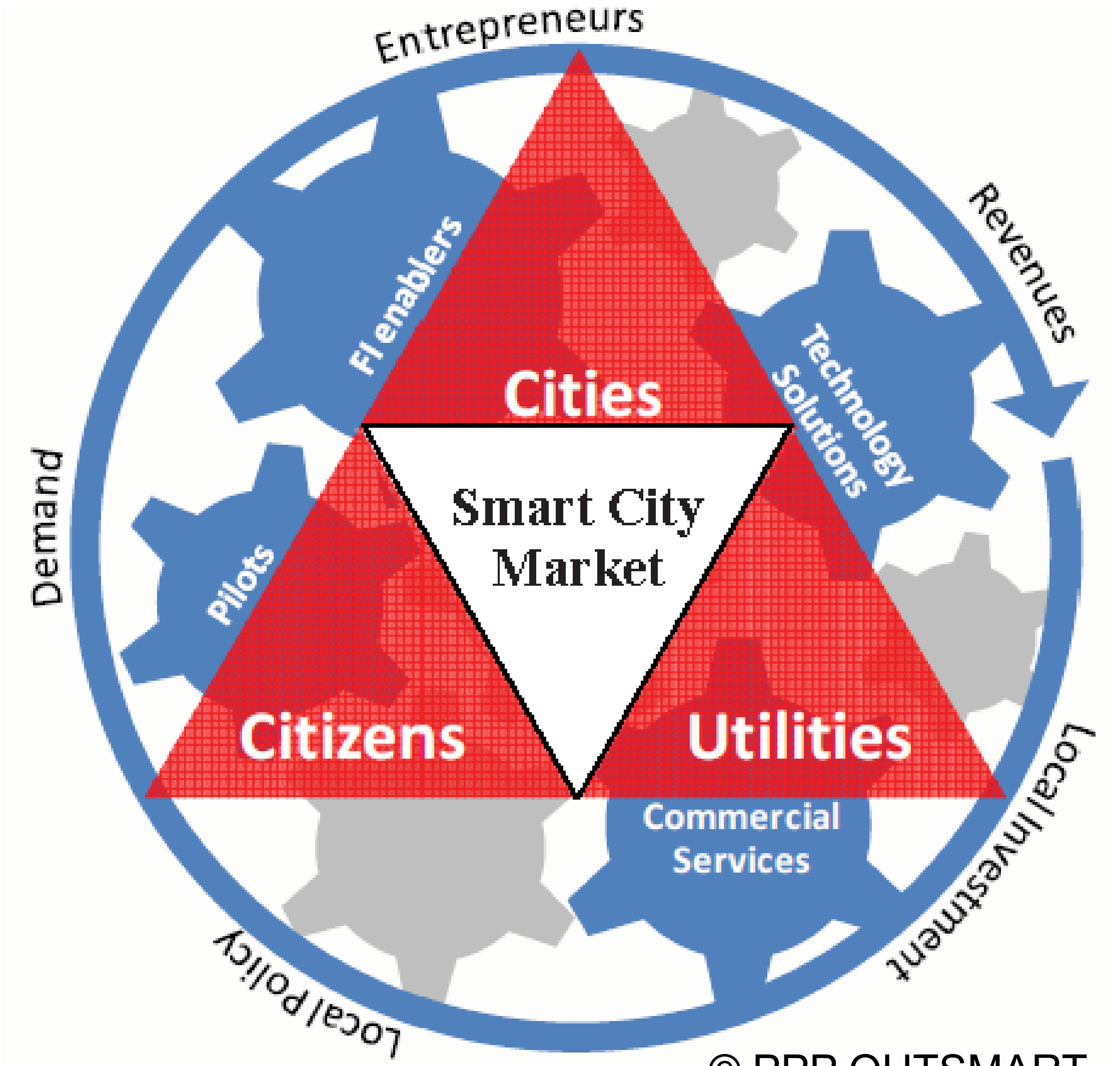
Smart City Rollout Phase Examples

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)



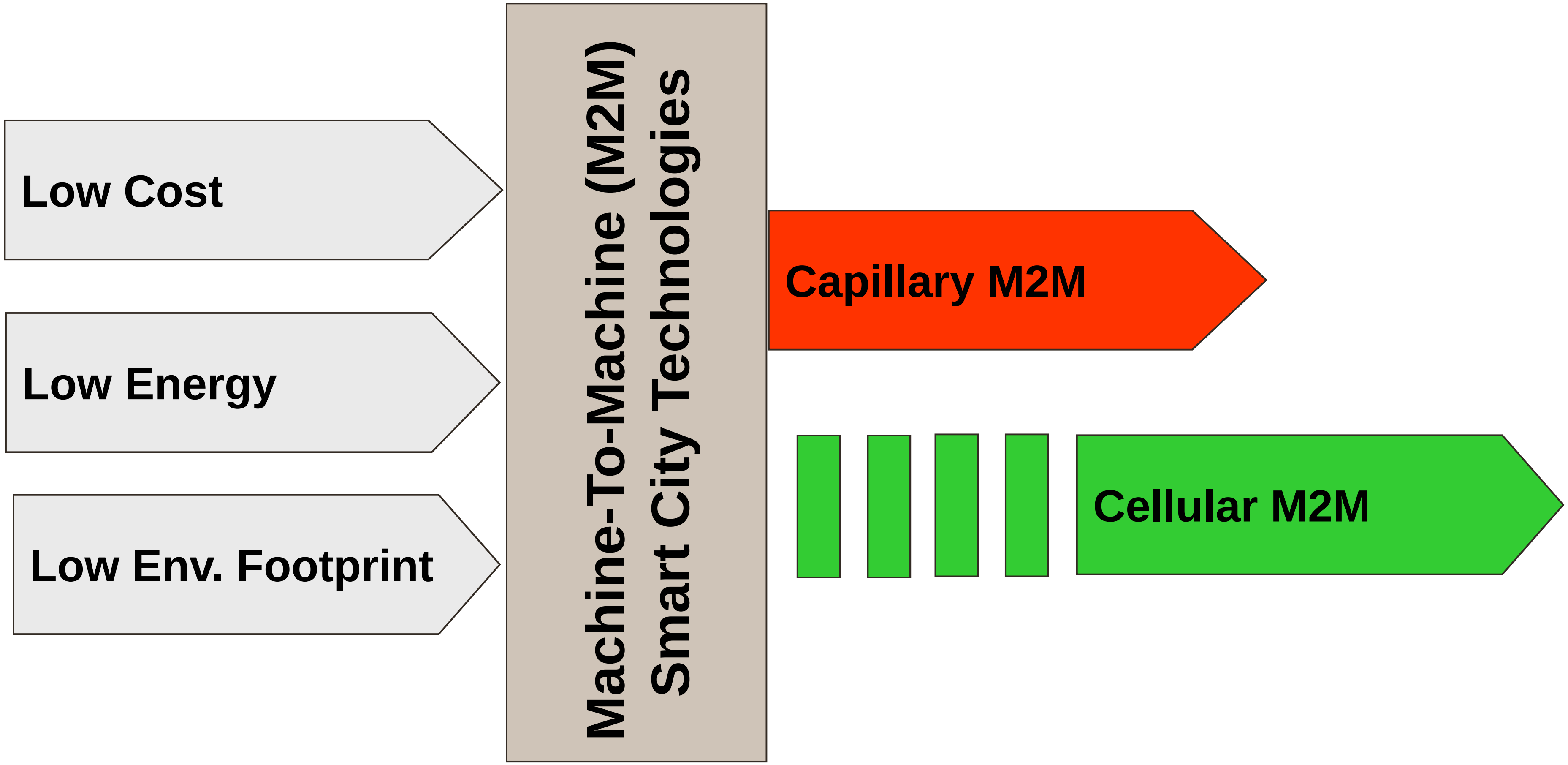
ICT Technologies as Enablers

- ICT arena is changing very quickly:
  - about a decade ago, headlines were dominated by companies like Vodafone, Orange, Telefonica, Nokia, Ericsson, Siemens, etc
  - today, headlines are only dominated by companies like Google, Apple, Facebook
  - ICT infrastructures and technologies have been sidelined to facilitators/enablers!

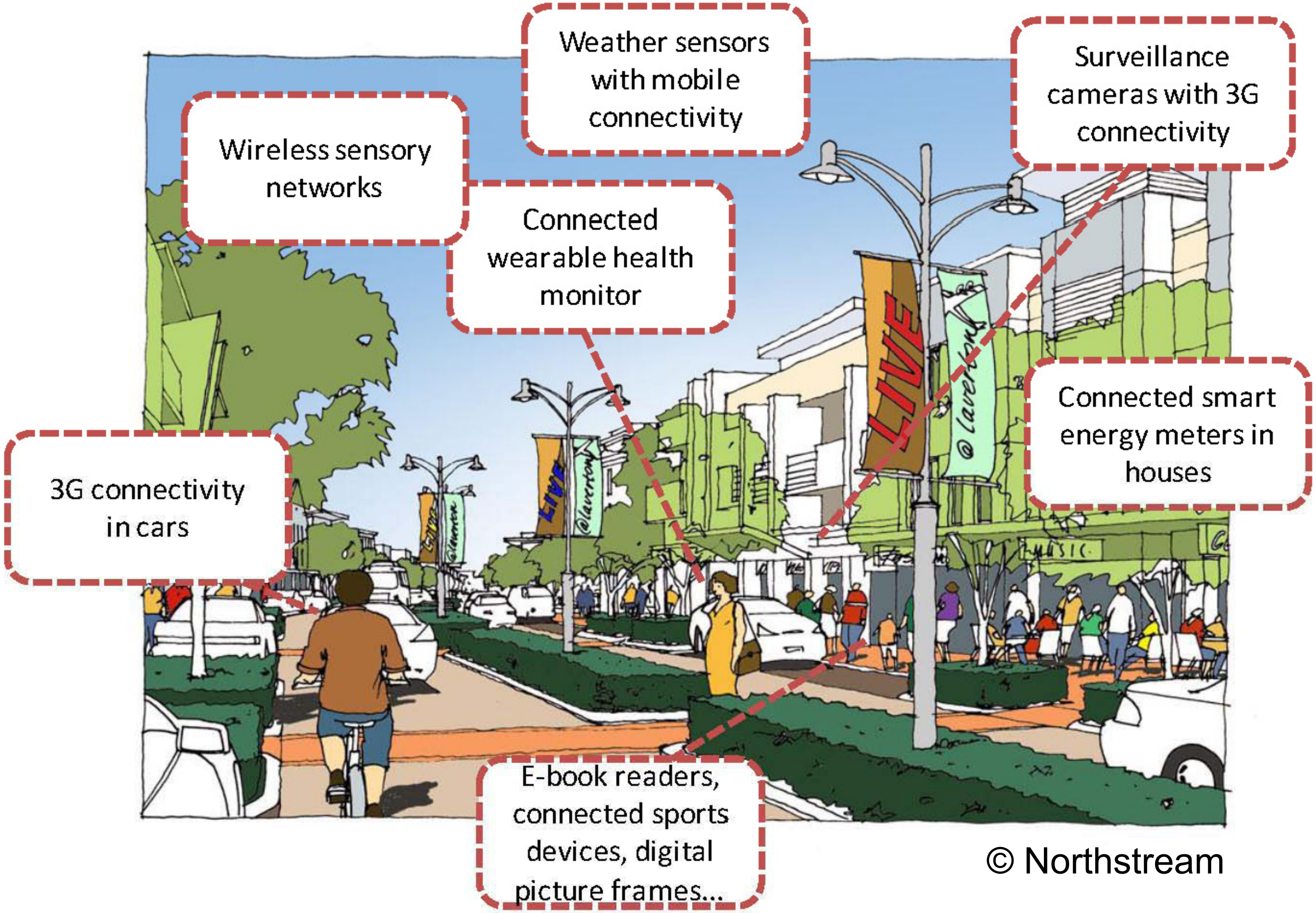
- A few additional observations from these latest trends:
  - whoever provides only hardware & infrastructure is loosing out on the long run
  - being close to the user (or to the problem) is paramount (see Apple's iPhone)
  - allowing for true scalability via ability for 3rd parties to capitalize on entire system, i.e. hardware and software and services, is key (see App Store concept which Steve Jobs by the way was against)
  - having a hand on the data is absolute key (see Google who search, but also IBM who store, Cisco who route, etc)

Smart City Technology Platform

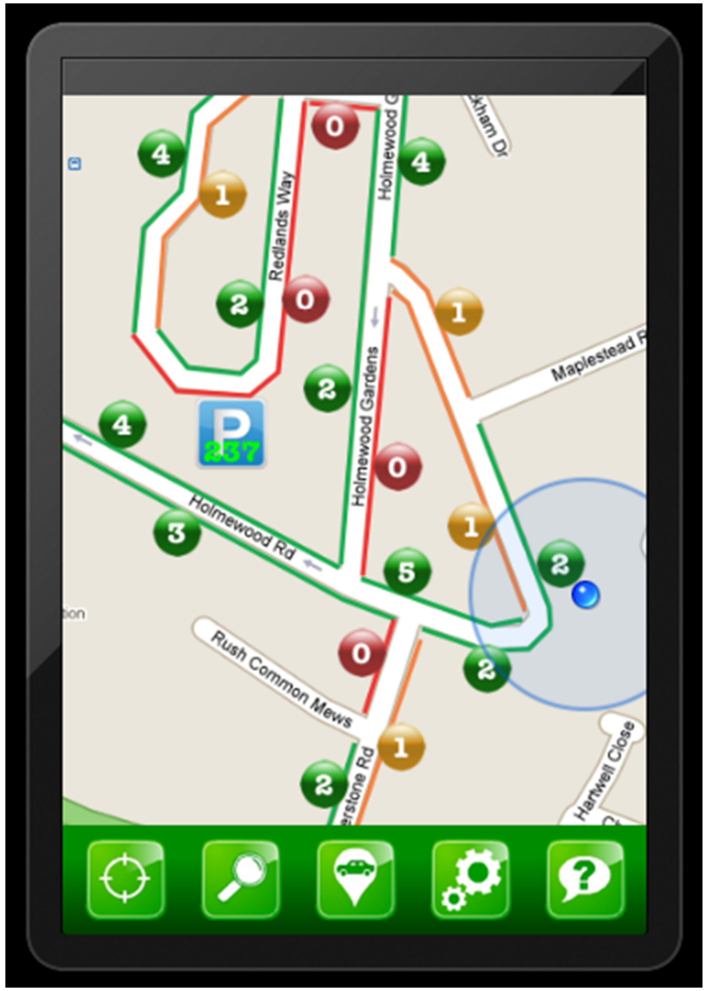
Wireless M2M Technologies



Yesterday's M2M Smart City Vision



Today’s M2M Smart City Reality



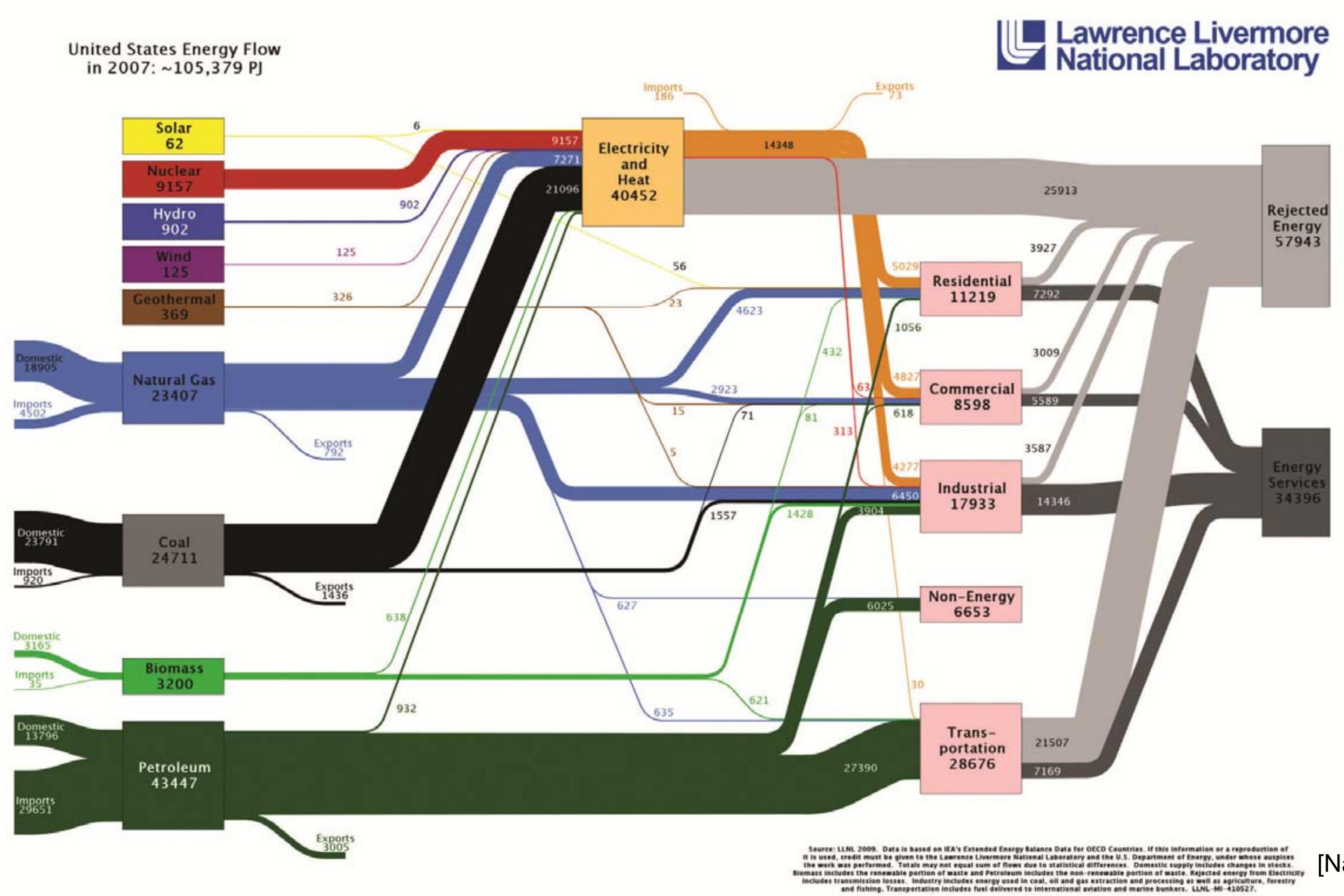
1.4
M2M in Smart Grids

Smart Grid Vision

- Historical Smart Grid Developments:
  - EU initiated the smart grid project in 2003
  - Electric Power Research Institute, USA, around 2003
  - US DOE had a Grid 2030 project, around 2003
  - NIST is responsible as of 2007
  - **Obama’s “National Broadband Plan” [March 2010]**

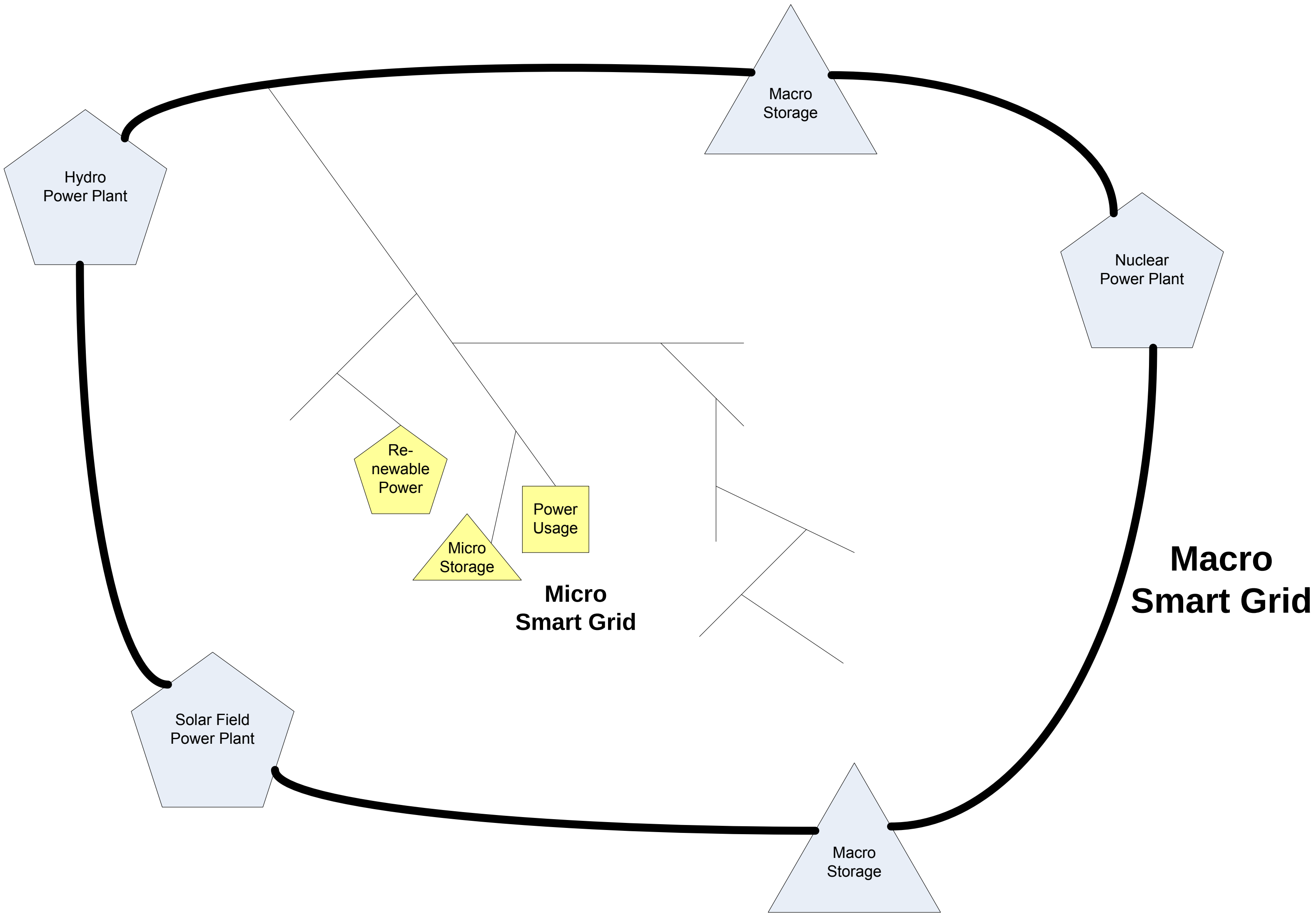
- Mission of ICT in Smart Grids:
  - enable energy efficiency
  - keep bills at both ends low
  - minimize greenhouse gas emissions
  - automatically detect problems and route power around localized outages
  - accommodate all types and volumes of energy, including alternative
  - make the energy system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

Reduce Waste & Dependency ...



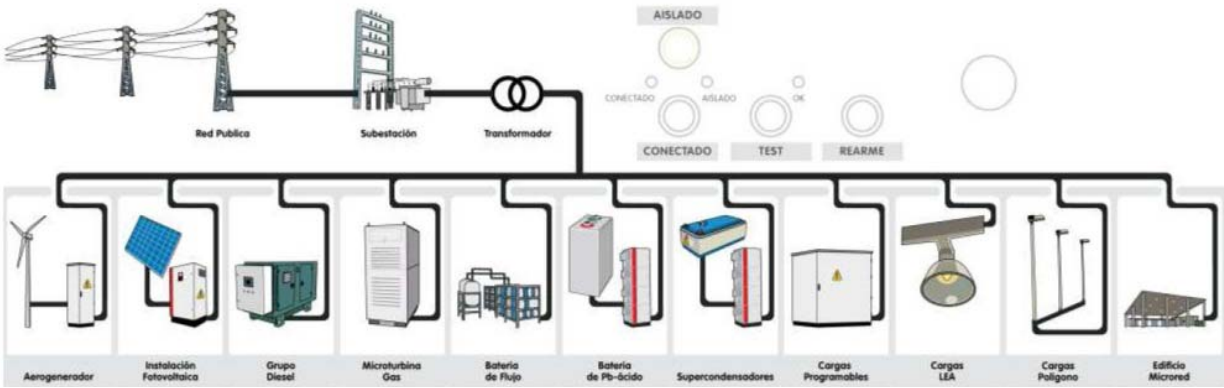
[National Broadband]

... with Smart Grids



Future Energy Landscape

Microgrids Play Central Role

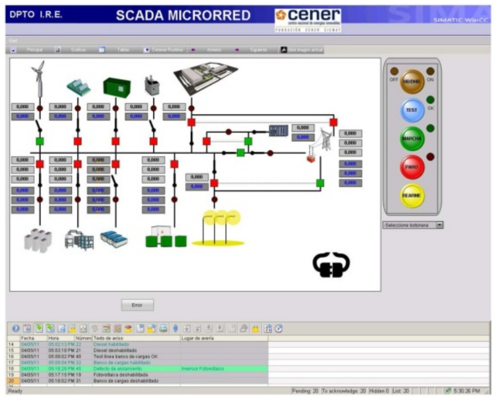


G- Instalación fotovoltaica de 25 kWp

G- Aerogenerador 20 kW tipo full-converter

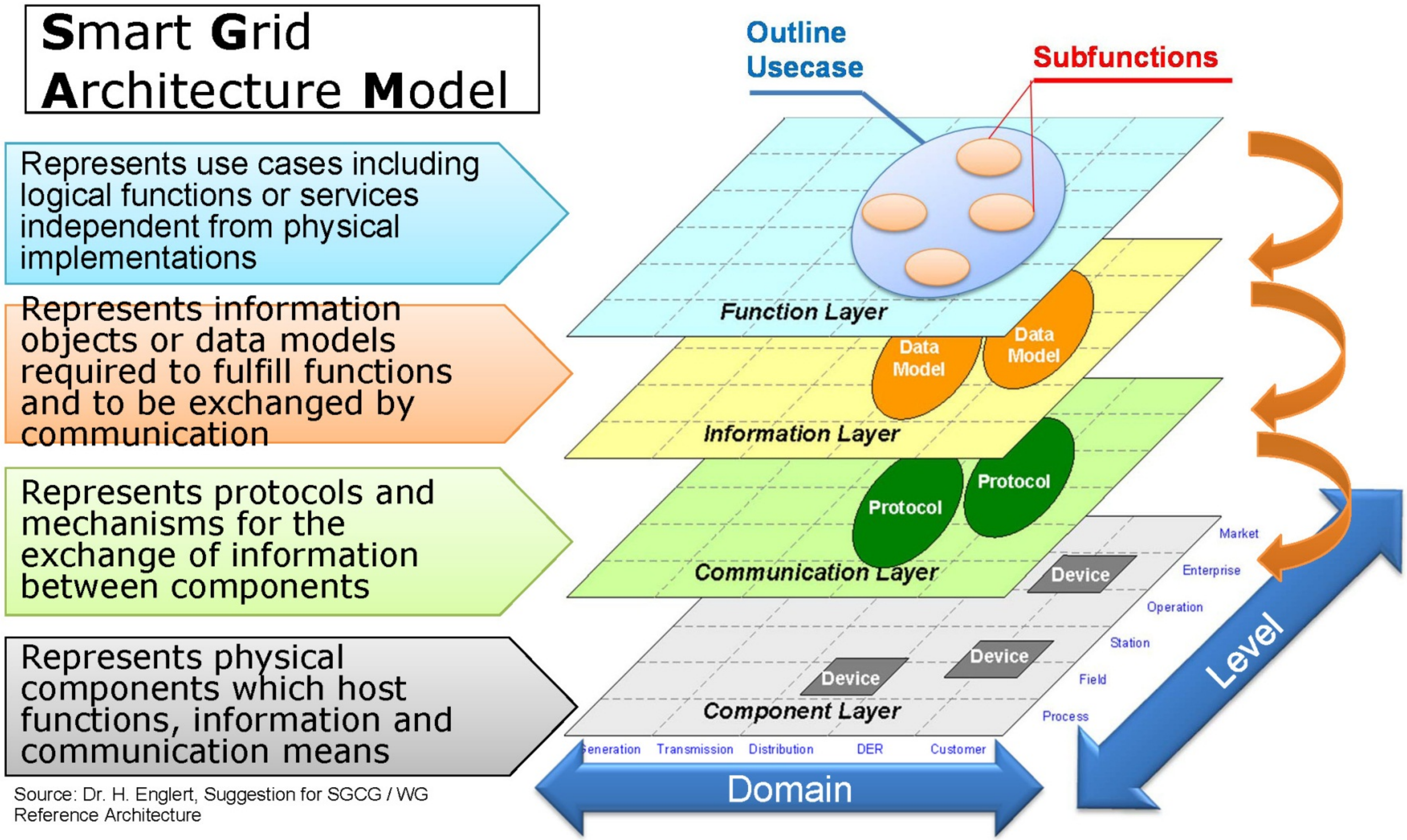
G- Grupo electrógeno diesel 55 kVA

A- Banco de baterías plomo ácido de gel, 50 kW x 2 horas



[© CENER]

Smart Grid Taxonomy [1/2]

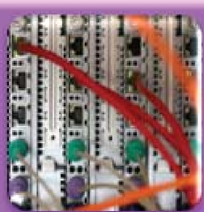


Source: Dr. H. Englert, Suggestion for SGCG / WG Reference Architecture

Smart Grid Taxonomy [2/2]

Layer 4: Applications
- Existing energy supplier applications (billing, service management)
- Demand brokerage apps (demand management, appliances, microgen credits)
- Other third party applications (lifestyle, warranties, security)

Layer 3: Smart grid management
- Network management (message mediation, routing)
- Device management (faults, software maintenance)
- Authentication, security and rights management



Layer 2: Communications network
- Powerline (energy grid)
- Existing public coms (DSL, PSTN, Cable, FTTH, Wireless)
- New dedicated grid networks (wireless mesh e.g. Trilliant)

Layer 1: Home power network and elements
- Smart meter (Electricity, Gas, Heat & Water)
- Energy appliances (Electic appliances, Gas appliances)
- Micro gen (Solar PV, Solar thermal, CHP, Biomass, Ground/air SHP, wind)

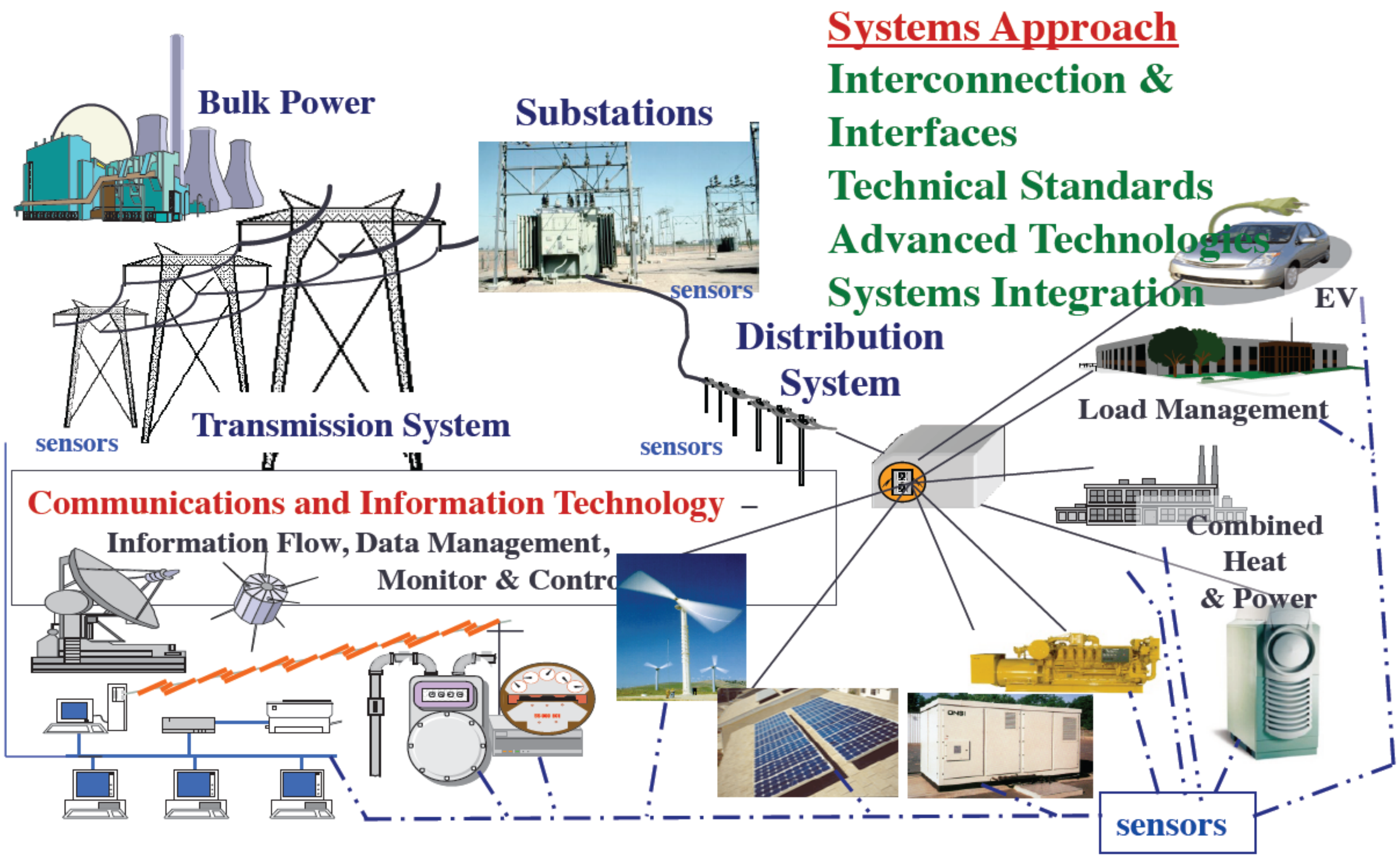
Source: telco2research.com

Smart Grid Comms Standards

- 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 C37.238™-2011 - IEEE Standard Profile for Use of IEEE 1588 Precision Time Protocol in Power System Applications:
  - IEEE C37.239™-2010 - IEEE Standard for Common Format for Event Data Exchange (COMFEDE) for Power Systems
  - IEEE 1031™-2011 - IEEE Guide for the Functional Specification of Transmission Static Var Compensators
  - IEEE 1250™-2011 - IEEE Guide for Identifying and Improving Voltage Quality in Power Systems
  - IEEE 1808™-2011 - IEEE Guide for Collecting and Managing Transmission Line Inspection and Maintenance Data

IEEE P2030 Interoperability Concept



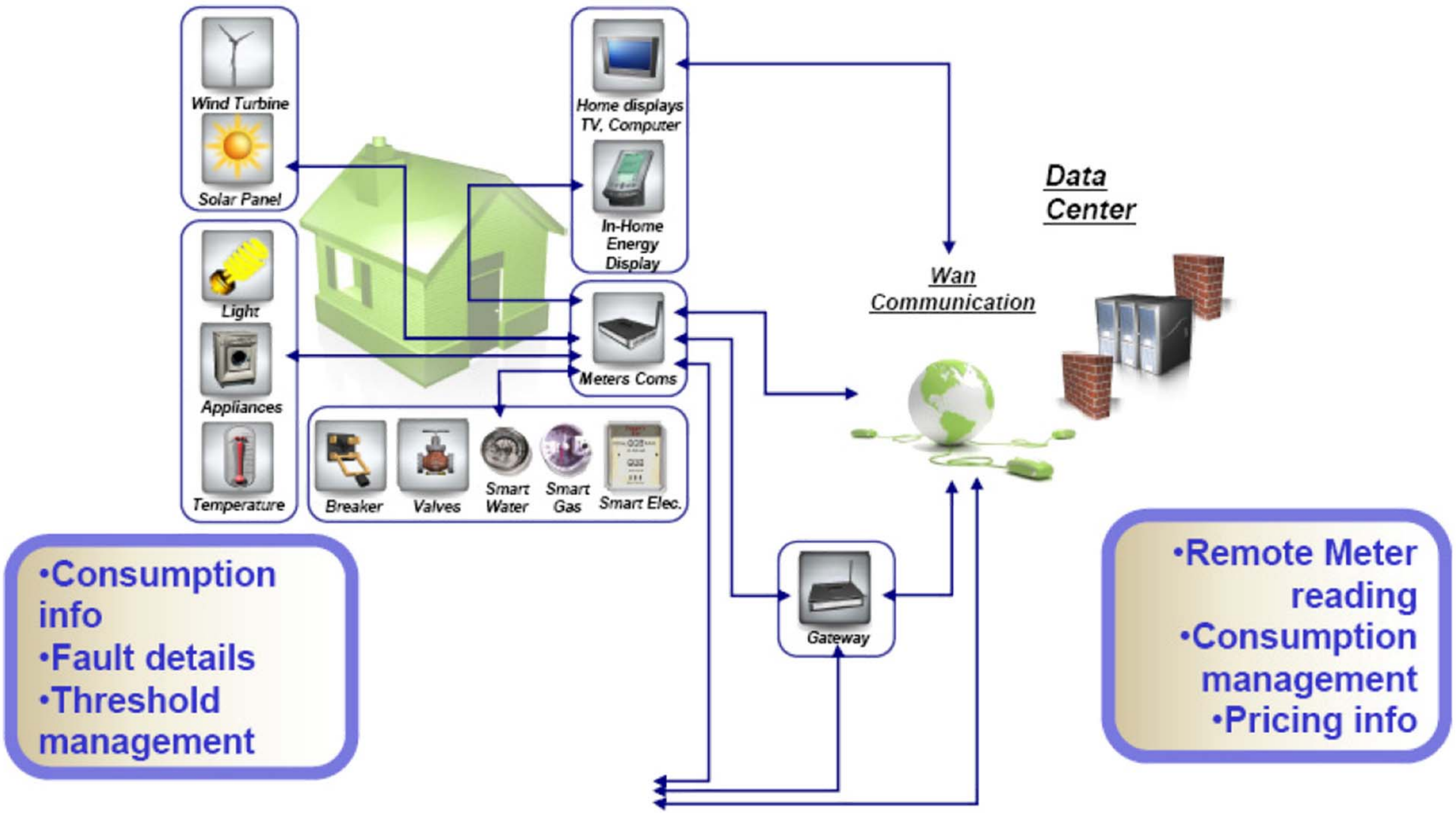
Source: IEEE Standards Association

IEEE P2030 Task Force 3

- Task Force 3 defines communication requirements between devices in the Smart Grid:
  - neutral to PHY/MAC standards used in the Smart Grid
  - deals with layers above PHY/MAC and below Layer 6
  - leave exact choice to designer to pick what is best for the application depending on geography, scalability, requirements, latency, etc.

- Specific role of TF3
  - develop suitability matrix for various PHY/MACs and list PHY/MAC layers that can be used for devices interfacing to the Smart Grid (e.g. IEEE 802.15.4g/k or IEEE 802.11ah)
  - use IP for a large set of reasons (scalability, security, well understood, etc)

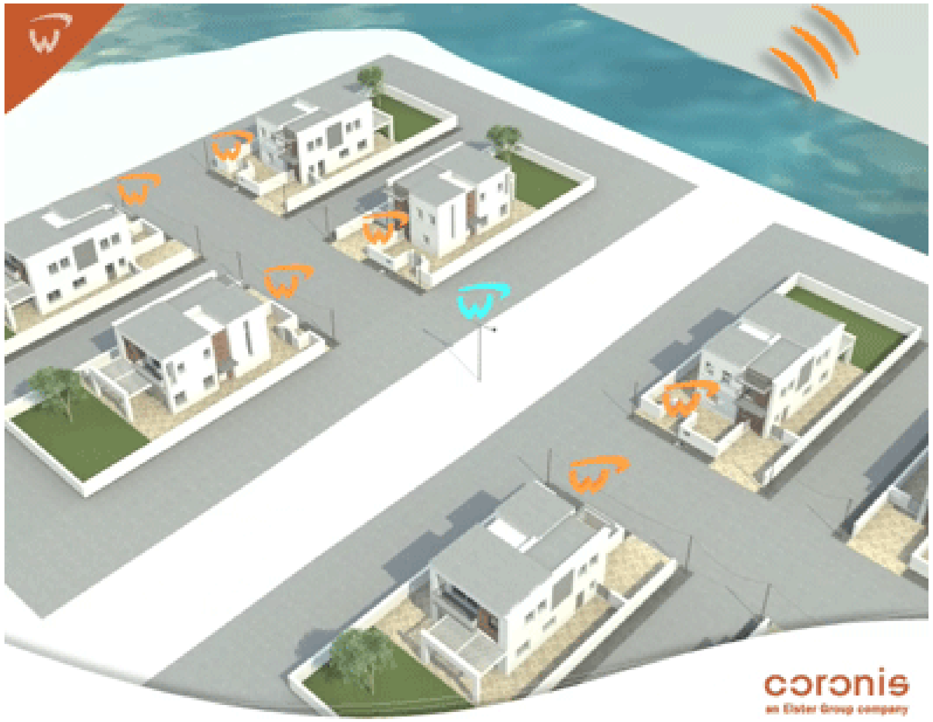
ETSI M2M Smart Grid Concept

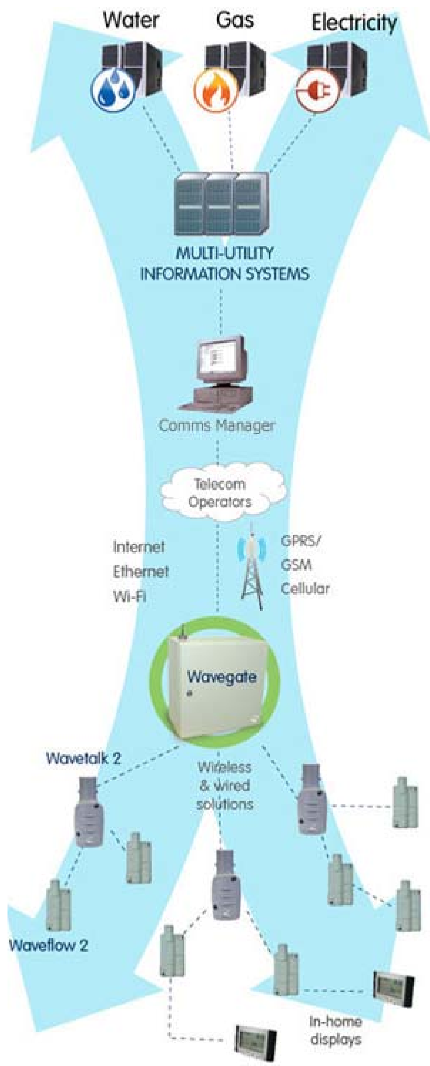


[© ETSI M2M]

Coronis' Automated Meters

- Coronis/Elster/Wavenis/WOSA Technology:
  - low RF power nodes in star topology until
  - higher power aggregation nodes
  - cellular (e.g. GPRS) gateways





[© Coronis]

2
Capillary M2M

2.1
Quick Intro to Capillary M2M

History of WSN → M2M

Year	Event
1967	REMBASS Remotely Monitored Battlefield Sensor System
1978	Distributed Sensor Networks for Aircraft Detection Lincoln Labs - Lacoss
1992	RAND Workshop - Future Technology Driven Revolutions in Military Conflict. Concepts behind Smart Dust emerge.
1993-1996	DARPA ISAT studies - many WSN ideas and applications discussed. Deborah Estrin leads one of the studies.
1994	LWIM - Low Power Wireless Integrated Microsensors - UCLA, Bill Kaiser
1997	Smart Dust proposal written - UCB, Kris Pister
1998	Seth Hollar makes wireless mouse collars
1999	Endeavour project proposed by Randy Katz, David Culler PicoRadio project started by Jan Rabaey
2000	Crossbow begins selling "Berkeley motes"
2001	Multiple demos proving viability
2002	Dust, Ember, Millennial, Sensicast founded
2003	IEEE 802.15.4 standard published Moteiv (now Sentilla) founded
2004	Zigbee 1.0 standard ratified TSMP 1.1 shipping
2005	Arch Rock founded
2006	Zigbee 2006 standard ratified 802.15.4-2006 standard ratified
2007	Wireless HART standard ratified RFC4944 published
2008-2009	IETF workgroup Routing Over Low-power Lossy links (ROLL) created IEEE 802.15.4e work group created
2010	IEEE 802.15.4e's MAC protocol ratified IEFT 6LoWPAN's RFC4944 updated IETF ROLL's RPL routing protocol ratified

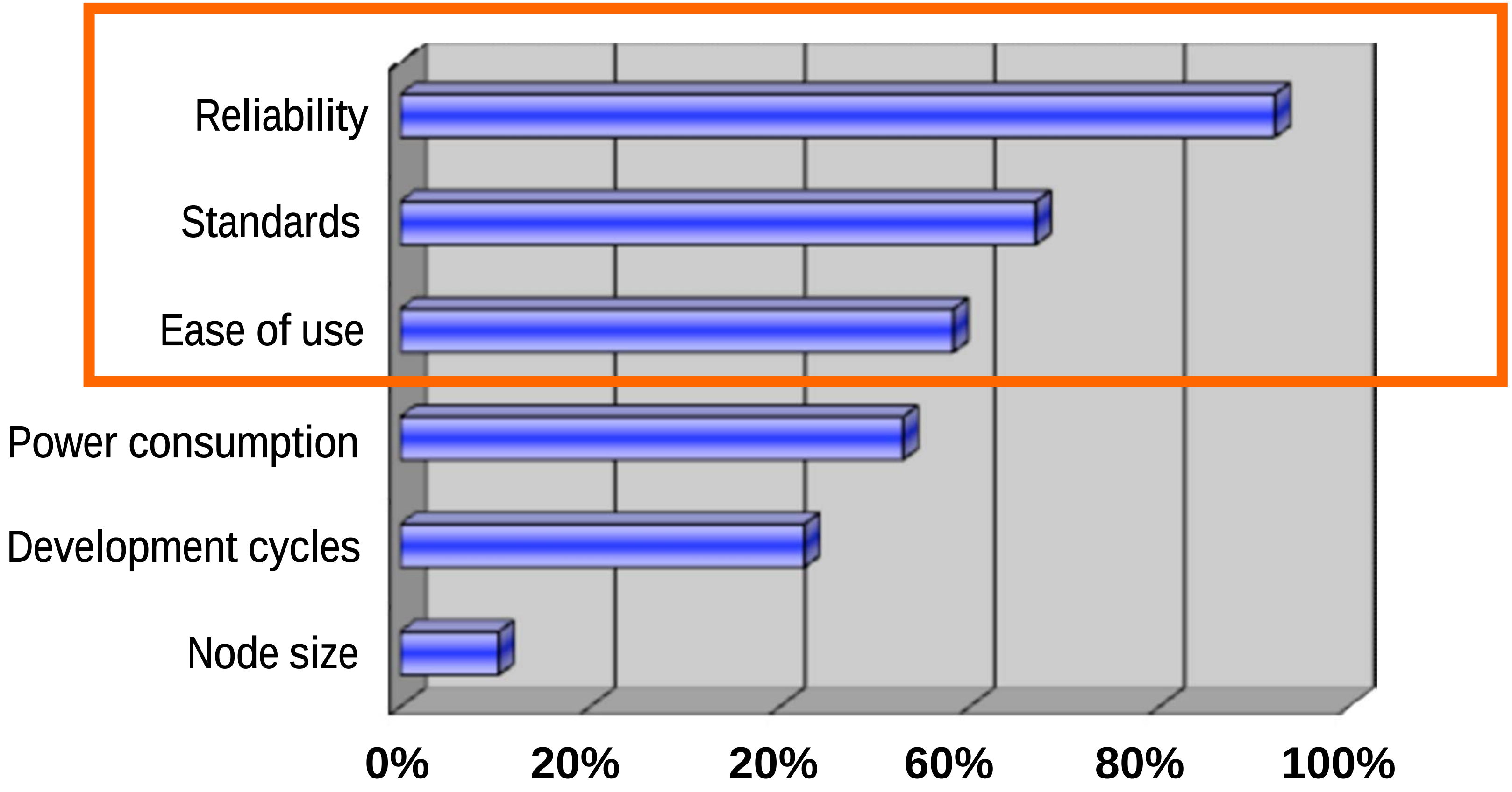
Characteristics of Capillary M2M

- What is “Capillary M2M”:
  - mostly embedded design
  - short-range communication systems
  - power consumption is major headache (go harvesting?)
  - ought to be standards compliant to facilitate “universal” connectivity

- What is it not:
  - cellular system (cellular connectivity only possible via gateway)
  - pure 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**.

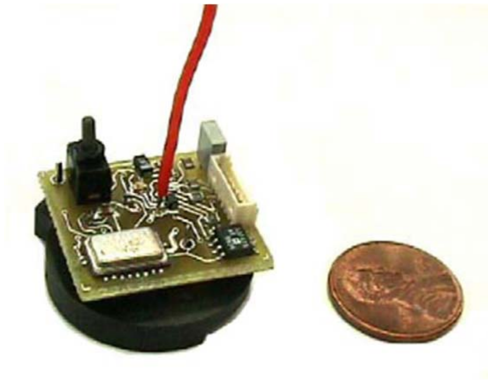
Barriers in Capillary M2M



* source: OnWorld, 2005

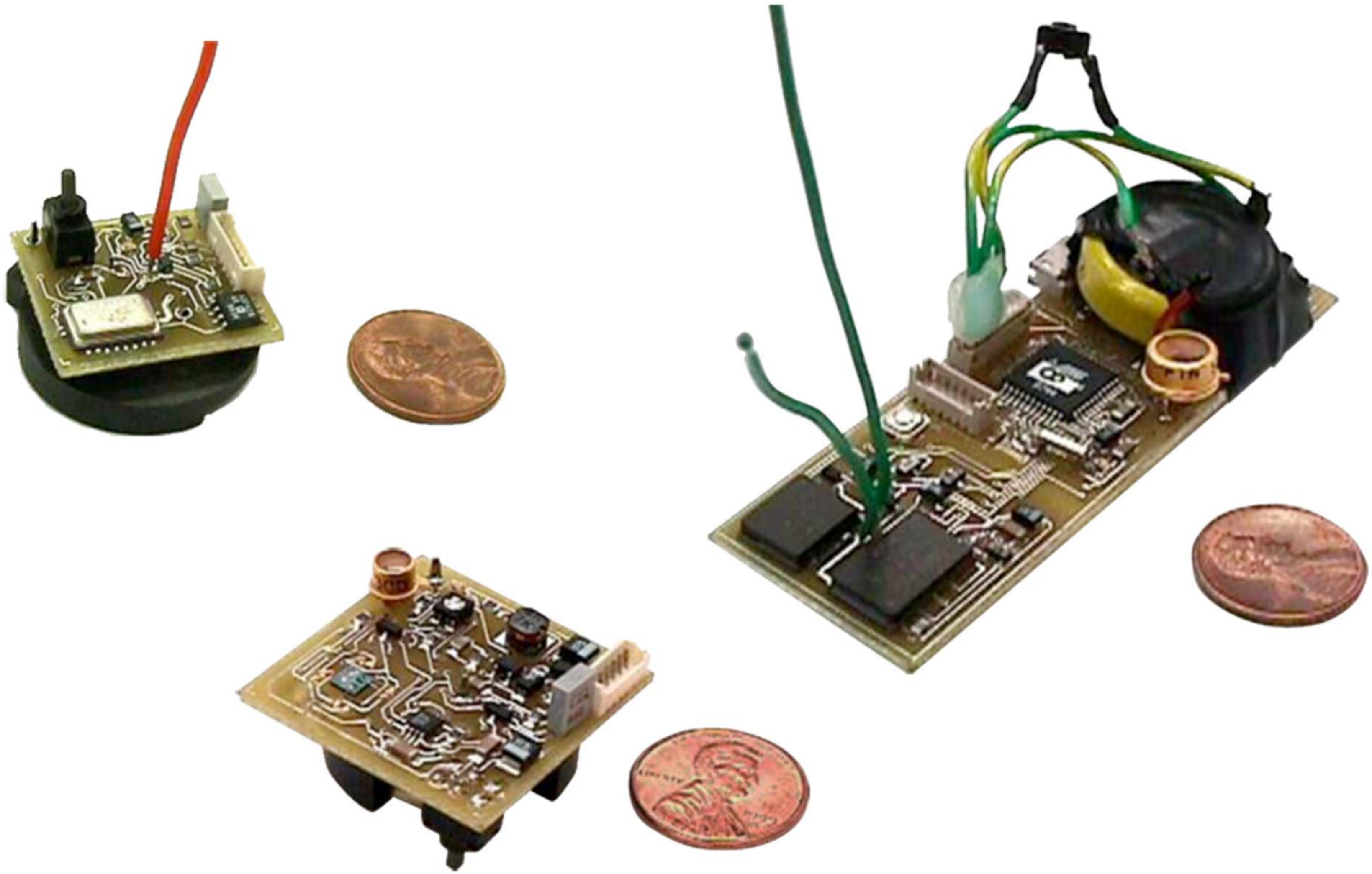
Design of Capillary M2M

- 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

Off-The-Shelf Hardware – Today?



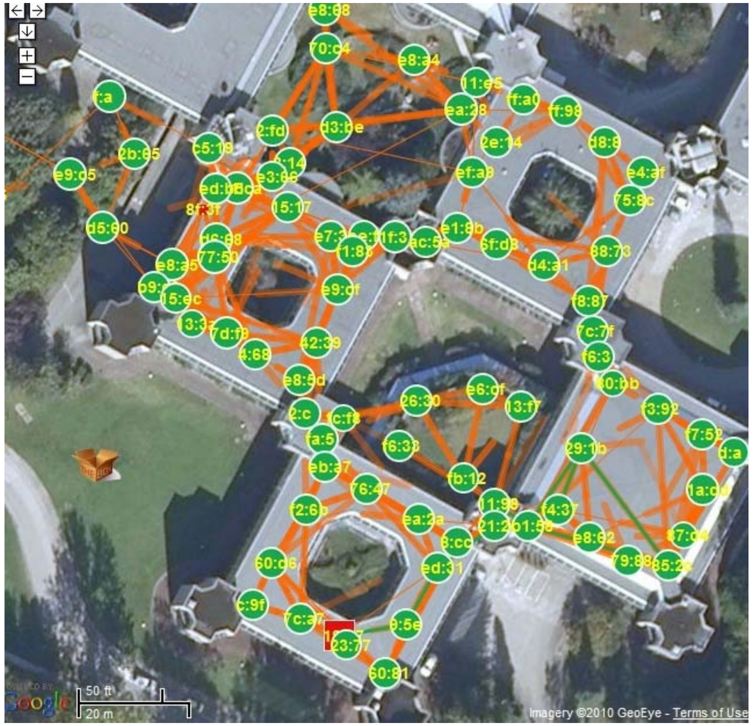
Hardware Differs Significantly

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

2.2
From Academia To Practice

Experimentation – Surprise, Surprise!

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

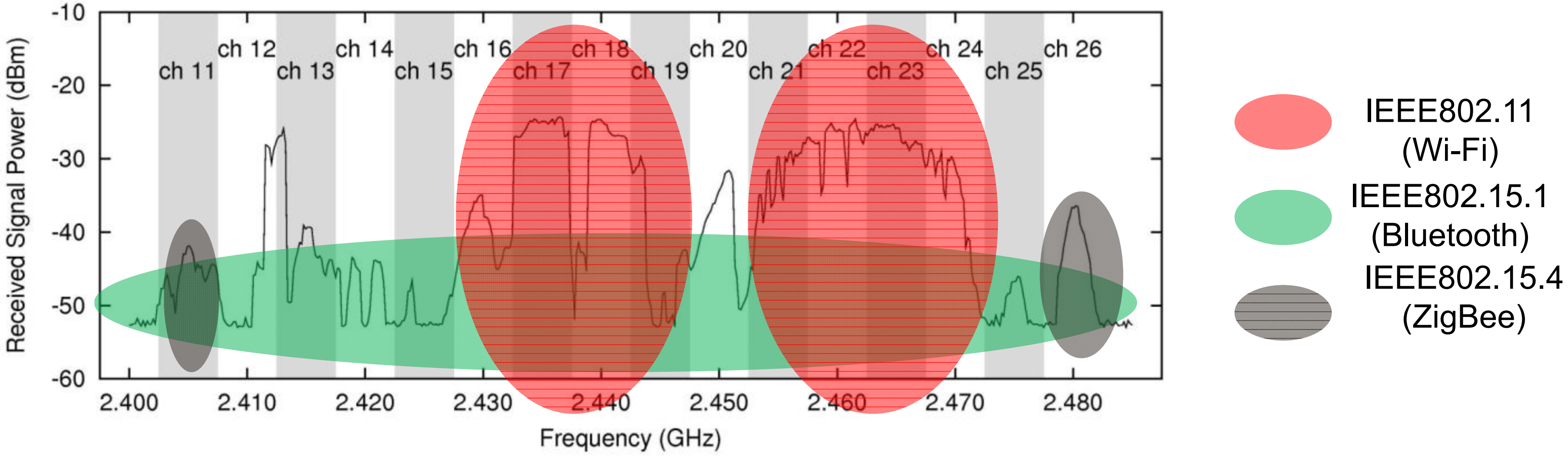


http://senseandsensitivity.rd.francetelecom.com/

Important Practical Challenges

- **External Interference:**
  - often neglected in protocol design
  - however, interference has major impact on link reliability
- **Wireless Channel Unreliability:**
  - MAC and routing protocols were often channel agnostic
  - however, wireless channel yields great uncertainties
- Position Uncertainty:
  - (mainly geographic) routing protocols assumed perfect location knowledge
  - however, a small error in position can cause planarization techniques to fail

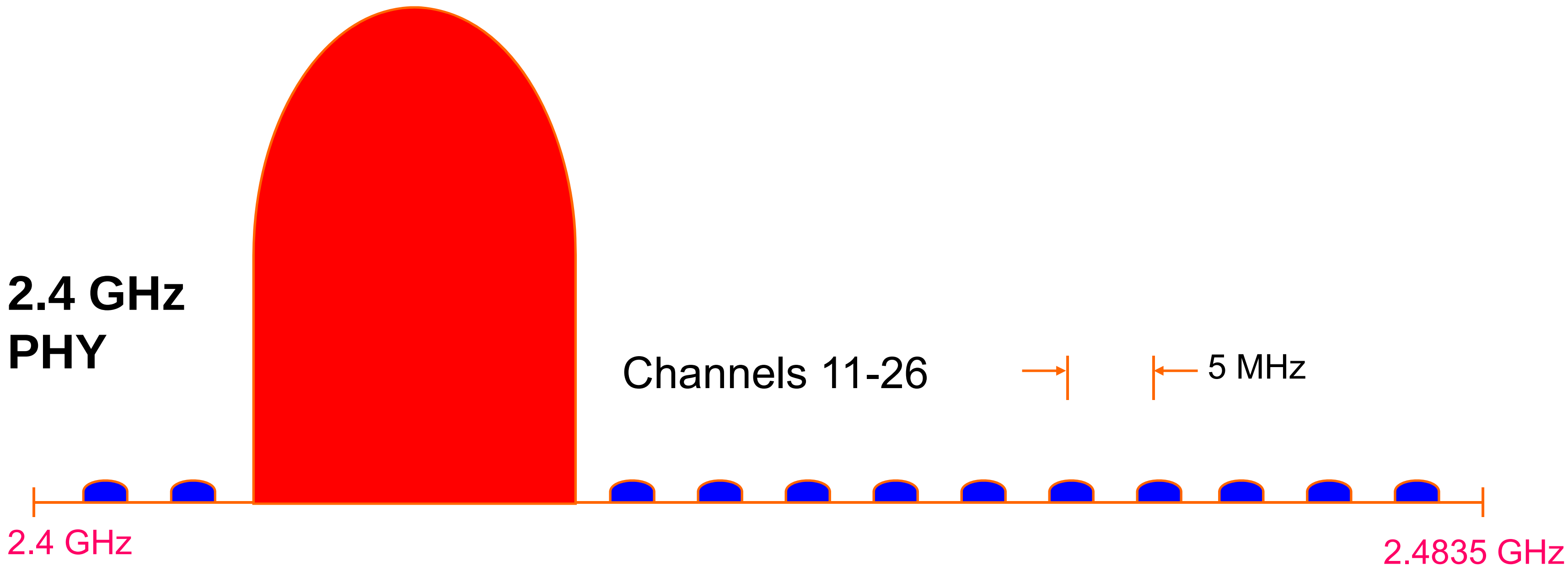
First Challenge: External Interference



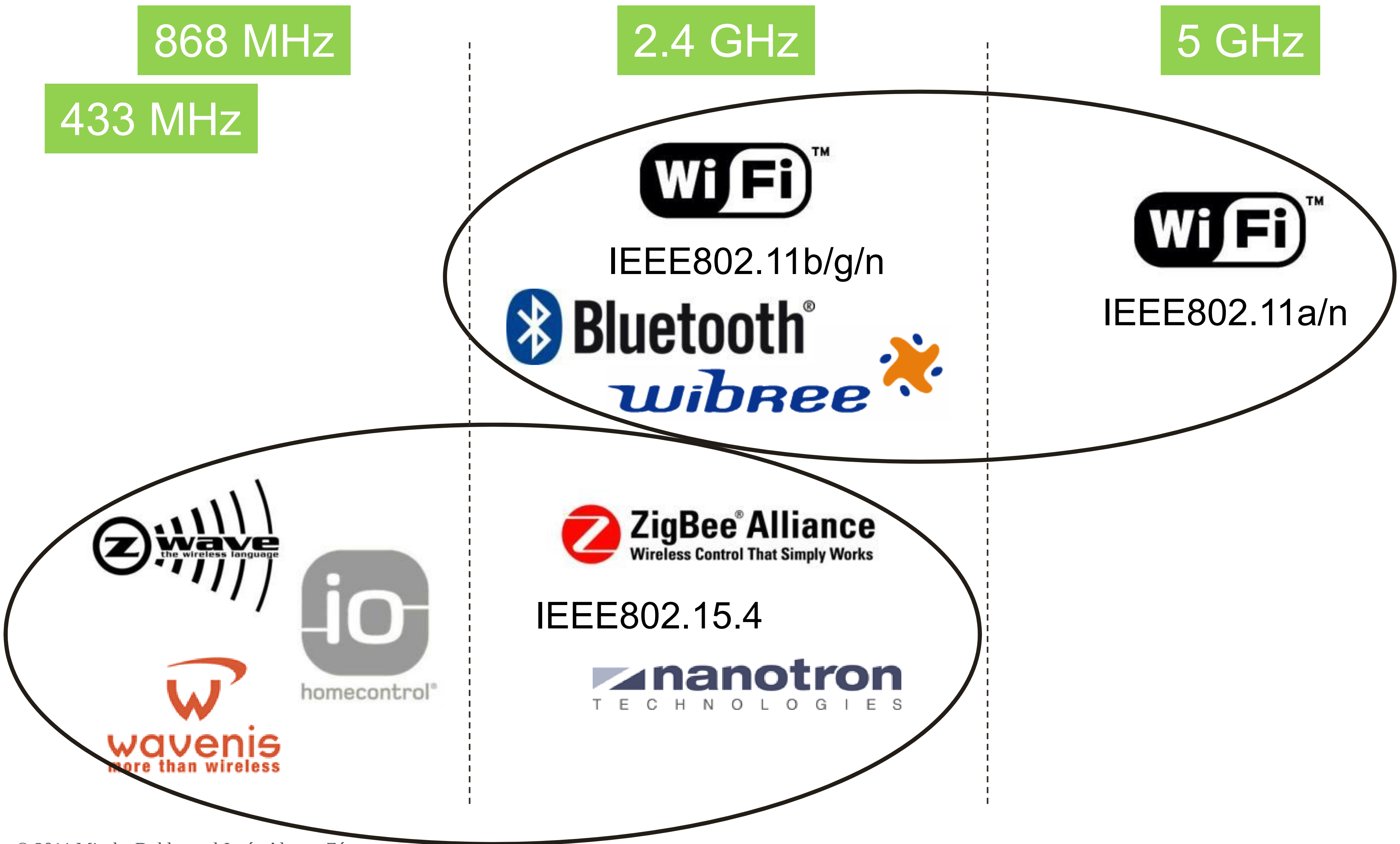
First Challenge: External Interference

Typical Tx power

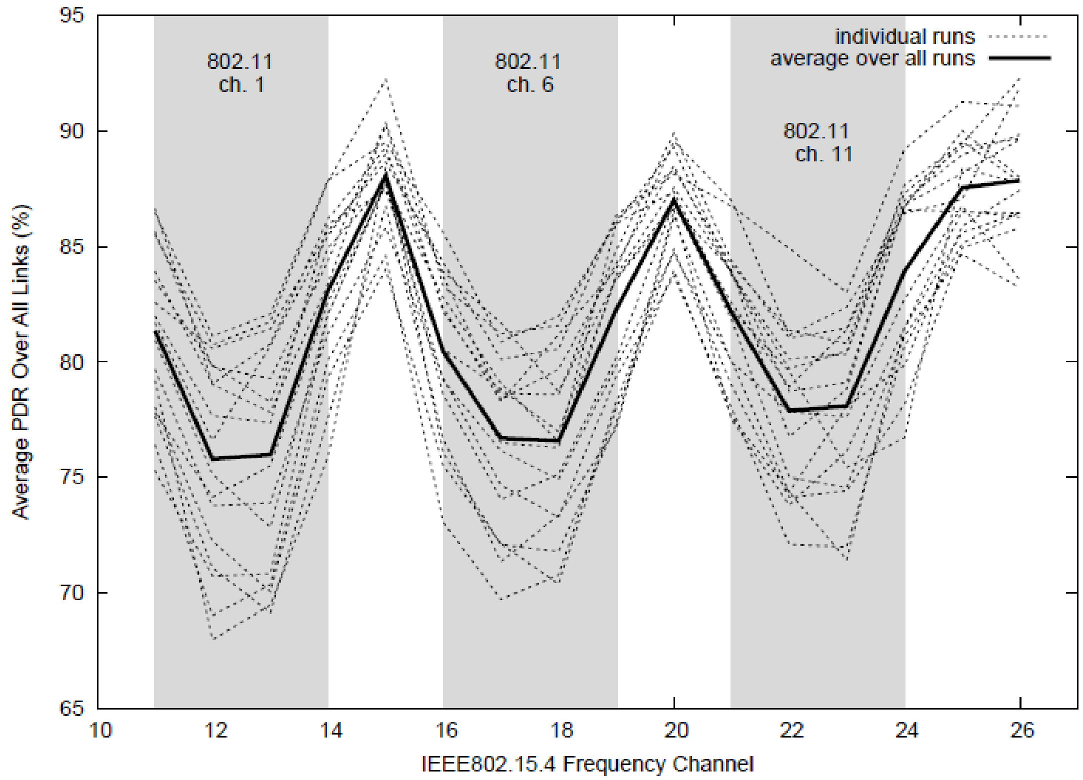
- IEEE802.11-2007: 100mW
- IEEE802.15.4-2006: 1mW



First Challenge: External Interference



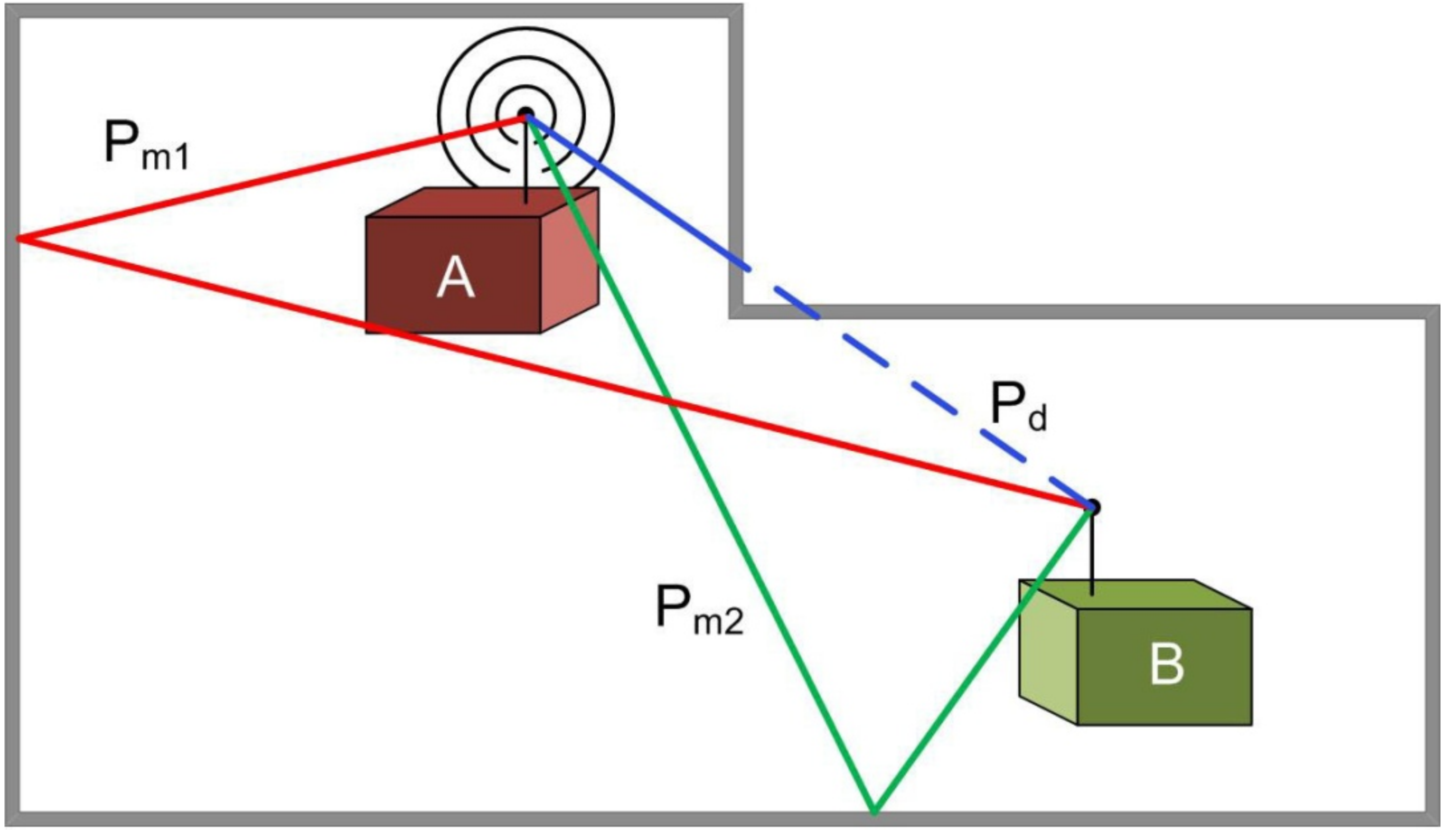
First Challenge: External Interference



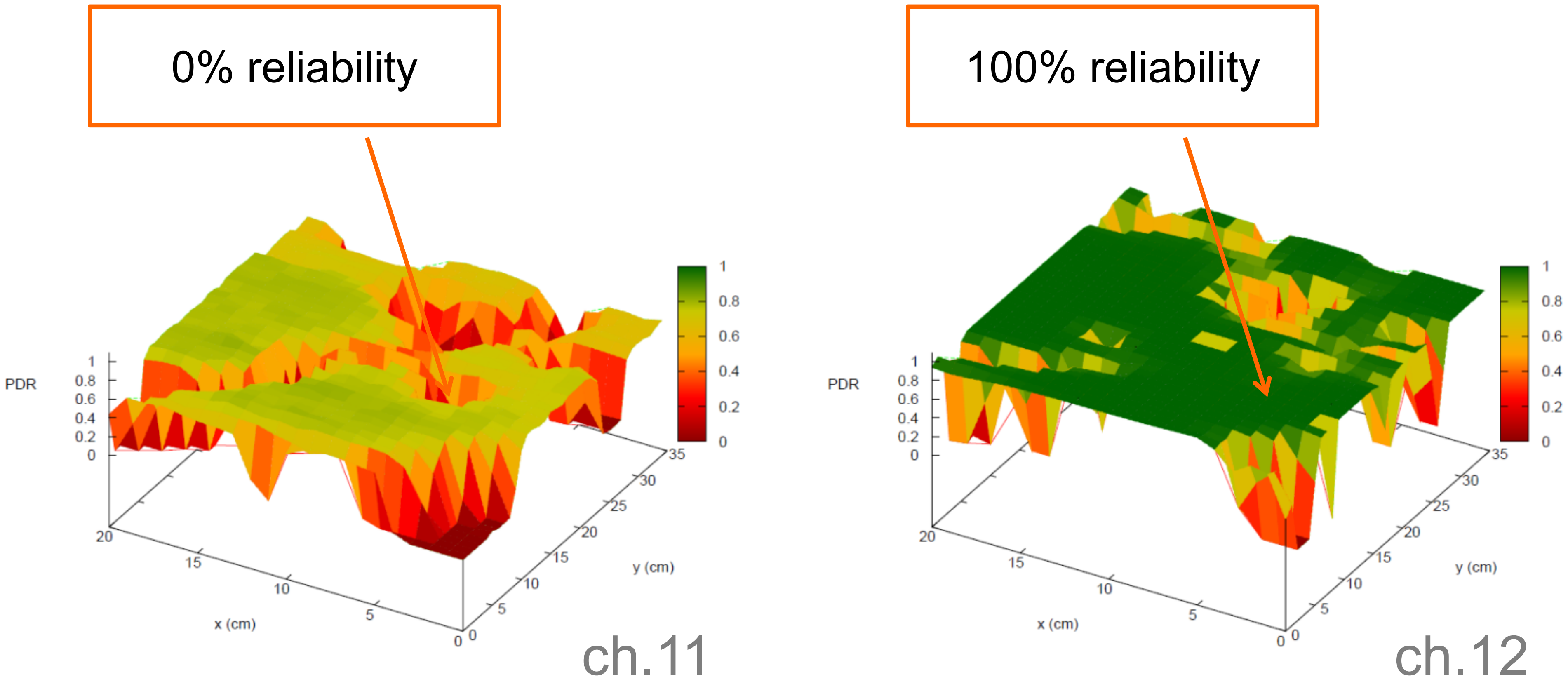
- 45 motes*
- 50x50m office environment
- 12 million packets exchanged, equaly over all 16 channels

*data collected by Jorge Ortiz and David Culler, UCB
Publicly available at wsn.eecs.berkeley.edu

Second Challenge: Multipath Fading

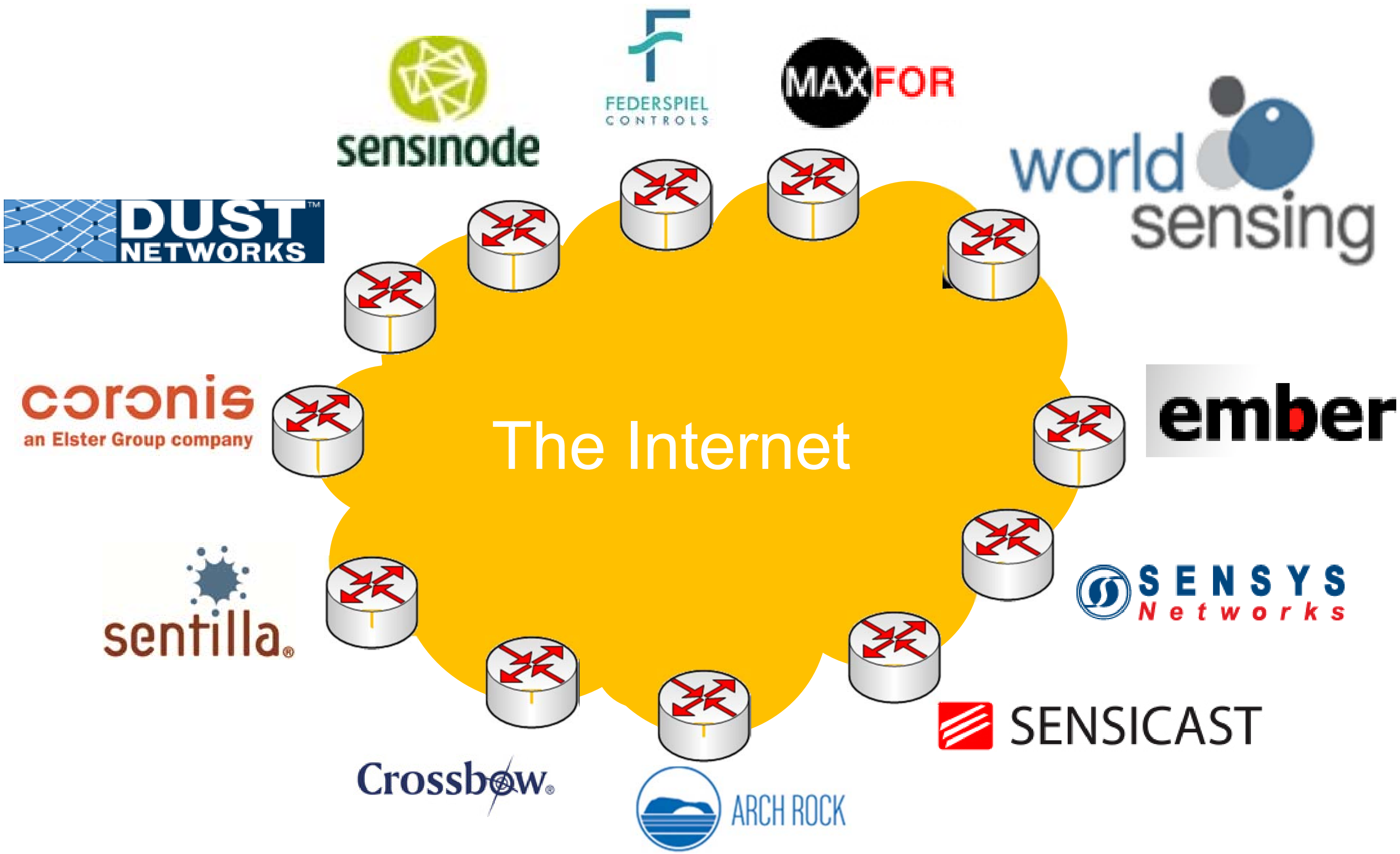


Second Challenge: Multipath Fading



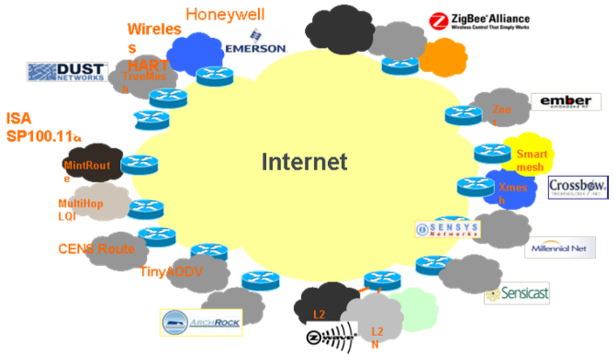
2.3
From Practice to Proprietary M2M Solutions

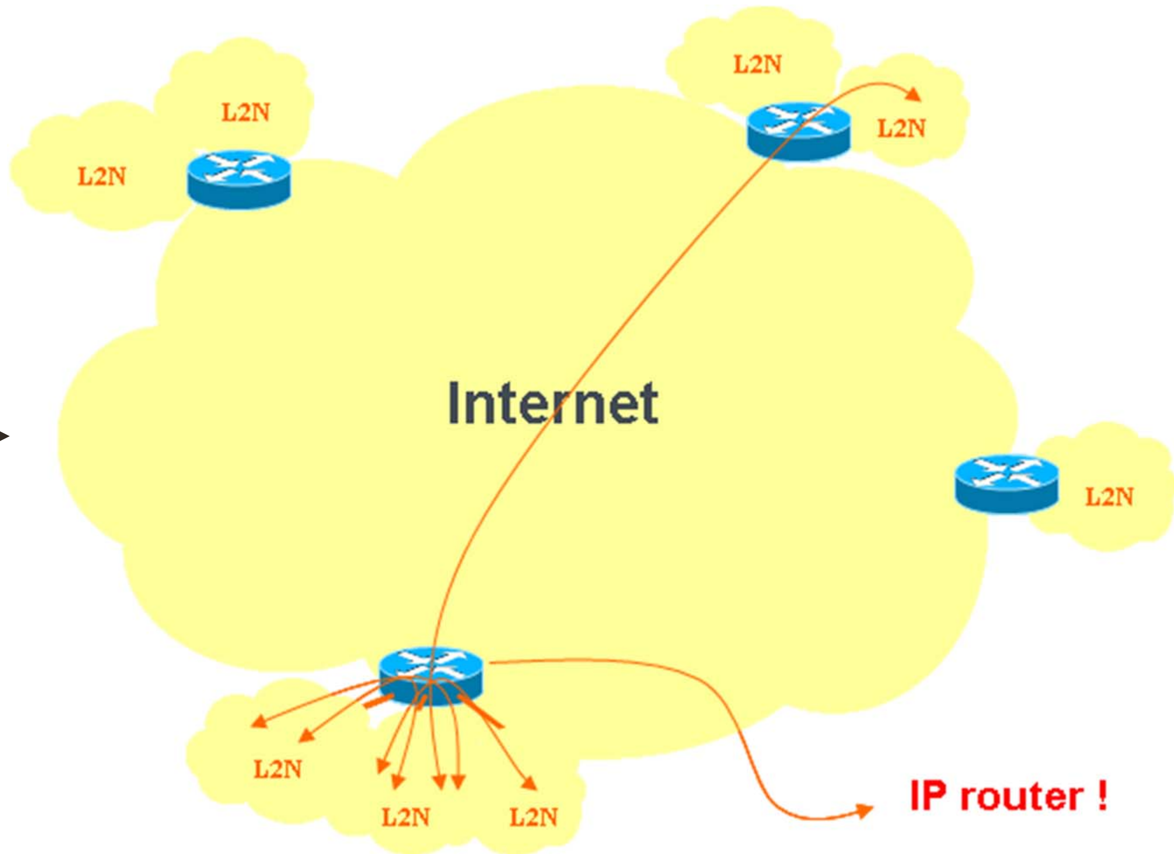
Key Embedded M2M Companies



2.4
Standardization Efforts Pertinent to M2M

Why Standardization?





Standardization Bodies

- 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)
  - ETSI (complete M2M solutions) → in cellular part

Standardized Protocol Stack

TRAN	UDP, TCP
routing	RPL
NET	IPv6
adaptation	6LoWPAN
MAC	IEEE802.15.4e
PHY	IEEE802.15.4

IETF	Application	IETF CORE
IETF	Transport	(Lightweight TCP), UDP
IETF	Networking	IETF ROLL (routing)
IETF	Networking	IETF 6LoWPAN (adaptation)
IEEE	MAC	IEEE 802.15.4E
IEEE	PHY	IEEE 802.15.4-2006

2.4.1

IEEE-Pertinent 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 802.15.4 (technology used e.g. by ZigBee and IETF 6LowPan)
  - IEEE 802.15.1 (technology used e.g. by Bluetooth/WiBree)
  - IEEE 802.11 (technology used by WiFi)

- Some facts and comments:
  - IEEE 802.15.4/15.4e/g has been the obvious choice but will get
  - serious competition from ultra-low power (ULP) IEEE 802.15.1 (WiBree)
  - low power IEEE 802.11 solutions are emerging (e.g. from Ozmo)

IEEE 802.15.4e – Overview

TRAN	UDP, TCP
routing	RPL
NET	IPv6
adaptation	6LoWPAN
MAC	IEEE802.15.4e
PHY	IEEE802.15.4

- Standards history:
  - 802.15.4e draft (d6P802-15-4e_Draft_Standard) was approved by the 802.15 WG and LMSC executive committee to proceed to Sponsor Ballot
  - 802.15 WG has approved the Ballot Resolution Committee (BRC) with the responsibility of resolving comments and editing/finalizing draft
  - Sponsor Ballot opened on 27 July 2011 and closed on 28 August with 96% of votes being affirmative

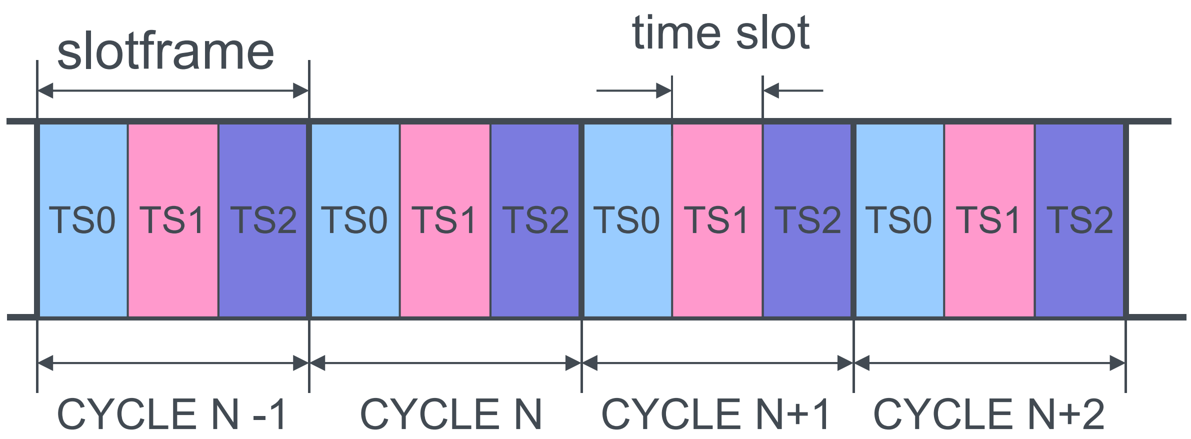
- Aim of amendment:
  - define a MAC amendment to the existing standard 802.15.4-2006
  - to better support industrial markets

- 3 different MACs for 3 different types of applications:
  - **LL:** **Low Latency**
  - **CM:** **Commercial Application**
  - **PA:** **Process Automation**

PA - Process Automation [1/2]

TRAN	UDP, TCP
routing	RPL
NET	IPv6
adaptation	6LoWPAN
MAC	IEEE802.15.4e
PHY	IEEE802.15.4

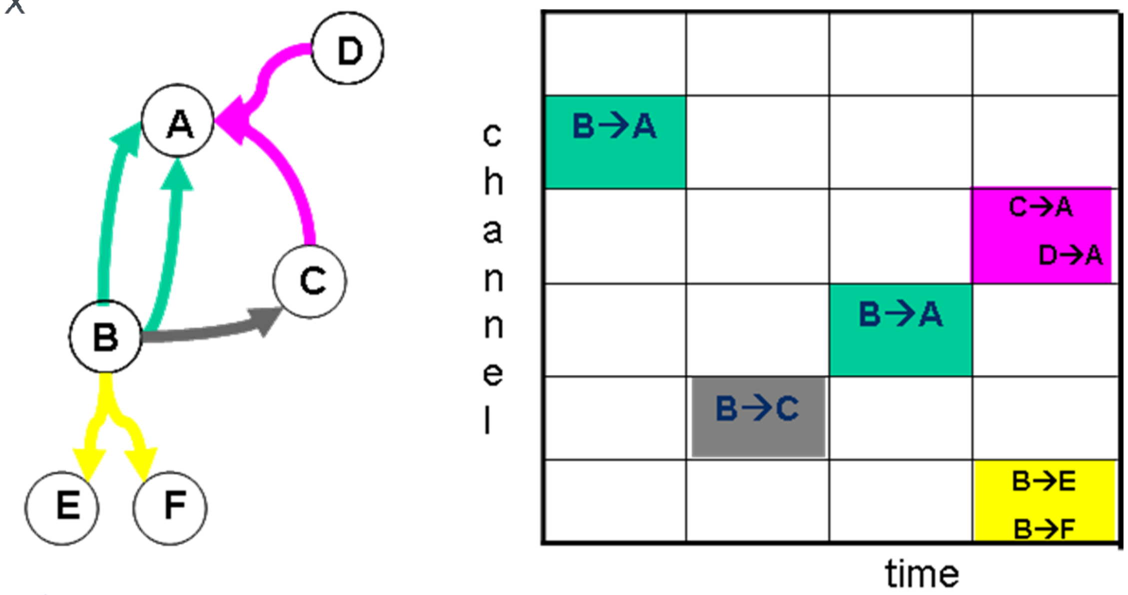
- Slotframe structure = sequence of repeated time slots:
  - time slot can be used by one/multiple devices (dedicated/shared link) or empty
  - multiple slotframes with different lengths can operate at the same time
  - SlotframeCycle: every new slotframe instance in time
  - Slotframe size: # slots in a slotframe



TRAN	UDP, TCP
routing	RPL
NET	IPv6
adaptation	6LoWPAN
MAC	IEEE802.15.4e
PHY	IEEE802.15.4

PA - Process Automation [2/2]

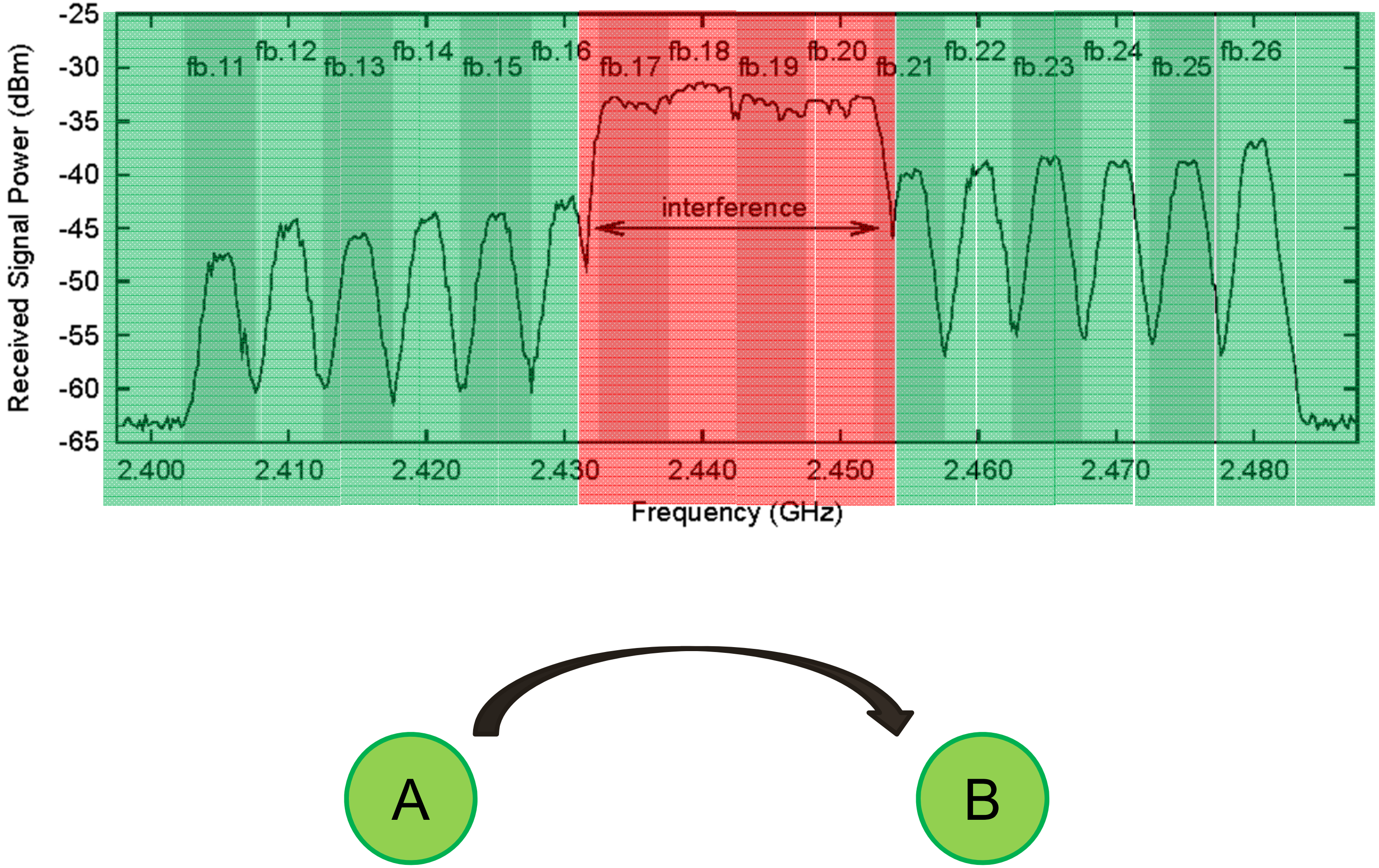
- Link = (time slot, channel offset) → **CHANNEL HOPPING**
- Dedicated link assigned to:
  - dedicated link: 1 node for Tx; 1 or more for Rx
  - shared link: 1 or more for Tx
- Prime aim to help:
  - channel impairments
  - system capacity



✓ 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

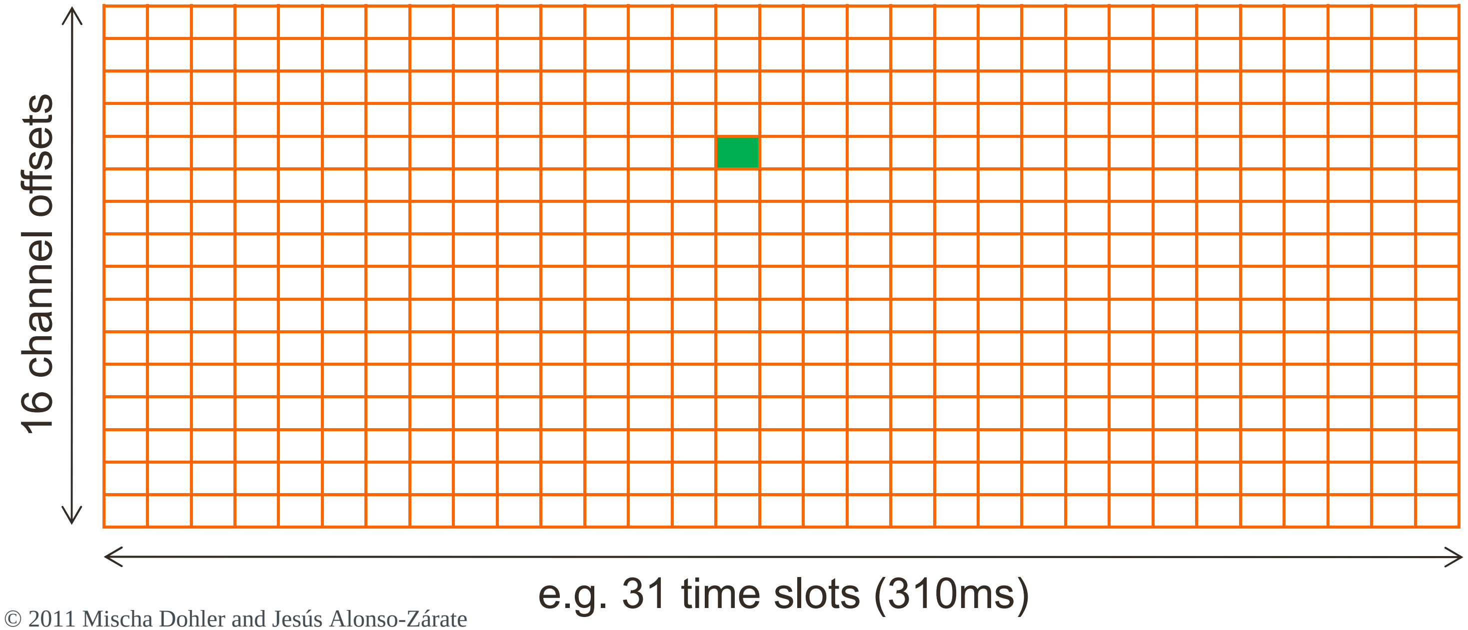
TRAN	UDP, TCP
routing	RPL
NET	IPv6
adaptation	6LoWPAN
MAC	IEEE802.15.4e
PHY	IEEE802.15.4

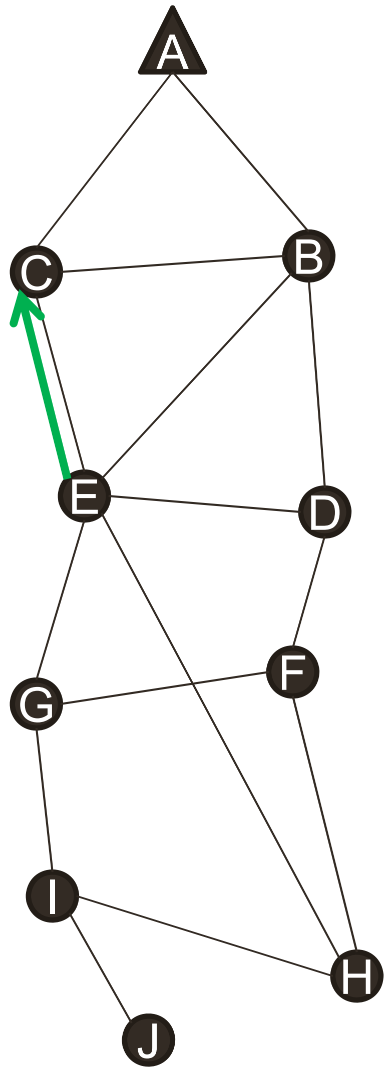


TRAN	UDP, TCP
routing	RPL
NET	IPv6
adaptation	6LoWPAN
MAC	IEEE802.15.4e
PHY	IEEE802.15.4

PA - Slotted Structure

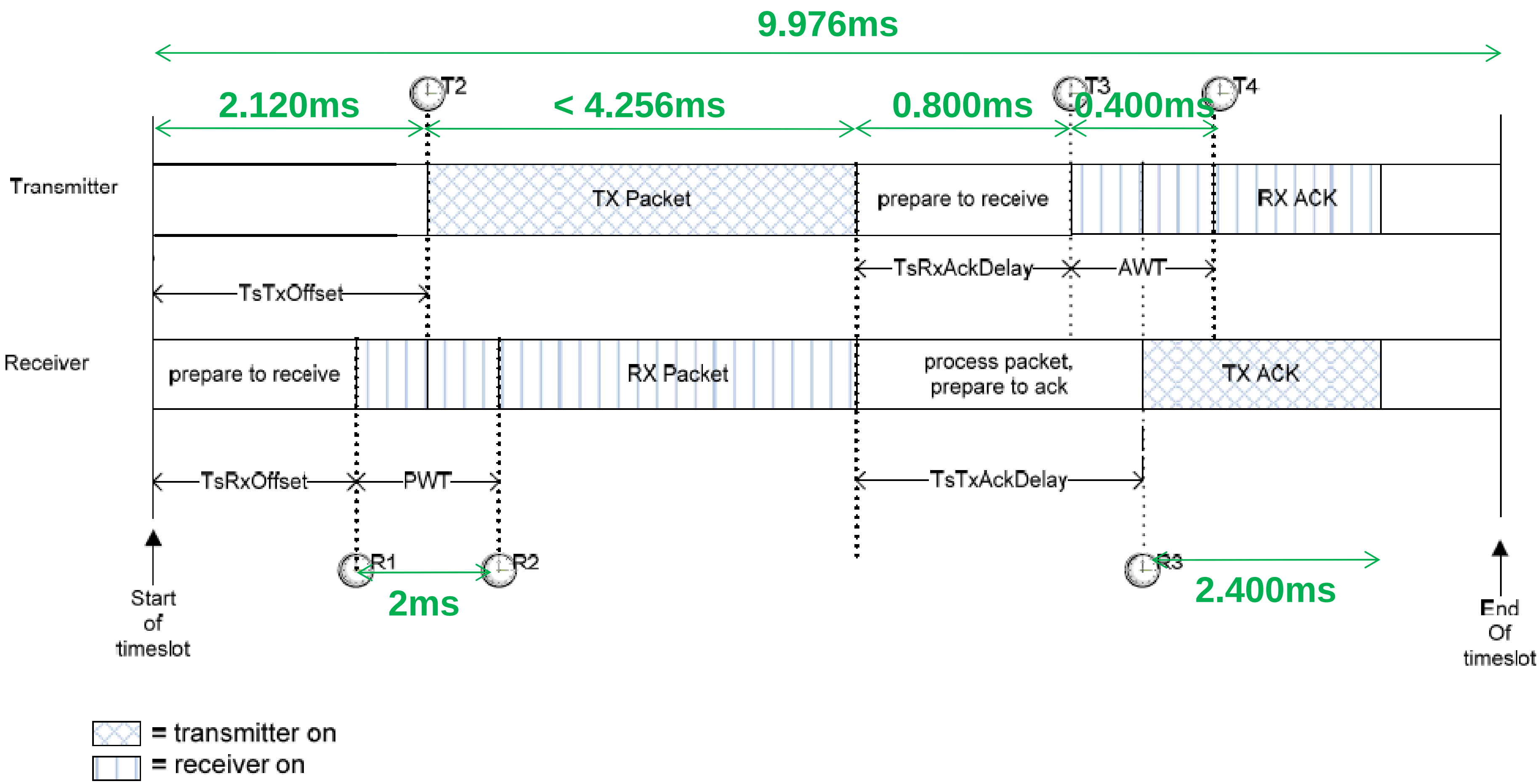
- A super-frame repeats over time
  - Number of slots in a superframe is tunable
  - Each cell can be assigned to a pair of motes, in a given direction





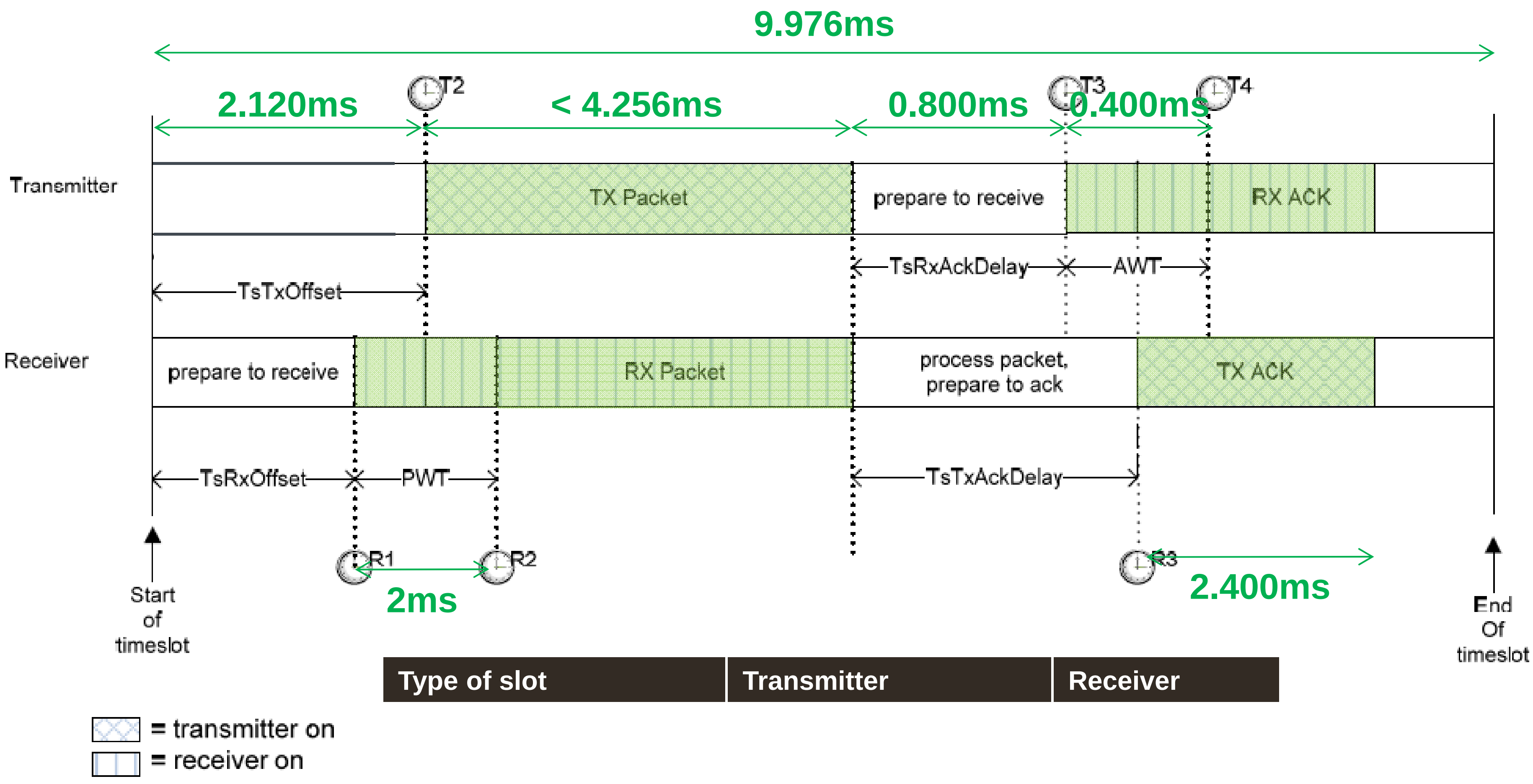
PA - Slot Structure

TRAN	UDP, TCP
routing	RPL
NET	IPv6
adaptation	6LoWPAN
MAC	IEEE802.15.4e
PHY	IEEE802.15.4



PA - Energy Consumption

TRAN	UDP, TCP
routing	RPL
NET	IPv6
adaptation	6LoWPAN
MAC	IEEE802.15.4e
PHY	IEEE802.15.4

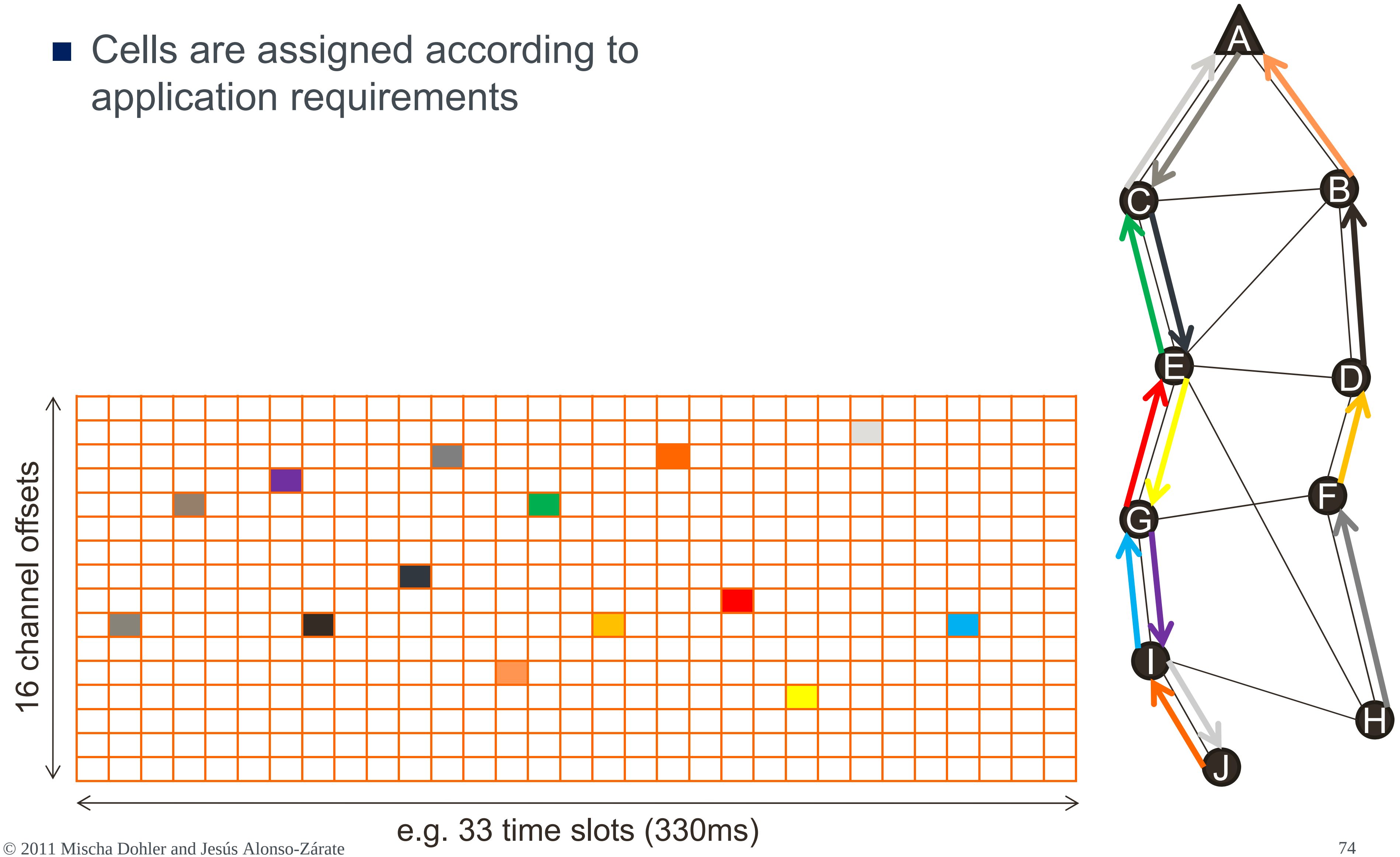


Type of slot	Transmitter	Receiver

TRAN	UDP, TCP
routing	RPL
NET	IPv6
adaptation	6LoWPAN
MAC	IEEE802.15.4e
PHY	IEEE802.15.4

PA - Slotted Structure

- Cells are assigned according to application requirements

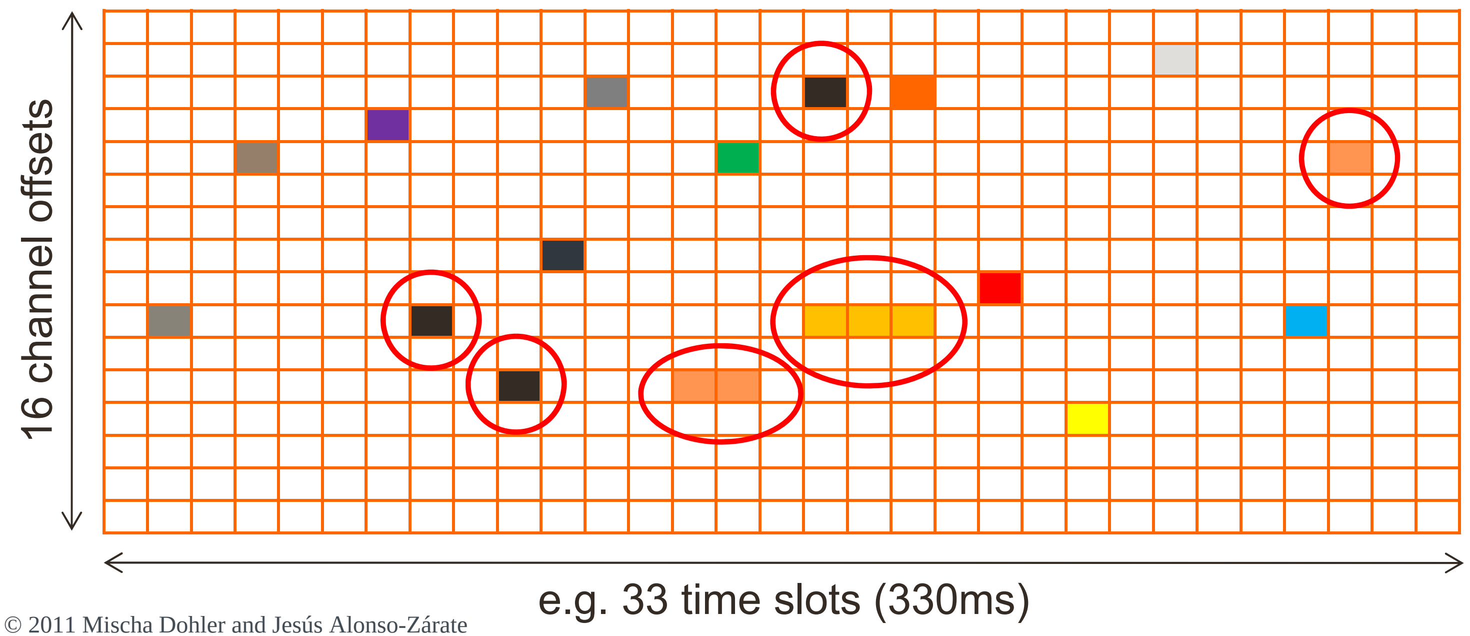


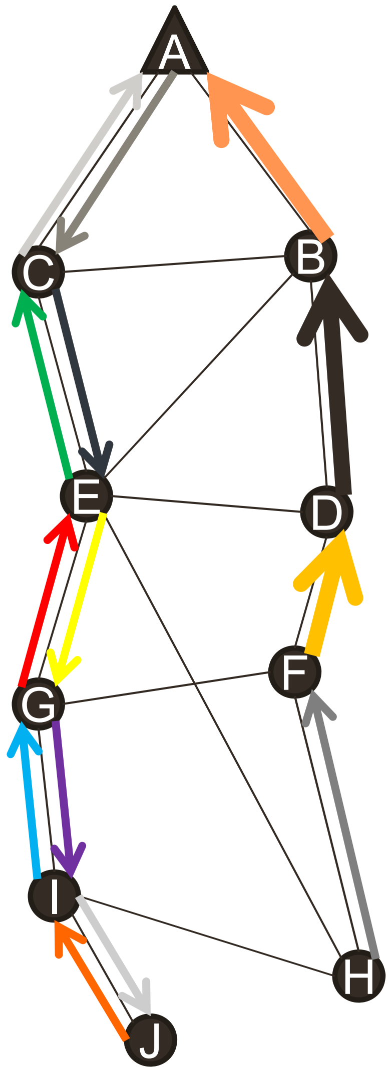
TRAN	UDP, TCP
routing	RPL
NET	IPv6
adaptation	6LoWPAN
MAC	IEEE802.15.4e
PHY	IEEE802.15.4

PA - Trade-Off [1/3]

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

…and energy consumption



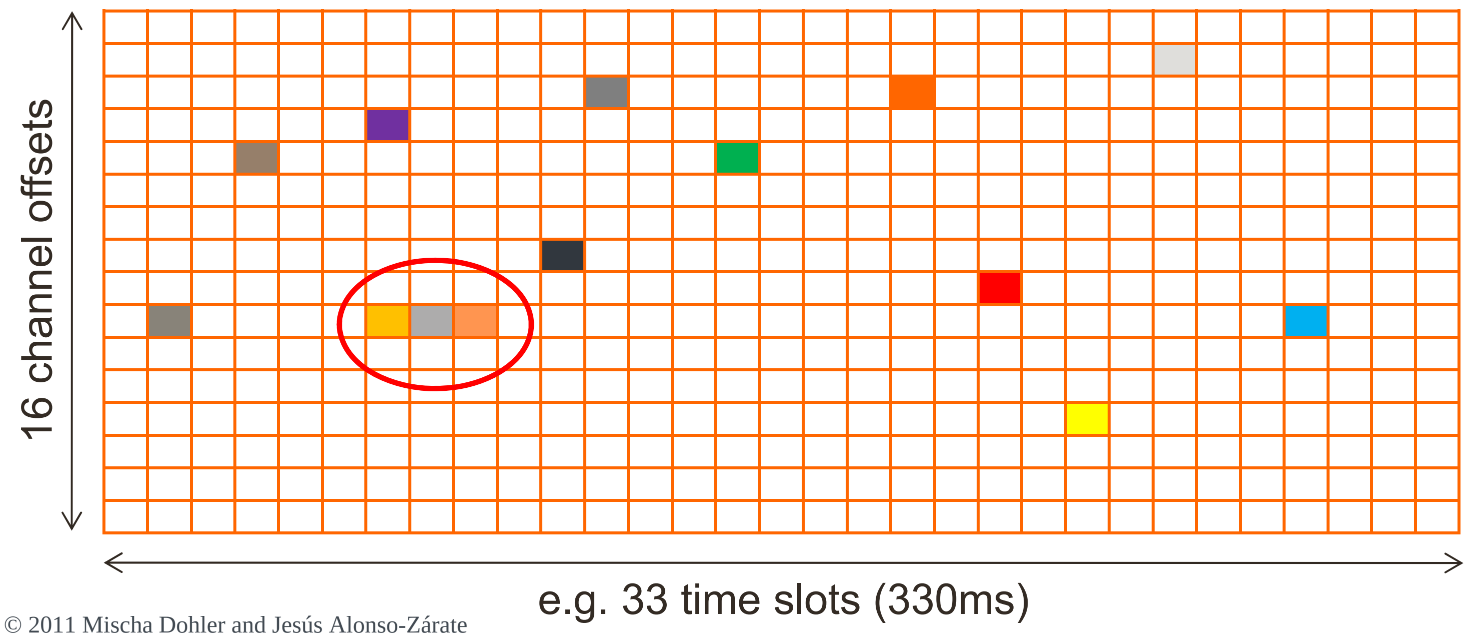


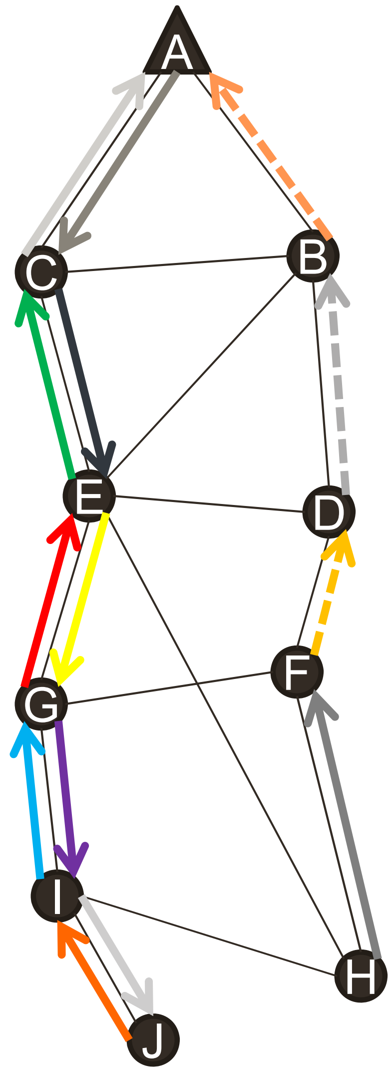
PA - Trade-Off [2/3]

TRAN	UDP, TCP
routing	RPL
NET	IPv6
adaptation	6LoWPAN
MAC	IEEE802.15.4e
PHY	IEEE802.15.4

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

…and energy consumption



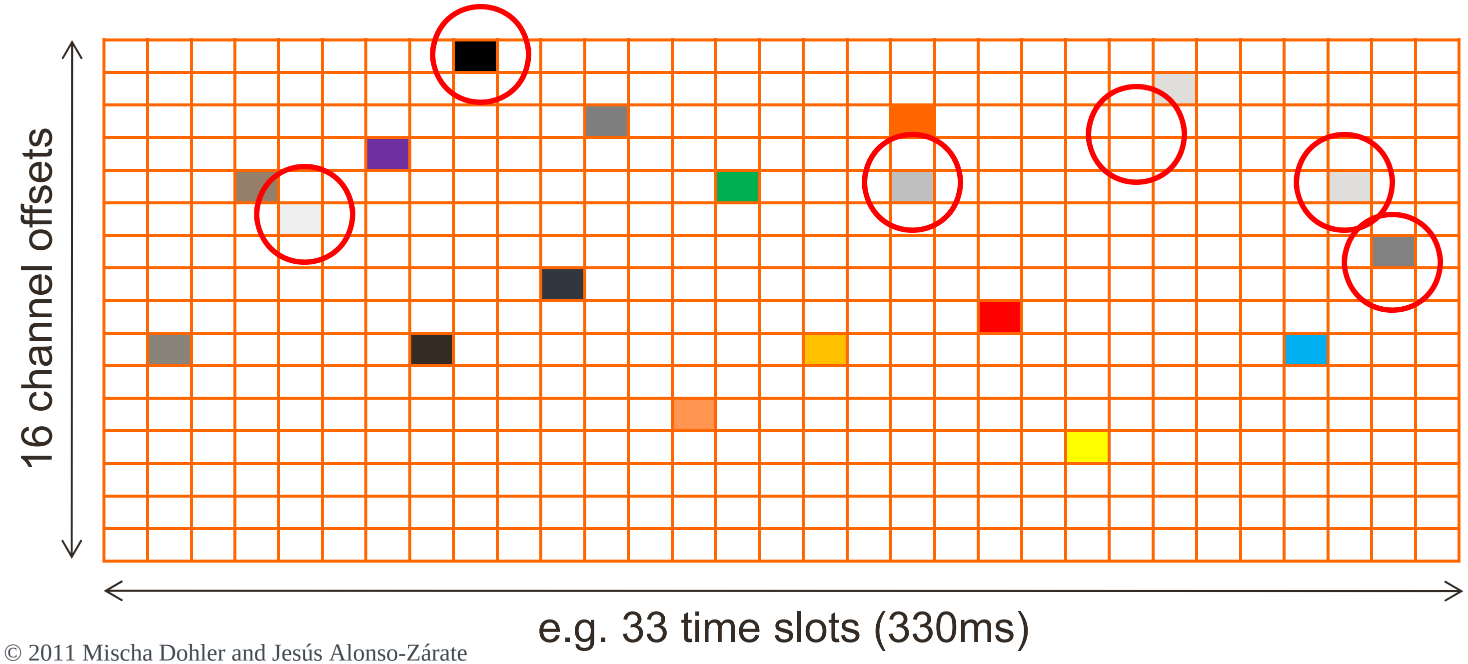


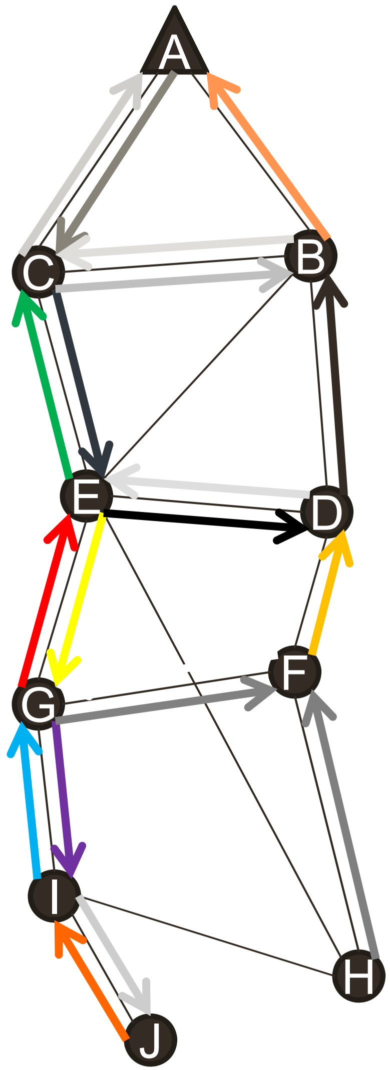
PA - Trade-Off [3/3]

TRAN	UDP, TCP
routing	RPL
NET	IPv6
adaptation	6LoWPAN
MAC	IEEE802.15.4e
PHY	IEEE802.15.4

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

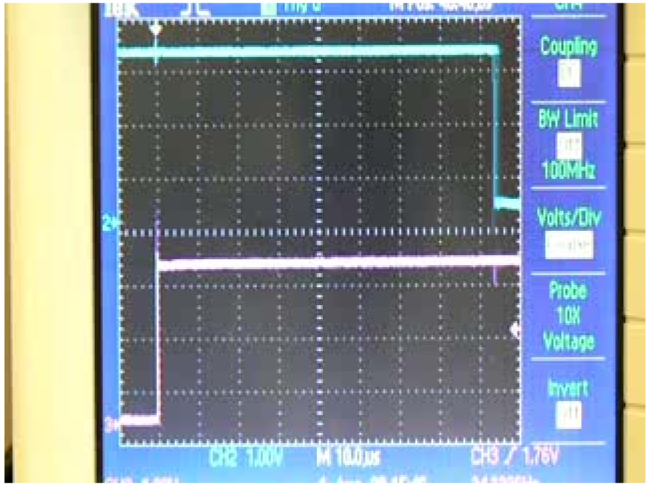
…and energy consumption



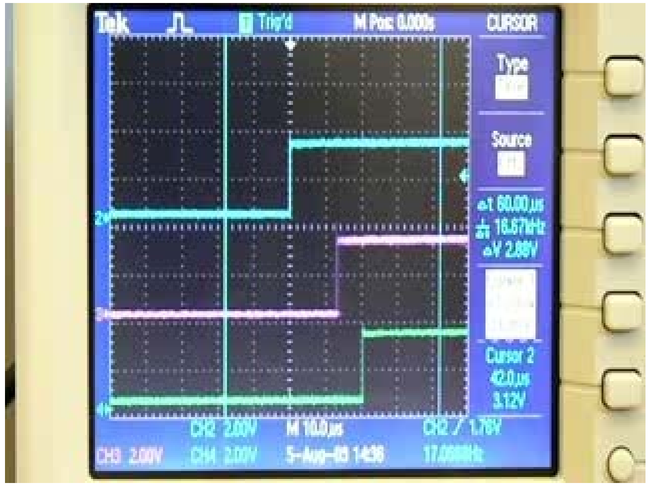


PA - Synchronization

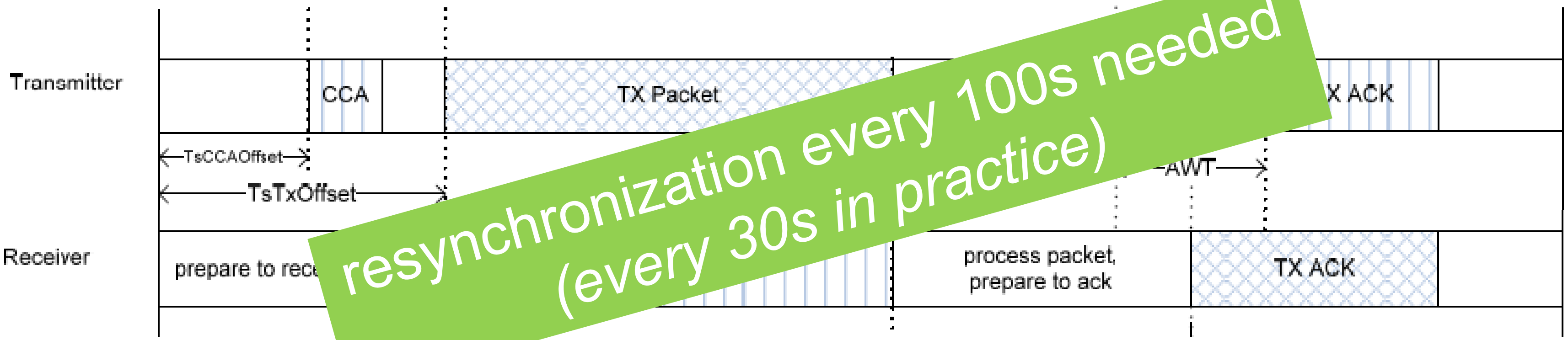
TRAN	UDP, TCP
routing	RPL
NET	IPv6
adaptation	6LoWPAN
MAC	IEEE802.15.4e
PHY	IEEE802.15.4



clocks drift
(10ppm typical)



Periodic realignment
(within a clock tick)



resynchronization every 100s needed
(every 30s in practice)

PA – Lifetime

TRAN	UDP, TCP
routing	RPL
NET	IPv6
adaptation	6LoWPAN
MAC	IEEE802.15.4e
PHY	IEEE802.15.4

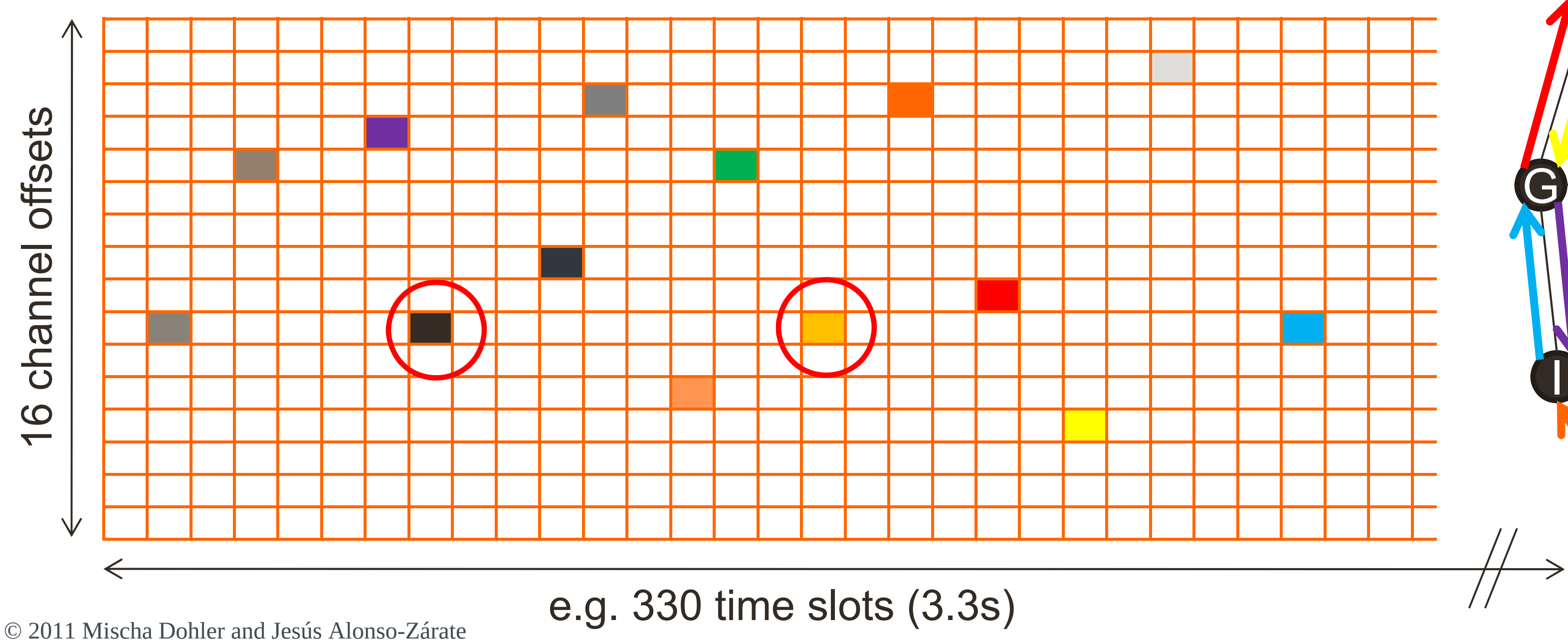
Type of slot	Transmitter	Receiver
“OFF”	-	-
transmission w. ACK	6.856ms	7.656ms
Transmission w.o. ACK	4.256ms	5.256ms
Listening w.o. reception	-	2.000ms

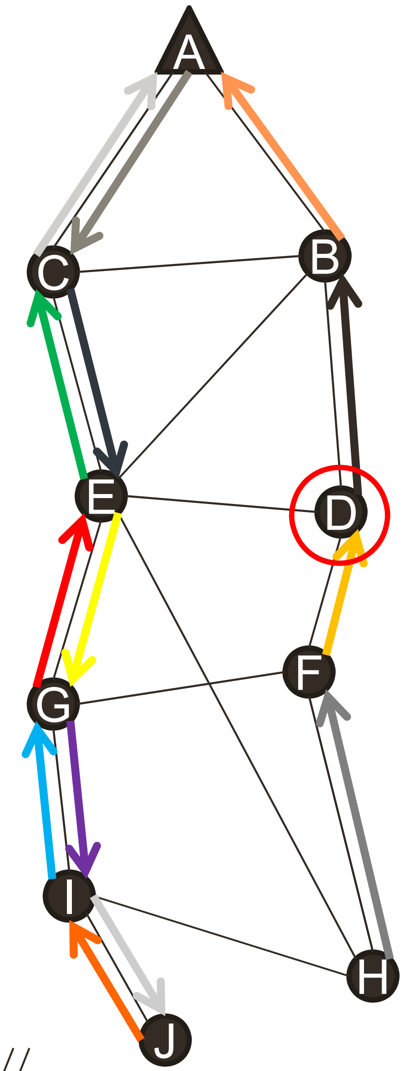
- Assumptions
  - 2400mAh (AA battery)
  - 14mA when radio on (AT86RF231)
- If my radio is on all the time
  - 171 hours of time budget (7 days of lifetime)
- If I only want to keep synchronization *(theoretical lower limit)*
  - 7.656ms from a time budget of 171 hours→ I can resync. 80×10^6 times
  - 76 years of lifetime (» battery shelf-life)
- A duty cycle of 1% → 2 years of lifetime

TRAN	UDP, TCP
routing	RPL
NET	IPv6
adaptation	6LoWPAN
MAC	IEEE802.15.4e
PHY	IEEE802.15.4

PA – Lifetime

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

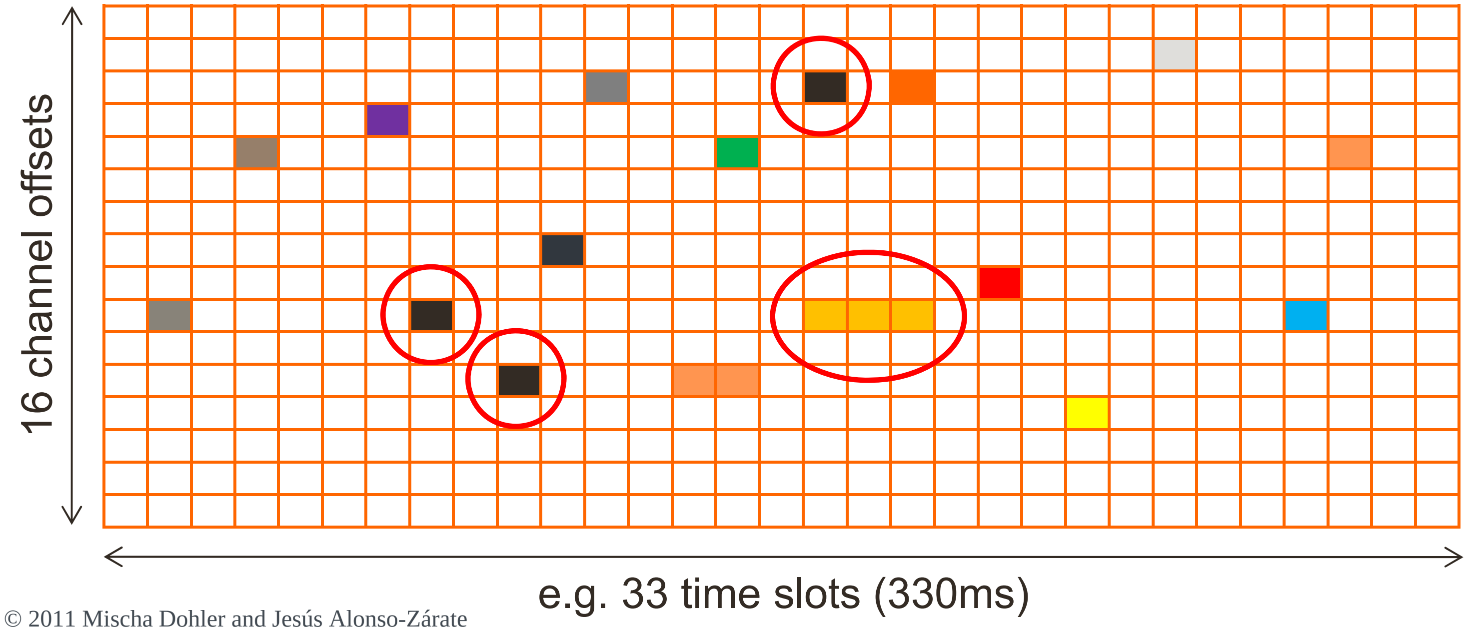


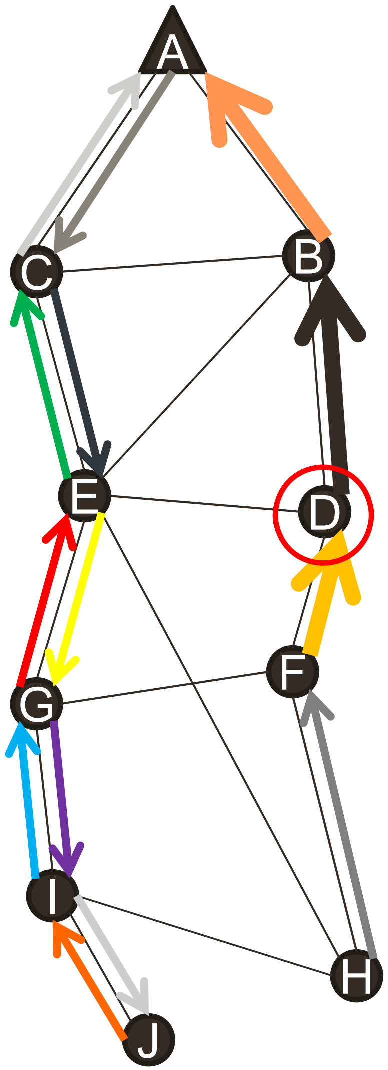


TRAN	UDP, TCP
routing	RPL
NET	IPv6
adaptation	6LoWPAN
MAC	IEEE802.15.4e
PHY	IEEE802.15.4

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





2.4.2

IETF-Pertinent M2M Standards

IETF – Overview

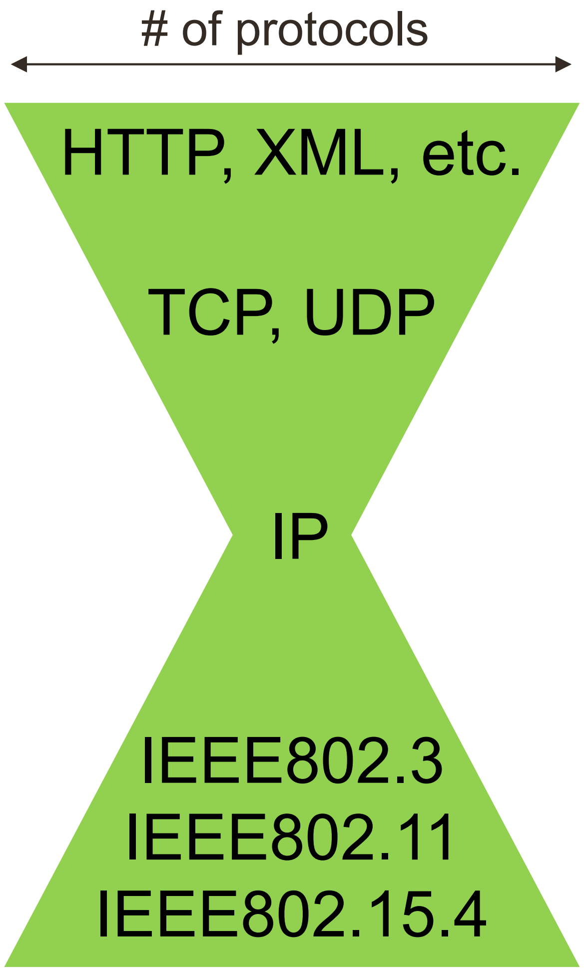
- Internet Engineering Task Force:
  - not approved by the US government; composed of individuals, not companies
  - quoting the spirit: “We reject kings, presidents and voting. We believe in rough consensus and running code.” D. Clark, 1992
  - more than 120 active working groups organized into 8 areas

- General scope of IETF:
  - above the wire/link and below the application
  - TCP/IP protocol suite: IP, TCP, routing protocols, etc.
  - however, layers are getting fuzzy (MAC & APL influence routing)
  - hence a constant exploration of "edges“

- IETF developments pertinent to Capillary M2M:
  - 6LoWPAN (IPv6 over Low power WPAN)
  - ROLL (Routing Over Low power and Lossy networks)
  - CORE (Constrained RESTful Environments)

Internet Protocol (IP) version 6

TRAN	UDP, TCP
routing	RPL
NET	IPv6
adaptation	6LoWPAN
MAC	IEEE802.15.4e
PHY	IEEE802.15.4



- 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

TRAN	UDP, TCP
routing	RPL
NET	IPv6
adaptation	6LoWPAN
MAC	IEEE802.15.4e
PHY	IEEE802.15.4

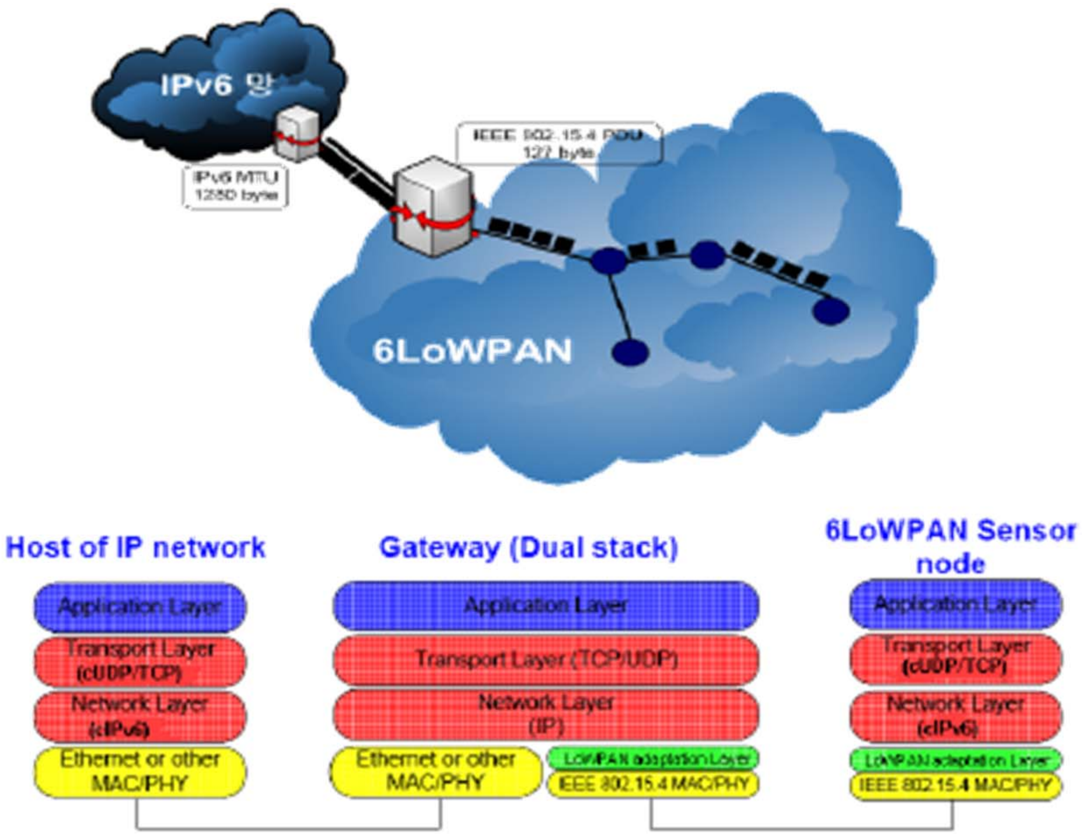
- 6LoWPAN has the following key properties:
  - IPv6 for very low power embedded devices using IEEE 802.15.4
  - provision of neighborhood discovery protocol
  - header compression with up to 80% compression rate
  - packet fragmentation (1260 byte IPv6 frames -> 127 byte 802.15.4 frames)
  - direct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

MAC	6LowPAN			Application data	MAC
7-11	2-11	2	4	111-98	4
IEEE 802.15.4	LowPAN	cIPv6	cUDP	PAYLOAD	CRC

TRAN	UDP, TCP
routing	RPL
NET	IPv6
adaptation	6LoWPAN
MAC	IEEE802.15.4e
PHY	IEEE802.15.4

IETF 6LoWPAN

- Typical architecture:



TRAN	UDP, TCP
routing	RPL
NET	IPv6
adaptation	6LoWPAN
MAC	IEEE802.15.4e
PHY	IEEE802.15.4

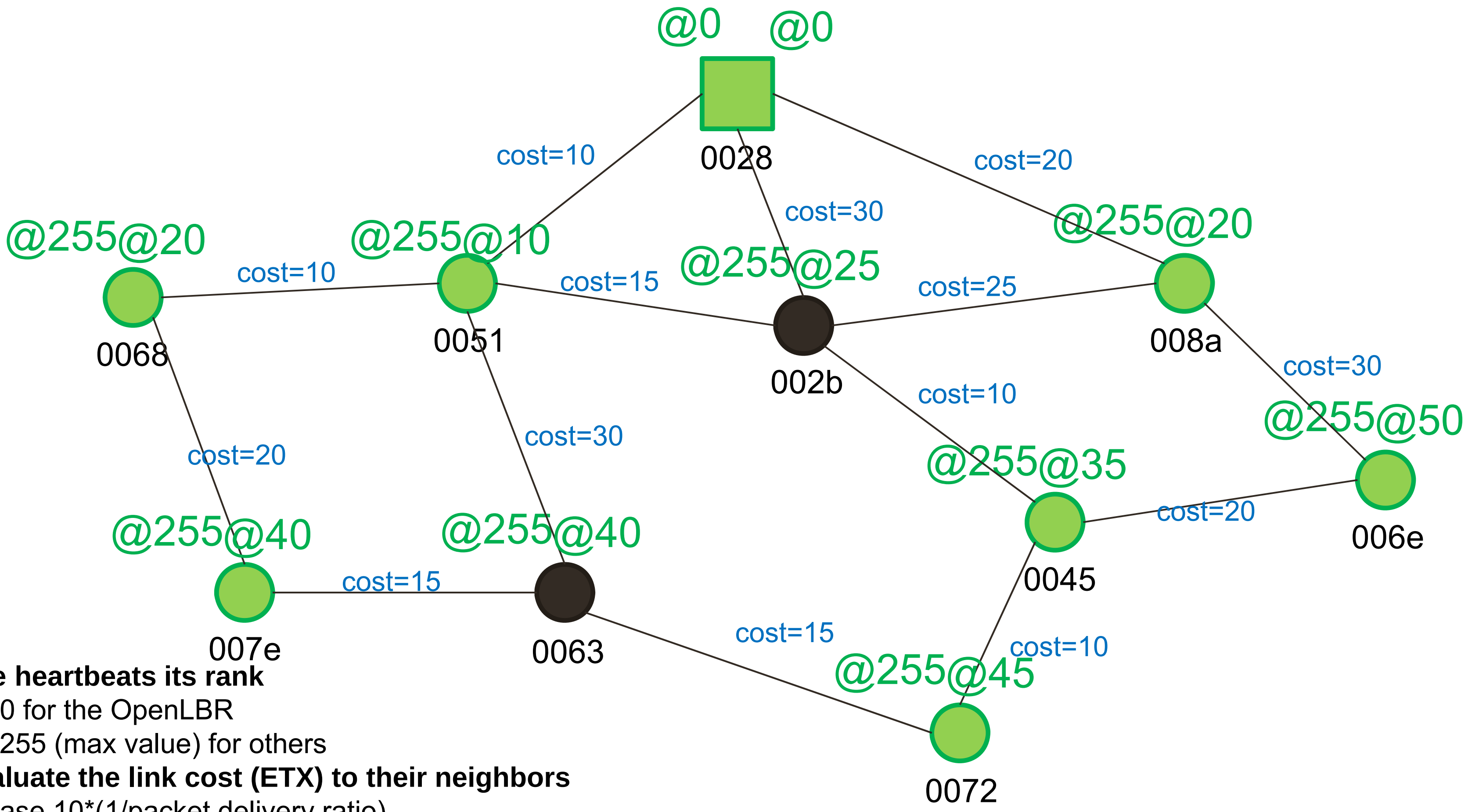
IETF ROLL – Status

- IETF WG “Routing Over Low power and Lossy networks”
  - Design a routing protocol for Wireless Mesh Network
  - Final stage of standardization
- Gradient Routing
  - Nodes acquire a “rank” based on the distance to the collecting node
  - Message follow the gradient of ranks

```
ROLL                                                    T. Winter, Ed.
Internet-Draft
Intended status: Standards Track                       P. Thubert, Ed.
Expires: January 29, 2011                                Cisco Systems
                                                       RPL Author Team
                                                          IETF ROLL WG
                                                         July 28, 2010

     RPL: IPv6 Routing Protocol for Low power and Lossy Networks
                        draft-ietf-roll-rpl-11

Abstract

   Low power and Lossy Networks (LLNs) are a class of network in which
   both the routers and their interconnect are constrained: LLN routers
   typically operate with constraints on (any subset of) processing
   power, memory and energy (battery), and their interconnects are
   characterized by (any subset of) high loss rates, low data rates and
   instability.  LLNs are comprised of anything from a few dozen and up
   to thousands of routers, and support point-to-point traffic (between
   devices inside the LLN), point-to-multipoint traffic (from a central
   control point to a subset of devices inside the LLN) and multipoint-
   to-point traffic (from devices inside the LLN towards a central
   control point).  This document specifies the IPv6 Routing Protocol
   for LLNs (RPL), which provides a mechanism whereby multipoint-to-
   point traffic from devices inside the LLN towards a central control
   point, as well as point-to-multipoint traffic from the central
   control point to the devices inside the LLN, is supported.  Support
   for point-to-point traffic is also available.

Status of this Memo

   This Internet-Draft is submitted in full conformance with the
   provisions of BCP 78 and BCP 79.

   Internet-Drafts are working documents of the Internet Engineering
   Task Force (IETF).  Note that other groups may also distribute
   working documents as Internet-Drafts.  The list of current Internet-
   Drafts is at http://datatracker.ietf.org/drafts/current/.

   Internet-Drafts are draft documents valid for a maximum of six months
   and may be updated, replaced, or obsoleted by other documents at any
   time.  It is inappropriate to use Internet-Drafts as reference
   material or to cite them other than as "work in progress."

   This Internet-Draft will expire on January 29, 2011.


Winter, et al.          Expires January 29, 2011                [Page 1]
```

IETF RPL – Gradient Routing

TRAN	UDP, TCP
routing	RPL
NET	IPv6
adaptation	6LoWPAN
MAC	IEEE802.15.4e
PHY	IEEE802.15.4



1. Each node heartbeats its rank
- Initially 0 for the OpenLBR
- Initially 255 (max value) for others

2. Nodes evaluate the link cost (ETX) to their neighbors
- In our case 10*(1/packet delivery ratio)
- Perfect link: cost=10
- Link with 50% loss: cost=20

3. Nodes update their rank as min(rank neighbor+link cost) over all neighbors
- The chosen neighbor is preferred routing parent

4. Continuous updating process

3
Cellular M2M

Cellular M2M: Outline

- **3.1 Introduction to Cellular M2M**
  - 3.1.1 Fundamentals of Cellular Systems
  - 3.1.2 Motivating Cellular Systems for 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
- **3.3 Cellular M2M Standardization Activities**
  - 3.3.1 Overview of Standardization in Cellular Communications
  - 3.3.2 M2M Activities in ETSI
  - 3.3.3 M2M Activities in 3GPP
  - 3.3.4 M2M Activities in IEEE
- **3.4 Concluding Remarks**

3.1

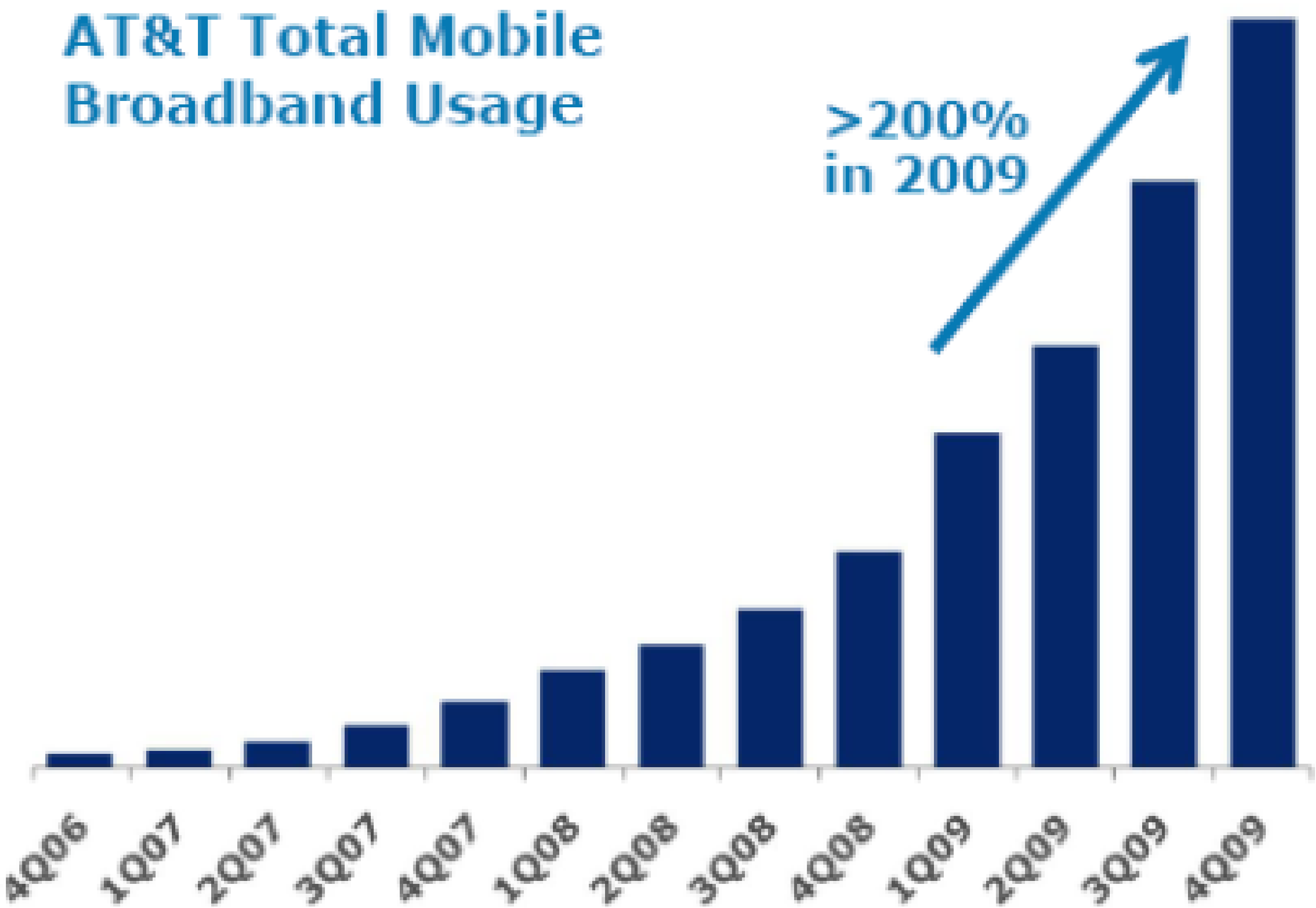
Introduction to Cellular M2M

3.1.1

Fundamentals of Cellular Systems

Data Traffic Evolution - PAST

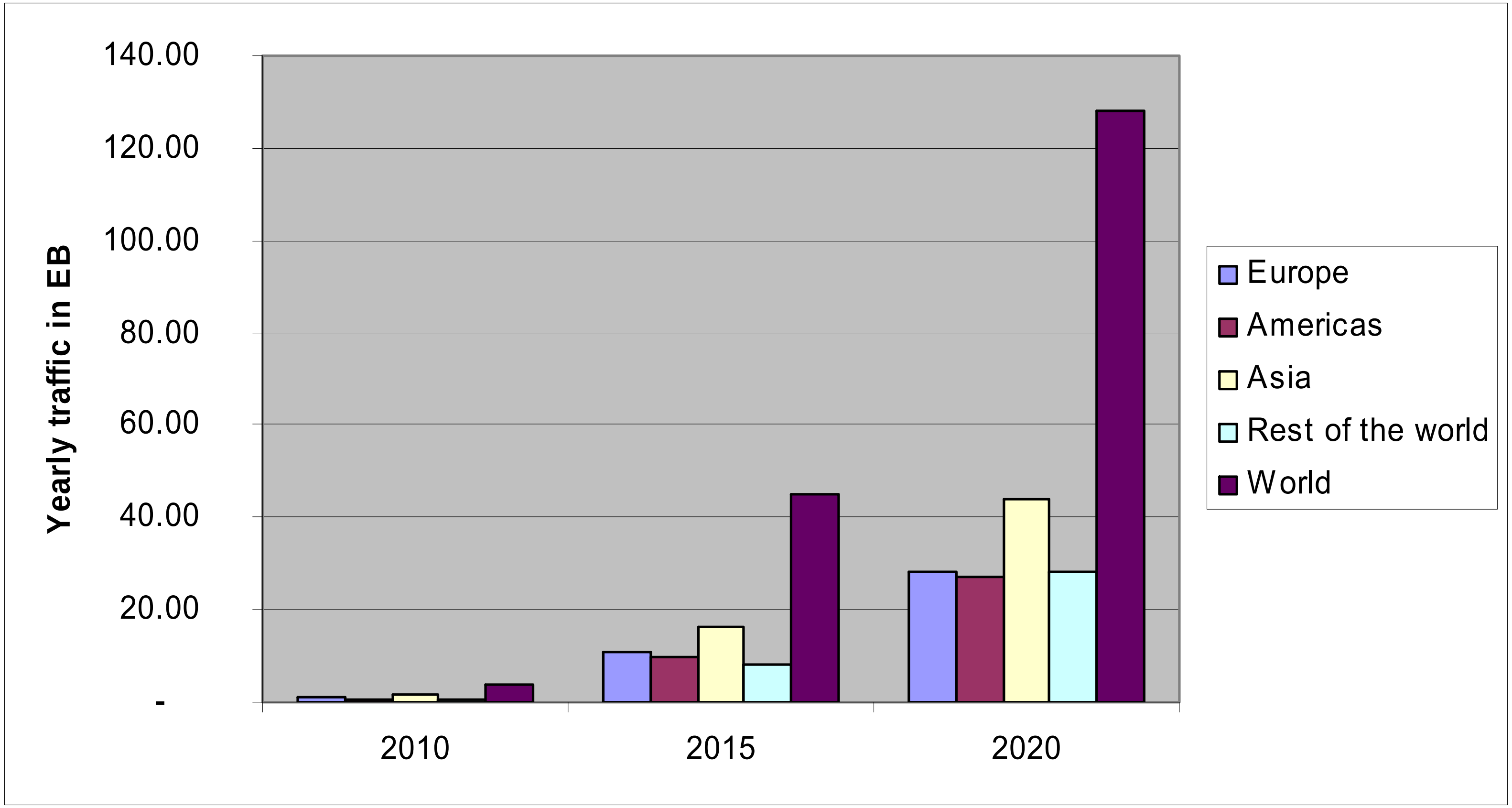
AT&T traffic evolution



Source: AT&T

Data Traffic Evolution - FUTURE

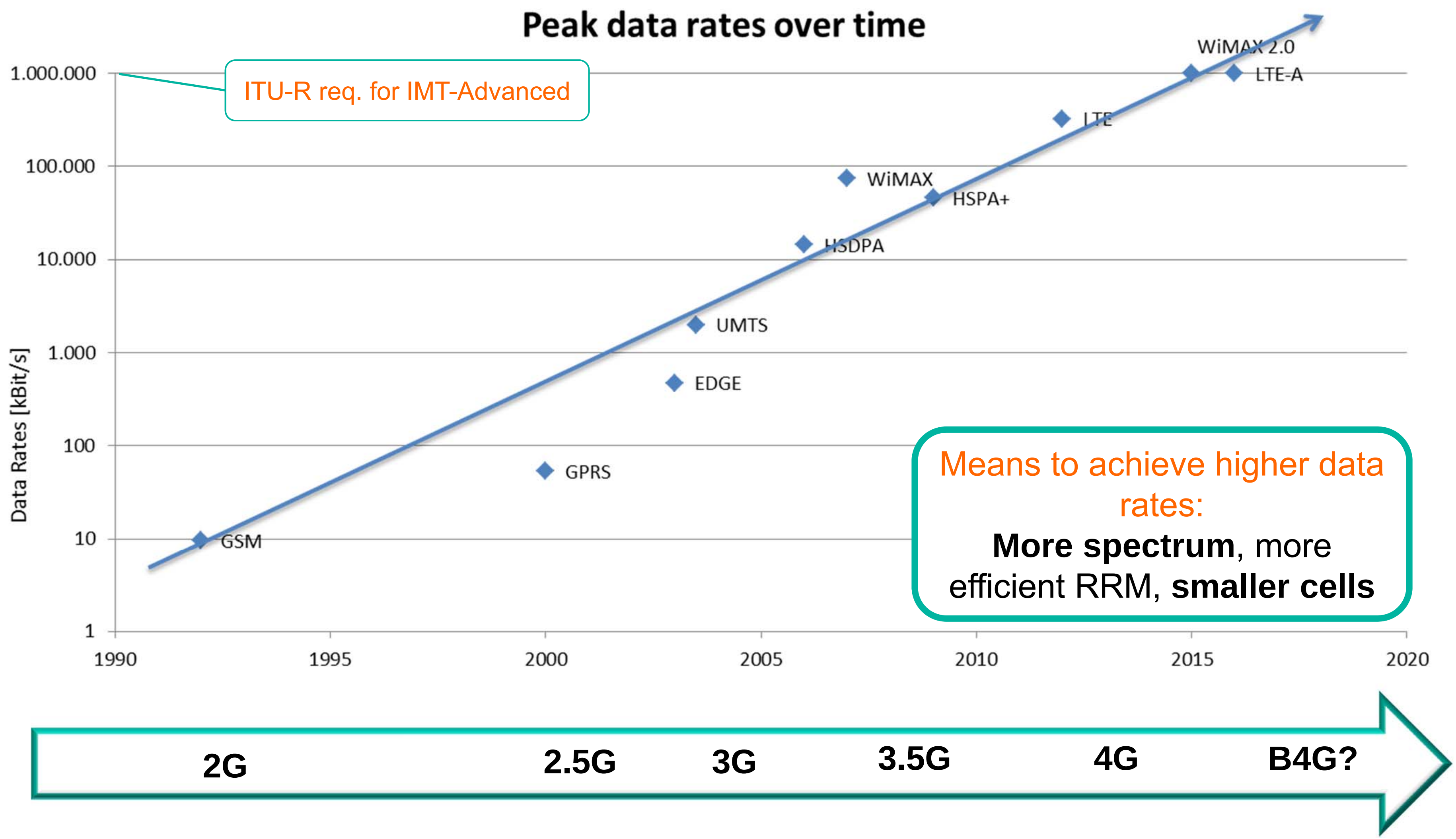
Total mobile traffic (EB per year)



Source: IDATE

Exabyte = 10^18

Cellular Evolution



Means to achieve higher data rates:
More spectrum, more efficient RRM, **smaller cells**

Source: NEC – Andreas Maeder, Feb 2012

Cellular Generation Salad [1/2]

- **2G Networks**:
  - GSM (Global System for Mobile Communications), 1990, worldwide
  - IS95 (Interim Standard 95), mainly US
- **2.5G Network**:
  - GPRS (General Packet Radio System), worldwide
- **3G Networks:**
  - EDGE (Enhanced Data Rates for GSM Evolution), GSM evolution
  - UMTS (Universal Mobile Telecommunication System) (3GPP-Release 4)
  - CDMA2000 (based on 2G CDMA Technology) (3GPP2), discontinued in 2008
  - WiMAX, IEEE 802.16 technology
- **3.5G Network:**
  - HDxPA (High Data Packet Access), 3GPP evolution (Release 5 and 6), 2007
  - HDPA+ with complementary EDGE (Release 7)

Cellular Generation Salad [2/2]

- **“3.9G” Network:**
  - December 2008: LTE (Long Term Evolution), UMTS evolution/revolution, worldwide, **Release 8**, small enhancements in **Release 9**

- **4G Networks:**
  - LTE-A (LTE Advanced), LTE evolution/revolution, worldwide, 2009 first submission to be considered for IMT-advanced, **Release 10**
  - WiMAX II, IEEE 802.16j/m high capacity networks

Note that both LTE and WiMAX are regarded as beyond 3G (B3G) systems but are strictly speaking not 4G since not fulfilling the requirements set out by the ITU for 4G next generation mobile networks (NGMN). NGMN requires downlink rates of 100 Mbps for mobile and 1 Gbps for fixed-nomadic users at bandwidths of around 100 MHz which is the prime design target of LTE Advanced and WiMAX II. Therefore, even though LTE is (somehow wrongly but understandably) marketed as 4G, it is not and we still need to wait for LTE-A.

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

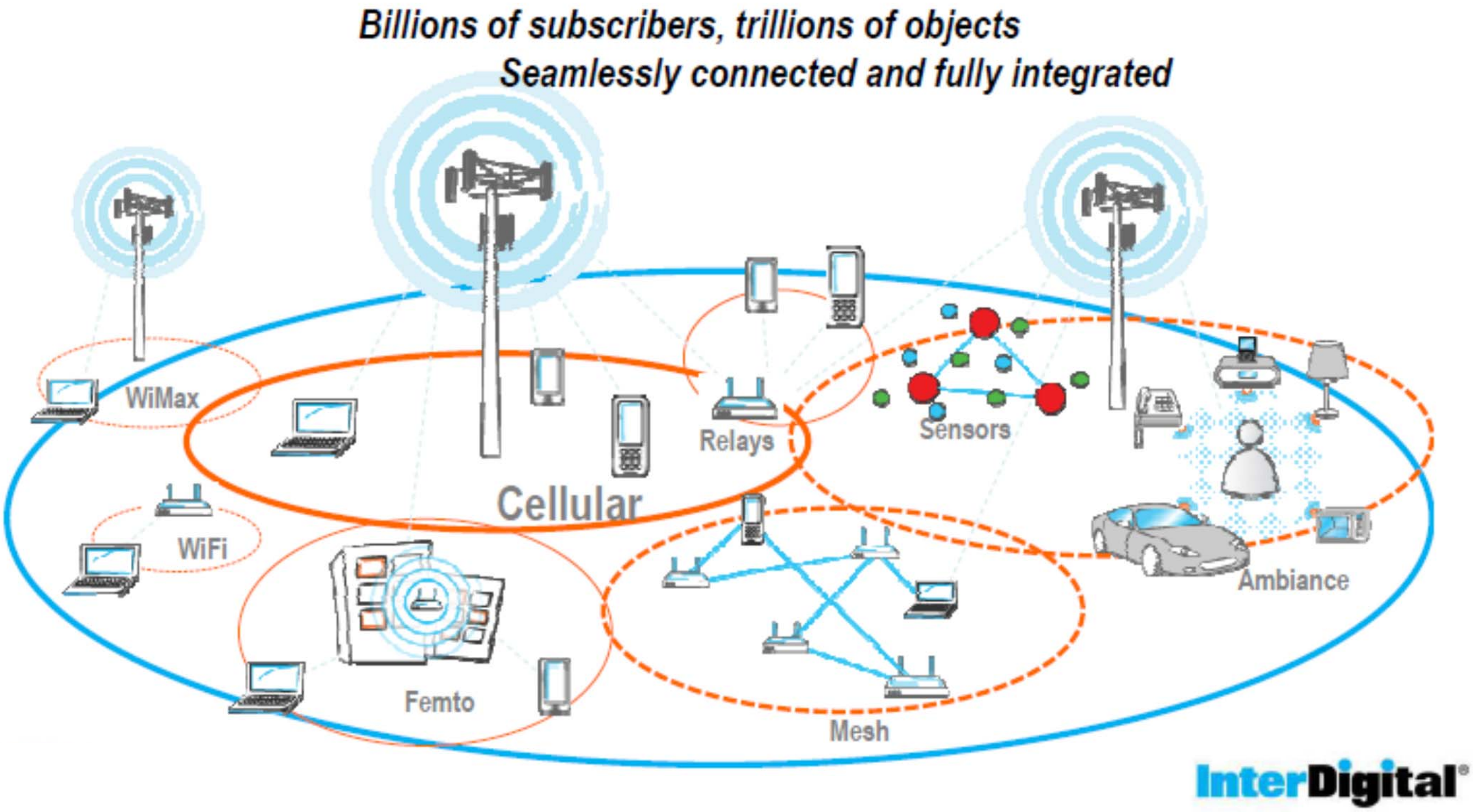
- **Technical Specification Group (TSG) Service and Systems Aspects (SA) Report – September 2010**:
  - http://www.3gpp.org/ftp/tsg_sa/TSG_SA/TSGS_49/Report/

- **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/

However, things are changing…

Vision of the Network of Things

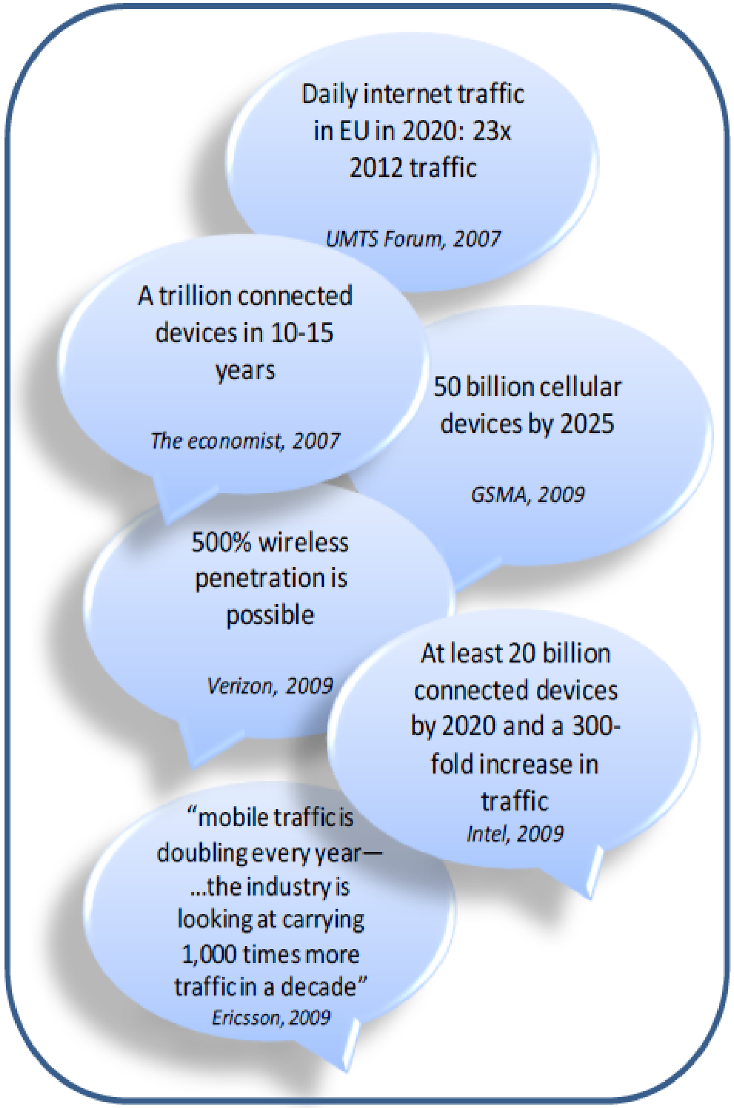


Presented by Interdigital: Globecom'11 – IWM2M, Houston

3.1.2

Motivating Cellular for M2M Applications

A Simple Motivation: Numbers



Source: "The revenue opportunity for mobile connected devices in **saturated markets**," Northstream White Paper, February 2010

A Simple Motivation: Initiatives

- **Global Initiatives:**
  - ETSI, GSMA, TIA TR-50 Smart Device Communications
- **Modules & Modems:**
  - Anydata, CalAmp, Cinterion, DiGi, Enfora, Ericsson, eDevice, Inside M2M, Iwow, Laird Technologies, Maestro, Moxa, Multitech, Motorola, Mobile Devices, Owasys, Quectel Industry, Sagem, Sierra Wireless, SimCom, Telit, Teltonika, uBlox
- **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

- 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
  - value of network is generally non-linearly related to number of objects (low ARPU)

Challenges for Mobile Operators

- So far, mobile operators are experts in communicating humans → M2M is a new market and a ***mentality shift*** is required in many transversal areas
- Fragmentation and complexity of applications
- (so far…) Lack of ***standardization***
- Technological competition
- Low revenue per connection (ARPU)
- Relatively high operational costs (the network has to be dimensioned for a number of devices that just transmit few information from time to time)
- Lack of experience → operators have to analyze and try!

Cellular M2M – What’s New?

- 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
- **Power Management**:
  - 8 power classes; min 20 mW = 13 dBm
  - (2dB power control steps)
- **Modulation**:
  - GMSK → constant envelope
- **PHY Data Rates**:
  - 9.6 kbit/s per user
- **Complexity**:
  - fairly low as of 2010

M2M

the lower, the better

can be easily handled

good for M2M PA

too low for many app

generally, good candidate

GSM – MAC Layer

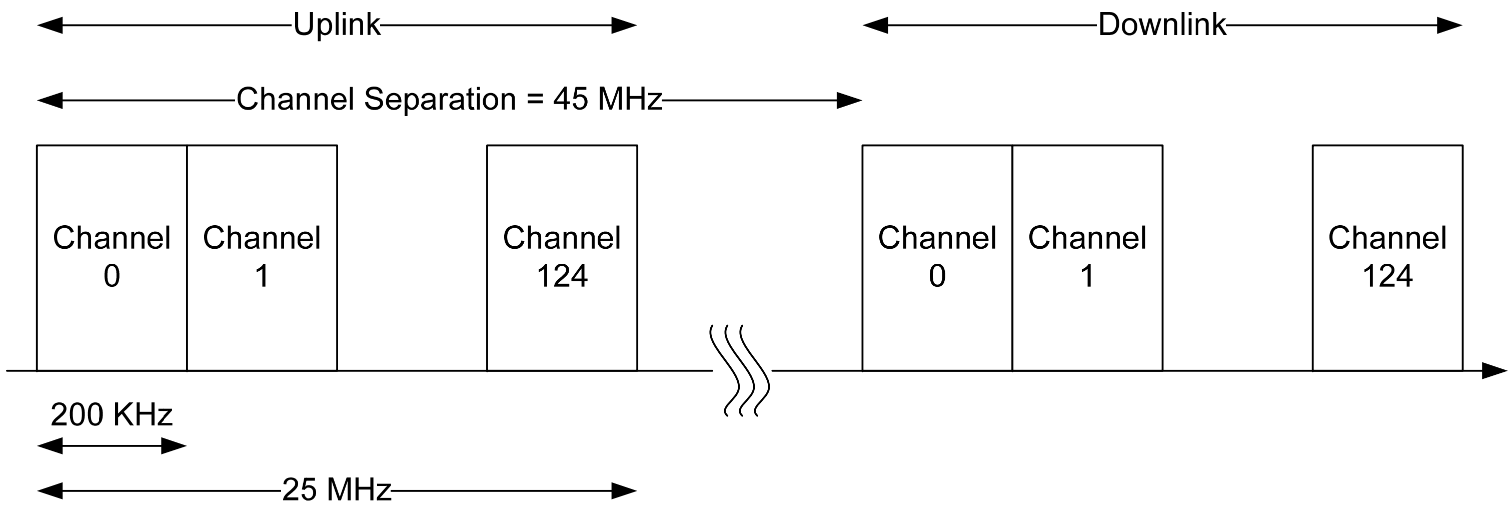
M2M

- **Duplexing**:
  - FDD

TDD would be better

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

can be easily handled



GSM – Traffic Types

M2M

- **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

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

3.2.2

3GPP Family: UMTS (3G), LTE (3.9G) & LTE-A (4G)

UMTS – PHY Layer

	M2M
Carrier Frequency:	
▪ around 2 GHz, and others	losses problematic
Power Management:	
▪ fast power control is must	**big** challenge
▪ (1dB power control steps)	
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

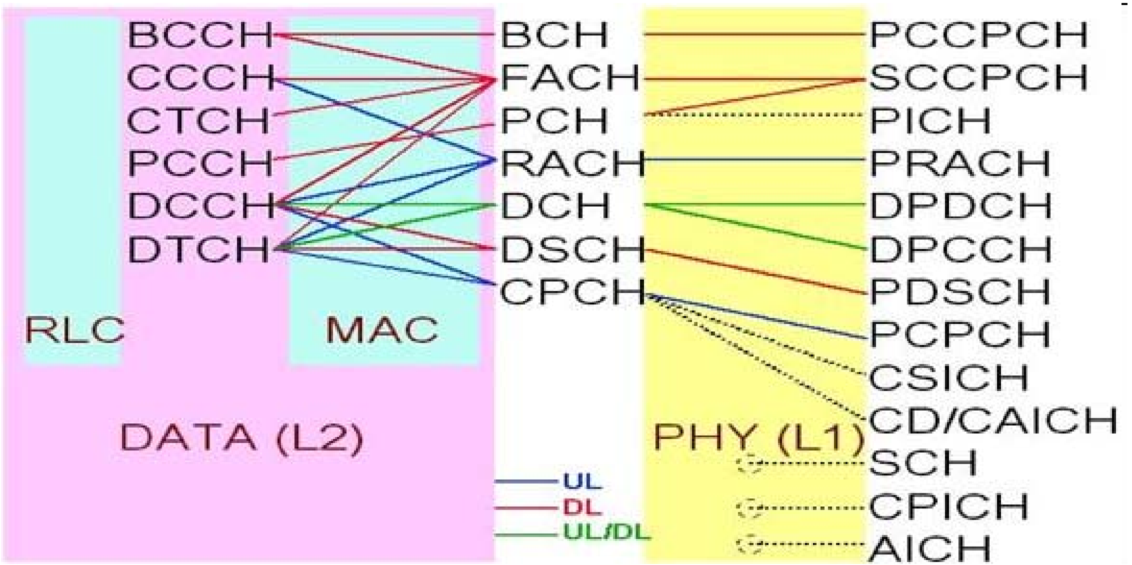
M2M

- **Duplexing**:
  - FDD

TDD would be better

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

could be handled but limited number of codes



UMTS – Traffic Types

	M2M
Conversational Class: voice, video telephony, gaming	little application in M2M
Streaming Class: multimedia, video on demand, webcast	little application in M2M
Interactive Class: web browsing, network gaming, etc	of use in control appl.
Background Class: email, SMS, downloading, etc	of use in wide range of M2M

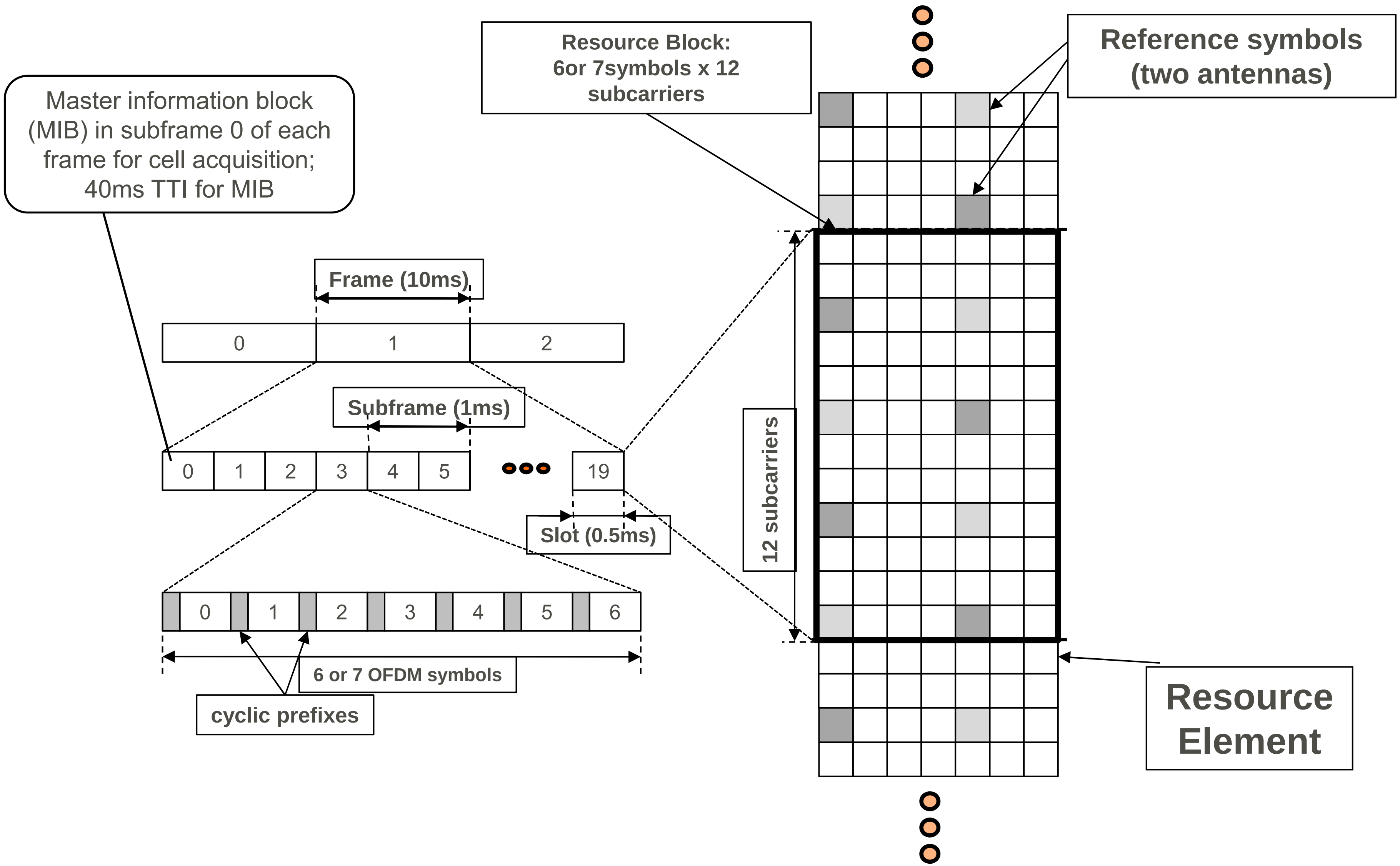
- **M2M Class**?
  - small data bundles, mission-critical

Beyond UMTS – LTE & LTE-A

- **LTE (Release 8 and 9)** = UMTS + …
  - 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
  - More User Capacity (x10)

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

Beyond UMTS – LTE & LTE-A



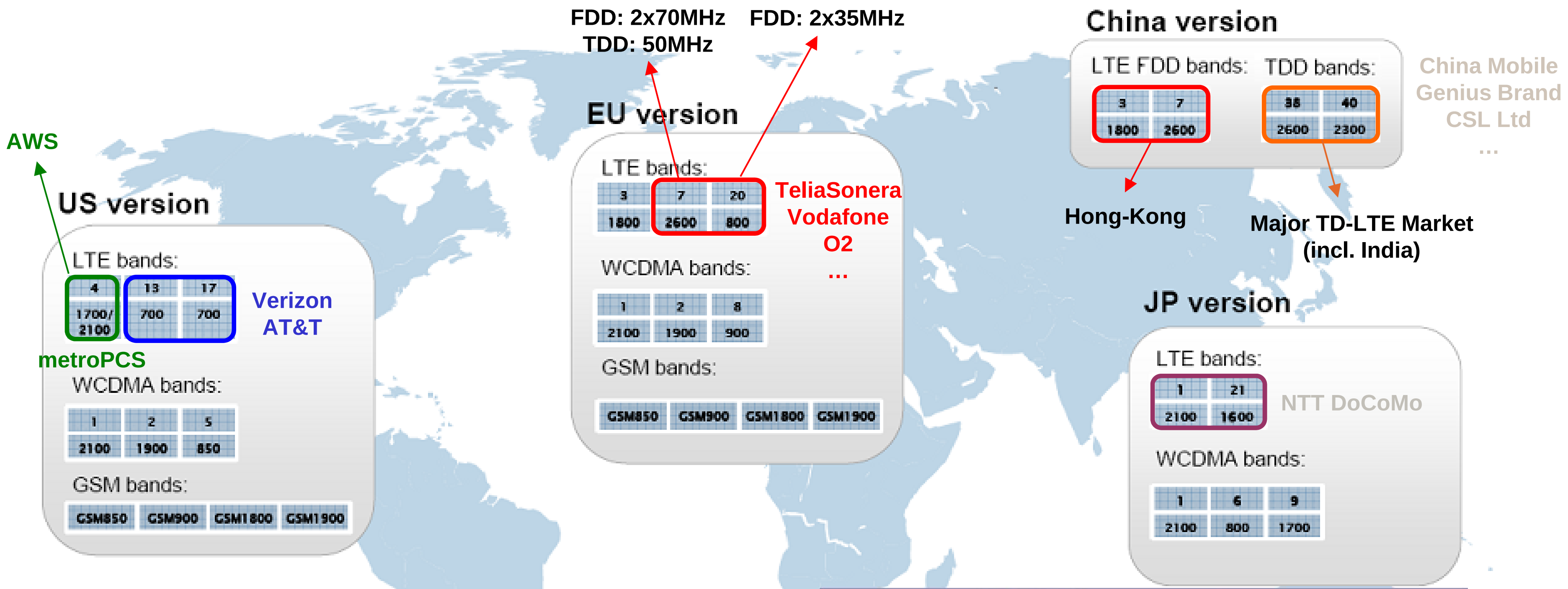
Key Limitations of LTE & LTE-A

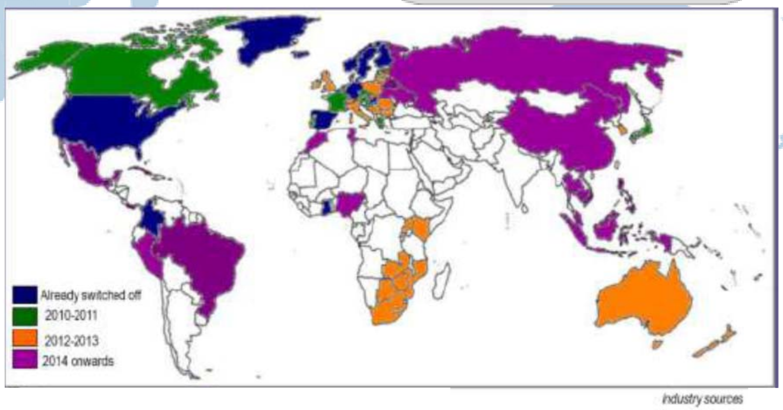
- Not efficient for small data transmission
- Scheduled Radio access → random access and more flexibility
- Device cost issues
  - Scalable bandwidth
  - Data rate (overdesigned UE categories)
  - Transmit power (max. 23dBm)
  - Half Duplex operation (simpler device)
  - RF chains with 2 antennas
  - 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

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!

3.3
M2M Cellular Standardization Activities

http://www.3gpp.org/ftp/Information/WORK_PLAN/Description_Releases/M2M_20120124.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

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

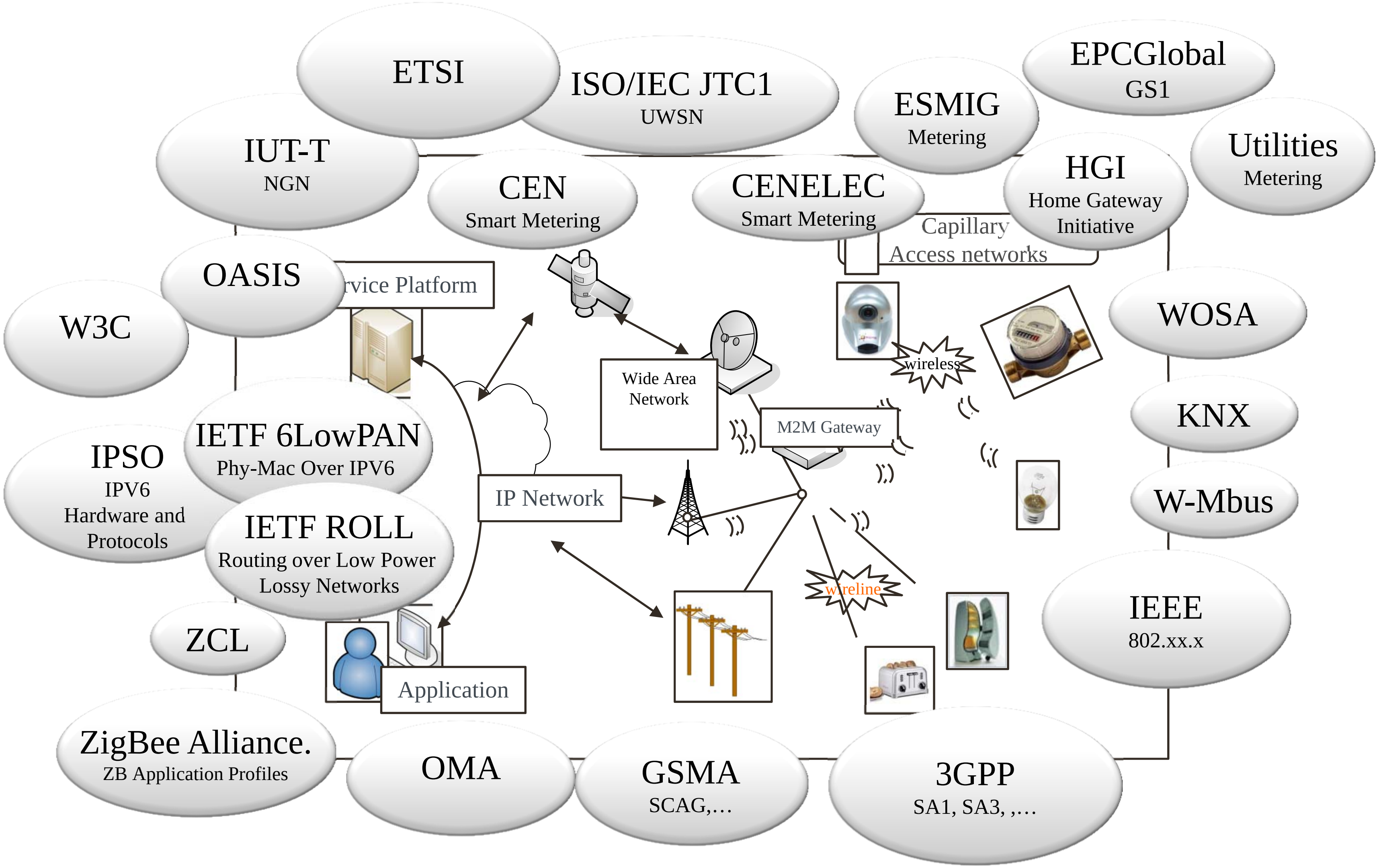
- The starting point is to have popular M2M applications identified and then refine scenarios in each application to identify the areas needing standards.

European Commission Mandates

- **European Commission Mandate 411**
  - **March 2009:** to build standards for European smart meters, allowing interoperability and Consumer actual consumption awareness

- **European Commission Mandate 490**
  - **March 2011:** to build standards for European Smart Grids

M2M-Related Standardization Bodies



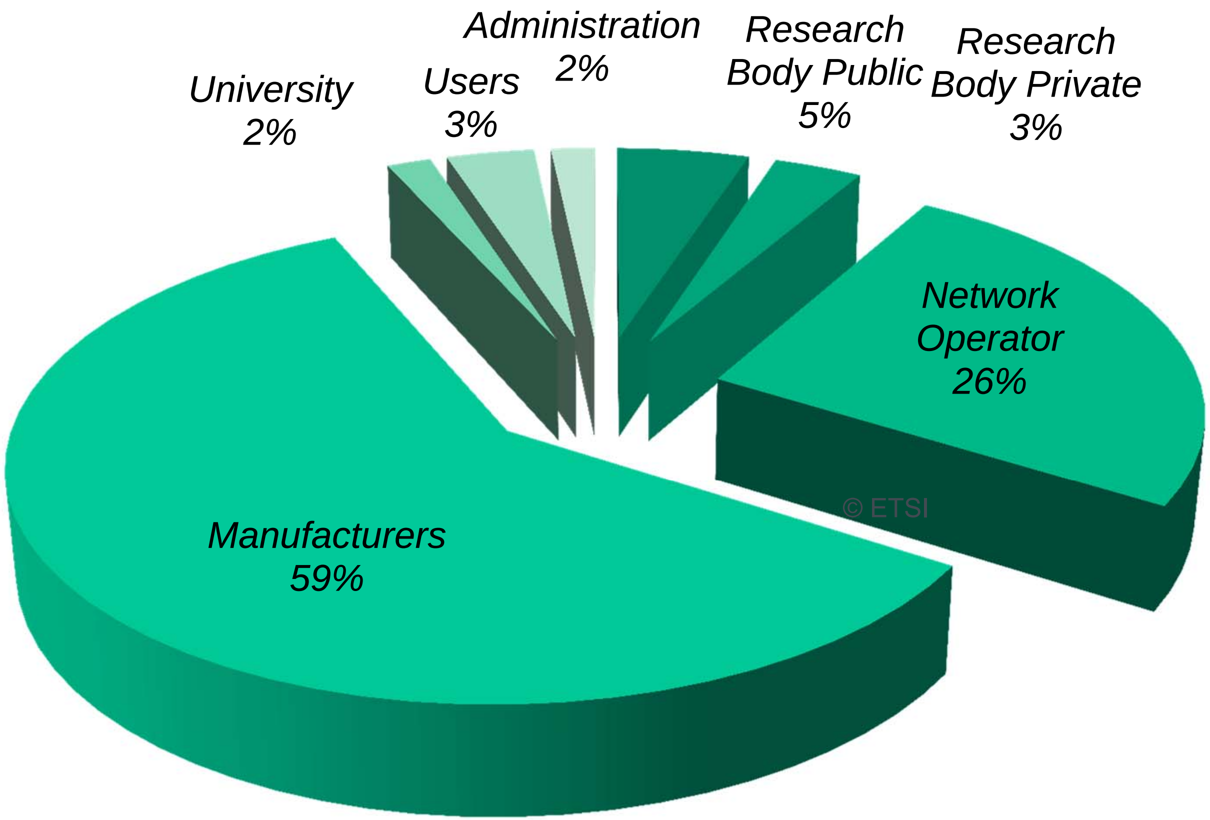
3.3.2

M2M Activities in **ETSI**

European Telecommunication Standards Union

ETSI: TC M2M

- 2009: Technical Committee (TC) created for M2M
- Mission: develop standards for M2M
- Very collaborative (e.g., with 3GPP, industry fora, etc.)
- Reuse of technologies rather than creating new ones
- Participants:



ETSI: TC M2M Vision

M2M Horizontal Service Platform

Standards re-use

Multi – Application

End to End

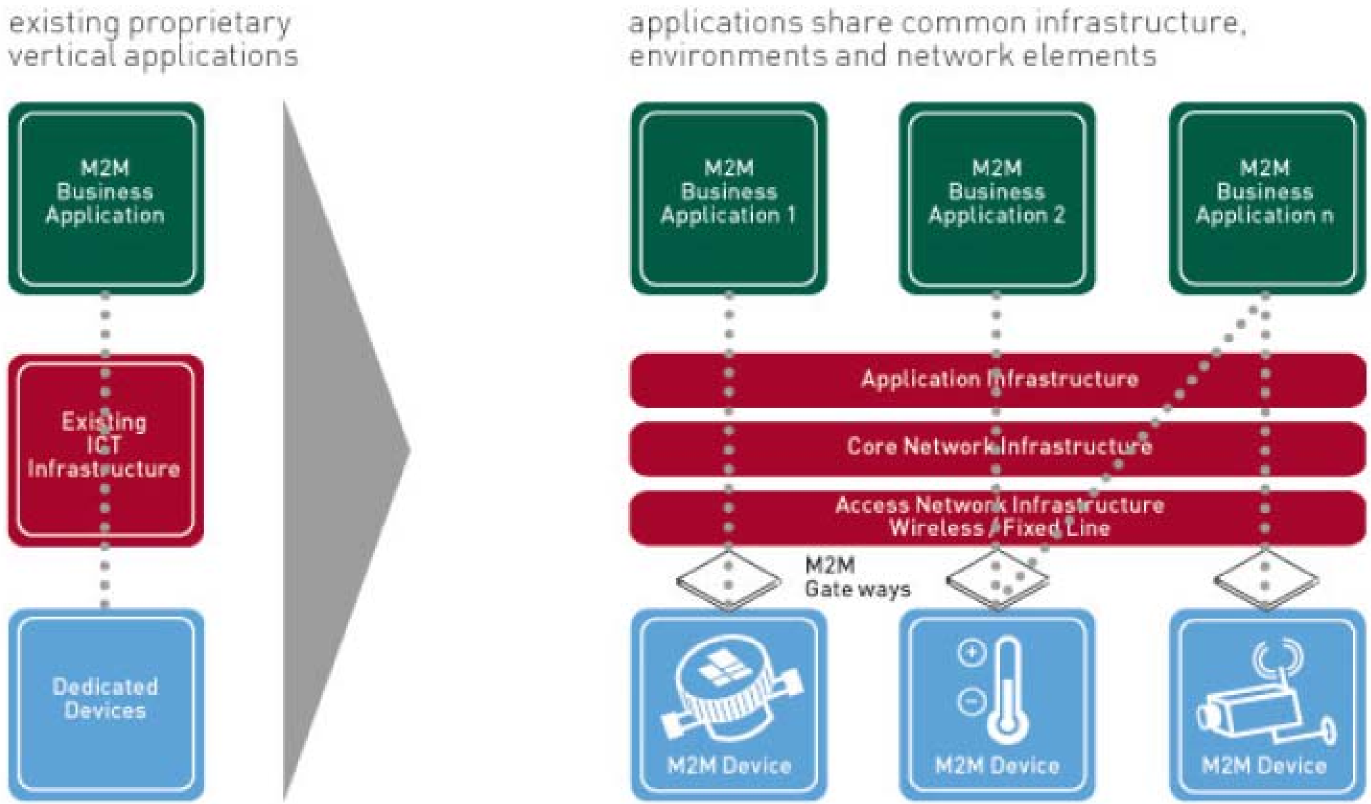
Technology Agnostic

M2M Service Capabilities

© ETSI

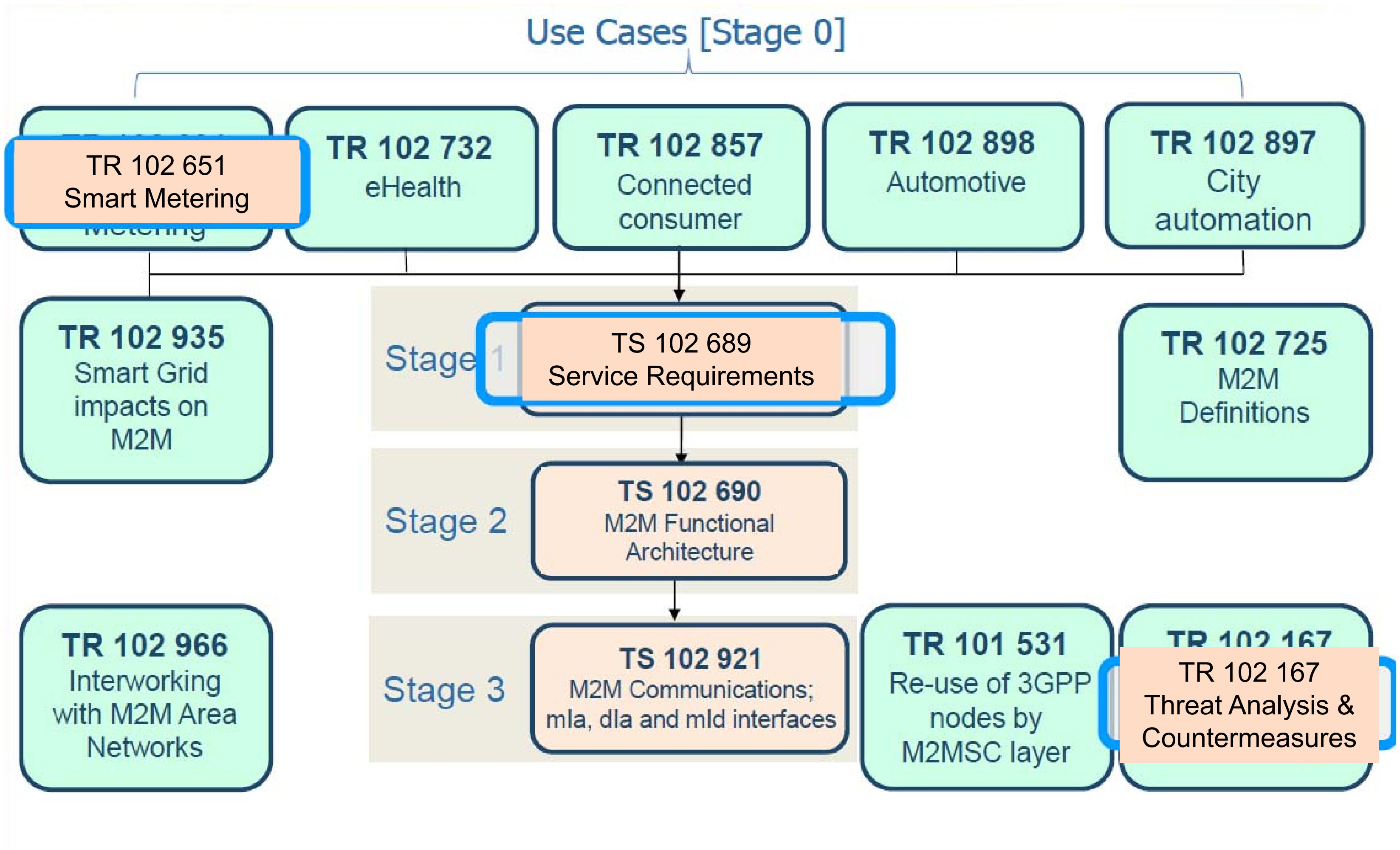
ETSI: TC M2M

- Mission: develop standards for M2M
  - Different solutions based on different technologies and standards can be interoperable



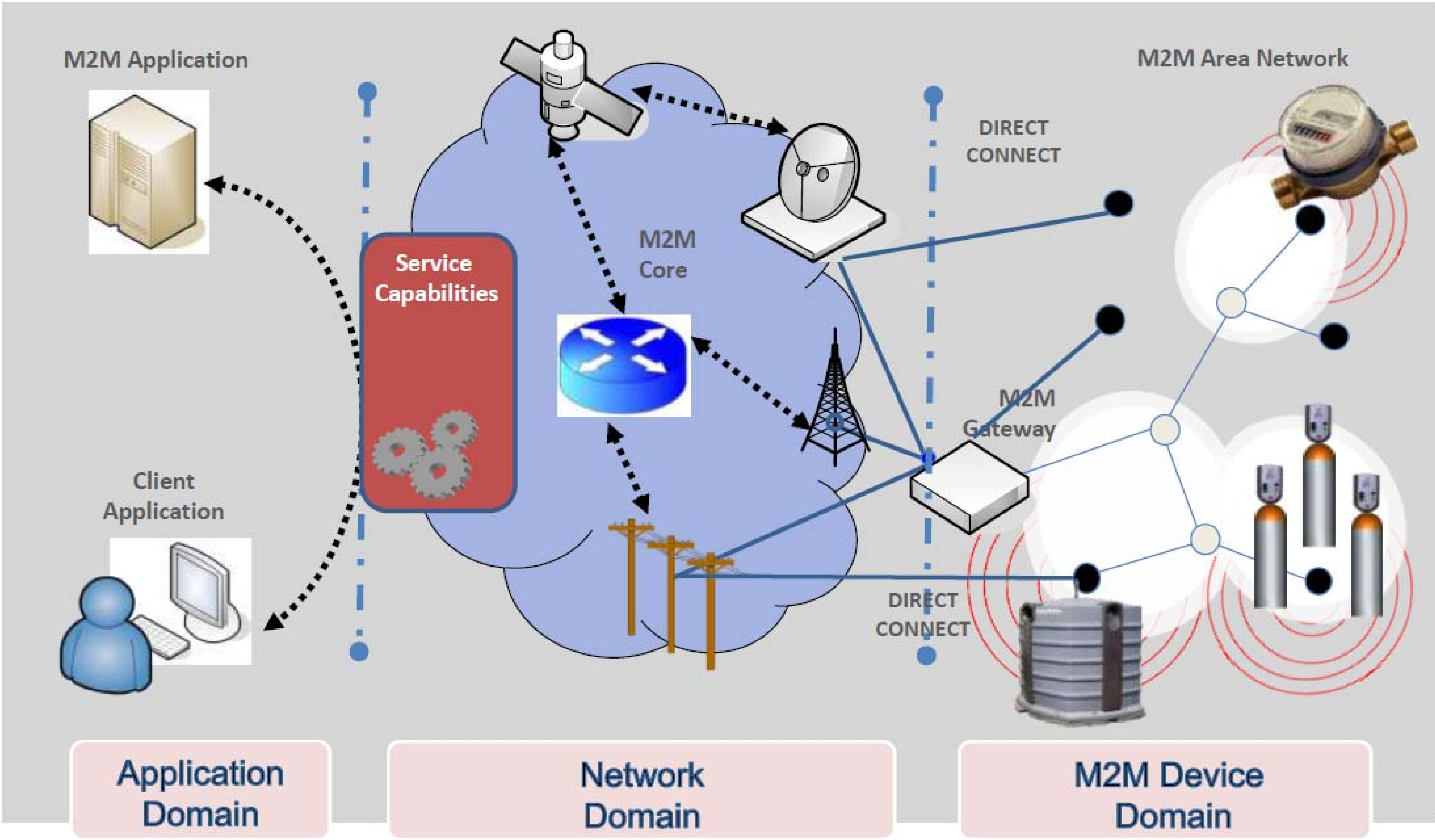
© ETSI

ETSI: TC M2M Tech Reports



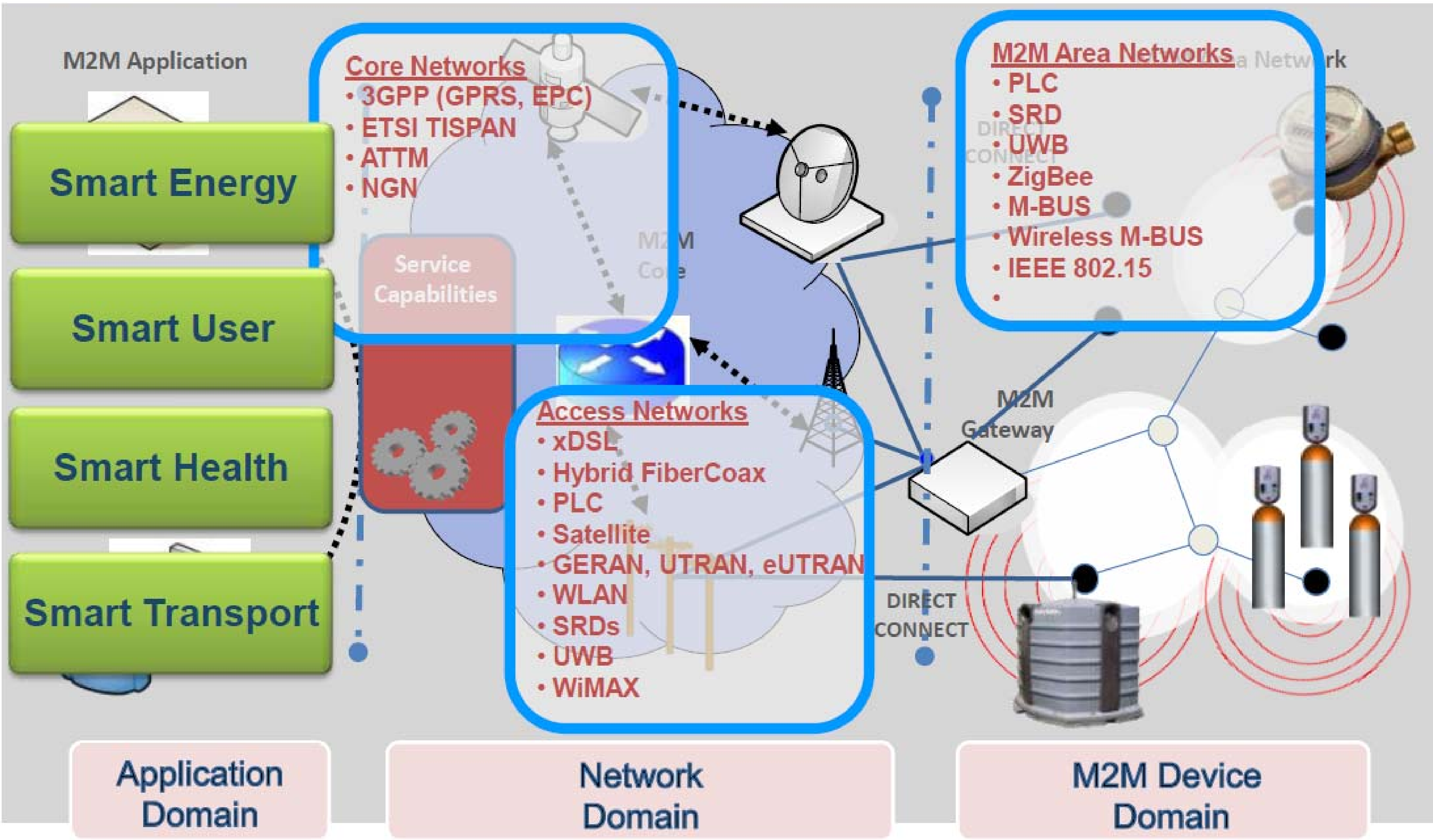
Some Open Documents at: http://docbox.etsi.org/M2M/Open/

ETSI: TC M2M Architecture



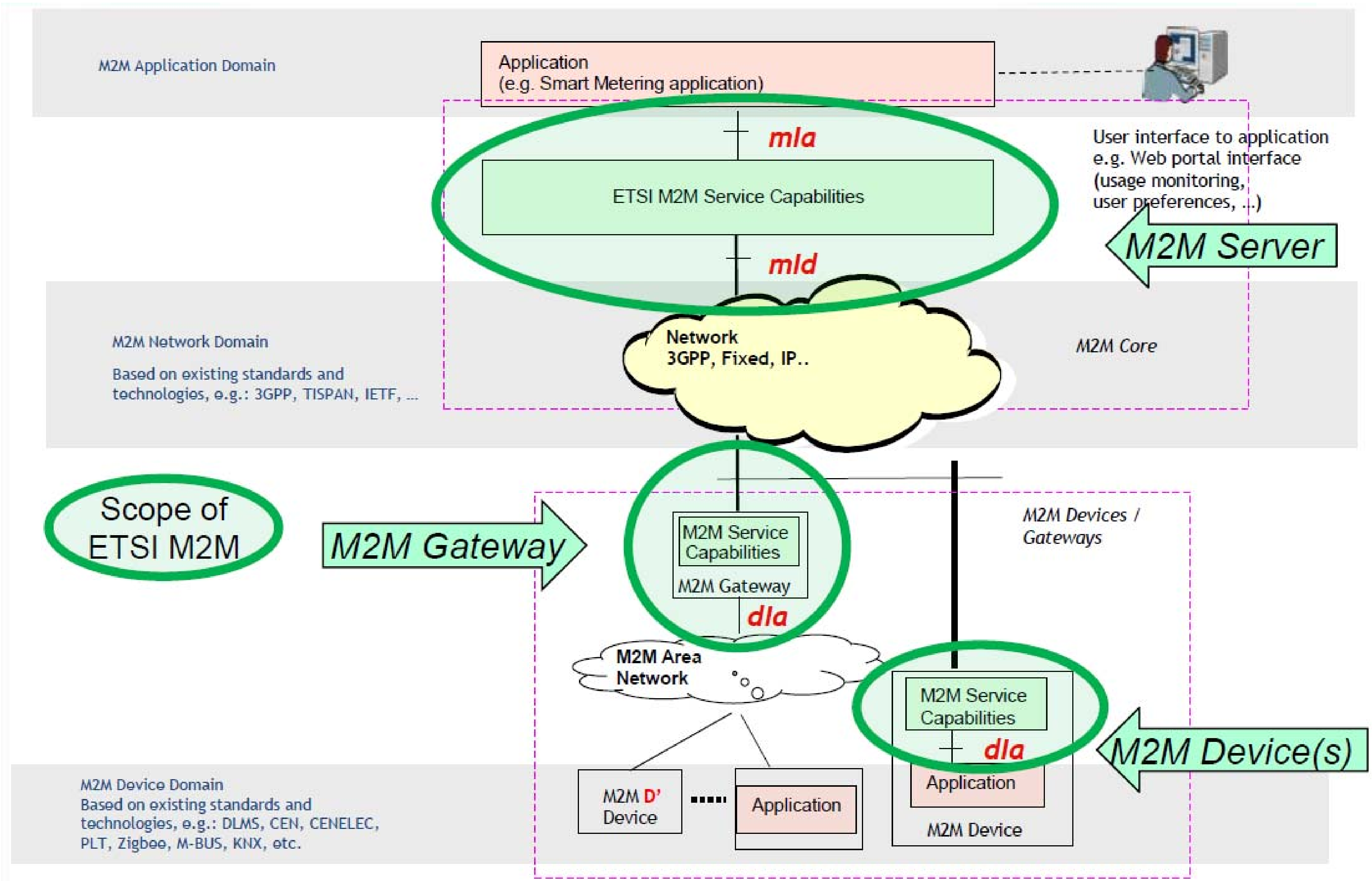
© ETSI

ETSI: TC M2M Architecture



© ETSI

ETSI: TC M2M High Level View



ETSI: TC M2M Activities

- September 2010: 1st Workshop on M2M Communications

- 26-27 October: 2nd Workshop on M2M. Agora, Sophia Antipolis
  - Present the M2M Release Package 1 Specifications
  - Future requirements for M2M standardization
  - Feedback from early M2M solutions

- More info at: **http://portal.etsi.org/m2m**

ETSI Smart Card Platform

- Created in 2000
- **SIM: S**ubscriber **I**dentity **M**odule → for than 4B in circulation
- Evolution to UICC (Universal Integrated Circuit Card)
  → CPU, RAM, ROM, EEPROM, I/O.

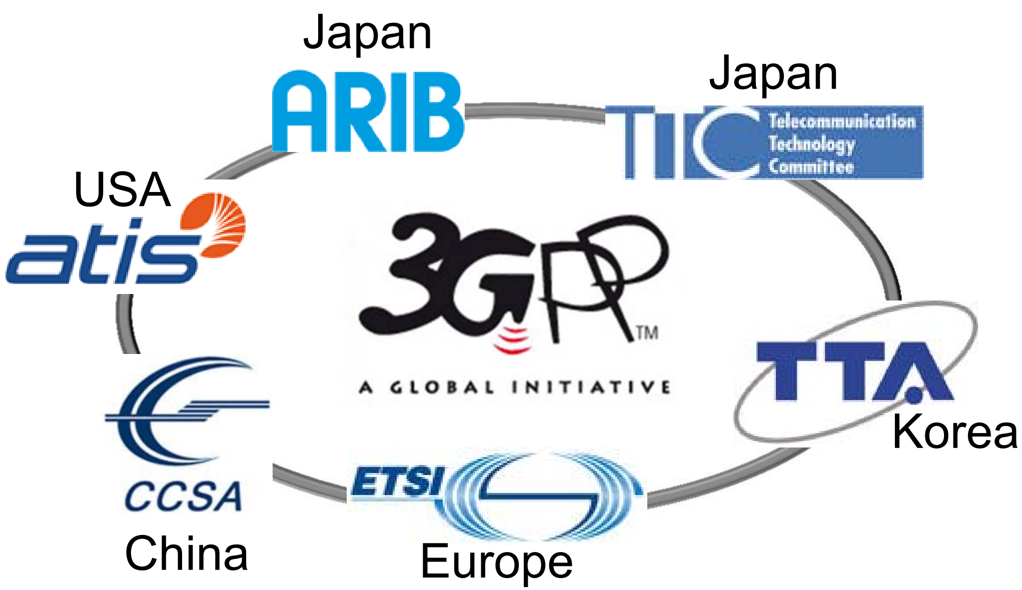
- M2M poses new requirements
  - Size, Shape, Environmental Conditions, Vibrations, ..
  - Remote Change of Subscription
- Removable vs. Soldered solution
- ETSI is defining requirements for:
  - **UICC** for particular use in M2M
  - New Form Factor (**MFF**) for M2M

© ETSI

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
Iub spec, Iur spec, Iu 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.

Documentation Related to M2M

- Release 8: April 2007
- TR 22.868: "**Study on Facilitating Machine to Machine Communication in 3GPP Systems**"
  - Motivation: *It appears that there is market potential for M2M beyond the current "premium [current] M2M market segment"*
- Main Conclusions:
  - M2M are different from H2H communications
  - De-activation/reduction of mobility signalling
  - Possibility to instruct groups of devices
  - Change subscription on the field (SIM cards)
  - Reduce periodic signalling
  - Alternative addressing issues (overcome limits of the IMSI)
  - Simplify terminals
  - …

Documentation Related to M2M

- Release 9: June 2010
- TR 33.812 Study on Security Aspects of Remote Provisioning and Change of Subscription for M2M equipment
- Main conclusions:
  - M2M equipment provided with tamper/theft protection
  - Change subscription out in the field
  - Power up M2M equipment without human intervention
  - Reuse existing infrastructure

Documentation Related to M2M

- Release 10 and 11
- Network improvements for MTC (NIMTC)

→ TS 22.368: **Service Requirements for Machine-Type Communications (MTC).** Stage 1 (first version June'10, last update **26 Sept. 2011**)

→ TR 23.888: **System Improvements for MTC →** architectural aspects of the requirements specified in TS 22.368 (first version, June 2010, last update **18 October 2011**).

→ TR 37.868 **Study on RAN improvements for MTC**
→ GERAN 43.868 **Study on GERAN improvements for MTC**
→ **Study on provision of low-cost MTC UEs based on LTE**
→ Many more ongoing studies…

3GPP M2M Definitions

- ***H2H***: Human to Human Communications
- ***M2M***: Machine to Machine Communications
- ***MTC***: Machine Type Communications
- ***MTC feature:*** Network functions to optimize MTC operation
- ***MTC User***: legal entity (company or person) that uses MTC terminals, usually the contractual partner for the operator
- ***MTC Device***: User Equipment (UE) for MTC with communicates with a server or another MTC device
- ***MTC Group***: group of MTC devices that belong to the same MTC Subscriber
- ***MTC Server***: entity which can communicate with other MTC devices and is connected to the Public Land Mobile Network (PLMN)
- …

TS 22.368:
Service Requirements for Machine-Type Communications (MTC).

Scope

- Identify and specify general requirements for machine type communications.
- Identify service aspects where network improvements (compared to the current human-to-human oriented services) are needed to cater for the specific nature of machine-type communications;
- Specify machine type communication requirements for these service aspects where network improvements are needed for machine type communication.

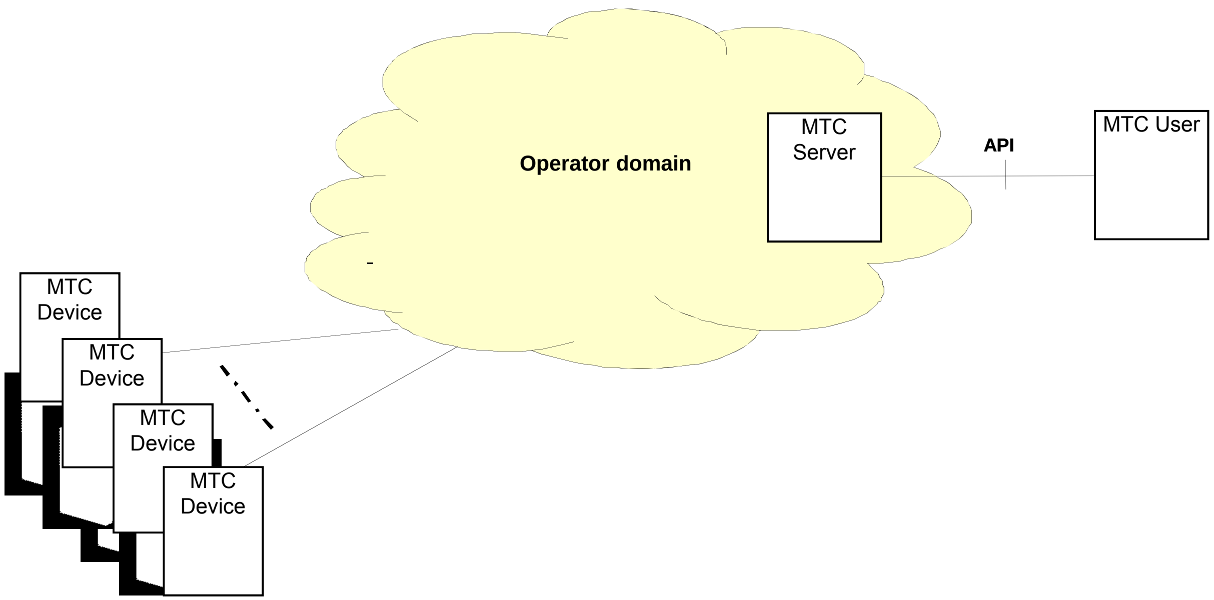
- Focus only on ***cellular segment*** (GSM, UMTS, and LTE, …)

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
  - Little traffic per terminal
  - No human interaction (reconfiguration, security, etc.)

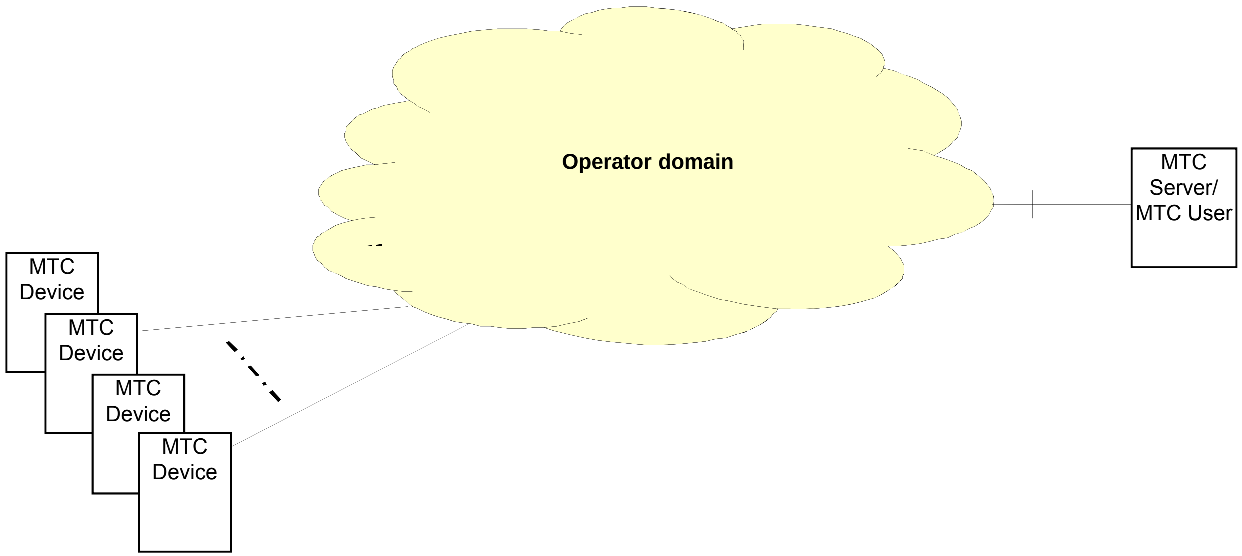
Types of Communication

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



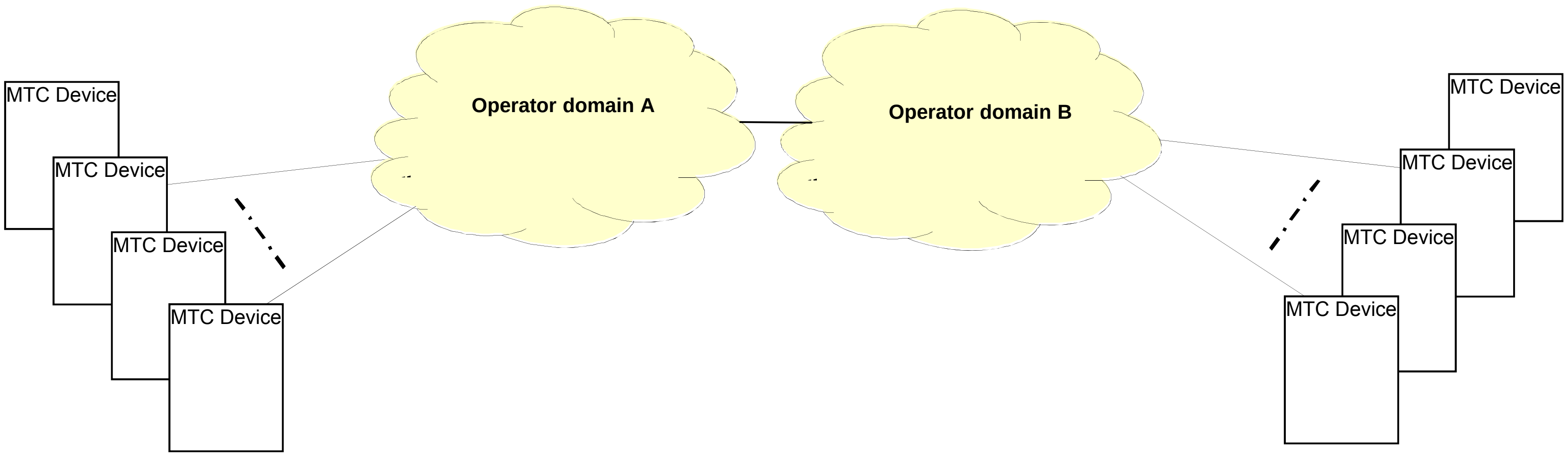
Types of Communication

- 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



Types of Communication

- Communication between MTC devices connected to different network operators without servers in between **IS NOT CONSIDERED** in the ongoing release (***future*** releases → research opportunity).



Features in M2M

- A ***feature*** is a system optimization possibility
- Not all MTC applications have the same characteristics
- Not every optimization is suitable for all applications
- Features are defined to provide some structure
- 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

Common Service Requirements

- General
- Device Triggering
- Addressing Issues
- Identifiers
- Charging
- Security
- Remote MTC Device management

General

- Features: ***dynamically*** bound to subscription
- Mechanisms to reduce peaks of traffic: congestion control, denial of services, traffic shaping, etc.
- Mechanisms to maintain continuous connectivity for large number of devices
- Energy-efficient mechanisms for devices

Device Triggering

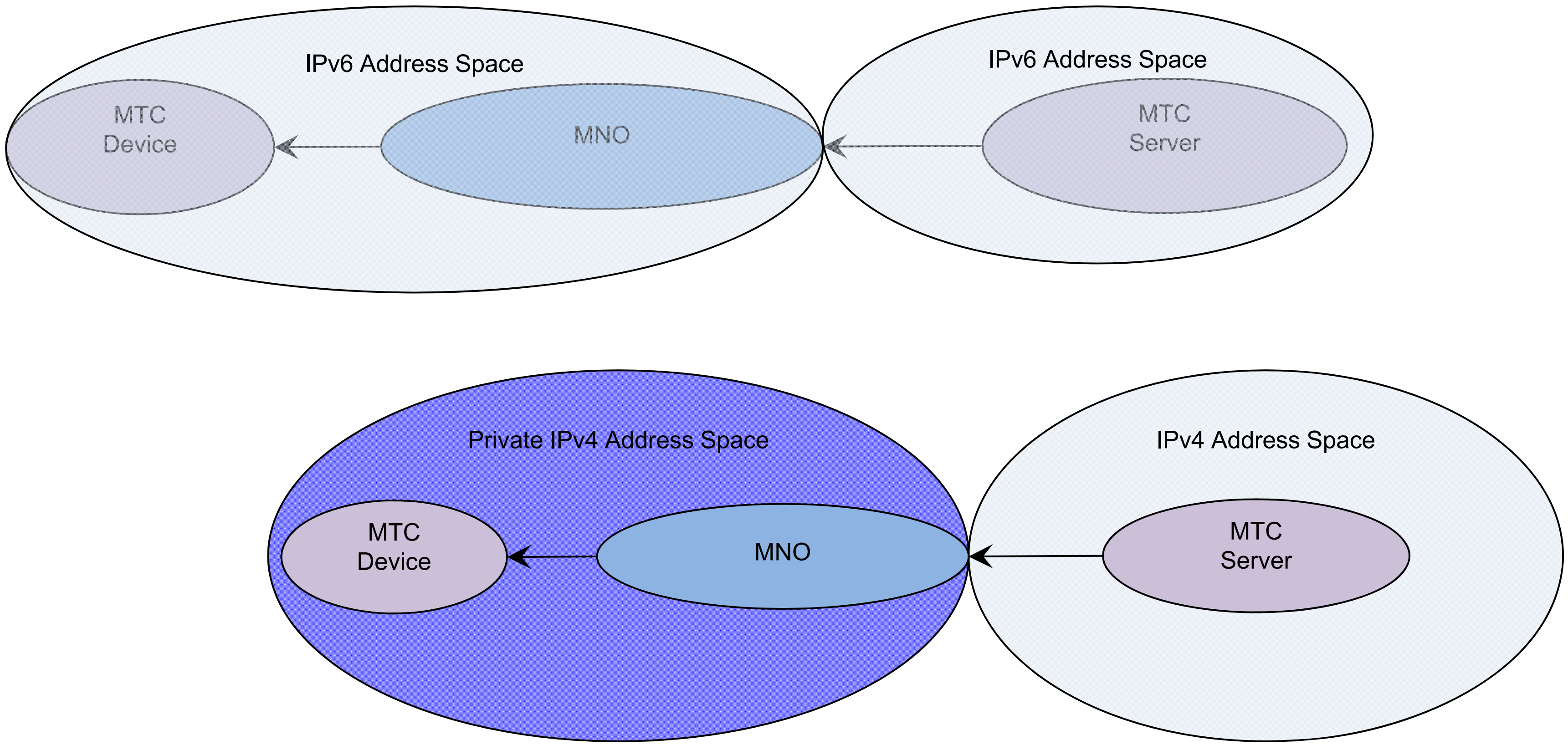
- Poll model for communications Server-MTC device.
- Security issues → identification of unauthenticated servers
- Broadcast of authenticated servers to the devices
- A device shall be able to receive a trigger:
  - Not attached: can listen to broadcast or paging channel
  - Attached and with a data connection established
  - Attached and without data connection established
- Current implementations based on SMS, for example, only work for online devices!

Addressing M2M Devices [1/2]

- Addressing is required for device terminated communications
- No identification → problems at the protocol level? Security?
- Do we really need to identify all the machines at the network operator level?

- Cellular identifiers:
  - IMSI (bound to the SIM card) → limit of 15 digits
  - IMSI+MSISDN (mobile phone number) → limit of 20 digits
- At networking level
  - IPv4 → 32 bits
  - IPv6 → 128 bits

Addressing M2M Devices [2/2]



It is also considered the case when the MTC Server is in a private IPv4 domain

Identifiers

- The same as in H2H communications:
  - The system shall be able to **identify each** of the devices
  - The system shall be able to unique identify the **MTC Subscription**

- 3GPP2 Steering Committee has created an Ad Hoc group to consider issues related to M2M numbering and addressing schemes.

Charging and Billing

- Traditional billing methods stop the widespread use of M2M
- Were designed for H2H communications

- Charge by groups of devices (bulk of CDR) and not individually

- Bulk Control signaling: Location update traffic in mobile applications → if M2M group of terminals moves, new location information has to be processed → how to charge this extra traffic?

Security

- Security for M2M comparable to that of non-MTC transmissions
- Lots of automated users → Denial of Service (DoS) Attacks
- Denial of Service due to:
  - Bad application design
  - Deliberately (jamming or authentication and mobility management traffic)
- Solutions required:
  - At the user side
  - At the network side
- Security at application layer to help security at network layer?

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]

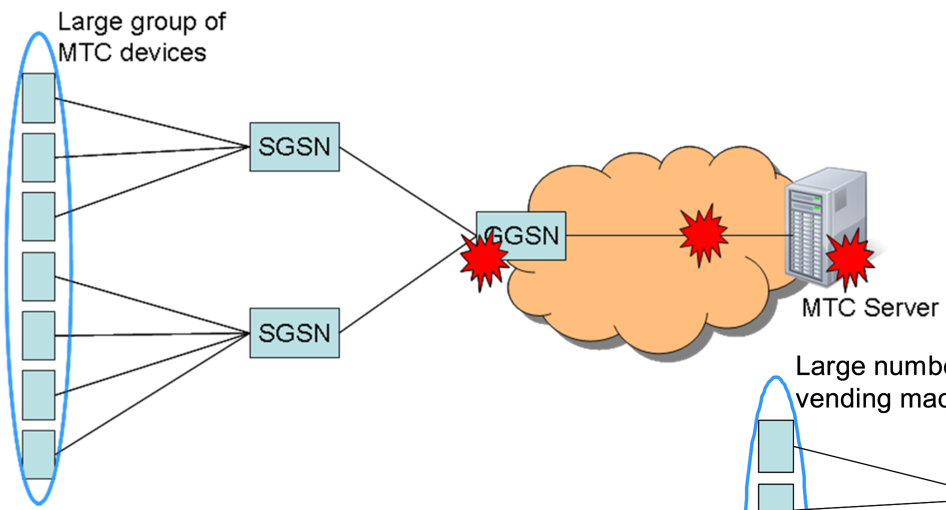
- Location specific trigger
  - Location information stored by the operator
  - Reduction of mobility control signaling
- Infrequent transmission
  - The network shall allocate resources only when needed
  - Apply duty cycling regarding connectivity (attach/detach)
- Group based policing and addressing
  - 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

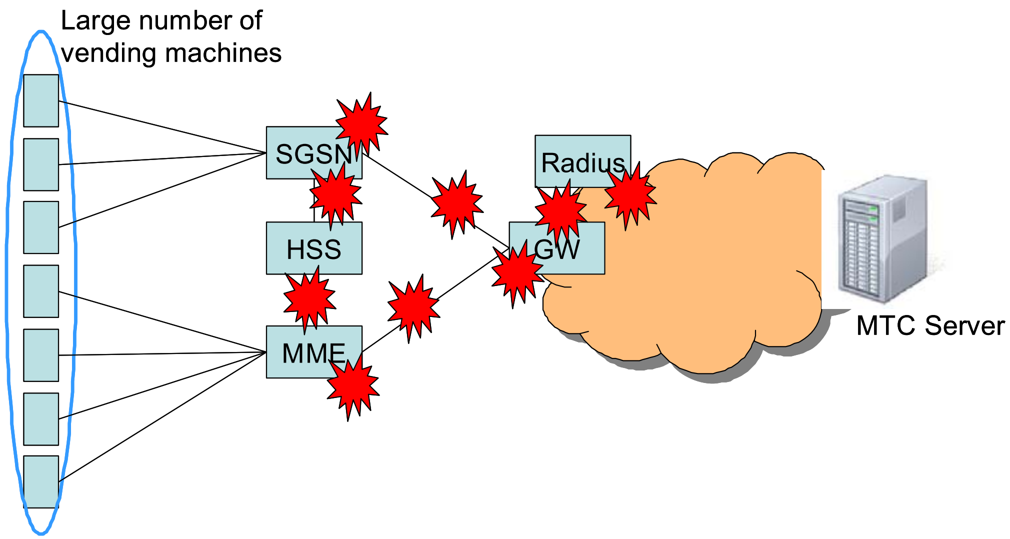
Some Use Cases [1/5]

- 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 [2/5]

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

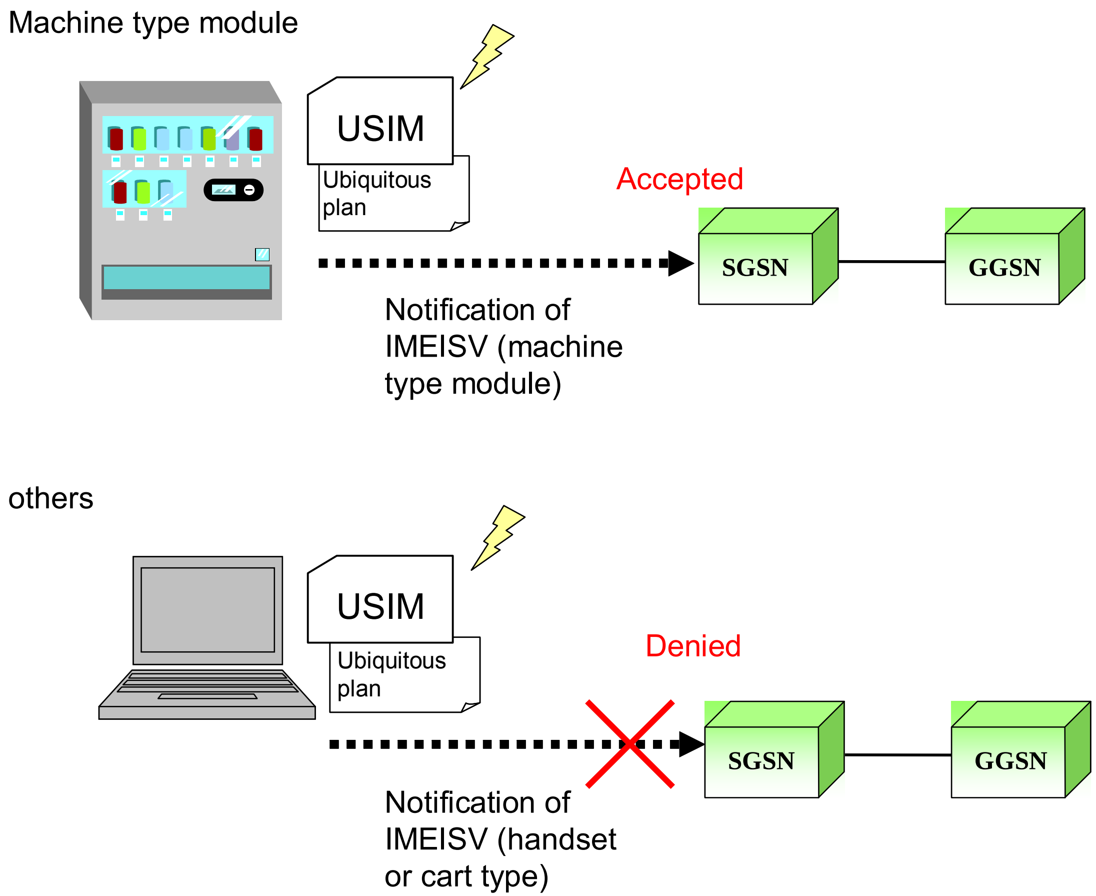




- National Holidays
- Power cut-off
- …

Some Use Cases [3/5]

- Access Control with Billing Plan

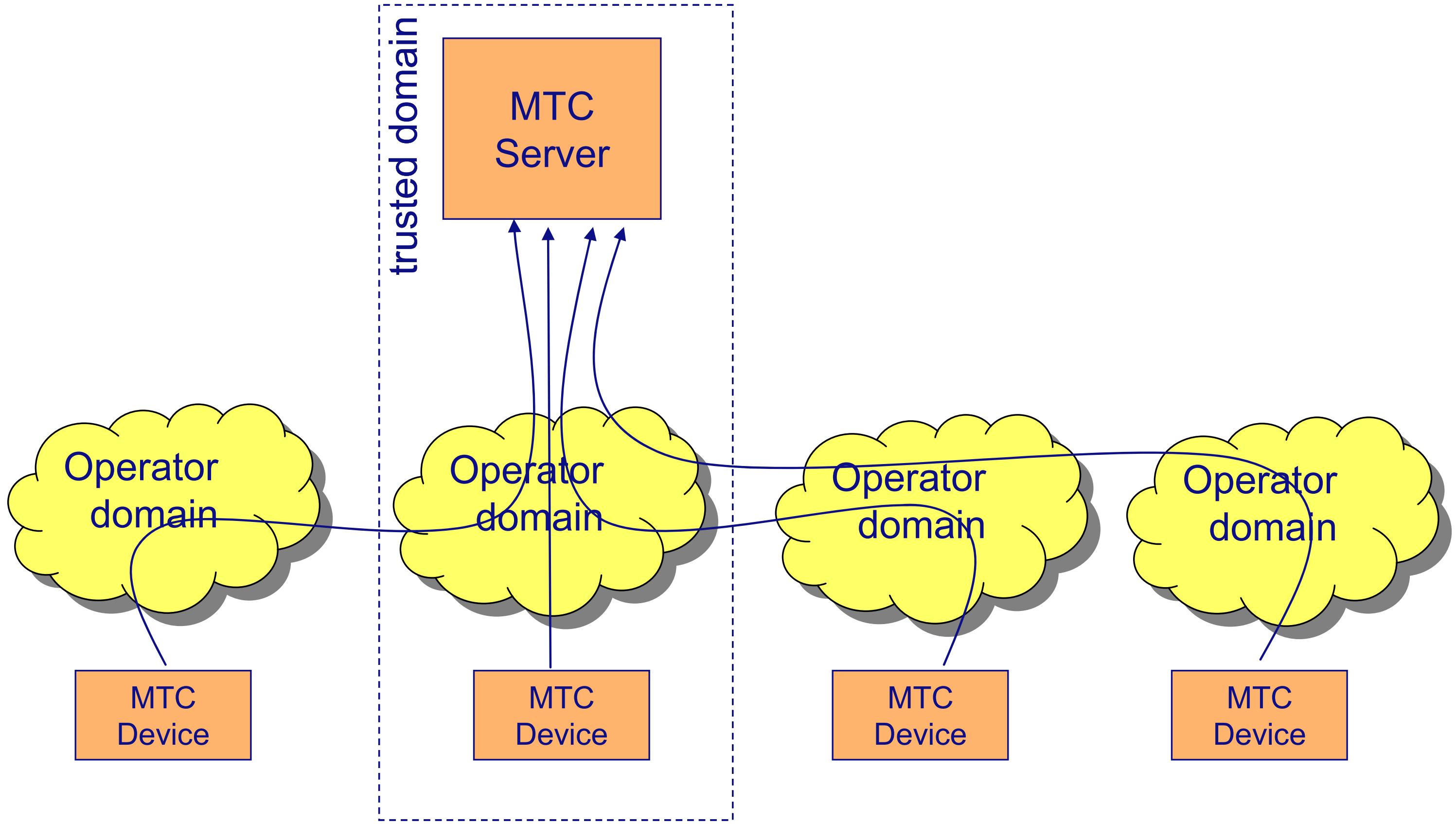


Some Use Cases [4/5]

- Extra Low Power Consumption
  - Tracking of: moving animals, cargo, prisoner, elder people, gas meters,
  - Special case for time controlled applications: duty cycling.
- Location Specific Devices Triggering
  - Applications where it is necessary to poll a specific group of devices
- Location Specific Devices Triggering
  - Applications where it is necessary to poll a specific group of devices whose position if known by the application
  - Efficient and scalable triggering mechanisms are required

Some Use Cases [5/5]

- End-to-end Security for Roaming



TR 23.888:
System Improvements for MTC

not dealt with in this tutorial

Ongoing Studies within Release 11

Ongoing Documents

- Study on RAN improvements for MTC (no date)
  - Technical Improvements on UTRA and EUTRA
- Study on GERAN improvements for MTC (March 2012)
  - GSM and EDGE Radio Access Networks
- Study on provisioning low-cost MTC UE terminals (June 2012)
  - Reduction of RATS → low-profile operation of LTE
- System Improvements for M2M - Features (September 2012)
  - Specify the requirements stated in TS 22.368
- RAN Overload Control for M2M (September 2012)
  - Specify the requirements stated in TS 22.368
- Release 12: Alternatives for M2M
  - Specify the requirements stated in TS 22.368

3.3.4

M2M Activities in IEEE 802.16

M2M in WiMAX

- **IEEE 802.16n**
  - focuses on "direct communication" to ensure connectivity
  - available PAR: 80216gman-10_0038r1

- **IEEE 802.16p**
  - licensed band operation; typical use cases
  - Stage 1: low power consumption, huge numbers of devices, fairly short burst transmissions
  - Stage 2: robust device integrity, high reliability, staged access priority, time tolerant operation, time controlled operation, low/no mobility, extremely low latency
  - enhancements to MAC with minimal changes to PHY (for hardware reuse)

3.4
Concluding Remarks

Concluding Remarks

- General:
  - cellular has so far only been passive M2M data bearer
  - operators aim to become more active given the market potential

- Cellular Pros & Cons:
  - Pros: ubiquitous coverage, sufficient ranges
  - Cons: delays, cost, generally design over-kill

- Standardization Activities:
  - ETSI has done pioneering steps in setting stone rolling on architecture
  - 3GPP is following suite, mostly referring to MTC
  - IEEE has commenced now via 802.16n/p
  - IETF will surely shortly kick in

More R&D Open Challenges [1/2]

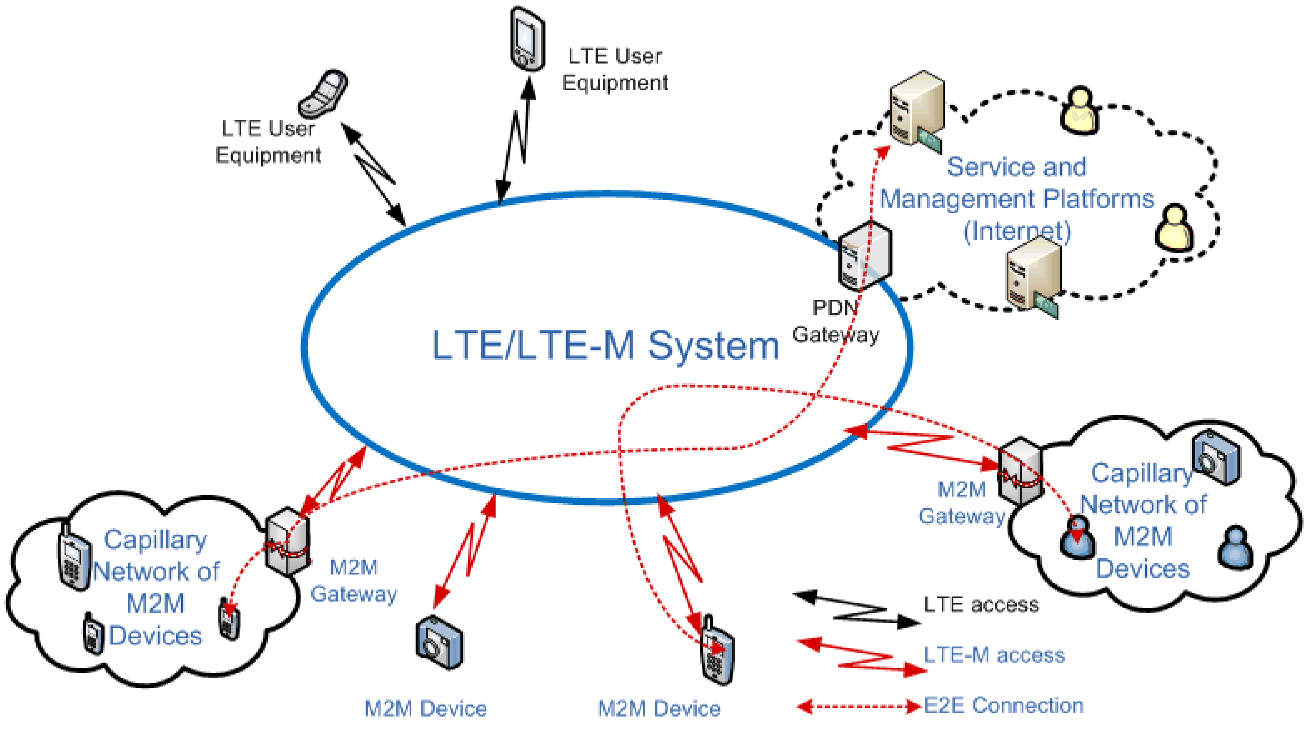
- Design for huge number of devices
- Reduction of control signaling
- Optimization for low data transmissions
- Cost reduction: e.g. remove previous RATs (GSM)
- Congestion control algorithms at RAN and Core Network
- Load distribution/balancing
- Security, e.g., denial of service
- Traffic Models

More R&D Open 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…

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)*

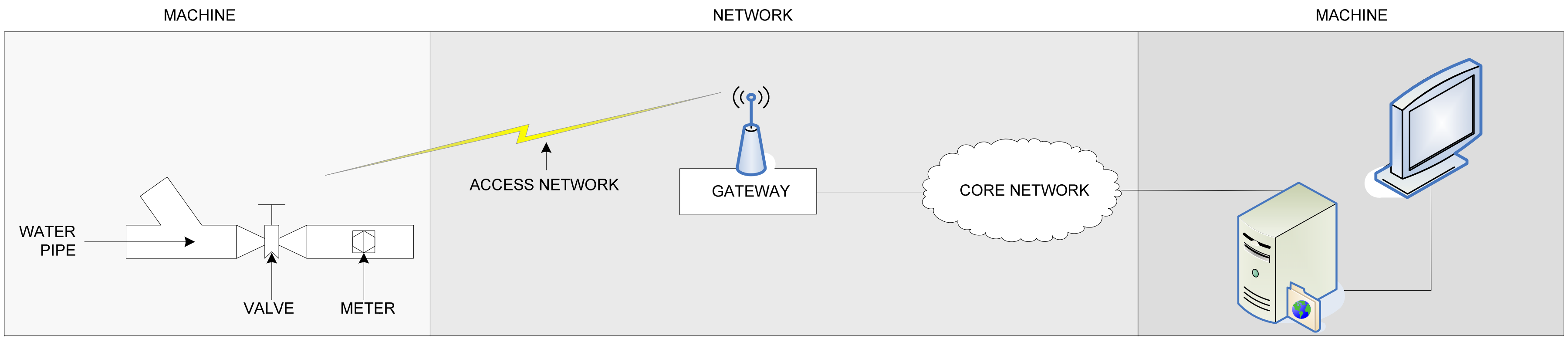
Duration: *Sept. 2010 – Feb. 2013*
Funding scheme: *IP*
Total Cost: *€11m*
EC Contribution: *€7.4m*

Contract Number: INFSO-ICT-258512

4
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**:

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

[Digi White Paper & Marc Portolés]

... But Need To Be Optimized [2/3]

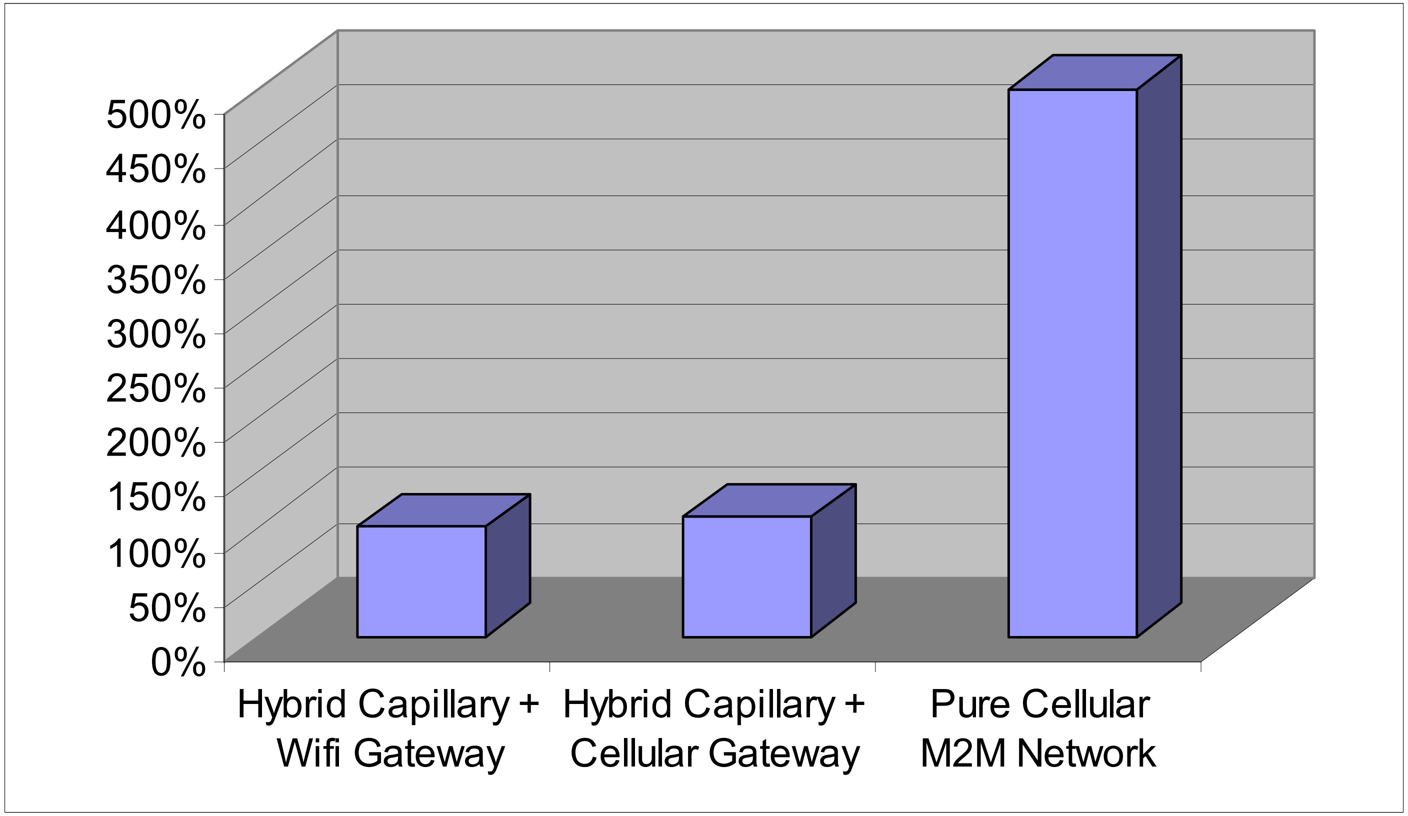
- **Example Power Consumption**:

Technology	Mobility	Data transfer performance		Energy consumption/ battery life	Quality of Service	Cross-Layer Design Penetration
		Physical rate	Spectrum efficiency			
2G (GSM)	Seamless global roaming	9.6 – 57.6 Kb/s	0.52 bit/s/Hz	Days	High (dedicated channels, voice over data priority)	High
3G (UMTS)		384 Kb/s (mobile) 2Mb/s (stationary)	Up to 2.88 bit/s/Hz			
3G LTE		100 Mb/s	5 bit/s/Hz			
Fixed WiMAX (802.16-2004)	Fixed	10 Mb/s (max up to 70 Mb/s)	3.75 bit/s/Hz	n/a	Normal (4 traffic classes, but not supported for network wide connections)	Medium
Mobile WiMAX (802.16e-2005)	Pedestrian Mobility	2-3 Mb/s (max up to 15 Mb/s)	2 bit/s/Hz	Hours		
802.11b	Nomadic subnet roaming	11 Mbps	0.55	Hours	Low (Best effort or 802.11e if employed)	Low
802.11a/g		54 Mbps	2.7			
802.11n		250 Mbps	7.22			
Bluetooth (2.0)	Fixed	Up to 2.1 Mb/s	2 bit/s/Hz	Hours	High (dedicated channels)	Low
UWB		675 Mb/s	1.35 bit/s/Hz		n/a	

[© Fabrizio Granelli, et al. “C4P: COMMUNICATION NETWORKS FOR POWER ENGINEERS,” Tutorial at SmartGridComms 2011, Brussels, Belgium.]

... 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:



Challenges for Capillary M2M

- Core Challenge #1 – **Delays:**
  - Connection Delay: optimize L2/L3 node discovery protocols
  - Communication Delay: ultra reliable & time-critical MAC urgently needed
- Core Challenge #2 – **Security:**
  - Requirements: room for efficient end-to-end security solution
  - Extras: fit security into standards, allow for aggregation, etc.
- Core Challenge #3 – **Standards:**
  - so far: too many proprietary solutions on market
  - need for: truly standardized embedded architecture
- Core Challenge #4 – **P2P Traffic:**
  - Traffic Pattern: a lot more P2P traffic is emerging than initially thought
  - Protocols: without jeopardizing converge-cast protocols, find solution

Challenges for Cellular M2M

- Core Challenge #1 – **Complexity & Power:**
  - Modulation: simple to detect in DL; constant envelope in UL
  - Processing: currently total over-kill; get it down by orders of magnitude
- Core Challenge #2 – **Data Rates:**
  - uplink: allow for more UL traffic without disturbing current traffic
  - downlink: mostly query; maybe embed into control plane
- Core Challenge #3 – **Delays:**
  - Connection Delay: e2e delays need to be improved by orders of magnitude
  - Communication Delay: generally solved; however for high rate only
- Core Challenge #4 – **Architectural Elements:**
  - Technical: handling many nodes, group management, HOs, etc, etc.
  - Billing: who and how pays the bill; compete with LAN/WLAN/WSNs

Conclusions

- What's New?
  - M2M has been around for a while in various forms
  - many unprecedented issues will arise with exponential explosion of use

- What's The Opportunity?
  - make your system, home, district, city, country, planet smarter
  - decrease carbon footprint, CAPEX & OPEX bills, etc
  - create unprecedented services

- What Are The Challenges?
  - perform true cross-layer, cross-system, cross-domain optimization
  - SINGLE-LAYER R&D HAS COME TO AN END

- What Are The Trends?
  - cellular M2M to overcome capillary M2M due to better interference management