Machine-to-Machine

An Emerging Communication Paradigm

Mischa Dohler, CTTC, Barcelona, Spain

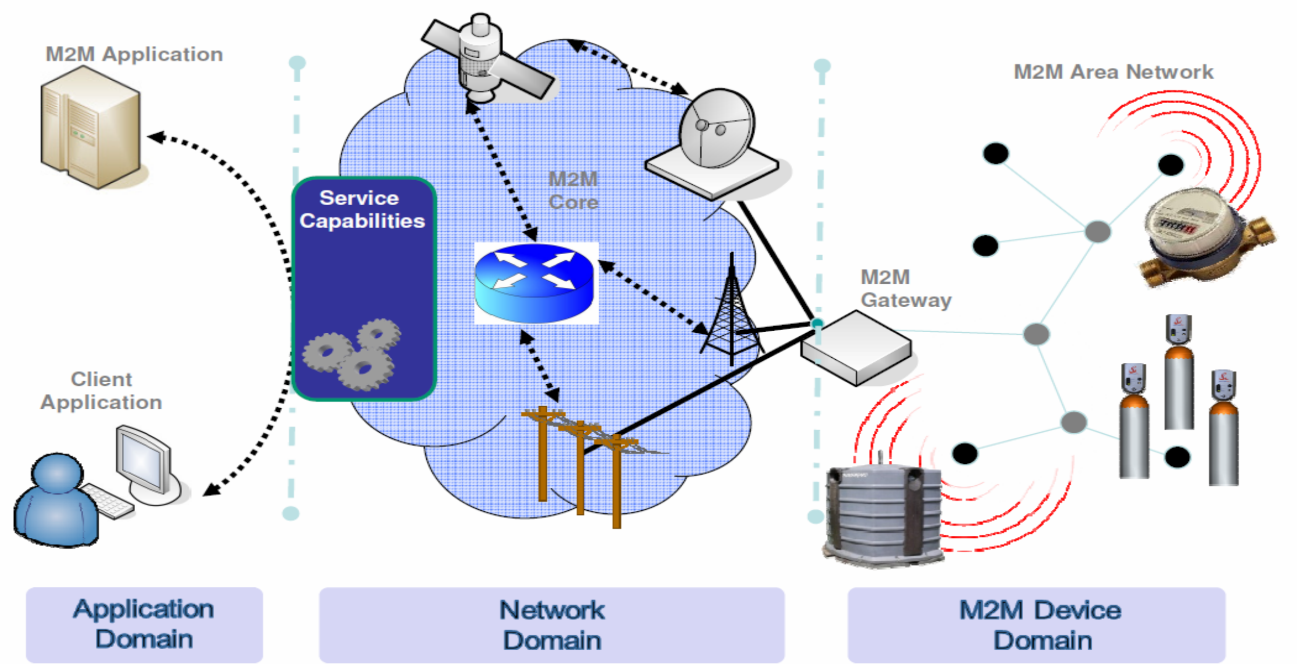
Thomas Watteyne, BSAC, UC Berkeley, USA

Jesús Alonso-Zárate, CTTC, Barcelona, Spain

Mobilight 2010, MONAMI 2010, PIMRC 2010, Globecom 2010, Berkeley, Sagemcom, C.O.I.T. Madrid, etc

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
  - etc, etc



© ETSI

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

- Predictions differ significantly, so let's do a sanity check:
  - ... 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 ...

- Oooouuuuuch!!!
  - 1GW nuclear power plant needs to run for more than 3 years to sustain this
  - Obama's National Broadband Plan targets power reduction and not increase
  - **It is important to get this vision and these numbers right!**

Tutorial Overview

1. M2M Introduction

1. A Quick Introduction
2. M2M Markets and Applications

2. Cellular M2M

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

3. Capillary M2M

1. Quick Intro to Capillary M2M
2. Academic WSN Research
3. Proprietary M2M Solutions
4. Standardization Efforts Pertinent to M2M

4. Concluding Observations

1. Conclusions
2. ICT BeFEMTO

1
Overview of M2M

1.1

A Quick Introduction

Quick Intro

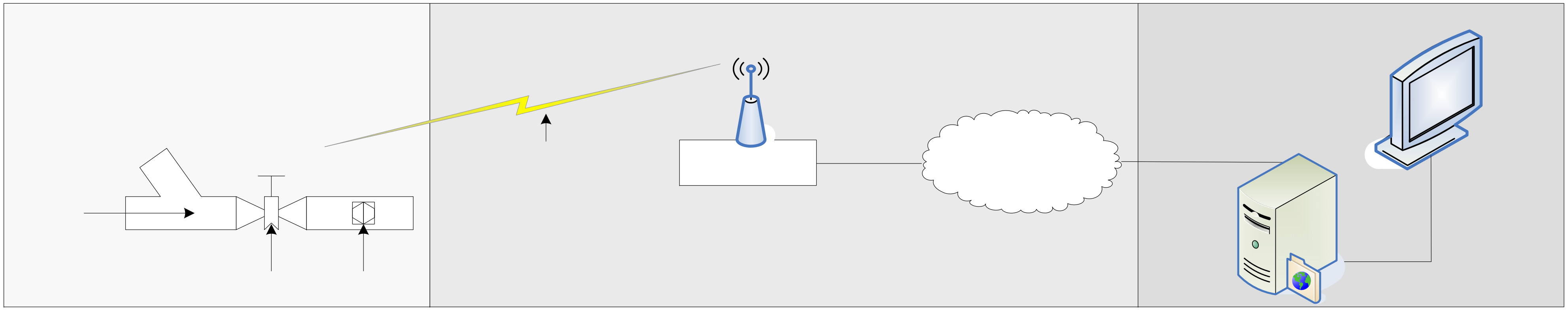
- **Machine** – To – Machine:
  - device (water meter) which is monitored by means of sensor [in “uplink”]
  - device (valve) which is instructed to actuate [in “downlink”]
  - keywords: physical sensors and actuators; cost

- 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

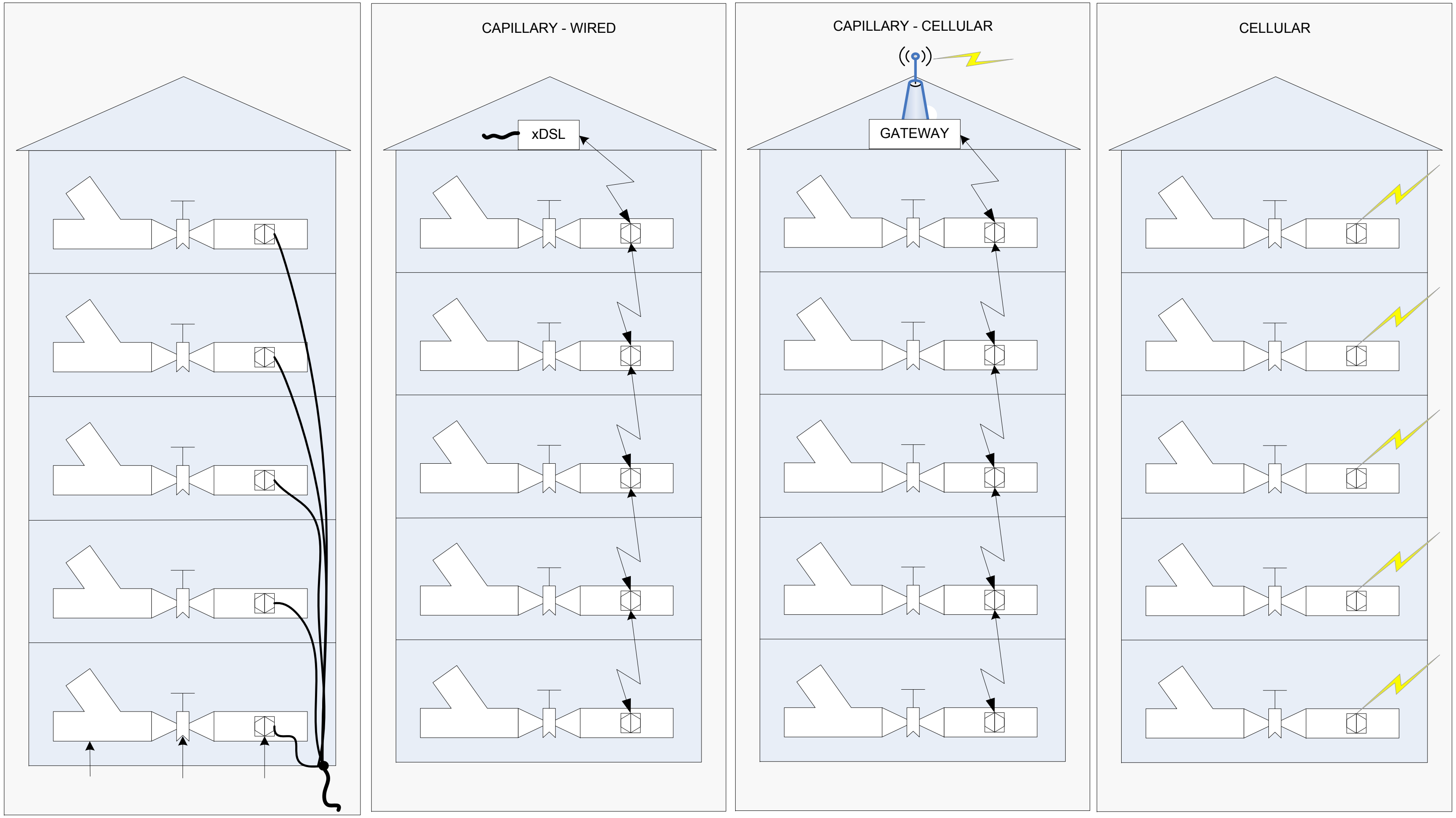
M2M End-to-End Network

- **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 core networks:
  - network address translation
  - packet (de)fragmentation; etc.
- **Core/Backend Network** – connecting the computer system:
  - IPv6-enabled Internet



M2M Access Networks [1/2]

- Connecting your smart meters through 4 example access methods:

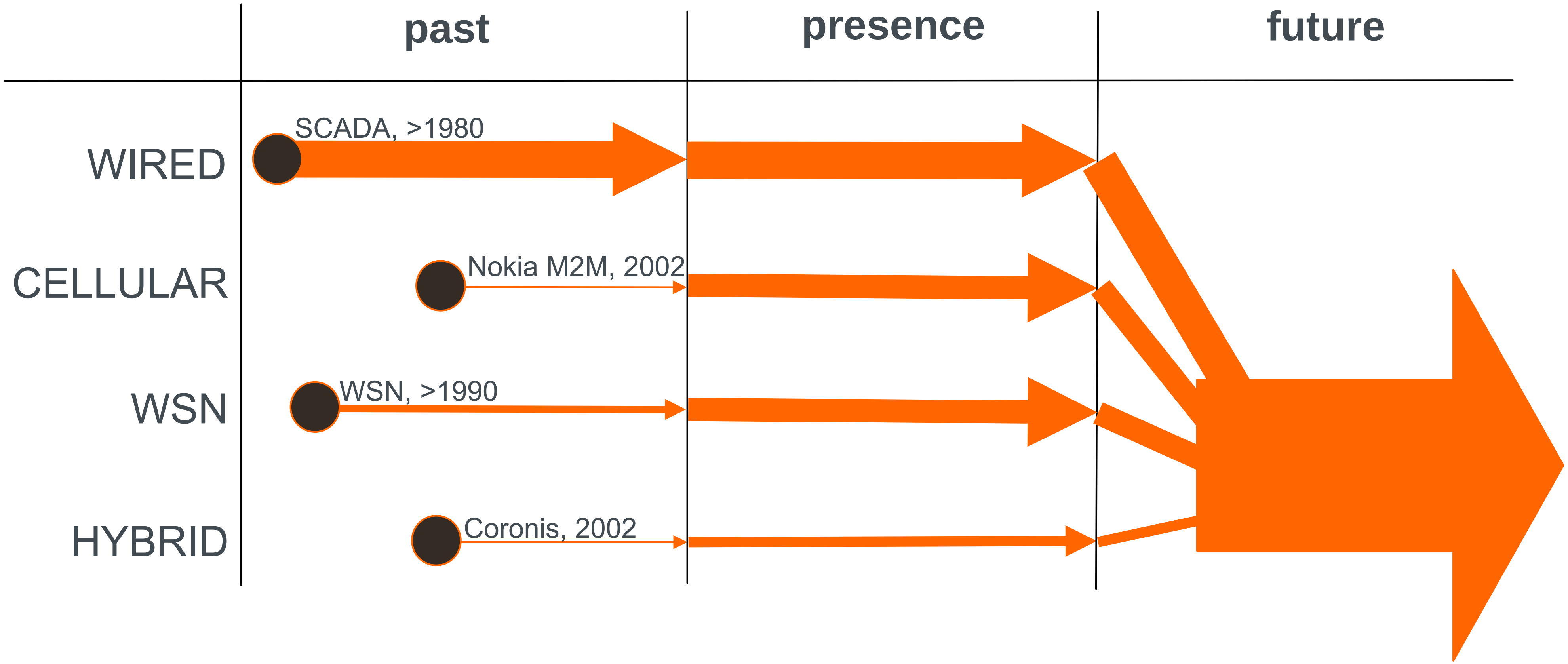


M2M Access Networks [2/2]

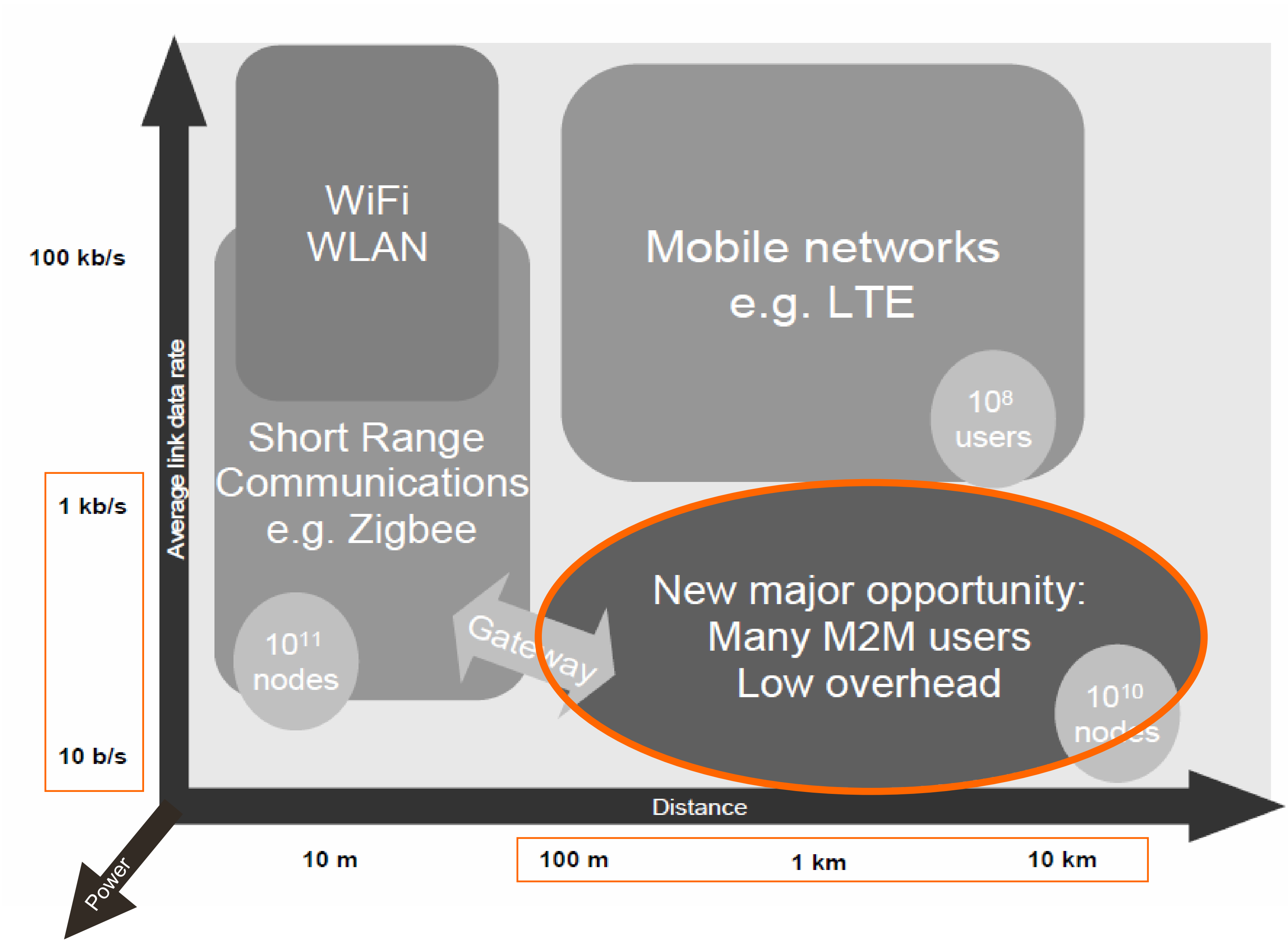
- **Wired Solution** – dedicated cabling between sensor - gateway:
  - pros: very, very reliable; very high rates, little delay, secure, cheap to maintain
  - cons: very expensive to roll out, not scalable
- **Wireless Cellular Solution** – dedicated cellular link:
  - pros: excellent coverage, mobility, 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 **cellular** community:
  - **nodes**: management of huge amounts
  - **rates**: fairly low and rather uplink
  - **power:** highly efficient (must run for years)
  - **delays**: large spread (real-time ... monthly)
  - **application**: don’t disturb existing ones

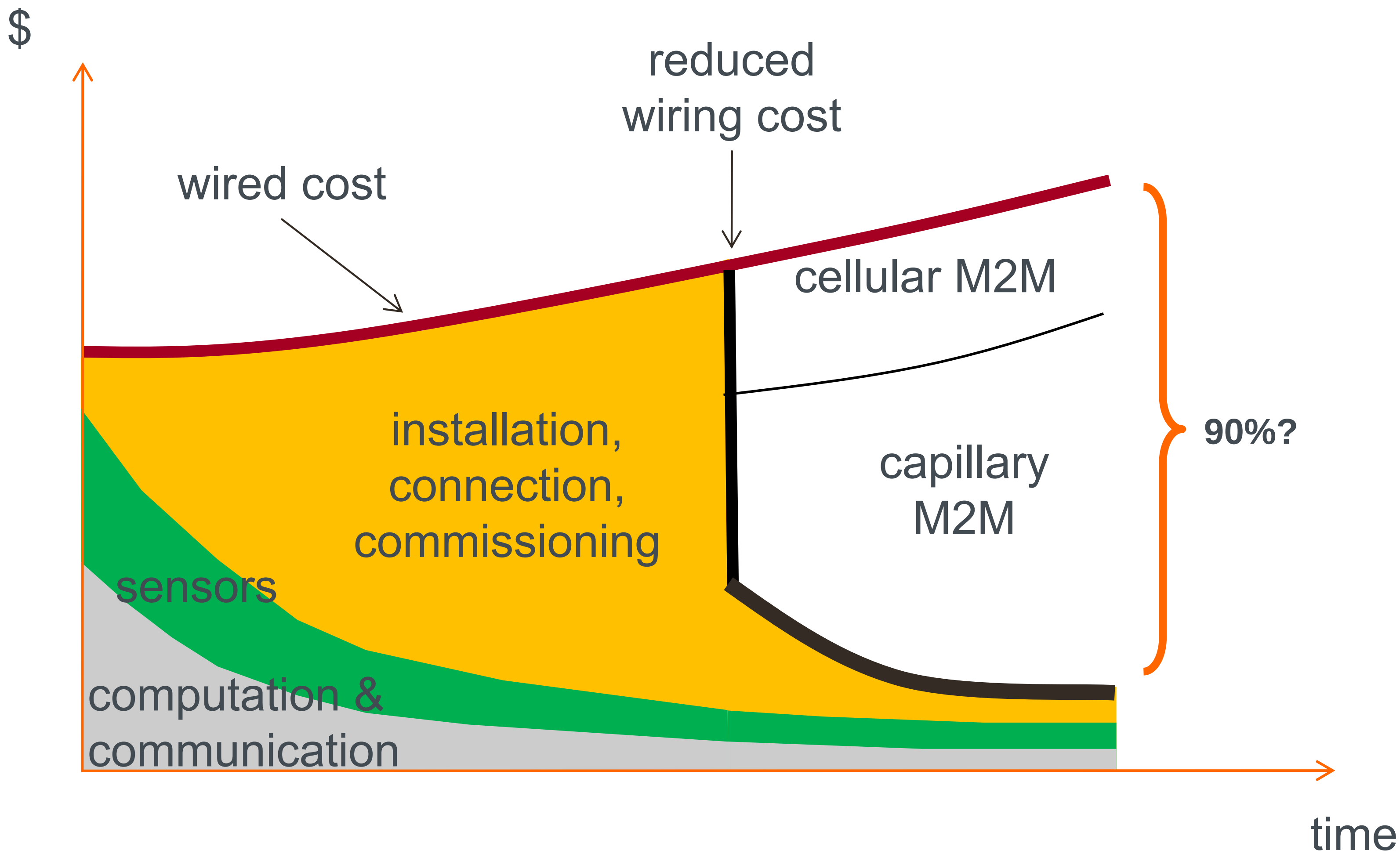
- Challenges for **capillary** community:
  - **delays**: large spread (real-time ... monthly)
  - **security**: suitable security over multiple hops
  - **standards**: lack of standardization across layers

- Is this possible?

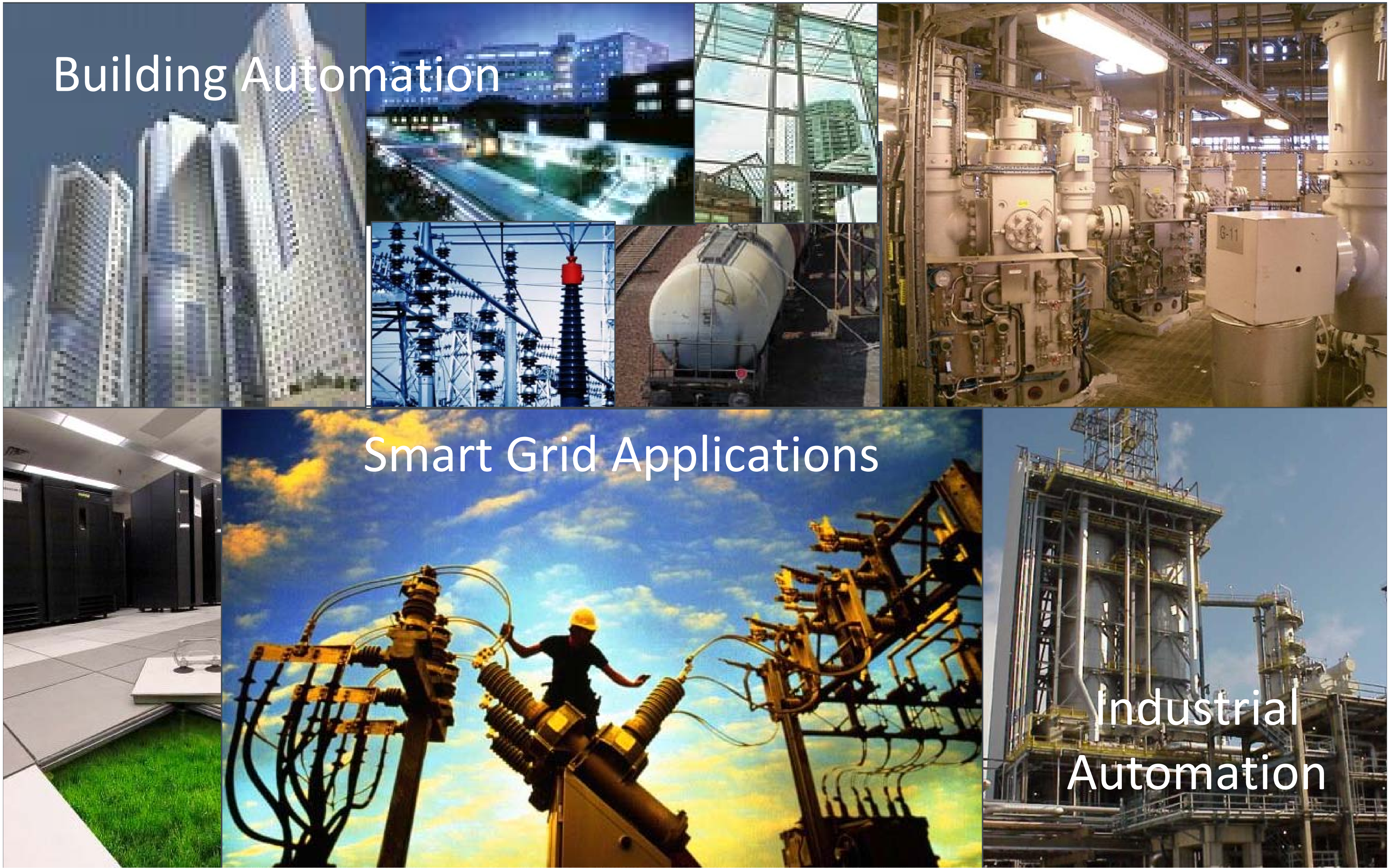
1.2

M2M Markets and Applications

Cost of Wireless M2M



Popular M2M Markets



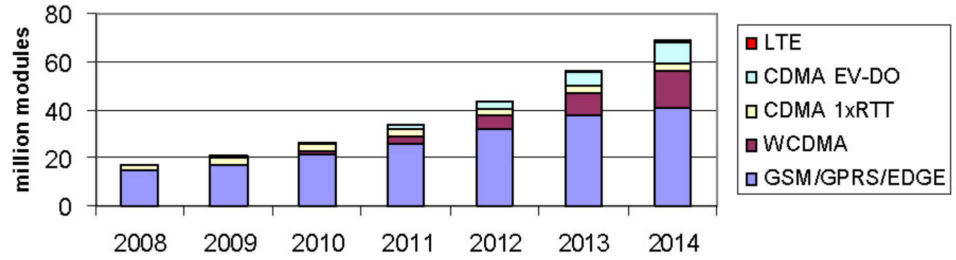
Cellular M2M Market Share

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

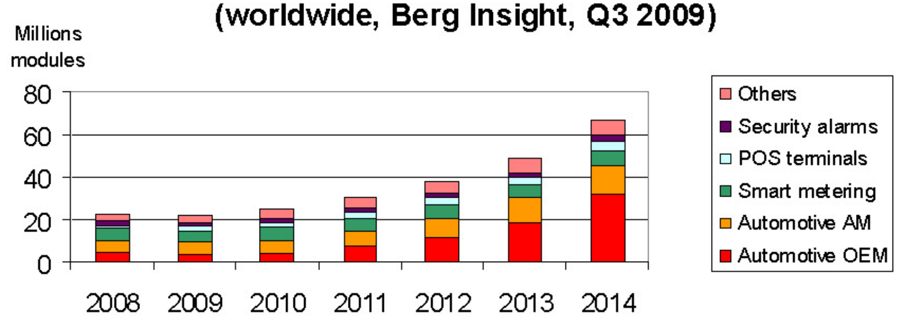
- Predictions on M2M LTE:
  - minor market until 2014
  - 2.5% (1.7M) of total M2M market
  - LTE module = twice 3G cost

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

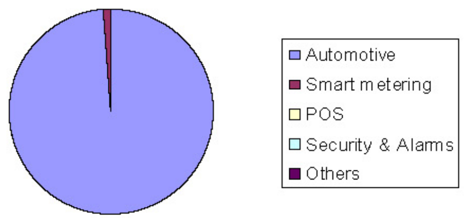
Worldwide Cellular M2M Module Shipments by Air Interface (ABI Research, Q3 2009)



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



LTE modules deliveries by Application (ABI Research forecast in Q3 2009 for 2014)



1.2.1

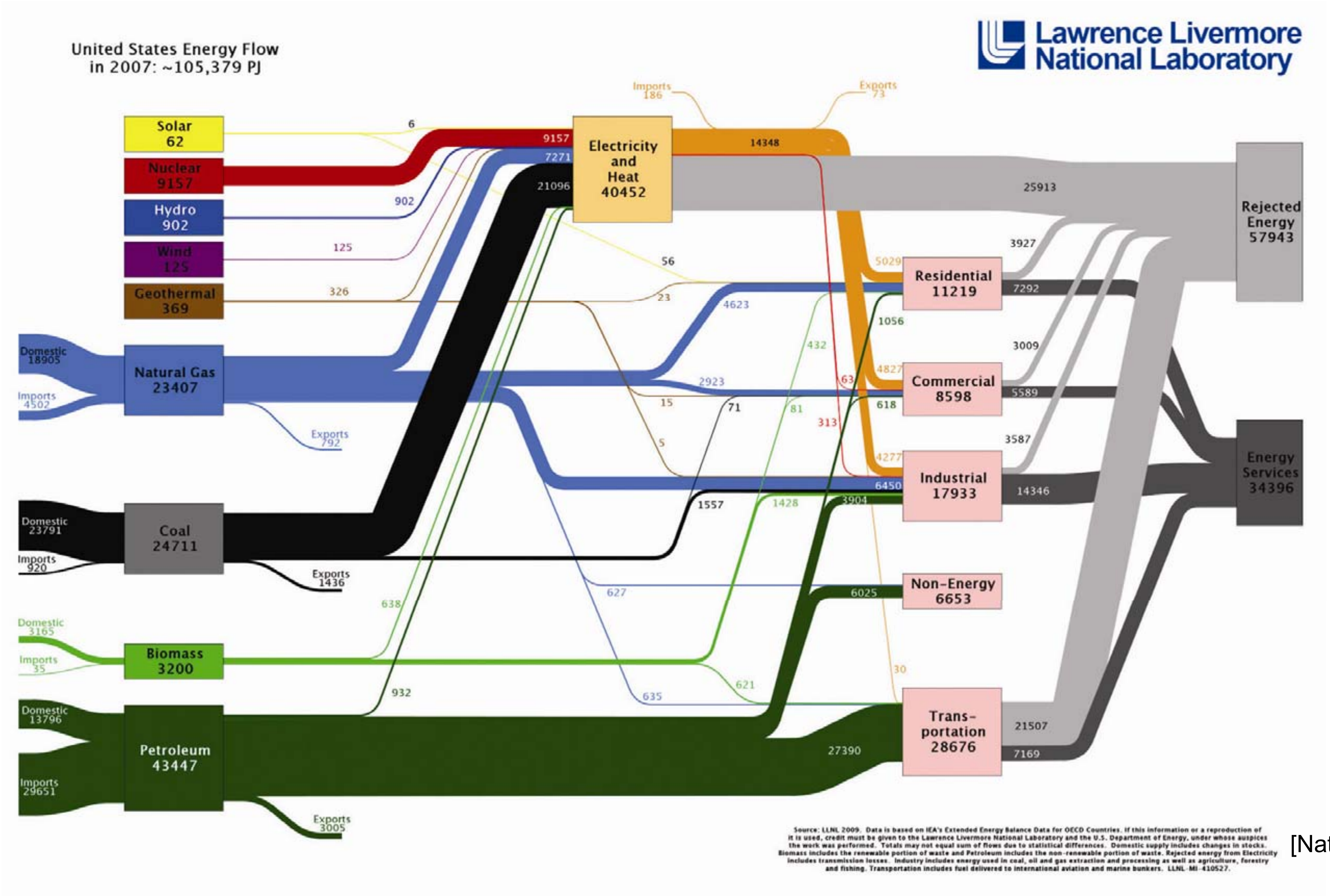
M2M in Smart Grids

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]**

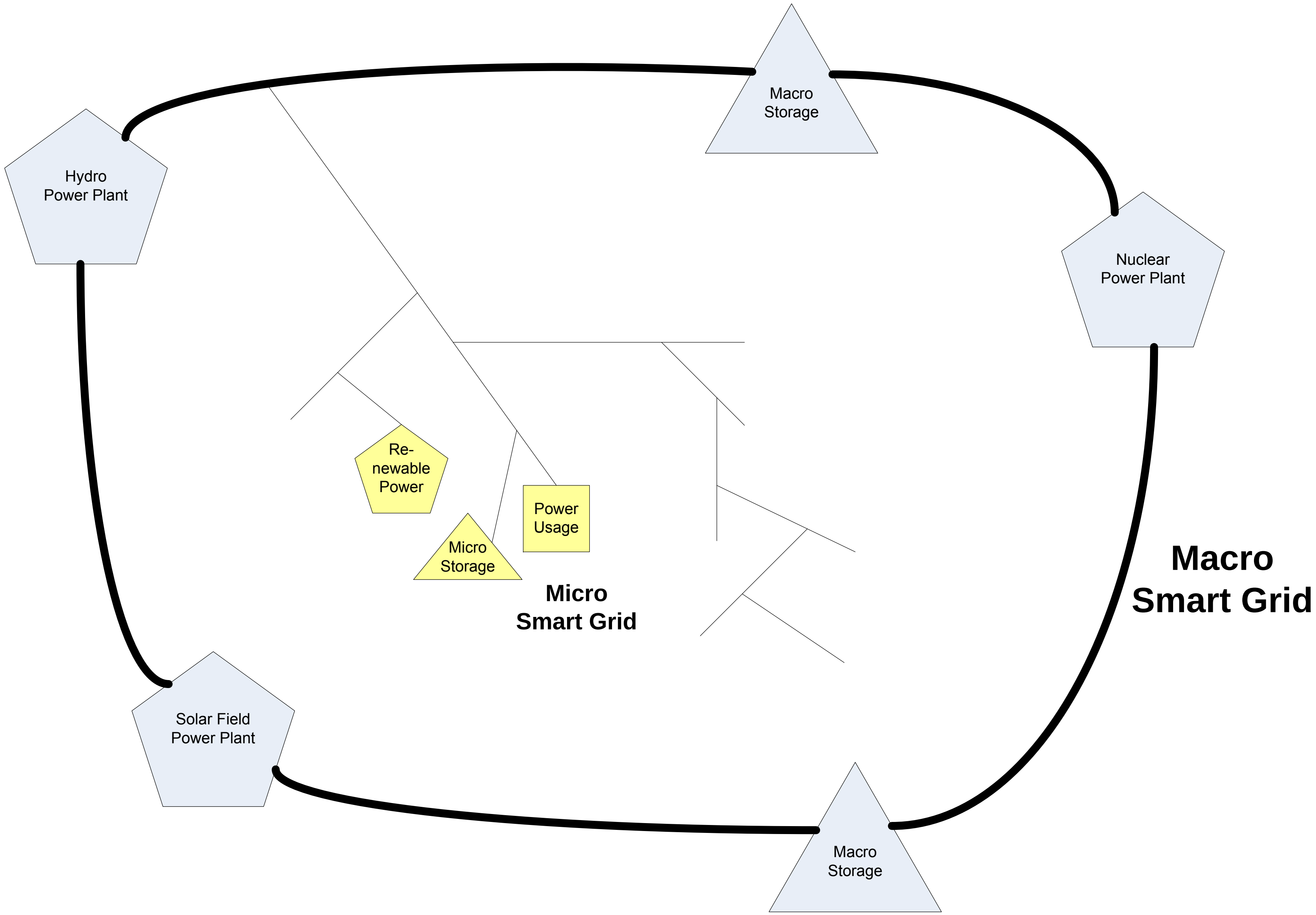
- Mission of ICT in Smart Grids:
  - enable energy efficiency
  - keep bills at both ends low
  - minimize greenhouse gas emissions
  - automatically detect problems and route power around localized outages
  - accommodate all types and volumes of energy, including alternative
  - make the energy system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

Reduce Waste & Dependency ...

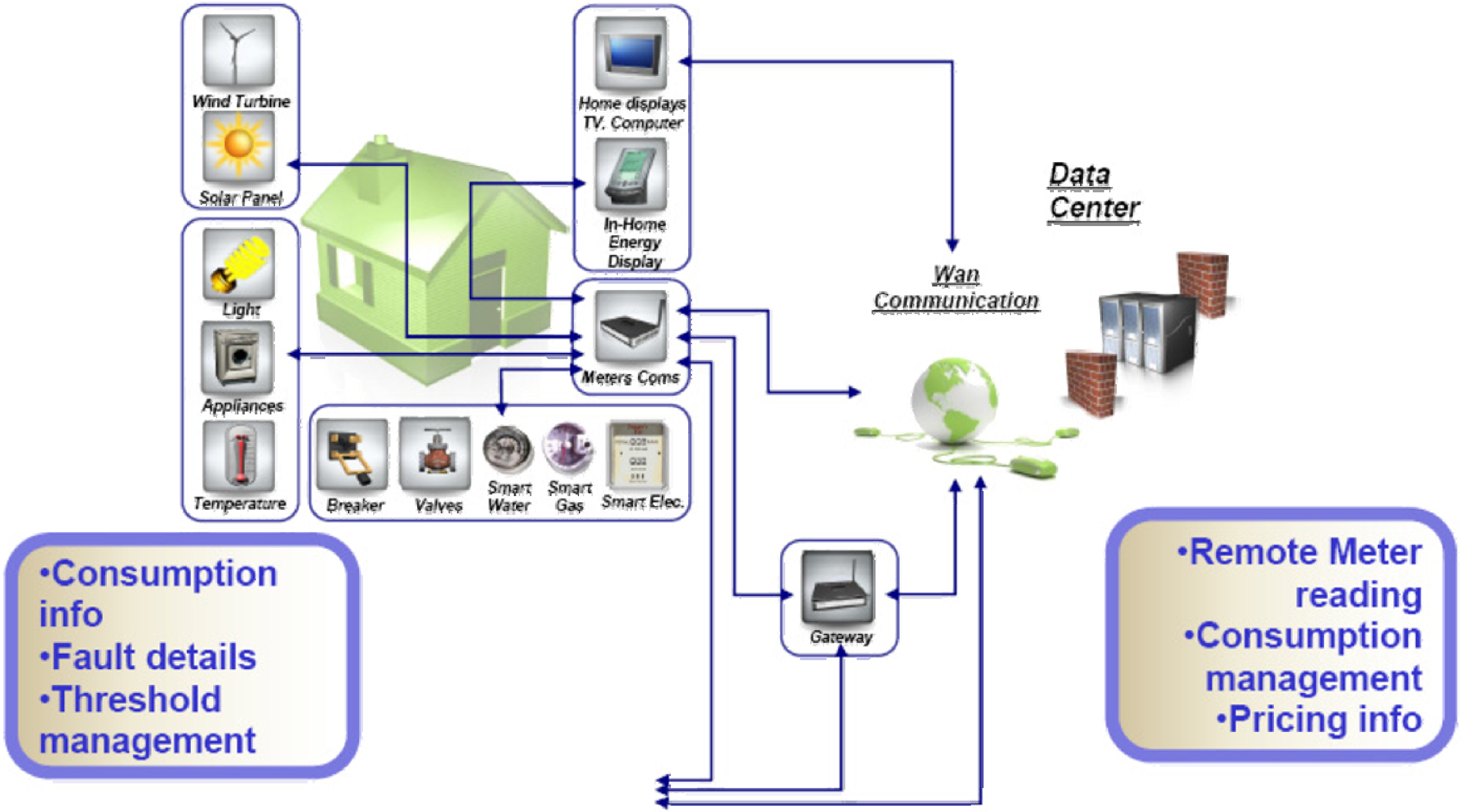


[National Broadband]

... with Smart Grids [1/2]



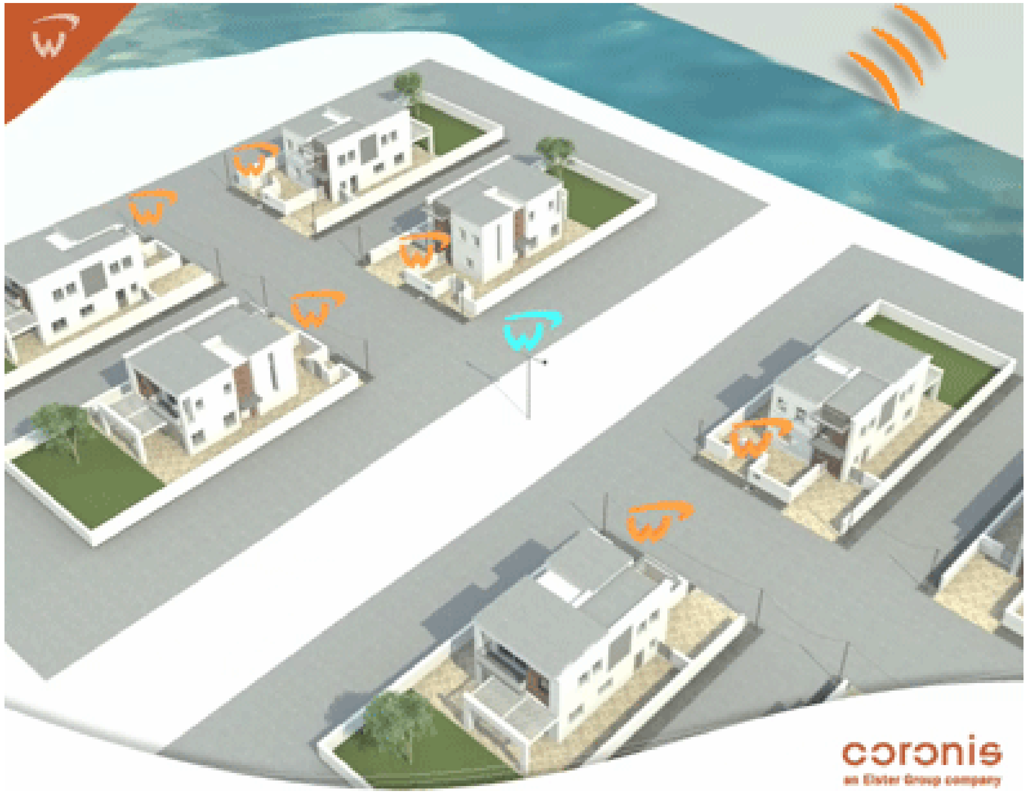
... with Smart Grids [2/2]

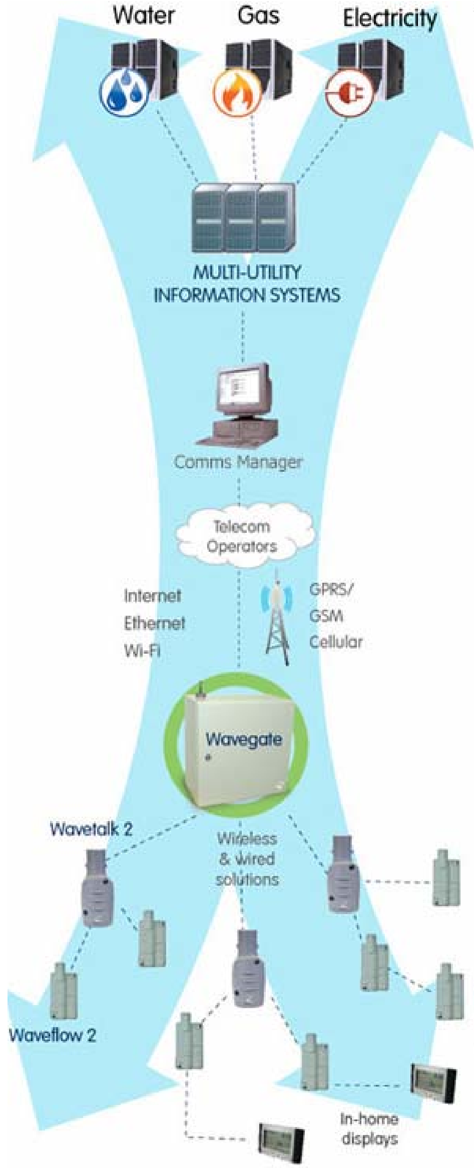


[© ETSI M2M]

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]

1.2.2

M2M in Smart Cities

Smart City Vision

- There is no “Obama Document” – and hence only a blurry vision ...
  - “Create a global network of self-sustained business townships to foster the knowledge economy.” [www.smartcity.ae]

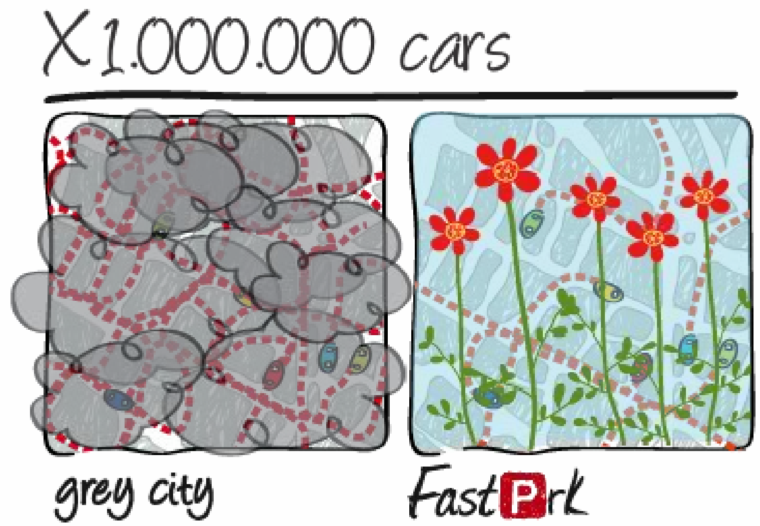
- Example embodiments of Smart Cities:
  - improve carbon footprint (automated parking search, lights, etc)
  - improve maintenance efficiency (automated container levels, etc)
  - improve emergency responses (automated notification, etc)
  - minimize theft (automated warning, security, etc)

- XALOC – Spanish “Smart City” project:
  - UB: local localization
  - CTTC: MAC, routing protocols
  - Worldsensing: hardware, implementation, test trial

Urban Parking Quests

Real cities...

- Barcelona 2010:
  - daily quest for parking spots
  - 1,000,000 (million) cars
  - average 16 minutes



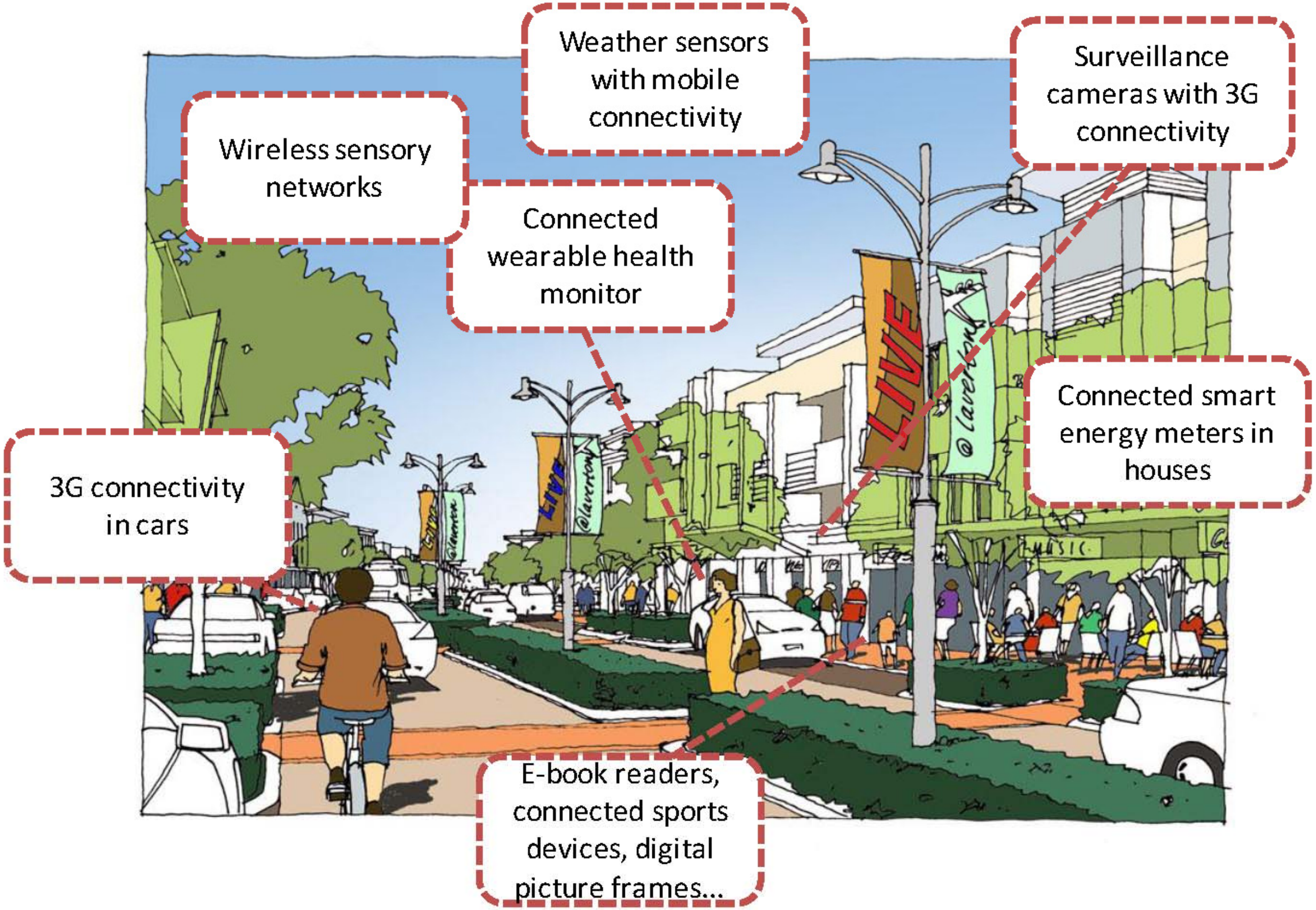
[www.worldsensing.com]

Urban Container Monitoring

- Recycling containers (Voiron, France):
  - reduces cost (no more random collection), reduced dissatisfaction (no more spillovers), protects investment (real time theft alert)
  - France Telecom technology: ultrasound level sensing, shock detection, local ad-hoc network and cellular backhaul.

M2M Connected Smart City

© Northstream White Paper on Revenue Opportunities, February 2010



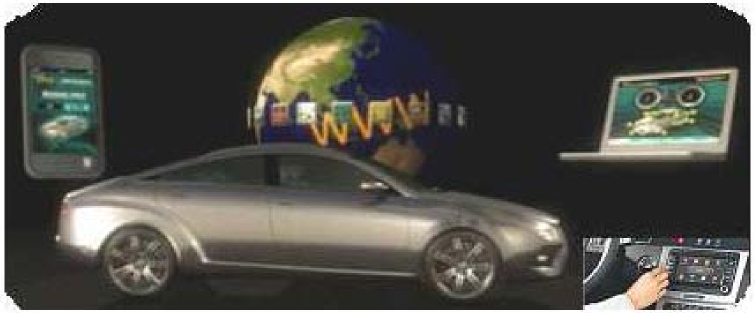
1.2.3

M2M in Automotive (Telematics)

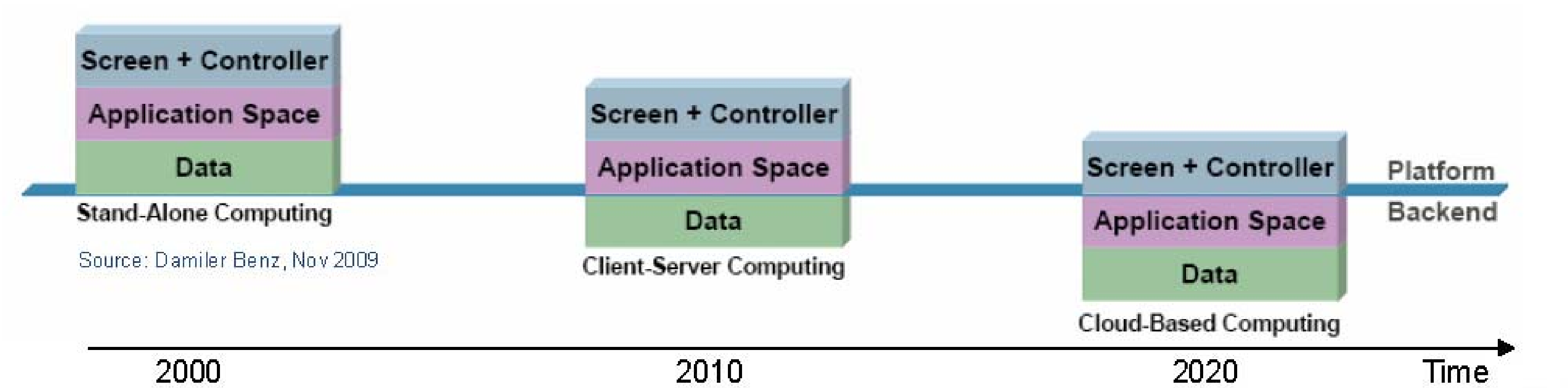
Sagemcom Vision on Automotive

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

- The next generation of car buyers will expect full connectivity and seamless integration in the vehicle. Less concern will be placed on the device used and more on the content provided!



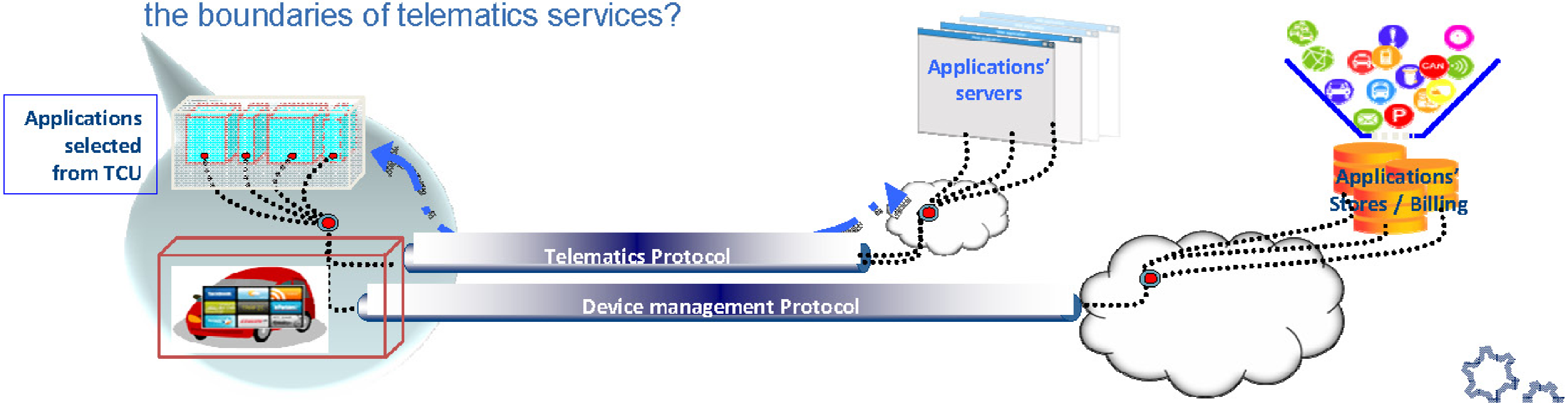
- Transition to Telematics 3.0 thanks to higher bandwidth: Data & applications off-board…



Sagemcom Vision on Automotive

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

- Ubiquity & Up-to-date
  - If applications remain in the cloud, they can be accessible from any device without any synchronisation.
  - If applications remain in the cloud, all the devices will be granted to use the last release.
  - Challenge: use when out-of coverage. Cache memory management? Security issues?
- Data traffic optimization
  - Some applications only require GPS location, but transmitted often; challenge to decrease overheads?! Challenge to share the GPS location : sent once in the cloud, but used by several applications? Security issues?
- Stand-by time
  - Some applications are triggered when the engine is off. Challenge to operate at low power?
- Protocol unification?
  - Each service provider defines its own telematics protocol. Challenge to decrease fragmentation to open the boundaries of telematics services?



2

Cellular M2M

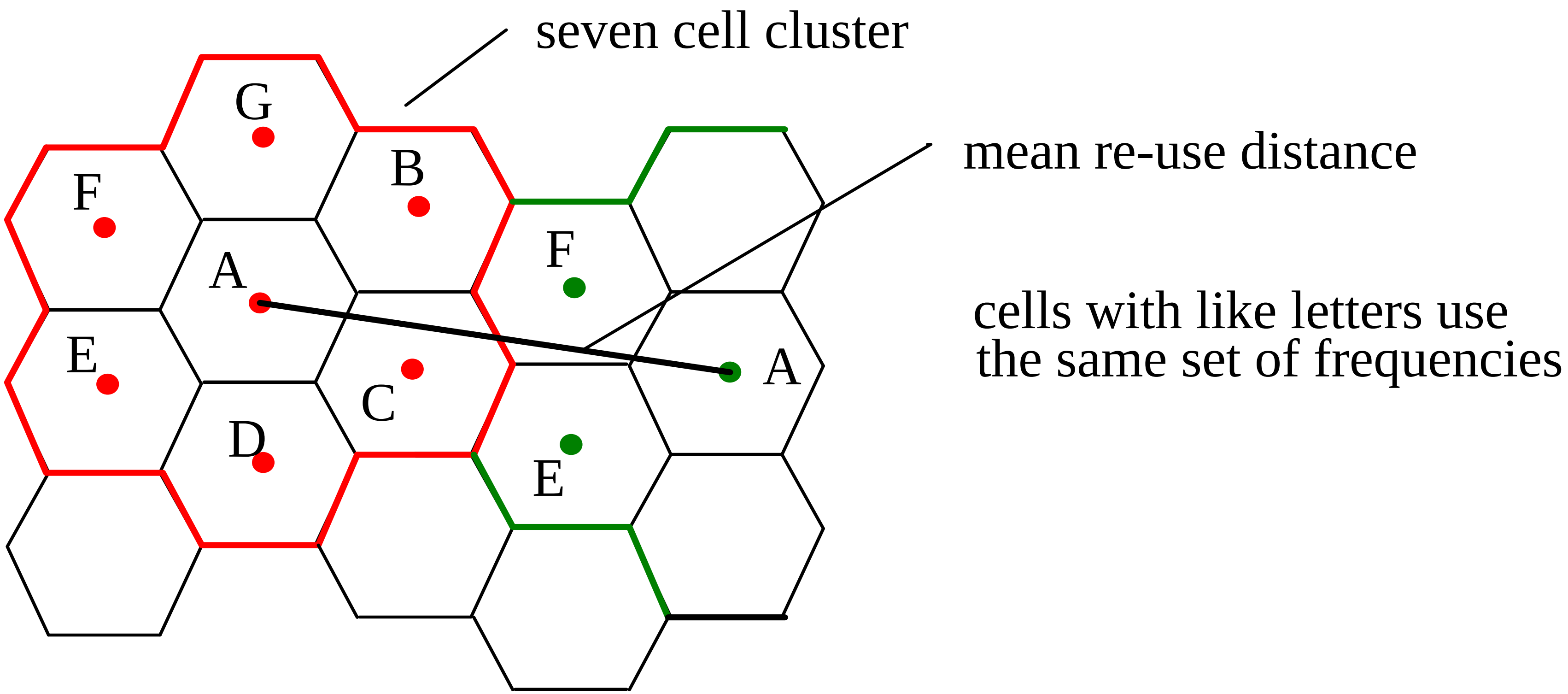
2.1
Introduction to Cellular M2M

2.1.1

Fundamentals of Cellular Systems

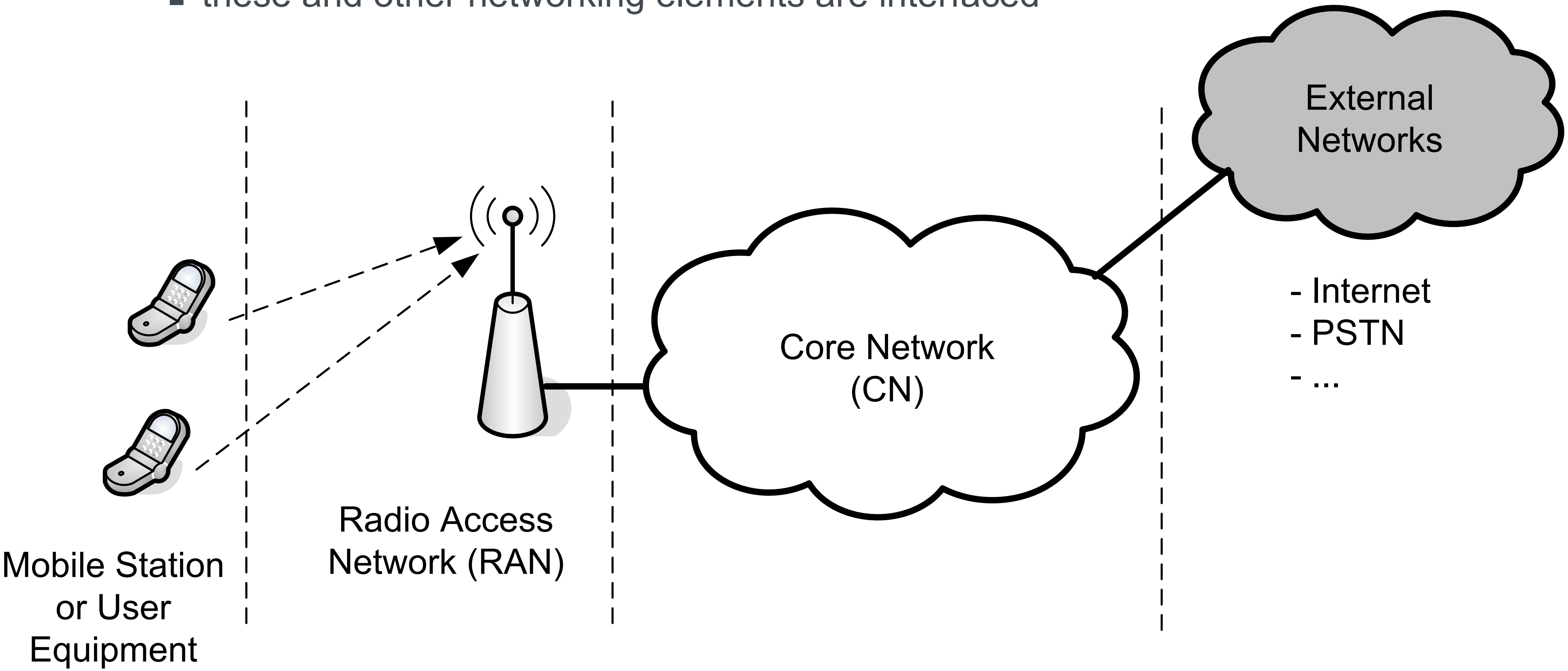
Quick Intro [1/2]

- **Cellular** Networks:
  - location "independent" communications
  - wide area communications (range in order of km)
  - coverage divided into cells (lower Tx power, higher capacity)



Quick Intro [2/2]

- Cellular **Networks**:
  - principle element is access network
  - supporting element is backhaul network
  - these and other networking elements are interfaced



Cellular Generation Salad [1/2]

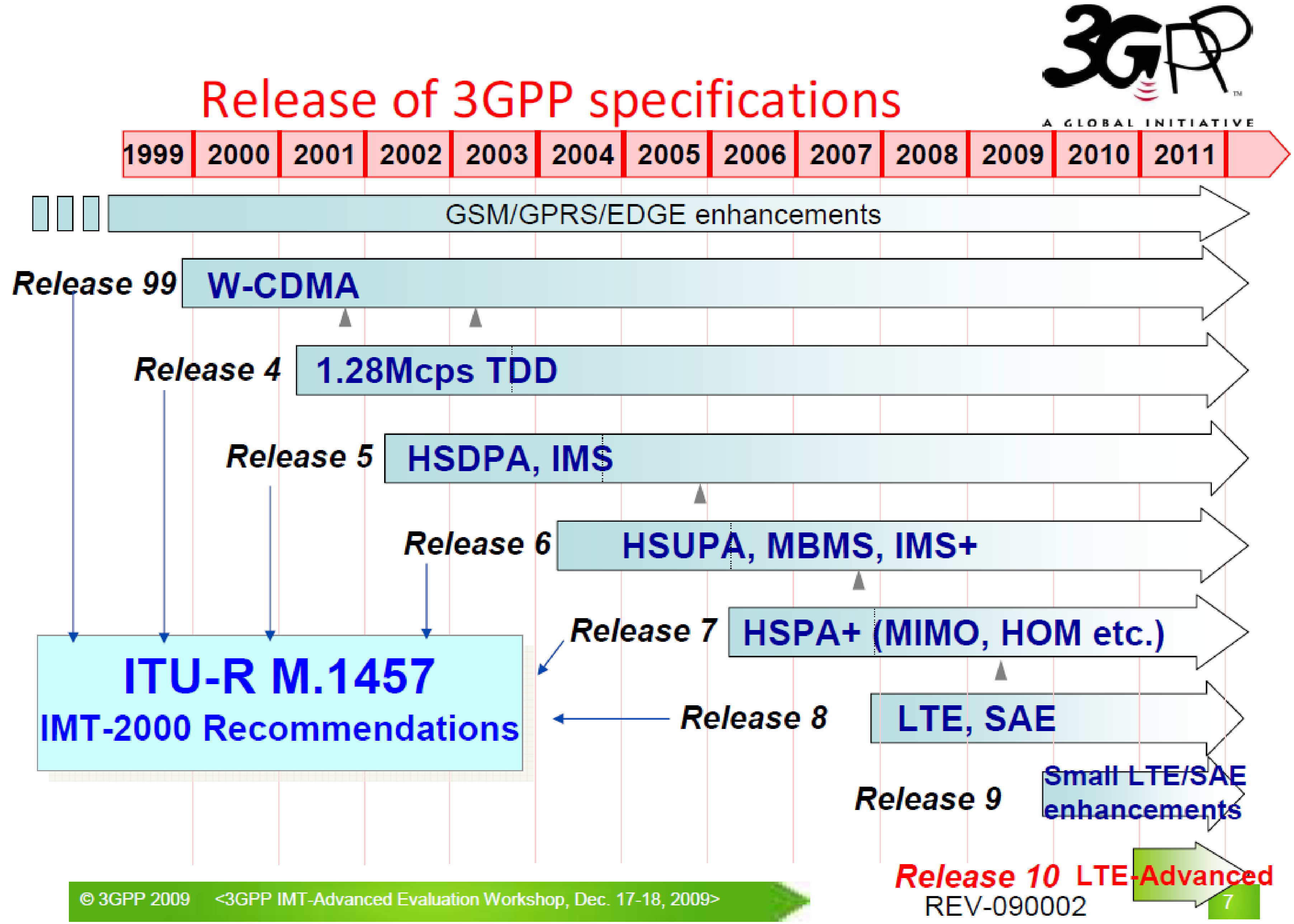
- **2G Networks**:
  - GSM (Global System for Mobile Communications), 1990, worldwide
  - IS95 (Interim Standard 95), mainly US
- **2.5G Network**:
  - GPRS (General Packet Radio System), worldwide
- **3G Networks:**
  - EDGE (Enhanced Data Rates for GSM Evolution), GSM evolution
  - UMTS (Universal Mobile Telecommunication System) (3GPP)
  - 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

Cellular Generation Salad [2/2]

- **"3.9G" Network:**
  - LTE (Long Term Evolution), UMTS evolution/revolution, worldwide
- **4G Networks:**
  - LTE-A (LTE Advanced), LTE evolution/revolution, worldwide
  - 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.

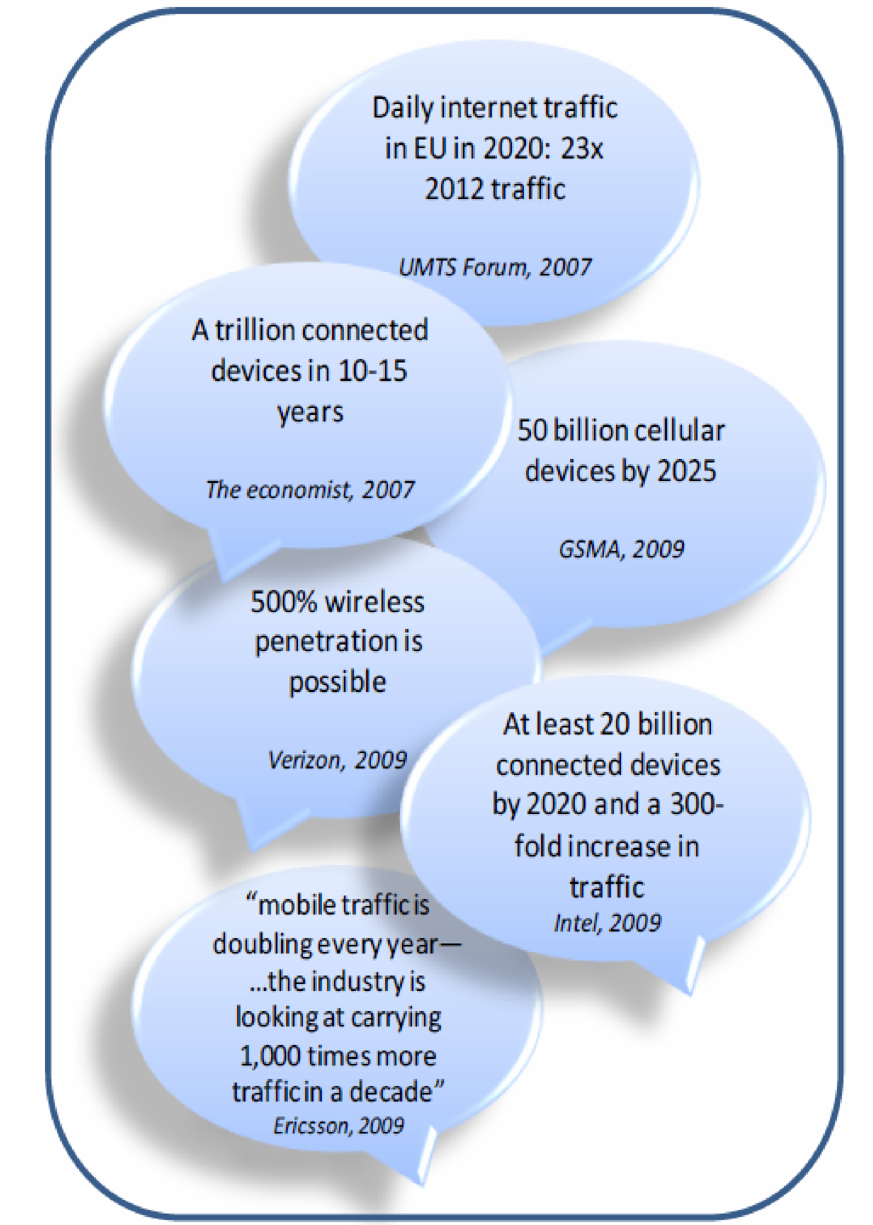
3GPP Detailed Timeline



2.1.2

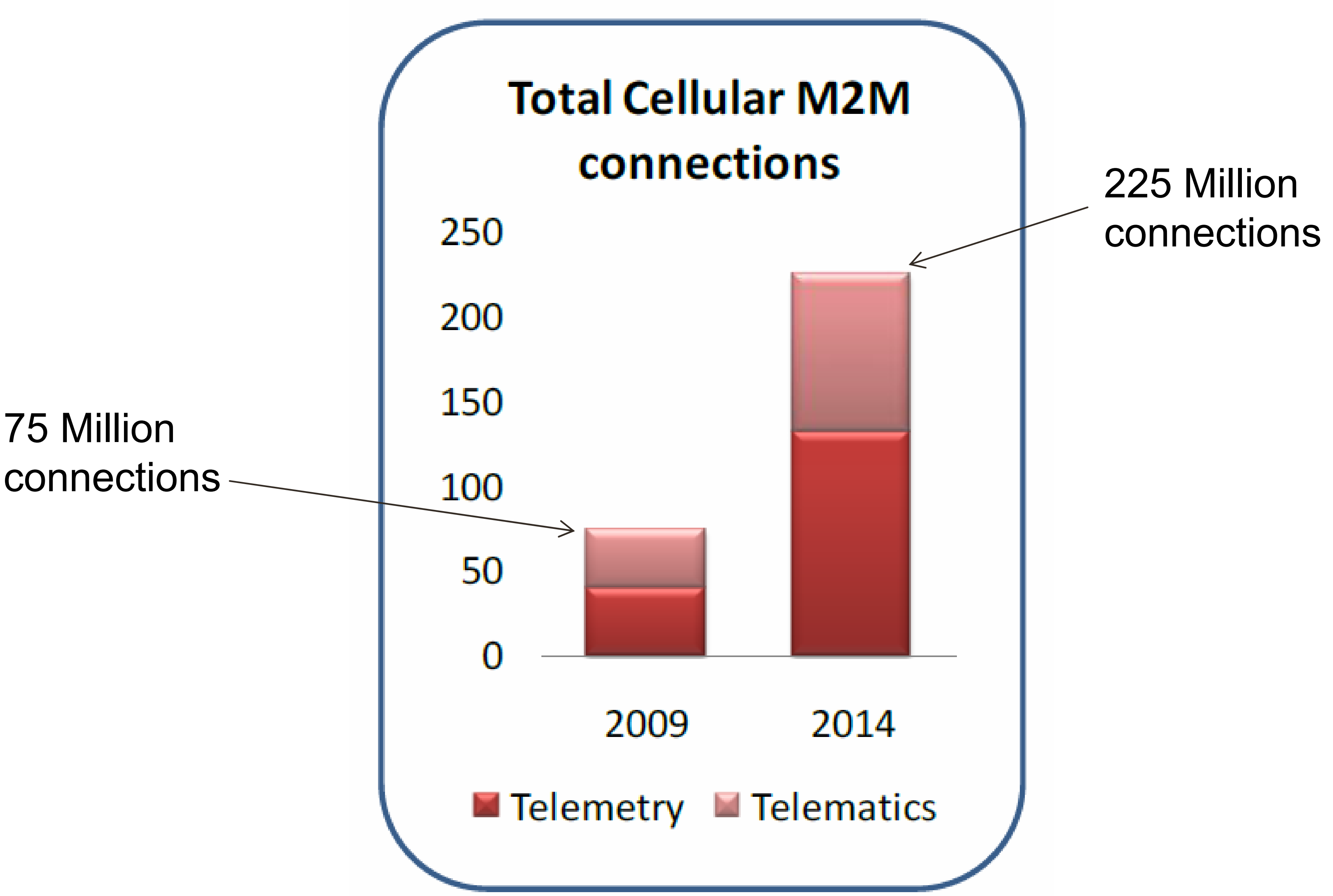
Motivating Cellular for M2M Applications

A Simple Motivation: Numbers



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

A Simple Motivation: 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 & Opportunities

- **THE advantage** of cellular M2M**:**
  - Ethernet/WiFi/etc only provides local coverage
  - Cellular networks provide today ubiquitous coverage & global connectivity
  - Users already familiar with and proven infrastructure
- 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

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
- Lack of ***standardization***
- Technological competition
- Low revenue per connection
- 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!

2.2

M2M in Current Cellular Networks

2.2.1

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

GSM – PHY Layer

M2M

- **Carrier Frequency**:
  - 900 MHz, 1.8 GHz, and others — the lower, the better
- **Power Management**:
  - 8 power classes; min 20 mW = 13 dBm — can be easily handled
  - (2dB power control steps)
- **Modulation**:
  - GMSK → constant envelope — good for M2M PA
- **PHY Data Rates**:
  - 9.6 kbit/s per user — too low for many app.
- **Complexity**:
  - fairly low as of 2010 — generally, good candidate

GSM – MAC Layer

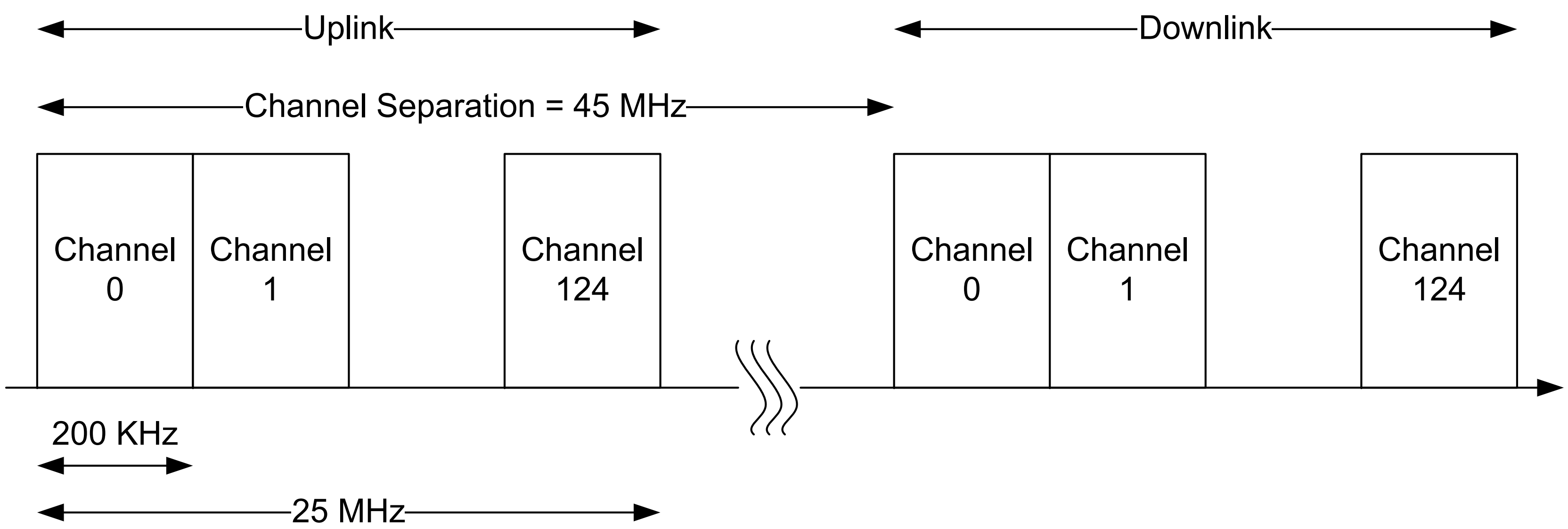
M2M

- **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)

  useful for device wake-up, data backup, configuration, remote diagnosis, etc.

- **Data**:
  - circuit switched data, 9.6Kbps

  often not sufficient

SMS – Some Figures

- SMS:
  - Year 2000, GSM World Congress: Coke vending machine with SMS over GSM
  - Recently: “Trash Can” system used in Somerville, Massachusetts, USA:
    - Litter bins send SMS to the authorities when full
  - Study by CISCO:
    - Video application: $ 0.017 per Mbyte
    - SMS: $ 20 per Mbyte

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

2.2.2

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 ▪ (1dB power control steps)	**big** challenge
Modulation:	
▪ CDMA → envelope depends on code	difficult for M2M PA
PHY Data Rates:	
▪ >100 kbit/s packet switched	sufficient for most app.
Complexity:	
▪ medium as of 2010	basic 3G configuration okay

UMTS – MAC Layer

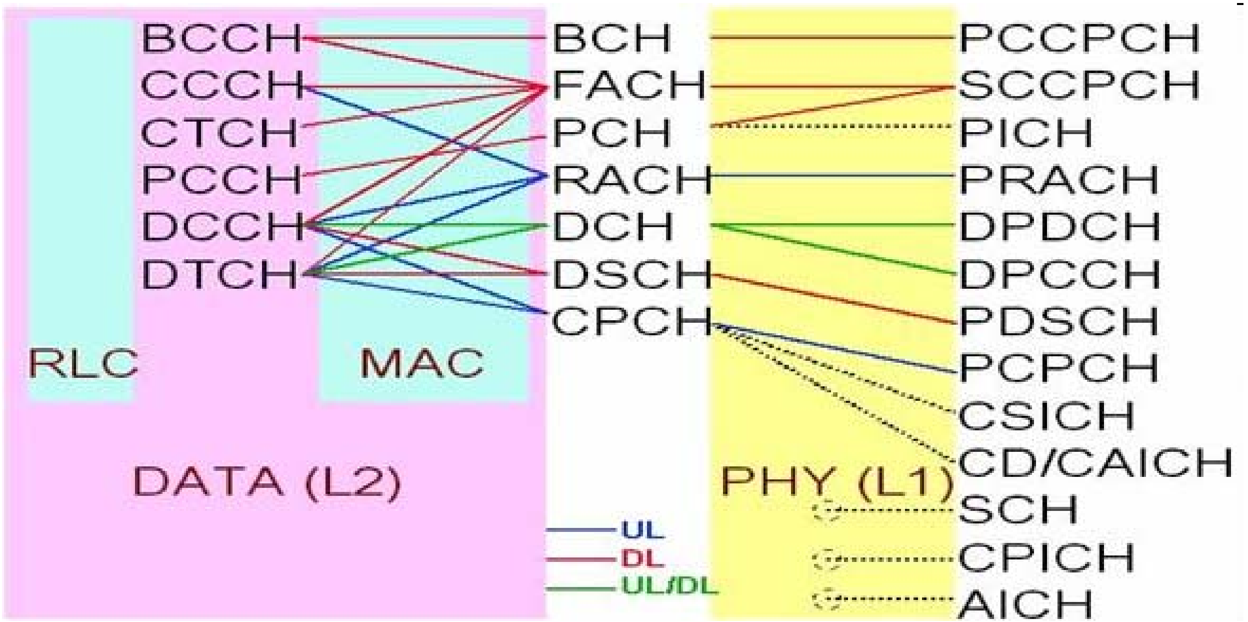
M2M

- **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

4G – New Generation Networks

- 2002 → ITU-R → 4G → IMT Advanced
  - International Mobile Telecommunications Advanced
  - All IP Packet Switched Networks (based on IPv6)
  - PHY layer based on Multicarrier Transmission (OFDMA)
  - Use of MIMO
  - Data rates:
    - 100 Mbps high mobility
    - 1 Gbps low mobility
  - Low latency
- Some “Beyond 3G” Systems, but not yet 4G:
  - LTE (100 Mbps DL, 50 Mbps UL) (Release 8 ***3GPP***)
  - WiMAX (128 Mbps DL, 56 Mbps UL) (802.16m ***IEEE***)

LTE – Overview

- Initiated in 2004 (Workshop @ Toronto, Canada)
- High-level requirements:
  - Packet Switching optimization
  - Reduce cost per bit
  - Increase services (at lower cost)
  - Flexibility of use of existing bands
  - Simplify architecture
  - Reduce terminal power consumption (extend lifetime)
- Good match with the needs of M2M!!!

LTE – Overview

- Key features of Evolved UTRAN (EUTRAN):
  - All IP (with VoIP capability) → twofold weapon:
    - Easier integration with other systems → can solve problems of coverage (e.g. USA).
    - Greater market competitiveness (e.g. Skype)
  - High ***Peak*** Data rates (DL at 100 Mbps and UL at 50 Mbps)
  - Very low latency (short set-up and transfer delay)
  - Radio Access Network (RAN) RTT < 10 ms
  - At least ***200*** active users per cell (high capacity)
  - Mobility
    - Optimization for 0-15 Km/h
    - High performance for 15-120 Km/h
    - Operability for 120-350 Km/h (even 500 Km/h)

LTE – Overview

- Key features of Evolved UTRAN (EUTRAN):
  - Coverage
    - 5 Km per cell (perfect match of requirements)
    - 30 Km per cell (slight degradation allowed)
    - 100 Km per cell → not excluded
  - Flexible bandwidth operation (up to 20MHz)
    - DL → OFDM
    - UL → Single Carrier FDMA (SC-FDMA)

      → to avoid the envelope fluctuations of OFDM at the transmitter of the devices
  - Frequency reuse factor = 1
  - Multi-antenna support

Beyond UMTS – LTE & LTE-A

- **LTE** = UMTS + …
  - … OFDMA (downlink) +
  - … SC-FDMA (uplink) +
  - … quicker RTT & throughput
- **LTE-A** = LTE + …
  - … many, many sexy features
  - … meeting IMT-Advanced specs

Environments		**DL LTE-Advanced Targets**		**UL LTE-Advanced Targets**	
		Sector (bps/Hz)	Cell Edge (bps/Hz)	Sector (bps/Hz)	Cell Edge (bps/Hz)
	Indoor	3	0.1	2.25	0.07
	Microcellular	2.6	0.075	1.80	0.05
	Base Coverage Urban	2.2	0.06	1.4	0.03
	High Speed	1.1	0.04	0.7	0.015
	Peak Spectral Efficiency	15		6.75	

2.3

M2M Cellular Standardization Activities

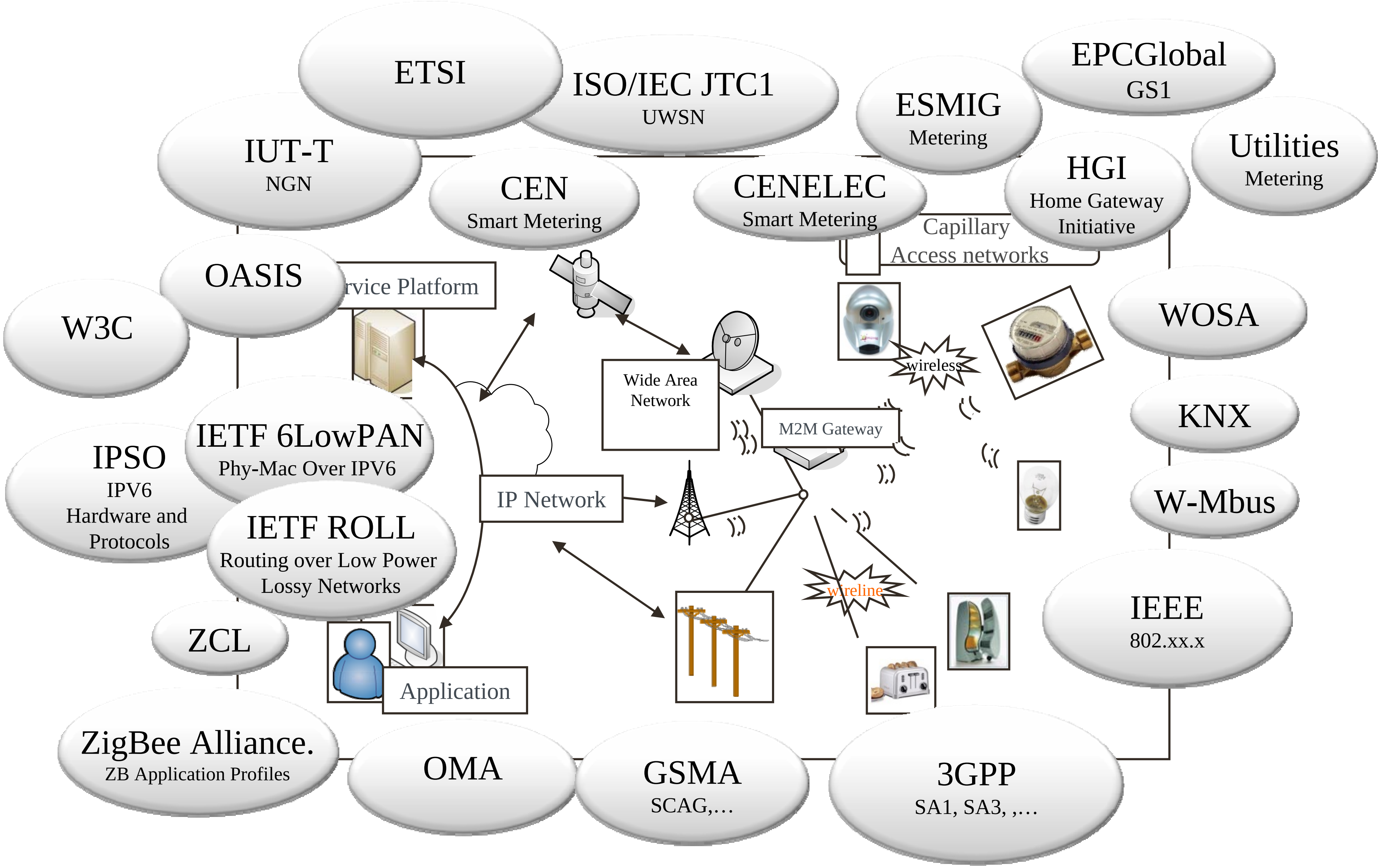
2.3.1

Overview of M2M Standardization

Standards for 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
- Due to potentially heavy use of M2M devices and thus high loads onto networks, interest from:
  - IEEE (802.11, 802.15, 802.16),
  - 3GPP (UMTS, HSPA, LTE)
- The starting point is to have popular M2M applications identified and then refine scenarios in each application to identify the areas needing standards.

M2M-Related Standardization Bodies

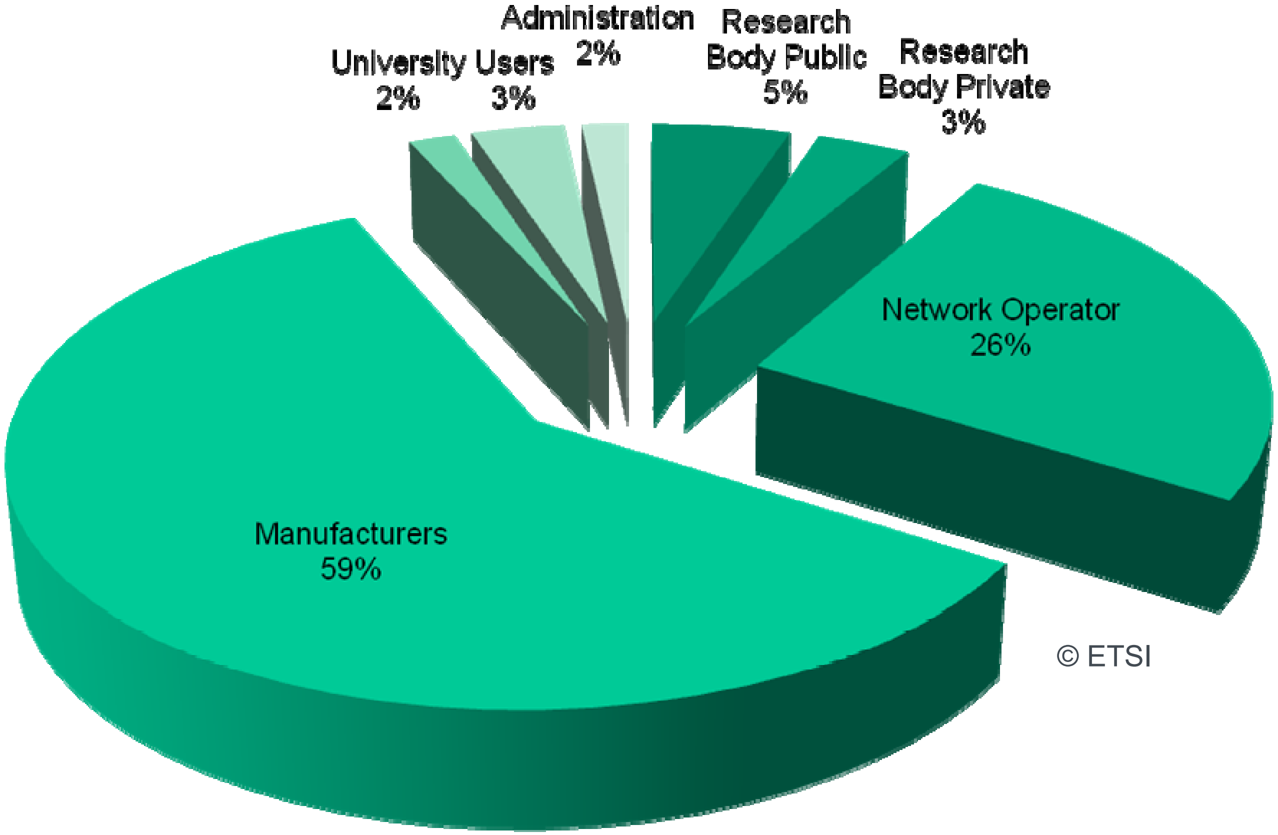


2.3.2

M2M Activities in ETSI

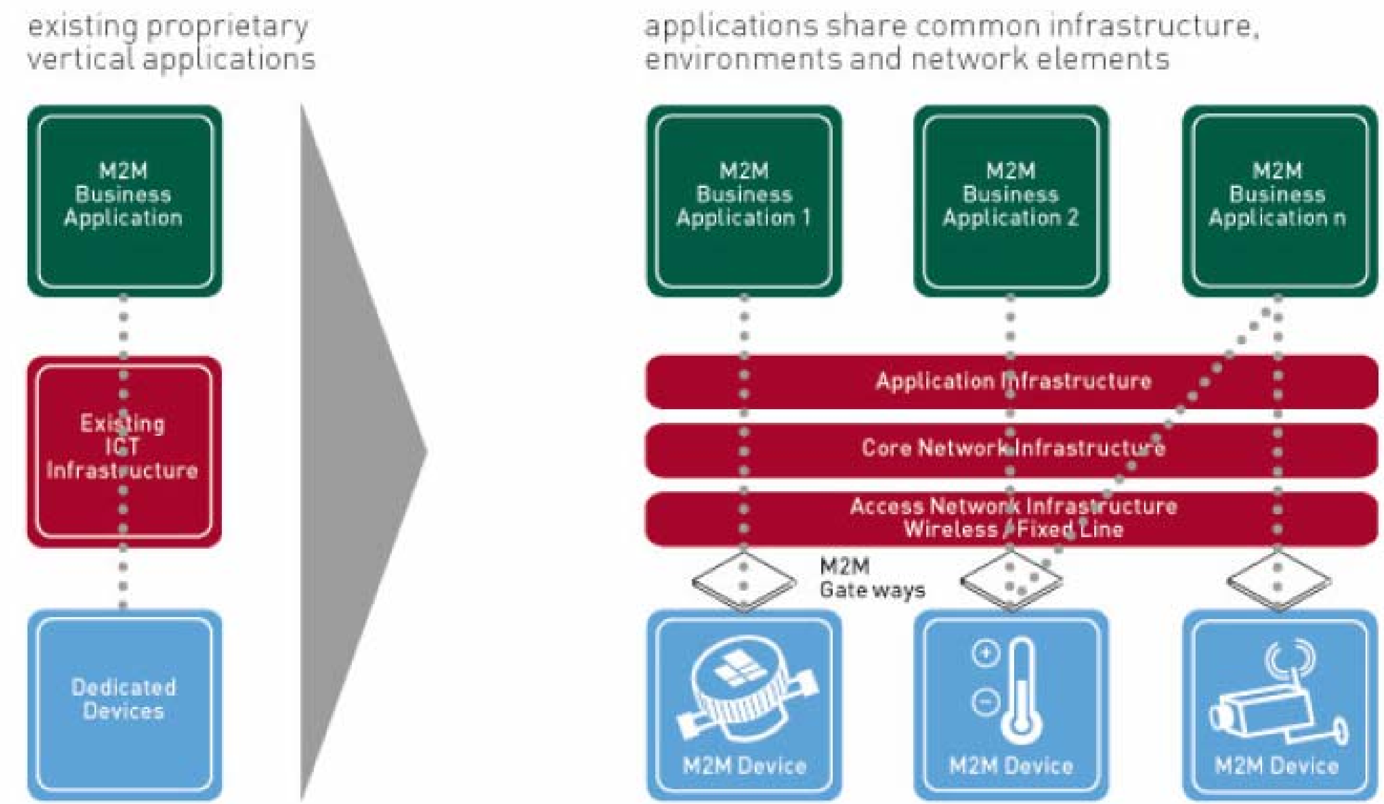
ETSI: TC M2M

- 2009: Technical Committee (TC) created for M2M
- Mission: develop standards for M2M
- Participants:



ETSI: TC M2M

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

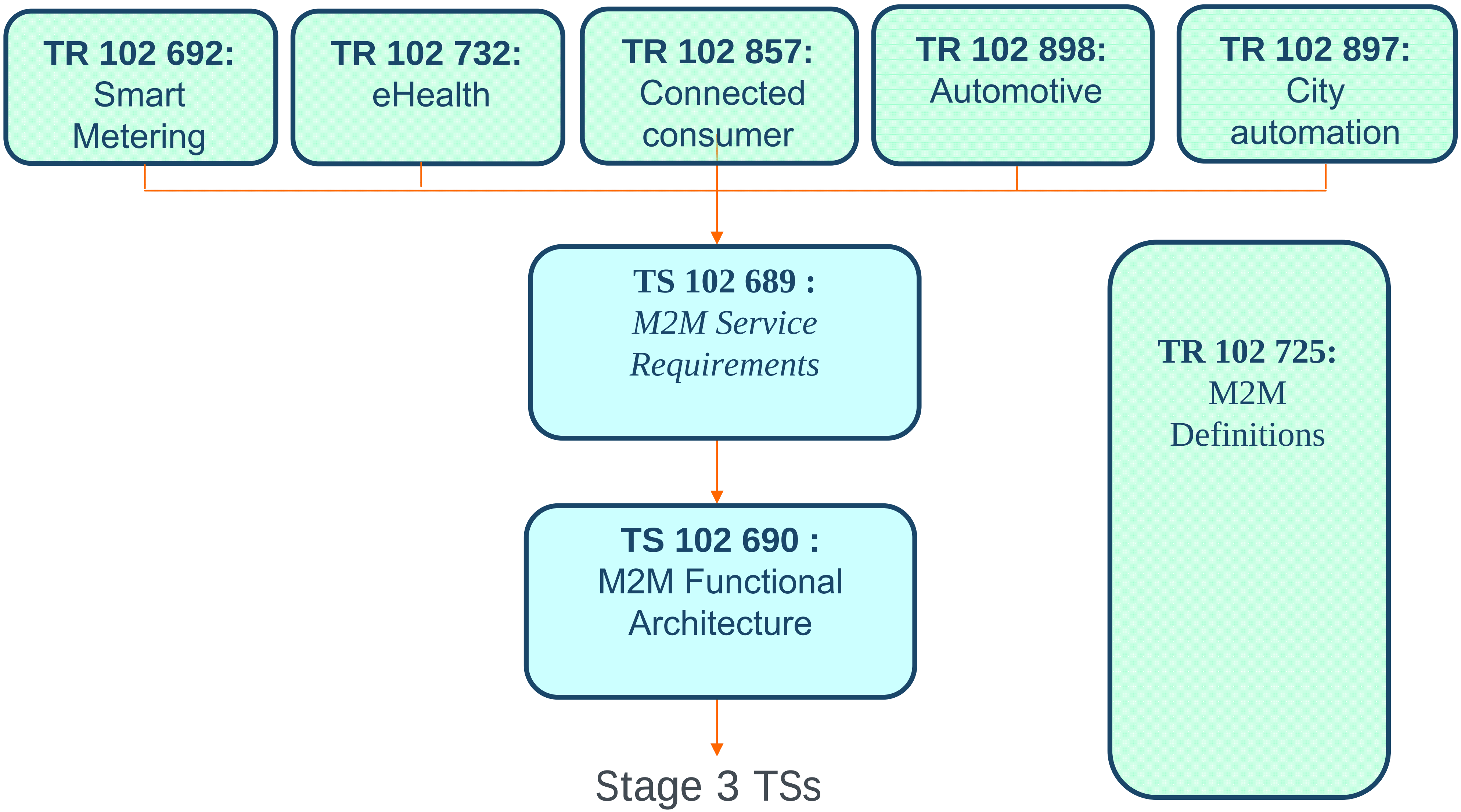


© ETSI

ETSI: Release Planning

- **Stage 0: Use cases documents**
  - Several documents are being developed in parallel
  - Derived requirements influence release 1 or subsequent releases specifications
- **Stage 1: Services requirements**
  - Content is stable, ongoing editorial corrections
- **Stage 2: Architecture**
  - Identified all capabilities and interfaces
  - Developing message flows
  - Target release date: **June 2010**
- **Stage 3: Refinement**
  - Ongoing discussions
  - Expected to start shortly
  - Target release date: **December 2010**

ETSI: TC M2M Tech Reports

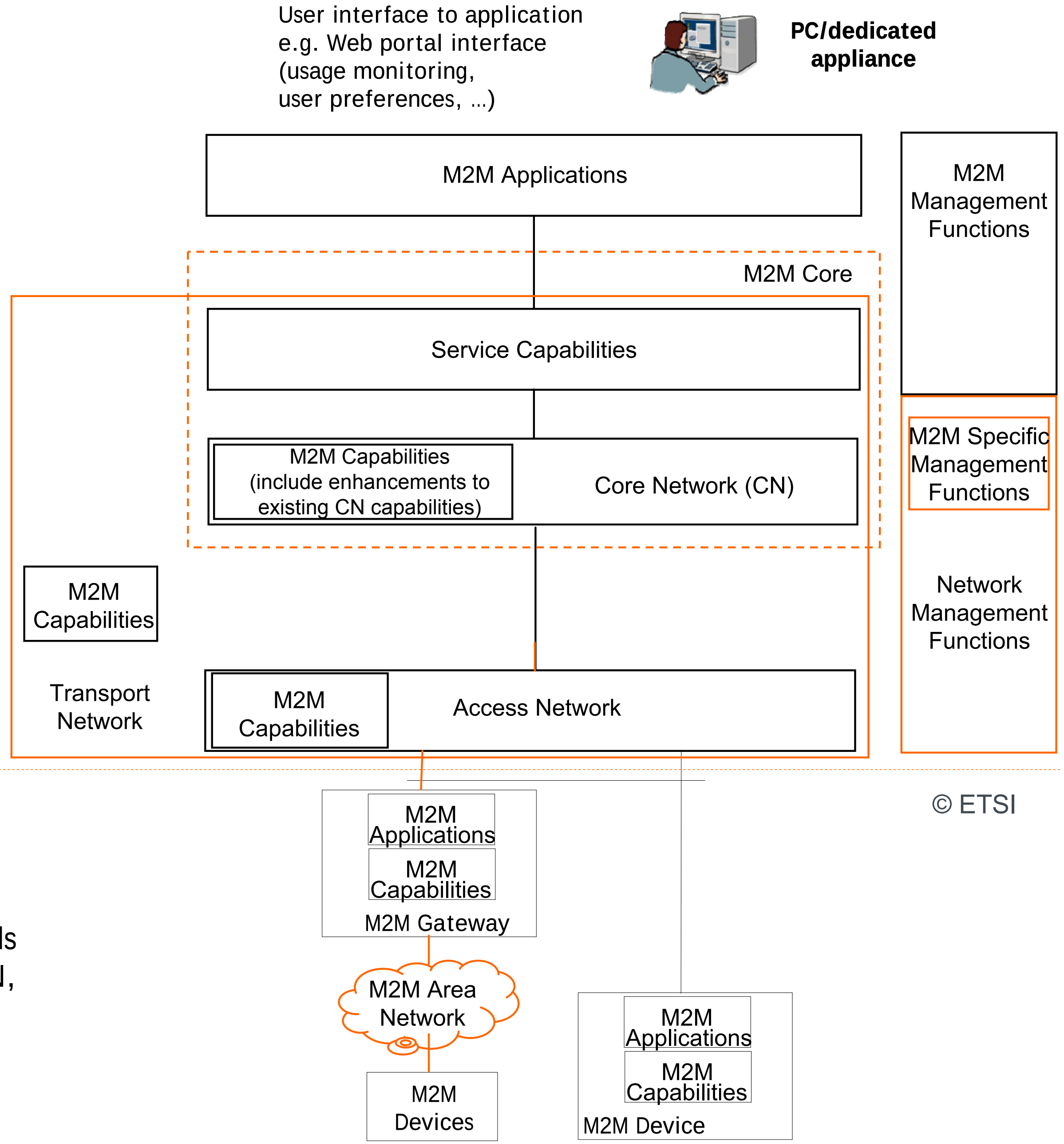


© ETSI

ETSI: TC M2M High Level View

Network and Applications domain
Based on existing standards 3GPP, TISPAN, IETF, …

M2M Device Domain
Based on existing standards and technologies, e.g.: WLAN, Bluetooh, Zigbee, UWB, etc.



Key Issue: Embedded SIM Cards

- SIM for M2M **smaller than regular** mobile communications
- **Embedded** in the devices
- **Tough requirements** on many aspects:
  - temperature range, vibration, humidity tolerance, etc.
- ETSI is working with 3GPP towards new definition of SIM cards:
- Removable vs. Soldered solution
- Three types of SIM cards:
  1) Consumer SIMs
  2) Reinforced SIMs (still removable)
  3) Industrial SIMs for use in extreme conditions

© ETSI

2.3.3

M2M Activities in 3GPP

Documentation Related to M2M

- January 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"*

- Since then, nothing new…but now…
  - Technical Specification
  - → TS 22.368: **Service Requirements for Machine-Type Communications (MTC).** Stage 1 (last update June 2010)
  - Technical Requirements
  - → TR 23.888: **System Improvements for MTC** → architectural aspects of the requirements specified in TS 22.368 (last update July 2010)

3GPP M2M Definitions

- ***H2H***: Human to Human Communications
- ***M2M***: Machine to Machine Communications
- ***MTC***: Machine Type Communications

- ***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:

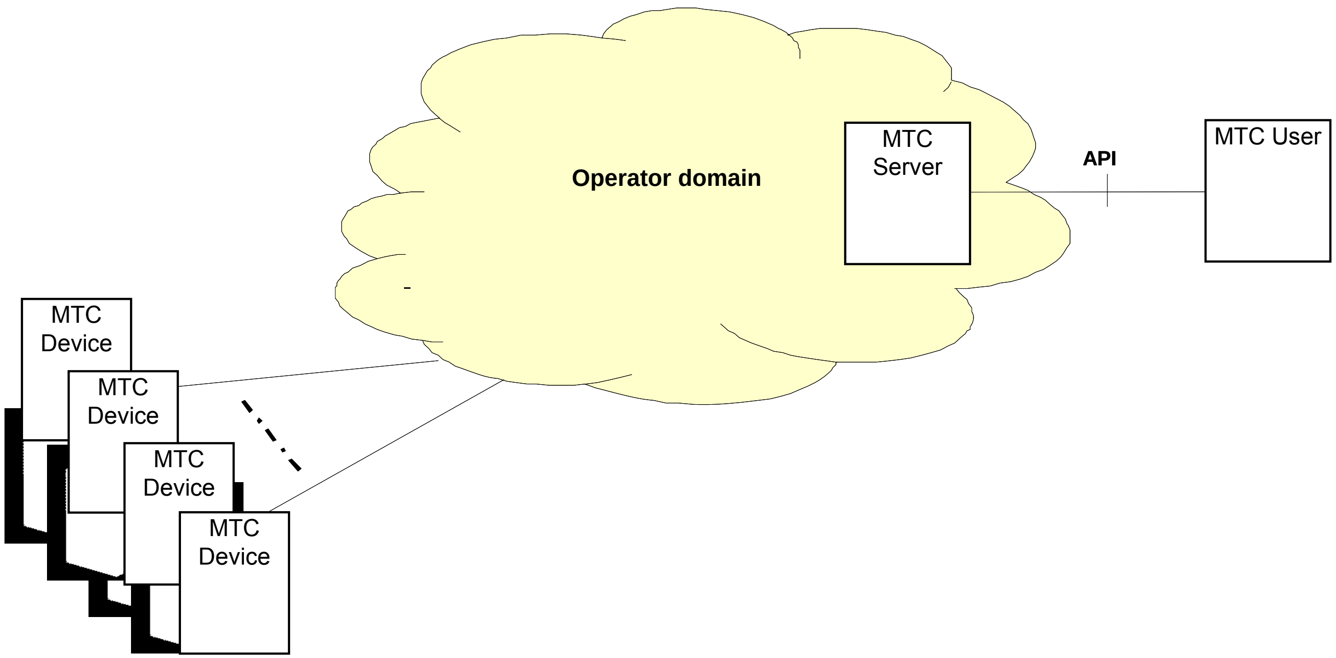
Service Requirements for Machine-Type Communications (MTC).

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.

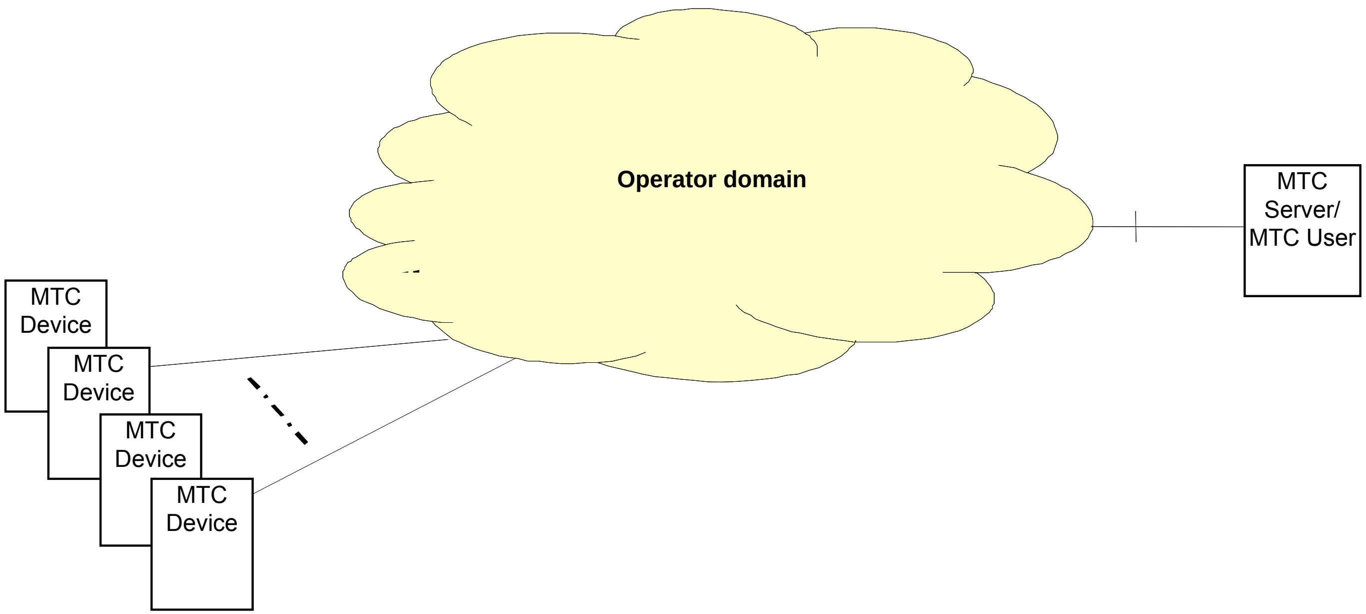
Types of Communication

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



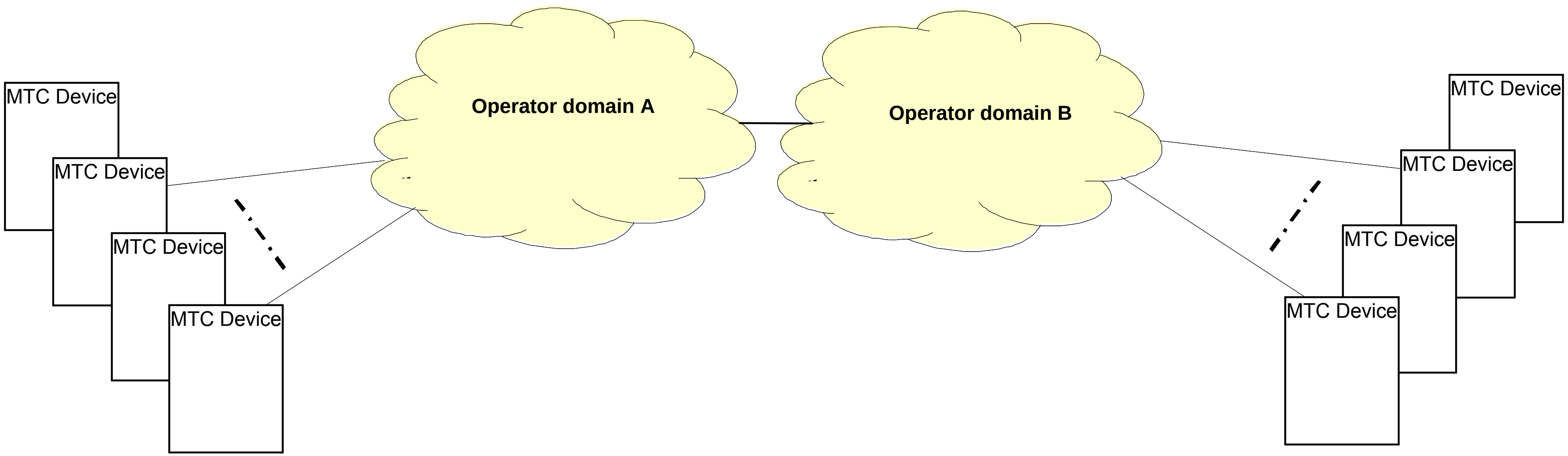
Types of Communication

- 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.



Features in M2M

- 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
  - Packet Switched only
  - Small Data Transmissions
  - Mobile originated only
  - Infrequent Mobile Terminated
  - MTC Monitoring
  - Priority Alarm Message (PAM)
  - Secure Connection
  - Location Specific Trigger
  - Network Provided destination for Uplink Data
  - Infrequent transmission
  - Group Based Policing
  - Group Based Addressing

Common Service Requirements

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

Requirements for Features

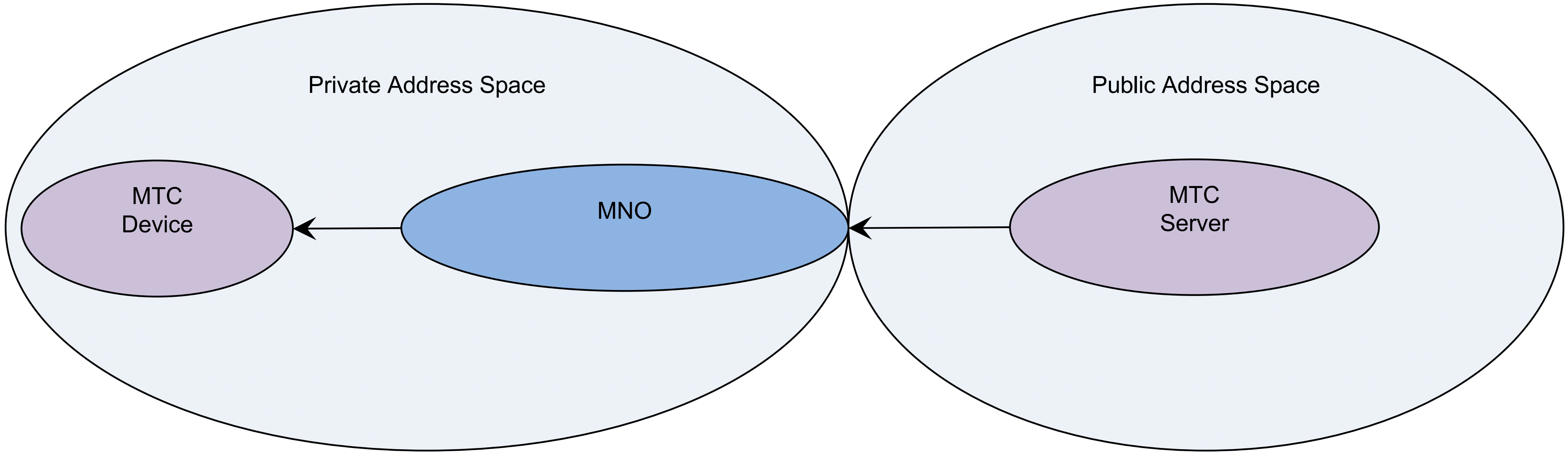
- Service requirements related to the MTC features:
  - Subscribe/unsubscribe to/from different features, which are independent of each other
  - The network operator shall provide a mechanism for the MTC subscribers to activate and deactivate features
  - The network shall provide a mechanism for the network operator to restrict the subscription of MTC Features
  - The network shall provide a mechanism for the network operator to restrict activation of MTC Features

Device Triggering

- Poll model for communications Server-MTC device.
- A device shall be able to:
  - Receive a trigger when offline (can listen to broadcast or paging channel)
  - Receive a trigger when online and without data connection established
  - Receive a trigger when online and with a data connection established
- Current implementations based on SMS, for example, only work for online devices!

Addressing M2M Devices [1/2]

- MTC Server in a Public address space shall be able to send a message to a MTC Device in a Private Address Space



Addressing M2M Devices [2/2]

- IMSI (bound to the SIM card) → limit of 15 digits
- IMSI+MSISDN (mobile phone number) → limit of 20 bits, but IMSI
- IPv4 → 32 bits
- IPv6 → 128 bits
- Do we really need to identify all the machines at the network operator level? Probably this is the direction to find solutions.
- No identification → problems at the protocol level? Security?
- Many open issues to be studied!

Identifiers

- The system shall be able to identify each of the devices
- The system shall be able to unique identify the MTC Subscription
- The system shall provide mechanisms for the network operator to efficiently manage numbers and identifiers related to MTC subscriptions
- The system shall be able to group devices with a sole identifier

Charging and Billing

- Traditional billing methods stop the widespread use of M2M
- Were designed for H2H communications
- Detailed tracking of traffic per terminal should be done at the server level, and not the by the operator
- 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 mobility signaling
  - Reduce reporting frequency
- Time Controlled
  - Transmission of data during defined time periods
  - Avoid signaling out of these periods
- Time Tolerant
  - Applications that can delay transmissions
  - Useful to avoid the overloading of the network: restrict access to delay tolerant MTCs
- Packet Switched Only
  - No need to provide addressable number (MSISDN)
  - Triggering should not be based on the MSISDN

Specific Service Requirements [2/3]

- Small data transmissions
- Mobile originated only
  - Reduction of management control signaling
- MTC Monitoring
  - Detect unexpected behavior, movement or loss of connectivity
  - Notify the subscriber or execute any action
- Priority Alarm
  - Case of theft or tampering
  - 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
- Network provided destination for uplink data
  - Devices shall be able to transmit to a specific IP address
- Infrequent transmission
  - The network shall allocate resources only when needed
- Group based policing and addressing
  - The system shall be able to apply combined QoS policy for a group of devices
  - The network shall enable the broadcast to a specific group of devices

TR 23.888:
System Improvements for MTC

Scope

- Analyzes architectural aspects of the System Improvements for Machine Type Communications requirements specified in TS22.368:
- Analyzes architectural aspects to gather technical content until it can be included in the relevant technical specs.

Key Issues [1/4]

- Group Based Optimization
  - Devices shall be grouped for management, charging, and operation
  - This may reduce redundant control information
  - Devices belonging to the same group may be in the same location
  - Each device should be accessible from the network
- MTC Devices communicating with one or more Servers
- IPv4 Addressing limitation
  - Devices might have a private IP address, but they have to be reachable from the MTC Server
- Online and Offline Small Data Transmissions

Key Issues [2/4]

- Low Mobility → reduction of signaling
  - Devices not move frequently, and they move in a small area (e.g. health care)
  - Devices not move frequently, and they move in a wide area (e.g. mobile sales)
  - Devices have fixed location (e.g. water metering)
- MTC Subscriptions
  - Features are controlled by subscriptions
- MTC Device Trigger
  - Poll model between Server and Devices
  - A device shall be able to receive a trigger in detached mode and in attached mode, either with or without a data session established
  - Existing solutions (unanswered call attempts, sensing and SMS) only work based on the MSISDN and for attached devices
  - Need for ***innovation*** here!

Key Issues [3/4]

- Time Controlled
  - Applications only run on certain periods of time
  - How to restrict access to some devices?
  - Network shall be able to negotiate and communicate “grant periods” and “forbidden periods” to devices or groups of devices
- Monitoring
  - Vandalism, theft, tampering of devices
  - Server shall detect events
  - Actions should be triggered, e.g., notify the subscriber.
  - Actions should be customizable
- Decoupling MTC Server from 3GPP Architecture
  - Decouple application from technology → flexibility, scalability
  - Enable third parties to enter the business offering services, not technology

Key Issues [4/4]

- Signaling Congestion Control
  - Case of malfunctioning of an application → may imply a lot of devices!
  - External event triggering a huge number of devices at once
  - Recurring application synchronized to the same time interval
  - Network operator cannot have control on application developers, and thus problems easily solvable, become a challenge, as the network has to be prepared for this kind of events.
- Identifiers
  - Devices 2 order of magnitude over humans
  - Impact on numbering (addressing)
- Potential overload issues caused by Roaming
  - International companies deploying M2M networks abroad
  - Failures in a mobile network operator can force devices to attach to another operator
  - Network shall be able to detect dangerous situations (e.g. unusual increase in the number of attached devices)

Solutions

- Up to the last version (July 2010), the document reports 37 solutions to Key Issues:
  - Discusses the impact on existing nodes functionality
  - Includes a qualitative evaluation of the solution
- The document is alive, and thus more solutions are expected to come in the future
- Examples:
  - Use of SMS for online small data transmissions
  - Limited paging for low mobility:
    - Preconfigured area associated to the subscription
    - Stepwise paging (previous location)
    - Paging within reported area (reactive paging)

Handling Many Users [1/2]

- ***Handling many users*** is one of the major challenges found across any document related to M2M standardization in 3GPP
- For the network operator perspective:
  - M2M User = individual + *N* devices
  - mobility capability could be removed for some devices
  - Avoid congestion
- For the M2M user perspective:
  - theft protection
  - possibility to change subscription out in the field e.g. after contract expiry without human intervention
  - Reconfigurability is desired
- Subscription handling
  - prohibitive to change the SIM to each machine in a deployed system
  - perceived as a major obstacle to M2M → ***innovation***

Handling Many Users [2/2]

- Main Technical Challenges:
  - Reduce unnecessary ***signalling***
  - Mechanisms to ***reduce peaks in the data and signalling traffic*** resulting from very large numbers of MTC Devices (almost) simultaneously attempting data and/or signalling interactions.
  - ***Maintain connectivity*** for a large number of MTC Devices.
  - ***Lower power consumption*** of MTC Devices.
  - MTC Devices may be kept ***offline or online*** when not communicating, depending on operator policies and MTC Application requirements.

2.4

Cellular M2M Business

Promising Forecast

- ABI Research
  - August 06, 2010
  - Predicts the global M2M market to reach $3.8 billion in 2015

- Ericsson
  - 50k millions of devices by 2020
  - 2020: 3k millions of medium-class users
  - 2020: USA:
    - 7 devices per user
    - More than 1k million vehicles connected
    - 3k million meters connected
  - M2M connection will x3 in 5 years

Major Carriers

- **Declining voice** revenues
- **Saturated market** in number of lines
- M2M show a high potential (new source)
- Main carriers all around the world share the same view: AT&T, Verizon, Sprint Nextel/Clearwire, T-Mobile USA, Telefonica, Vodafone, etc.
- Obama's Brodband National Plan: Smart grids (smart metering) seem to be a key force for the development of 4G
- More applications than just smart grids
- Good **revenue opportunity**

Business Week, John Woodget (Intel), June 2009

"Business models capable of monetizing the hyper-connected world are not yet there"

Business Models

- M2M: Low ARPU per device
- High number of devices
- Diversified applications
- Need to find a value chain that works for all
- Open questions:
  - What business model to pursue with M2M services?
  - Will be the service driven by an operator, by a partner, a mix option?
  - Who bills the end-costumer?
  - Bundled-pricing or usage-based pricing?
  - Who pays for the bandwidth?

Business Models: Example

- TomTom
- LIVE service: exchange of traffic information
- Service is sold to consumers by TomTom
- No dependence of consumer to be subscribed to any operator
- TomTom has an internal agreement with Vodafone
- Vodafone plays a “behind-the-scenes” role

Business Models

- (at least) Three players:
  - Network operators
  - Solution providers
  - Specialist equipment providers
- In any case, the network operator will be always there to provide the long-range connectivity
- **Operators do not have the specific know-how**
- Alternatives:
  - Partnerships
  - Aggregators
  - White label
  - Integrator

Business Models: Partnerships

telenor	New business unit "Telenor Objects" and co-operation with Telit and Volvo for in-car SIM card	Telit, Volvo
T-Mobile	Echelon and T-Mobile alliance to reduce the cost of a secure smart grid network for utilities; also co-operation with Celevoke to sell wholesale data services to M2M clients	Celevoke, Echelon
verizon wireless	Co-operation with OnStar/GM, also Verizon Wireless and Qualcomm announce joint venture to provide advanced M2M solutions (nPhase)	Qualcomm, OnStar by GM
at&t	Emerging devices business unit launched in October 2008; combined platform with Jasper Wireless	Jasper wireless
orange	"Orange M2M Connect" platform; strategic partnerships with Wavecom, Alcatel, and Cinterion. Orange (France and Spain) are co-operating with Securitas Direct to use wireless GSM network for more advanced surveillance solutions	Wavecom, Cinterion Wireless Modules, Securitas Direct
vodafone	New M2M platform July 2009, Vodafone Spain also co-operates with Securitas Direct	Securitas Direct
Telefónica	Telefónica's Smart M2M platform in co-operation with Telit	Telit

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

Business Models: Aggregators

- Mobile Virtual Operators, combine:
  - Services from various operators
  - Technology providers
- And sell bundled M2M products.

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

Business Models: White Label

- Cooperation with the aggregator
  - The operator sells the product with its brand, using technology developed by a third

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

Business Models: Integrator

- Operators can do everything
  - Requires resources (effort and time)
  - Not affordable for small operators

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

2.5
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
  - IETF will surely shortly kick in
- Open Issues:
  - quite some, to be discussed in the last part of this tutorial

3

Capillary M2M

3.1

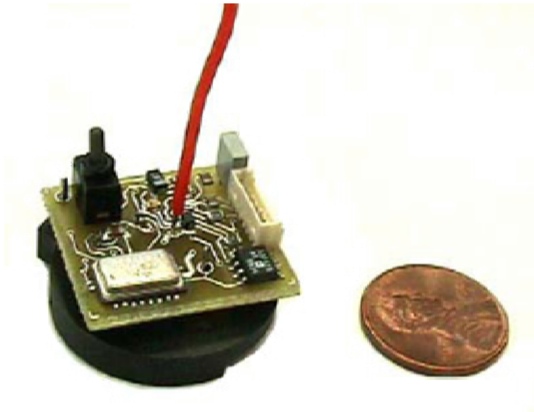
Quick Intro to Capillary M2M

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 standardized low-power solutions**.

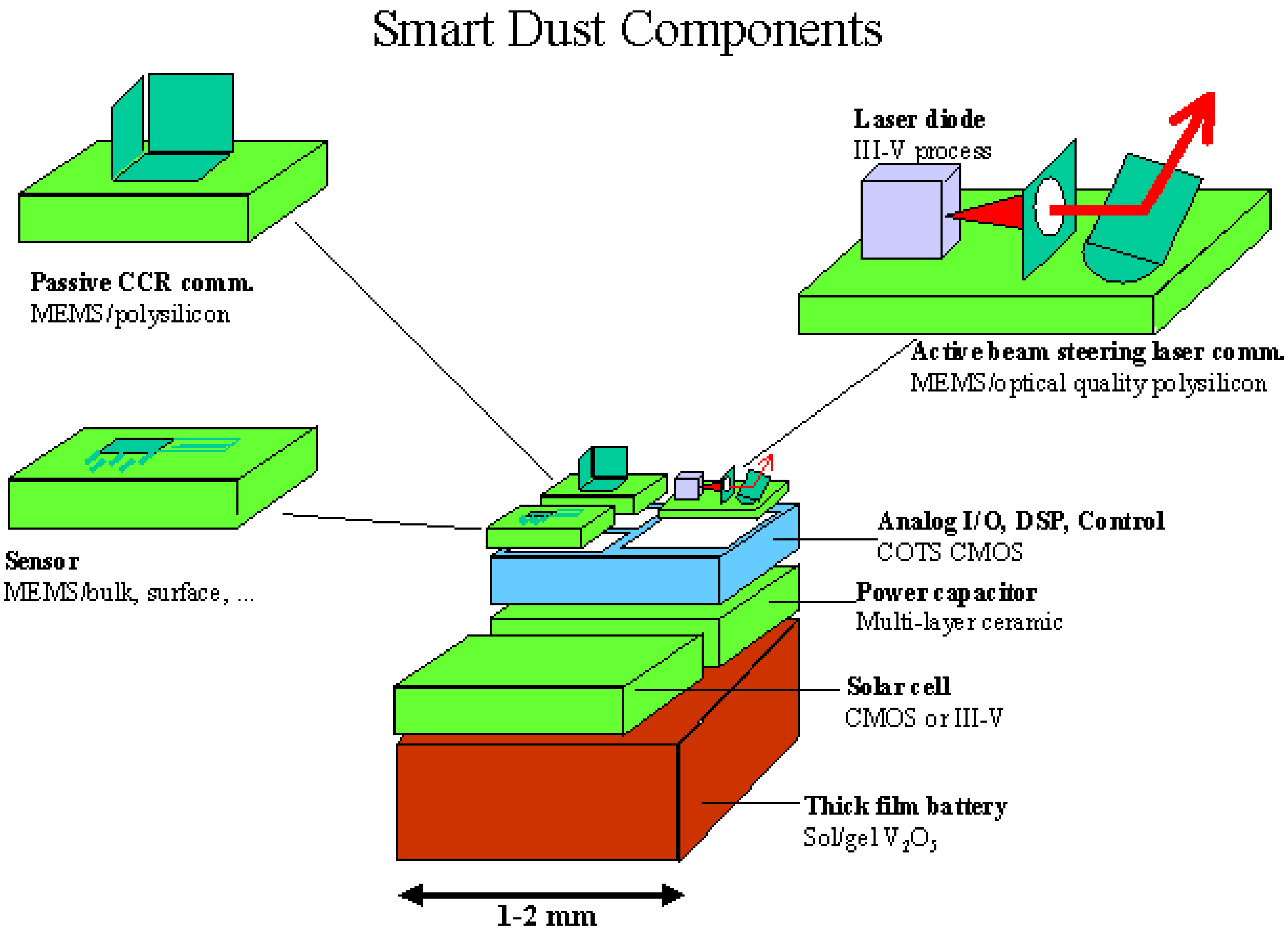
Design of Capillary M2M

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

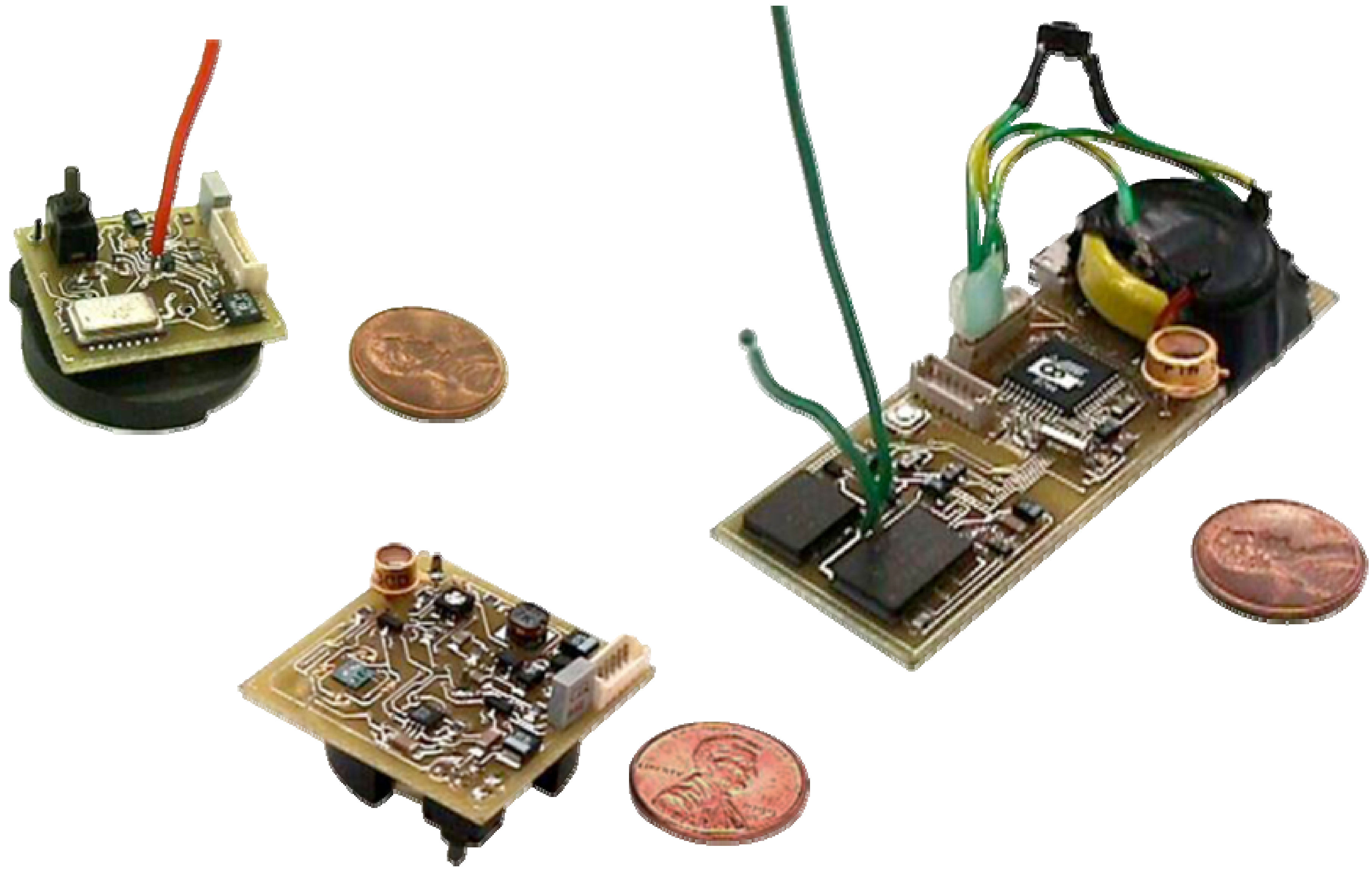


- These nodes should be:
  - low – cost
  - low – complexity
  - low – size
  - low – energy

Smart Dust Vision - 1997

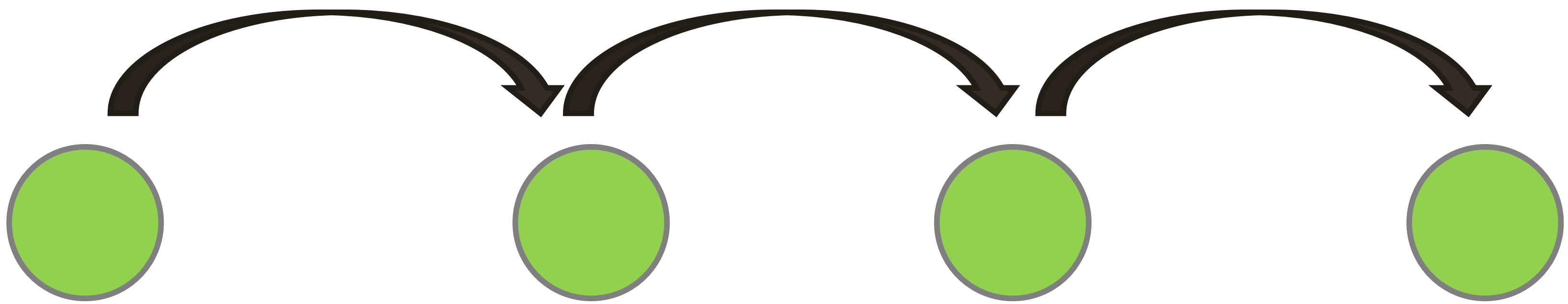


Off-The-Shelf Hardware - Today



Energy in Capillary M2M

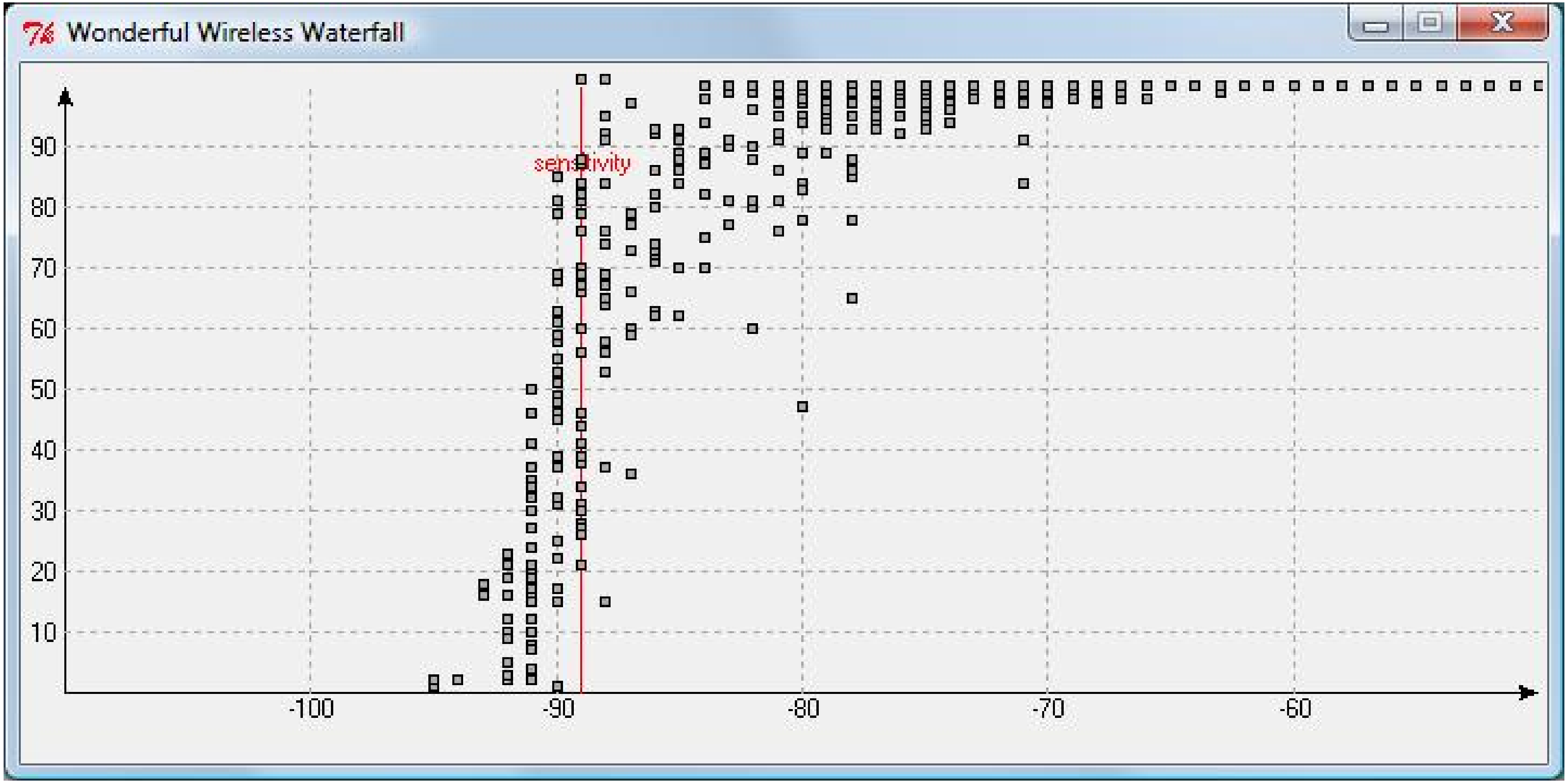
Operation	Time	Power	Energy Required	Technology
Fill a packet with analog samples	1 s	0.025 mW	25 µJ	MSP430 @ 4 MHz, 80 Samples
Transmit or Receive a packet	0.006 s	50 mW	300 µJ	CC2420



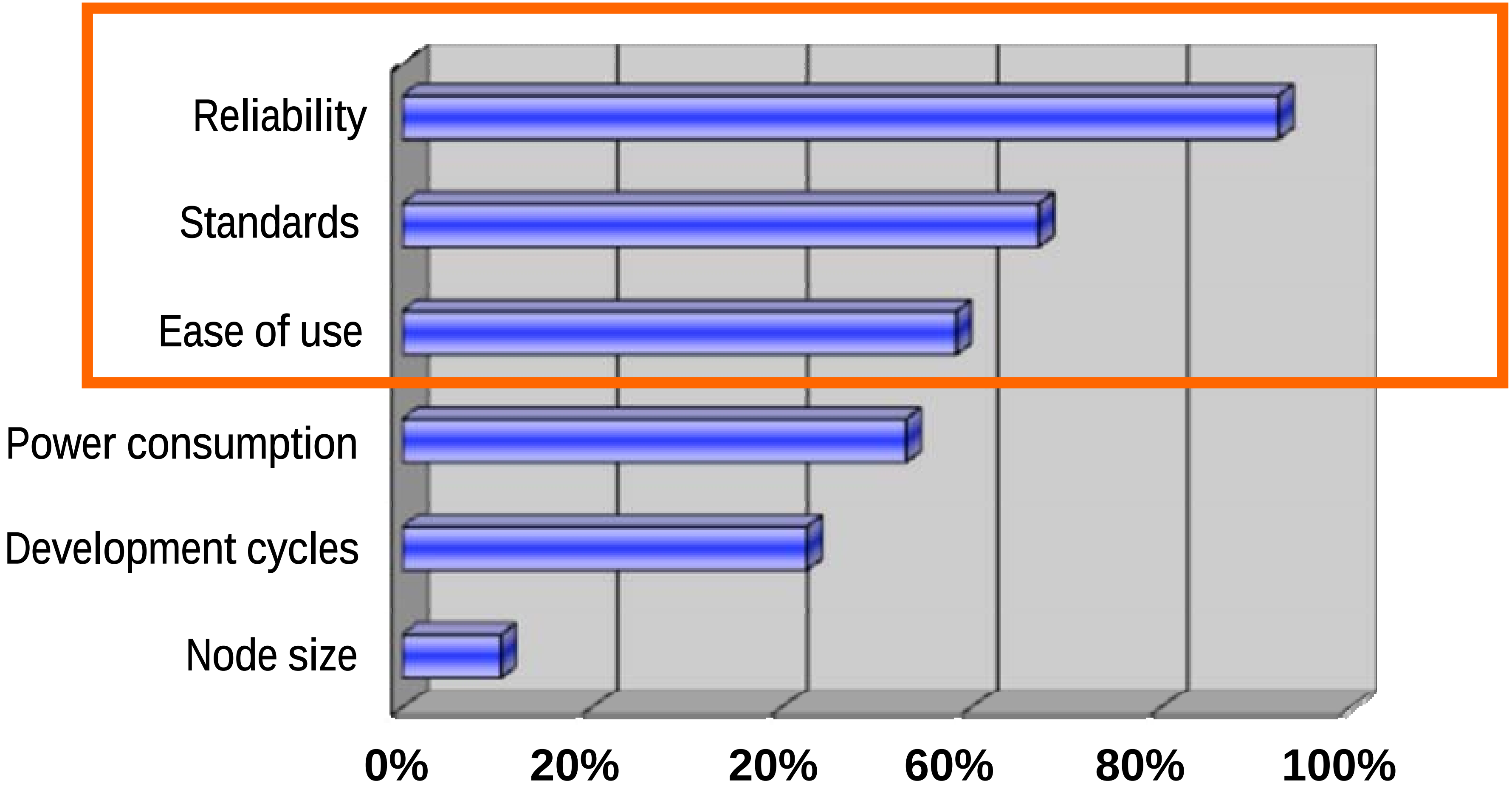
2.5 mJ to generate and pass this packet along

100x more than to build it

Connectivity in Capillary M2M



Barriers in Capillary M2M



* source: OnWorld, 2005

Requirements on Capillary M2M

- Fundamental design differences:
  - Application: wide variety (≠ any wireless system)
  - Control: decentralized (≠ cellular, broadcast, satellite)
  - Info Flow: highly directed (≠ ad hoc)
  - Energy: highly constrained (≠ any wireless system)
  - Run-Time: very long (≠ any wireless system)
  - Nodes: huge amounts (≠ any wireless system)

- This means that, unlike other systems, M2M needs to be:
  - reliable (same as wired, otherwise no adoption)
  - standardized (should work universally)
  - autonomous (no human operator, self-healing)
  - easy-to-use (Internet integration)
  - energy efficient (batteries can not be replaced)
  - highly secure (confidentiality, integrity, authentication)

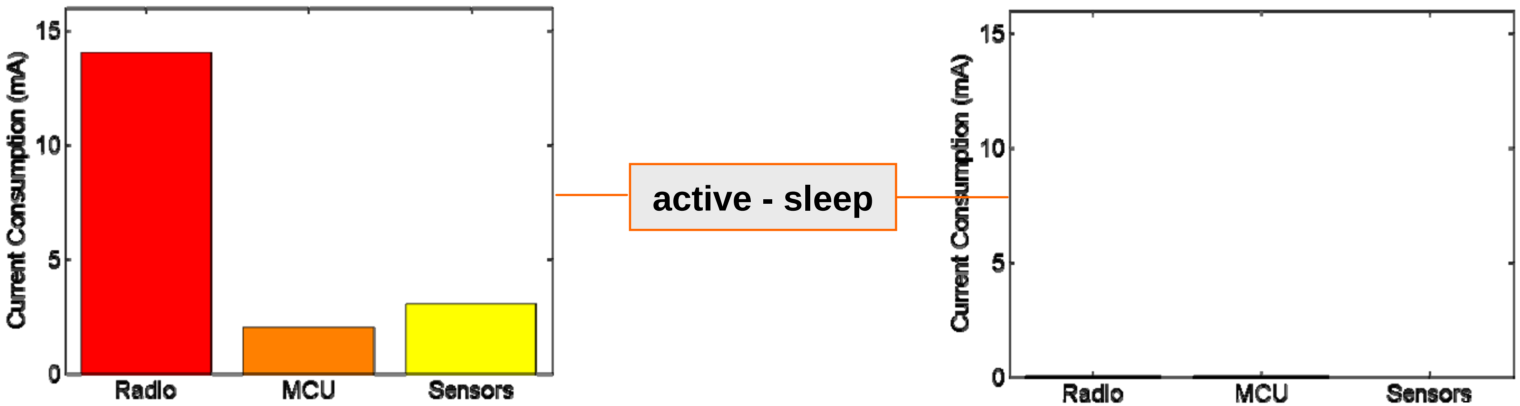
3.2
Academic WSN Research

3.2.1
MAC Protocols

Sources of Energy Dissipation

- Whilst not jeopardizing performance, minimize energy dissipation :
  - **Collisions**: a node is within the transmission range of two or more nodes that are simultaneously transmitting so that it does not capture any frame
  - **Overhearing**: a node drains energy receiving irrelevant packets or signals (irrelevant packets may be for example unicast packets destined to other nodes)
  - **Overhead**: protocol overhead may result in energy waste when transmitting and receiving irrelevant control packets
  - **Idle Listening**: a node does not know when it will be the receiver of a frame

- Energy consumption of a node using a CC2500 radio chip, MSP 430 MCU and accelerometers:



Reservation vs. Contention MAC [1/2]

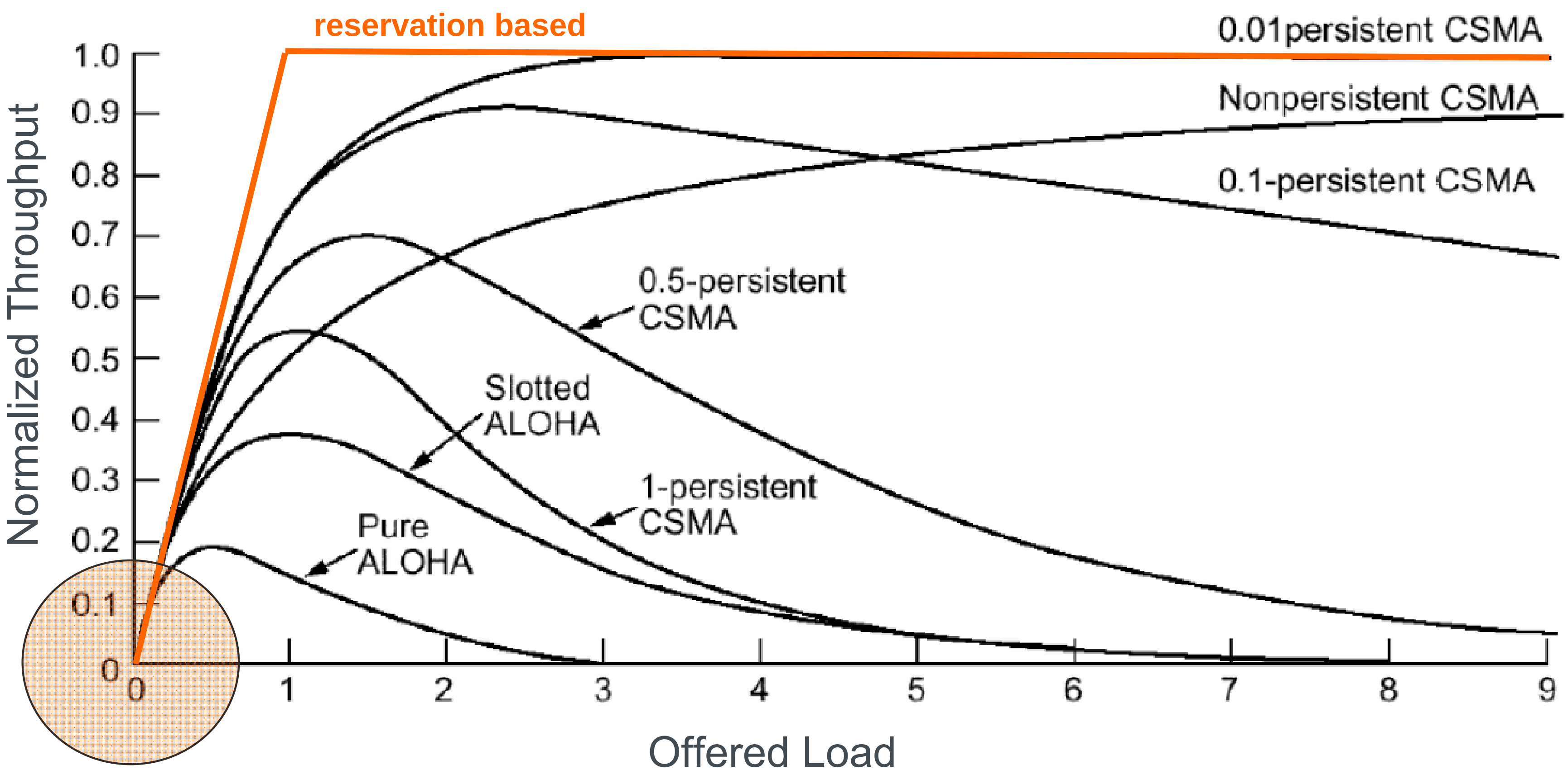
- **Reservation-based MACs**:
  - knowledge of topology and strict synchronization requires large overheads and/or expensive hardware
  - this renders TDMA solutions less attractive in large-scale WSN rollouts

- **Contention-based MACs**:
  - contention-based protocols suffer from degraded performance in terms of throughput when the traffic load increases
  - the distributed nature prevents them to achieve the same efficiency as ideal reservation-based protocols

- In low-load regions, both **perform the same** since contention is not an issue.

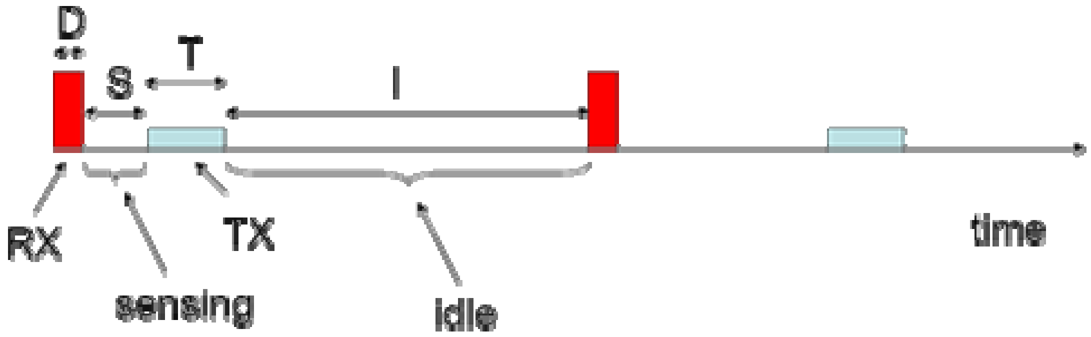
Reservation vs. Contention MAC [2/2]

- Example of throughput versus offered load:



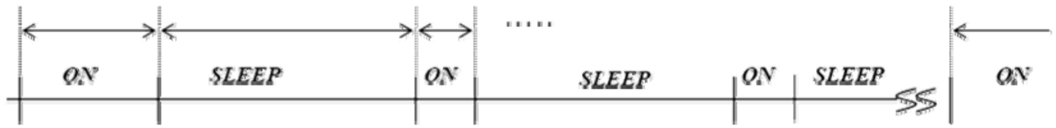
Not Throughput But Duty Cycle

- Example energy calculation:



  - $E = E_{RX} * D + E_{RX} *S + E_{TX} * T$

- Example activity factor calculation:



  - $AF_{on} = T_{on} / (T_{on}+T_{sleep})$
  - $E_{charge} = 5000$ J $= P_{sleep}\ T_{sleep} + P_{on}\ T_{on}$
  - AF = 1: $E_{charge} = P_{on}\ T_{on} = 50\ 10^{-3}\ T_{on}$; $T_{on} = 10^5$ s = approximately one day only!
  - **if the requested node lifetime is 10 years, the AF_{on} must be 1/3650 < .1 %**

WSNs M2M MAC Taxonomy

- M2M WSNs are highly application tailored, requiring differentiation:
- **Framed MACs for Periodic & High-Load Traffic**
  - typical to time-critical M2M applications
- **Contention-Based MACs with Common Active Periods**
  - medium load traffic typical to industrial monitoring M2M applications
- **Sampling Protocols**
  - rare events typical to metering M2M applications
- **Hybrid Protocols**
  - typically used for load balancing

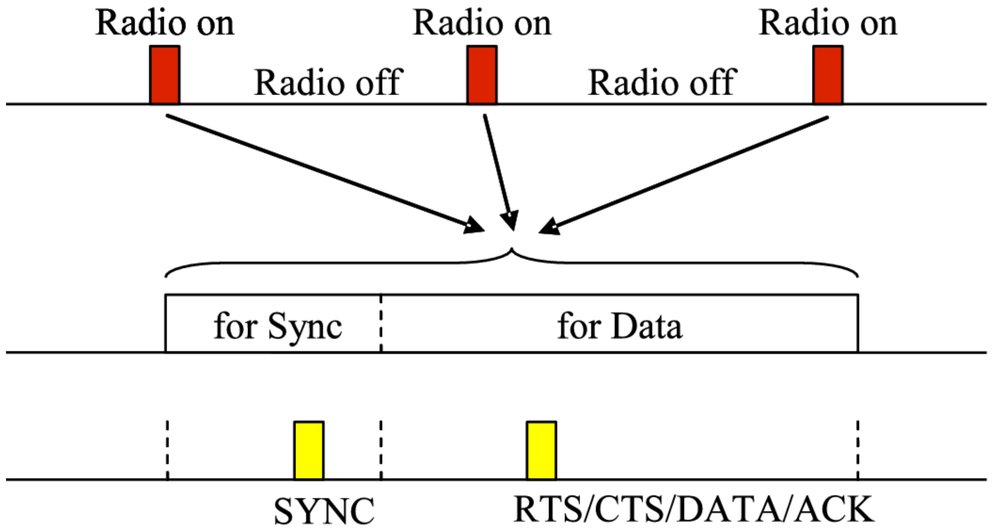
Framed MACs – Basic Idea

- Basic characteristics of the protocols:
  - periodic and high-load M2M traffic is most suitably accommodated by means of reservation-based protocols
  - in the context of WSNs, such protocols are variants of TDMA
  - TDMA is attractive because – once the schedule is set up – there are no collisions, no idle listening, and no overhearing.
  - **TDMA also offers bounded latency, fairness and good throughput in loaded (but not saturated) traffic conditions**

- There are several ways to schedule data, such as:
  - **Scheduling communication links:** specifying sender-receiver per slot, i.e. receiver knows when it will be addressed a packet, which eliminates overhearing
  - **Scheduling senders:** specify slots used by senders; all nodes listens all slots
  - **Scheduling receivers:** specify slots used by a receiver; need to know neighbors' slots

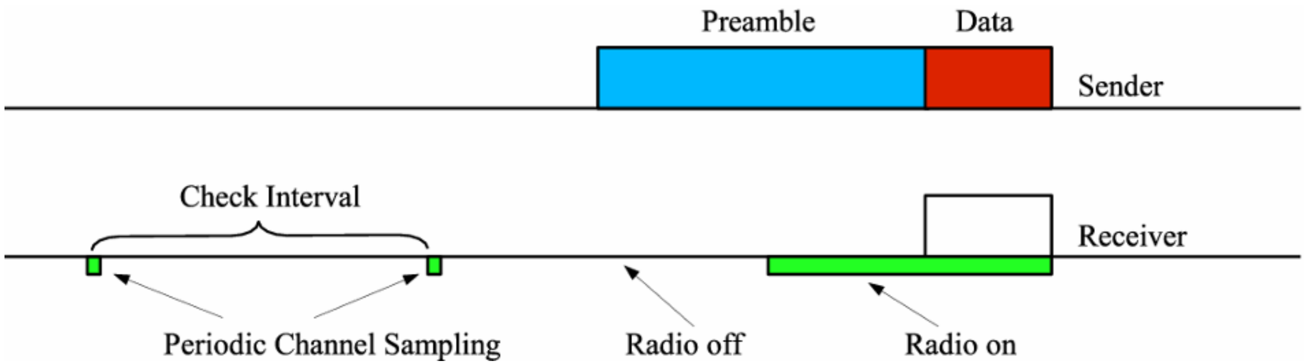
Contention Based – Basic Idea

- **Canonical SMAC Protocol:**
  - copes with idle listening by repeatedly putting nodes in active and sleep periods:
    - active periods are of fixed size whereas the length of sleep periods depends on a predefined duty-cycle parameter
    - splits the active period into two sub-periods: one for exchanging sync messages and the other for exchanging data messages; data message exchange may require RTS, CTS and ACK utilizations
  - copes with deafness by making nodes share common active periods which requires synchronization



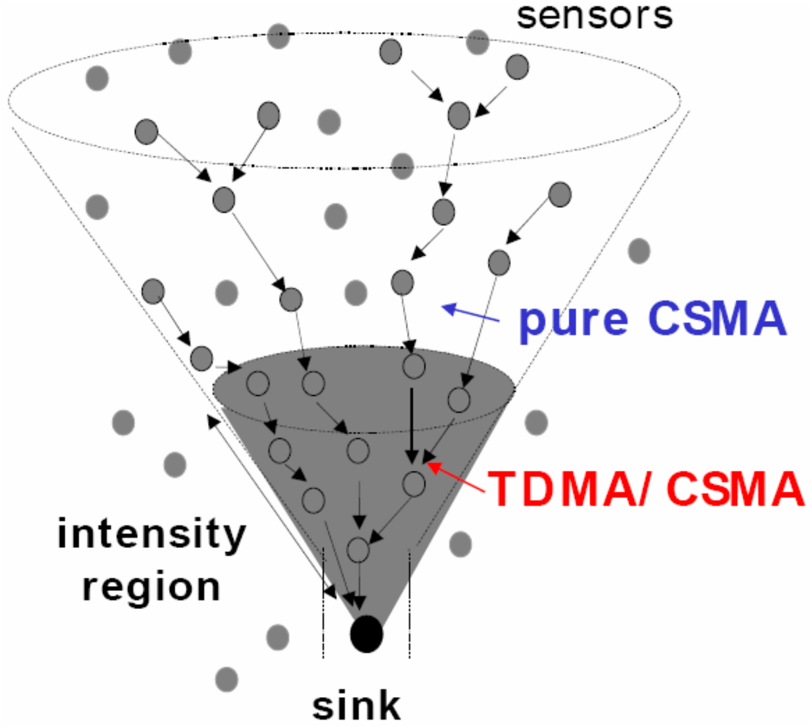
Sampling Protocols – Basic Idea

- **Cycled Receiver, LPL (Low Power Listening) and Channel Polling Protocols are very similar:**
  - according to the duty-cycle parameter, nodes periodically switch their radios on to sample the channel
  - if a node finds that the channel is idle, it goes back to sleep immediately; however, if it detects a preamble transmission on the channel, then it keeps its radio on until it receives the subsequent data frame
  - after the reception of the data frame, the node sends an ACK frame, if needed, and goes back to sleep afterward.
  - to be effective, the duration of the preamble transmission needs to be at least as long as the Check Interval (CI)



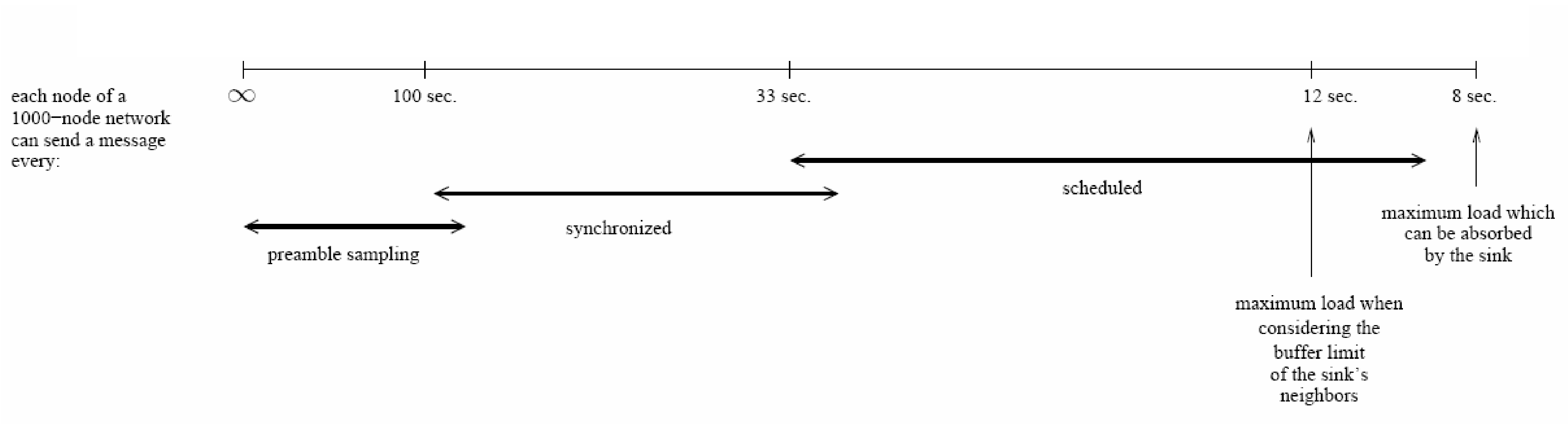
Hybrid Protocols – Funneling MAC

- Basic characteristics:
  - uses TDMA in regions close to the sink and CSMA elsewhere
  - since most of traffic pattern in sensor networks is convergecast, nodes in regions close to the sink experience higher traffic loads
  - traffic intensity in those regions is high so that more then 80% of packet loss happens in the two-hop neighborhood of the sink when a CSMA-based MAC protocol is used



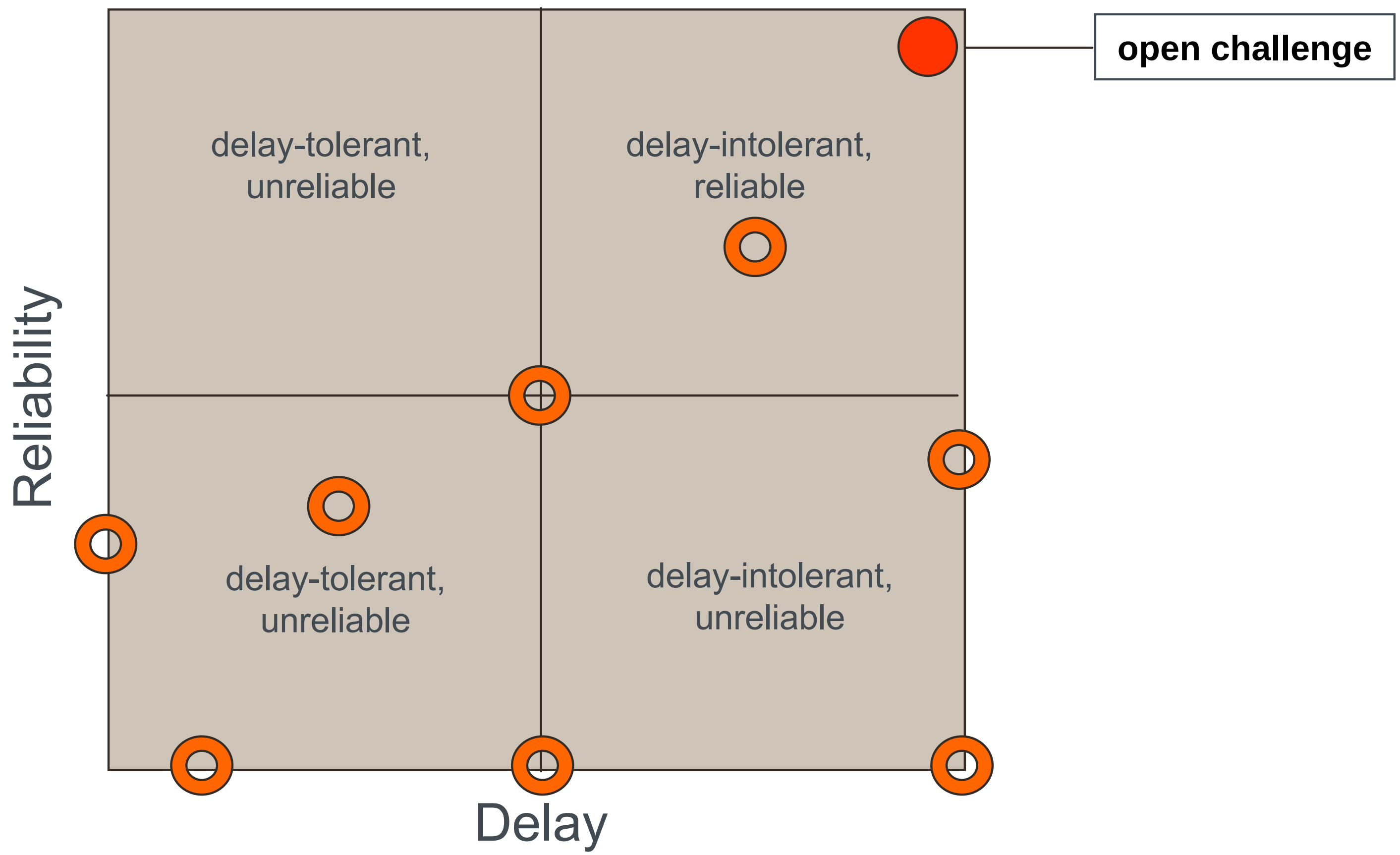
Hybrid Protocols – MAC Switching

- Taking limited buffers and other practical factors into account, the following MAC switching rules can be derived in a 1000-node M2M WSN:



No 100% M2M MAC Available

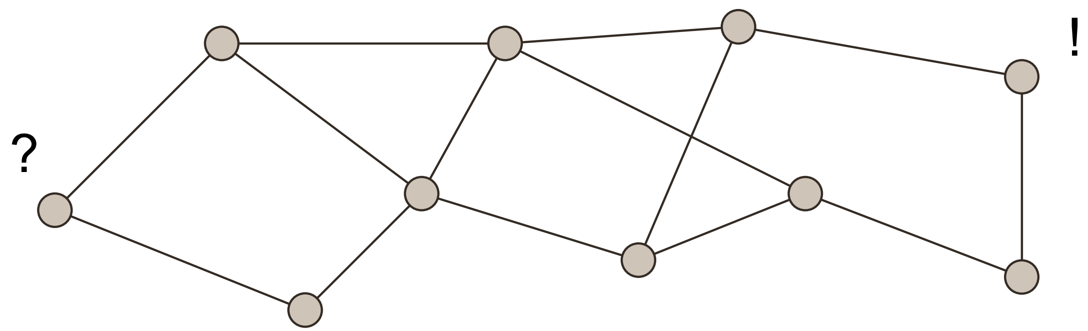
- Currently, there is no MAC available which is highly reliable and offering hard-delay constraints.
- There is clearly a physical limit but design could still be improved!



3.2.2
Routing Protocols

Routing in Multi-Hop Networks

- Goal: find a sequence of hops from source to sink
- Problem: each node has local view (neighbors)
- Constraints:
  - Query-based application? Periodic reading?
  - Mobility? Load?
  - Etc.
- Approaches:
  - Proactive: set up a structure before using it (frequent traffic)
  - Reactive: find routes on demand; forget afterwards (sporadic traffic)

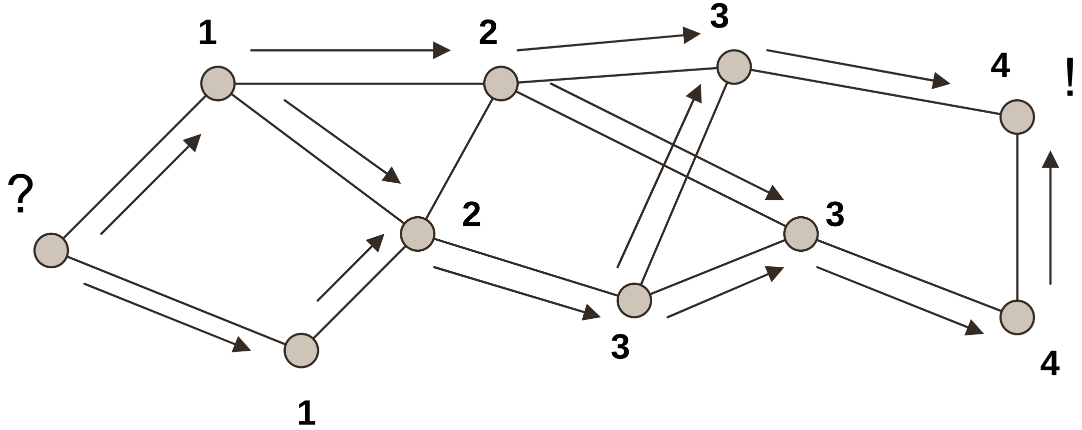


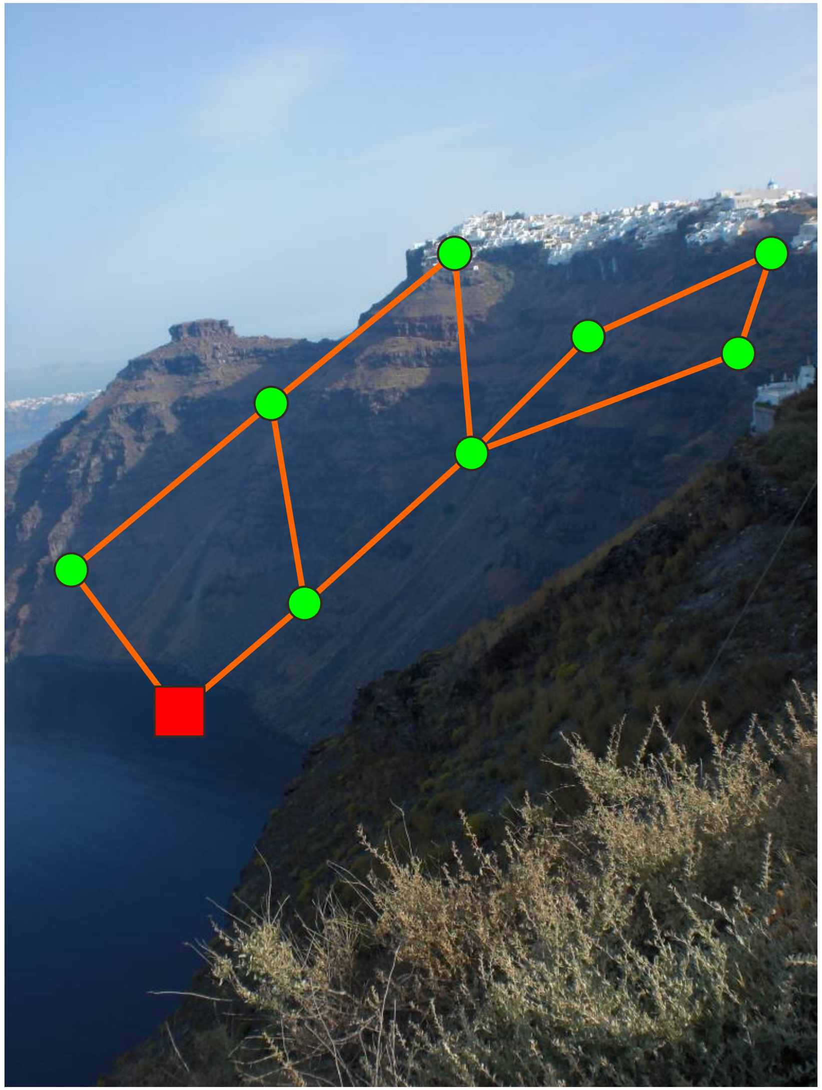
WSN Routing Families

- The following taxonomy is typical used in the context of WSNs:
  - **Flooding-Based Routing (FBR)**
  - Routing over Hierarchical Structures
  - Using Geographical Information for Routing
  - Relative Coordinate Routing
  - **Virtual Coordinate Routing (VCR)**

Gradient-Based Routing [1/3]

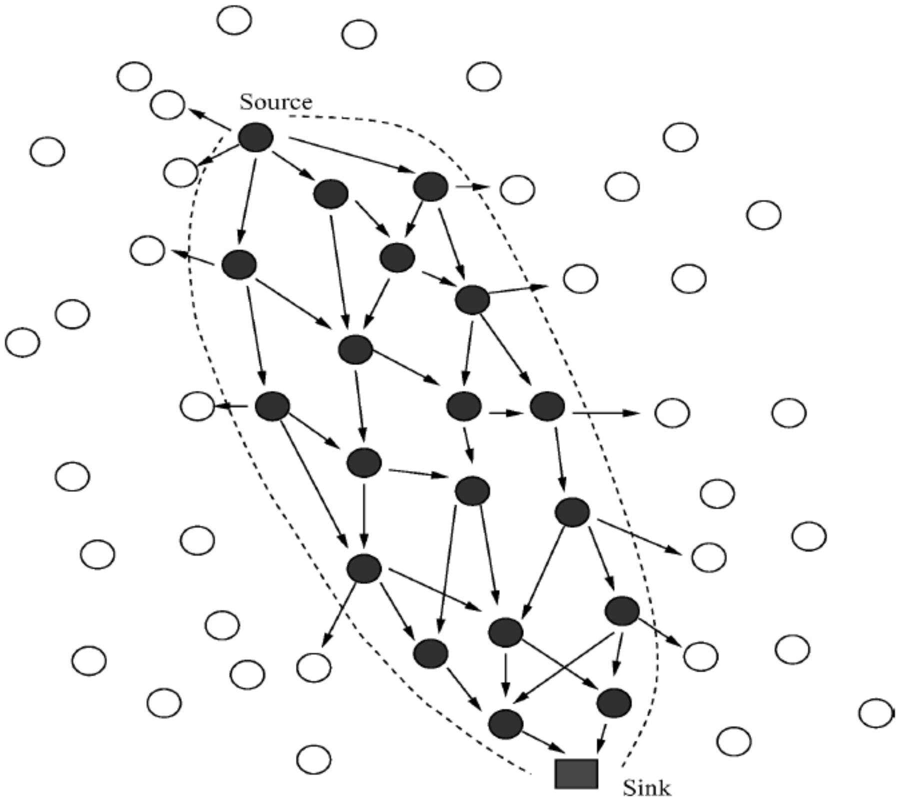
- Gradient set up by flooding
- Permanent gradient
  - Greedy routing over pre-set heights
  - Minimum number of hops
  - Graph must be stable





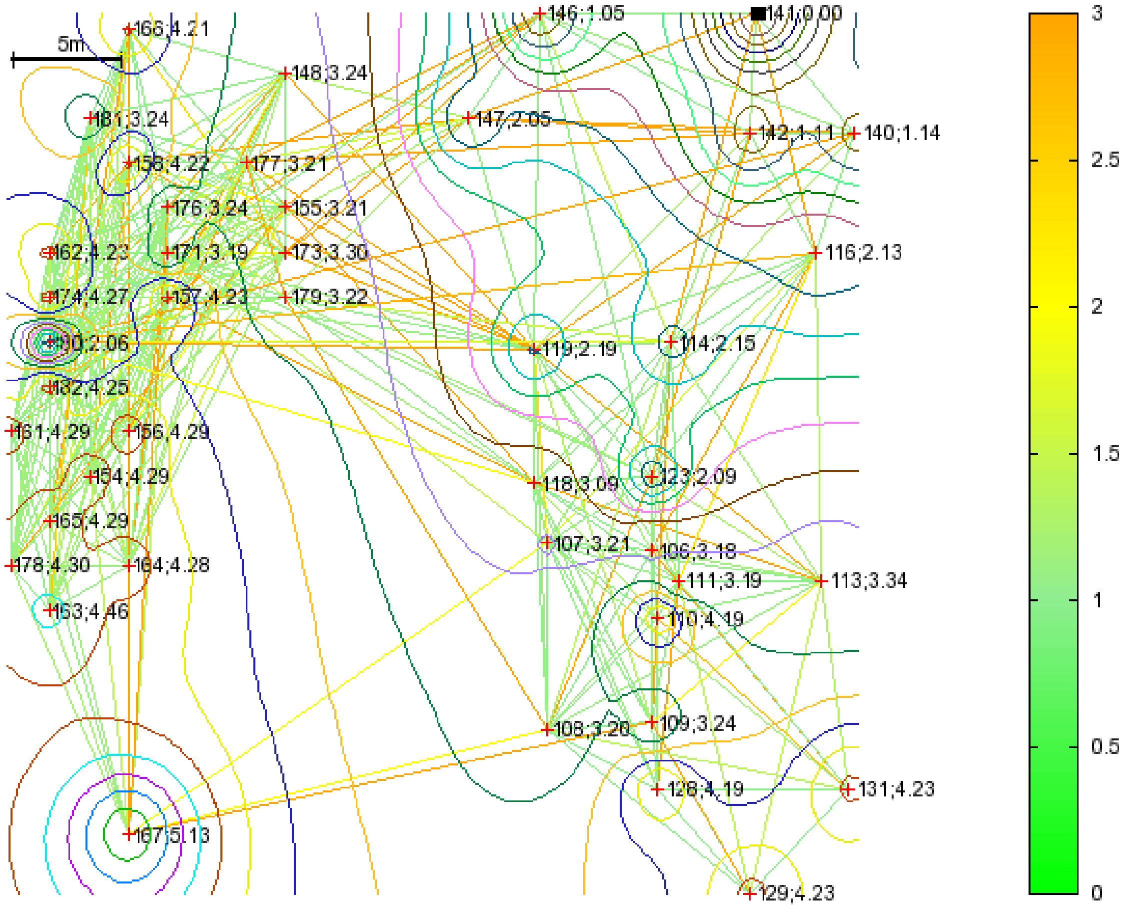
Gradient-Based Routing [2/3]

- Reliability through redundancy: GRAB [YZL05]
  - link unreliability → duplicate messages
  - Width of *band* set at source node
  - Credit field in message
  - at source: Init(credit)
  - at hop: Credit -= Δ(height)
  - at hop: Credit==0?drop
- Non-integer height
  - Modulate integer height
  - Battery, neighorhood, etc.



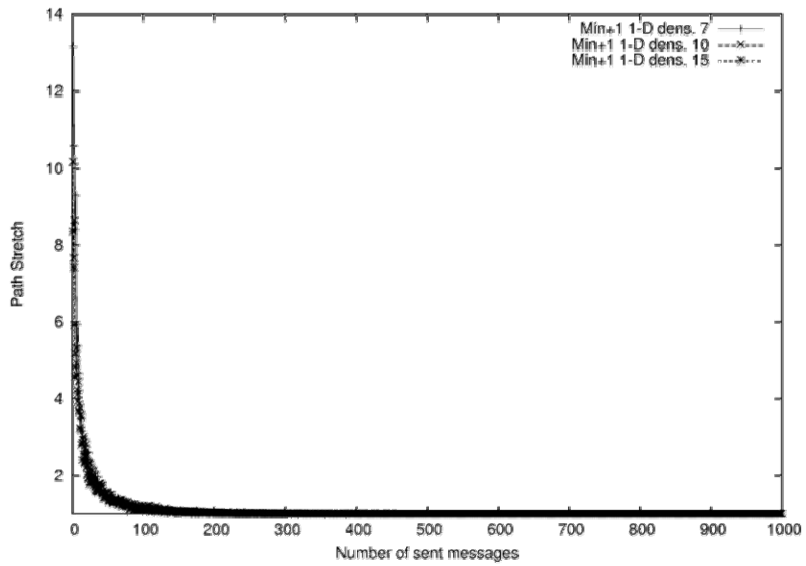
Gradient-Based Routing [3/3]

- IETF ROLL insights:
  - RPL draft standard since April 2010
  - Gradient routing identified as the basis for collection
- ETX
  - Expected Transmission Count
  - Inverse over link packet delivery ratio
  - Assumes maintaining local statistics on a link-by-link basis
  - The height of a node indicates how many times a message sourced at that node is retransmitted before it reaches the sink



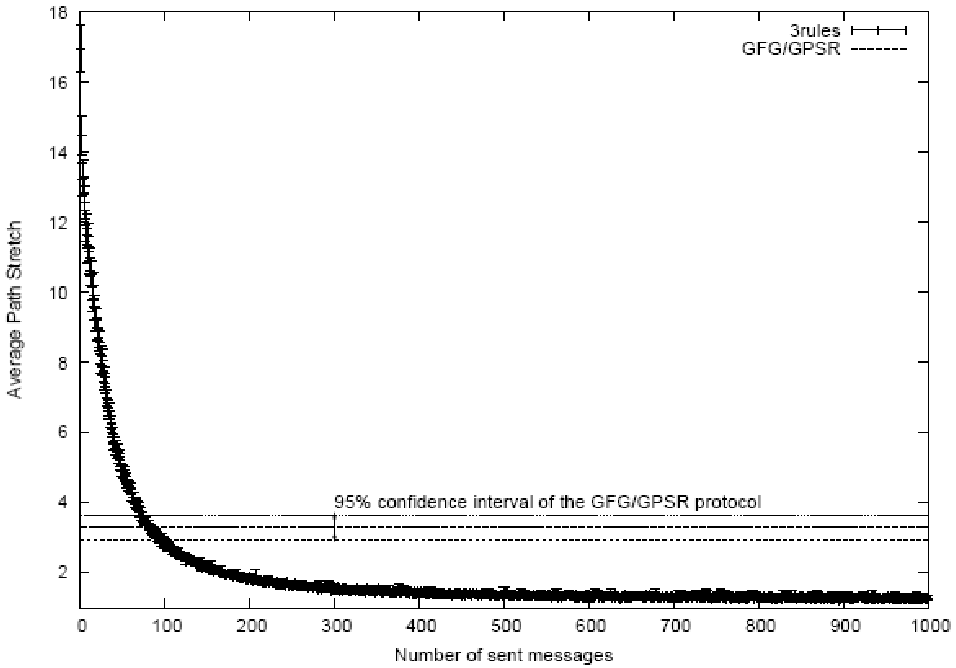
Virtual Coordinate Routing [1/3]

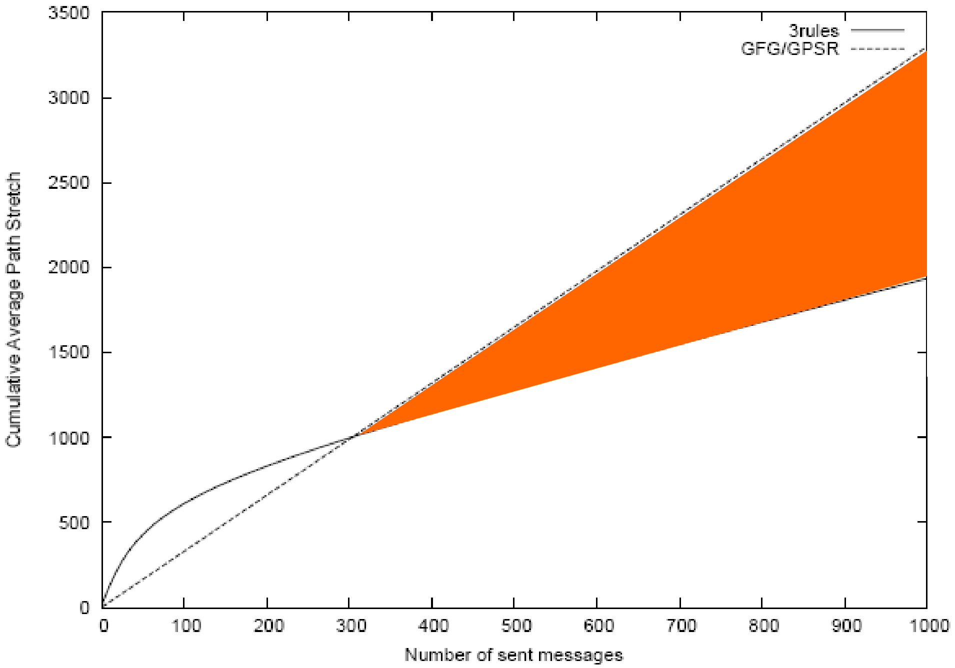
- At startup (no initialization phase)
  - each node sets its virtual coordinate at *null*
  - sink node chooses 0
- Whenever a node transmits a message
  - each node learns its neighbors' virtual coordinate
  - updates its virtual coordinate with the min of its neighbors' + 1
  - sink node always stays at 0
- Virtual coordinates converge to **shortest path** (optimal case) !



Virtual Coordinate Routing [2/3]

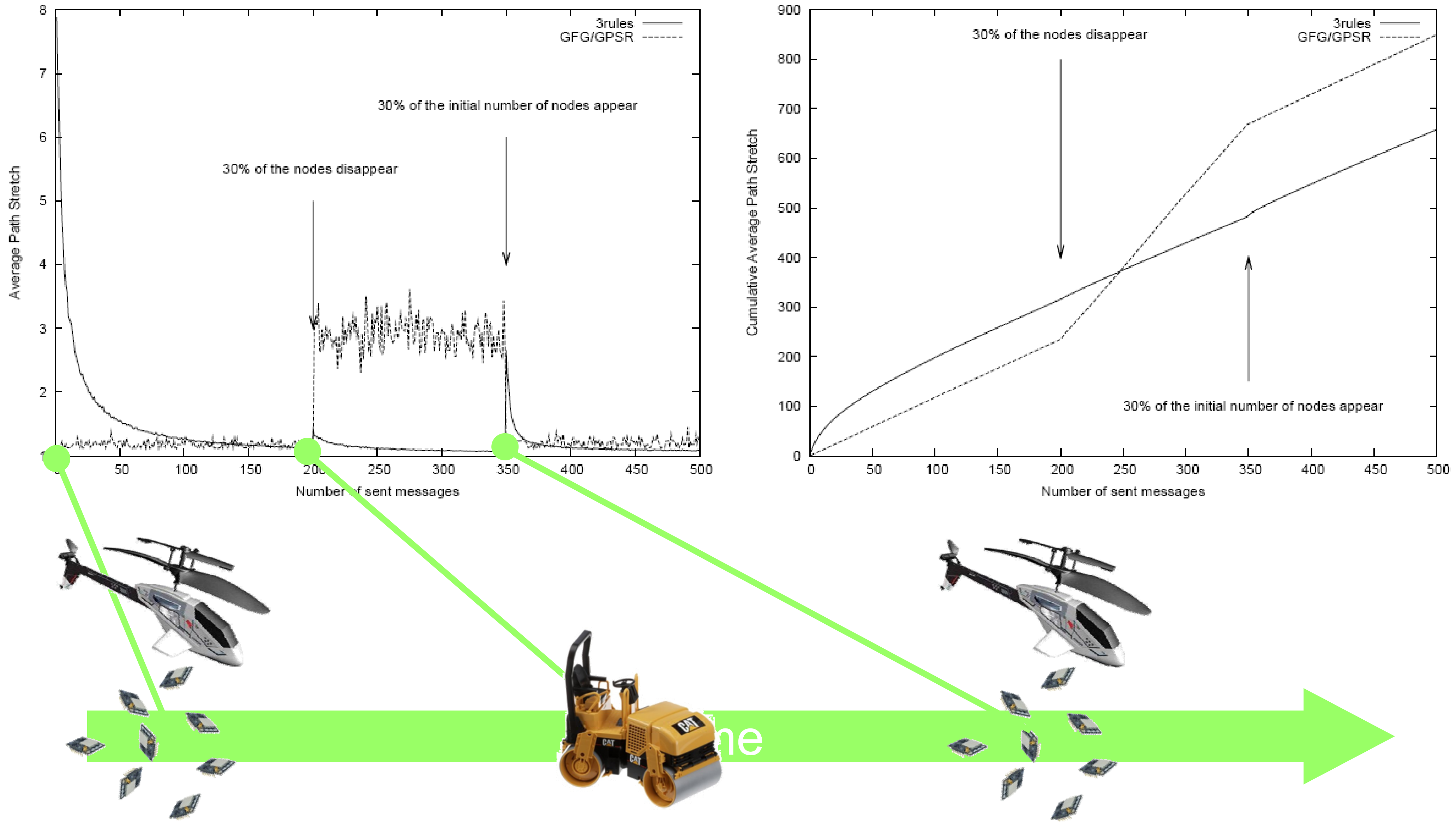
- The protocol is very energy efficient:





Virtual Coordinate Routing [3/3]

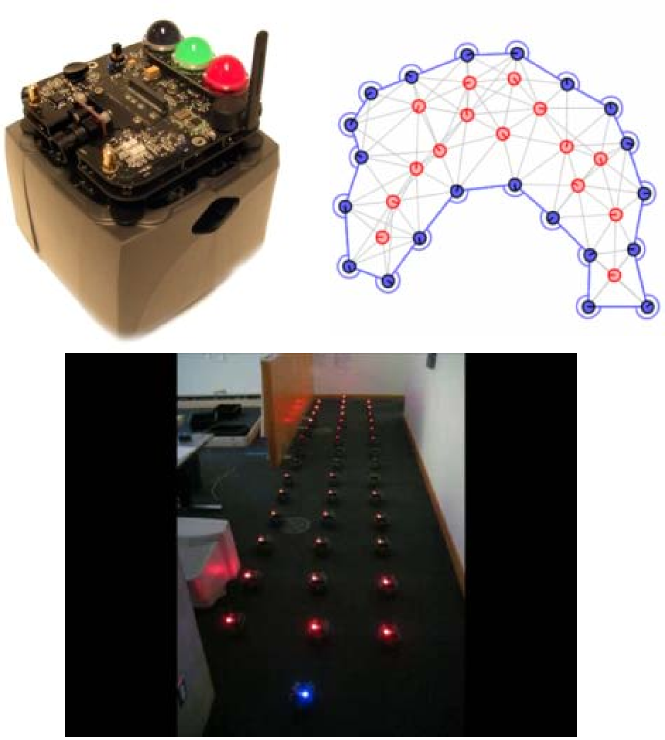
- The protocol is very robust to nodes (dis)appearing:



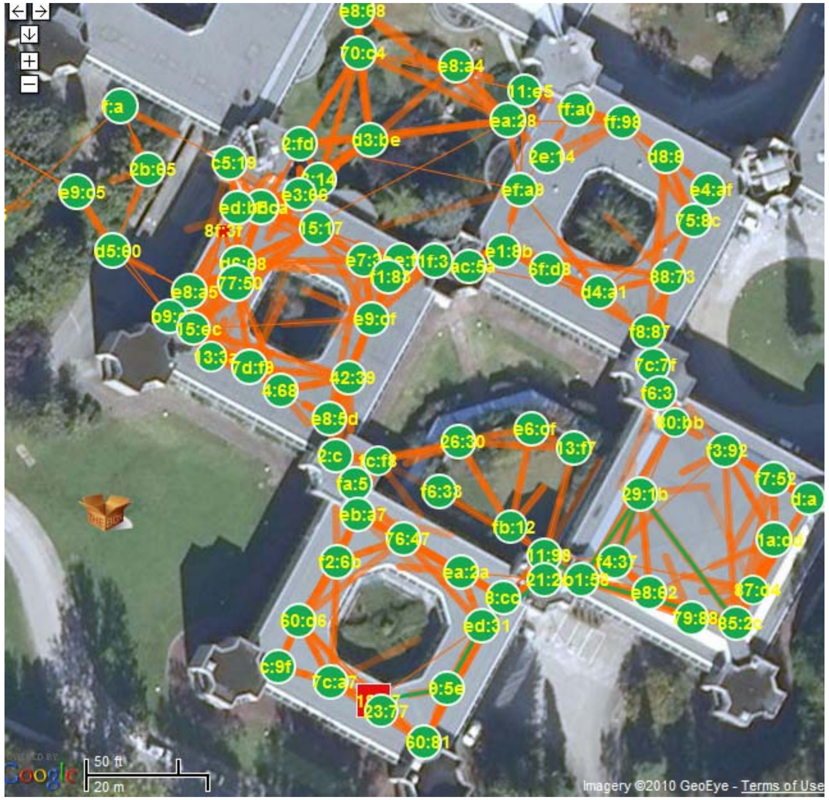
3.2.3

From Academia To Practice

Experimentation – Surprise, Surprise!



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

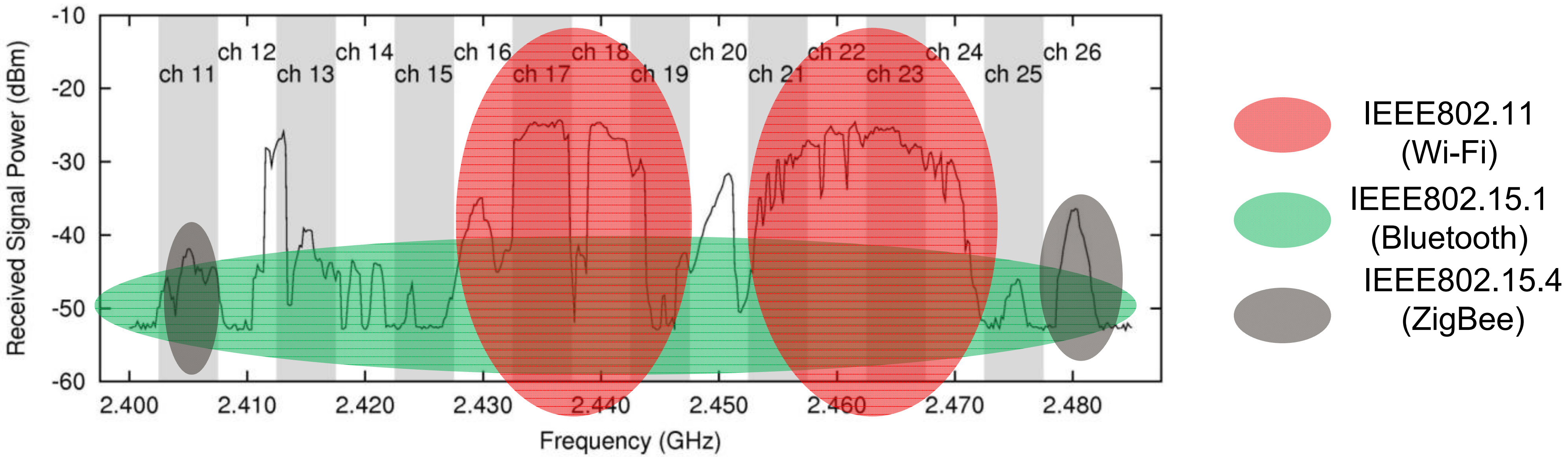


http://senseandsensitivity.rd.francetelecom.com/

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

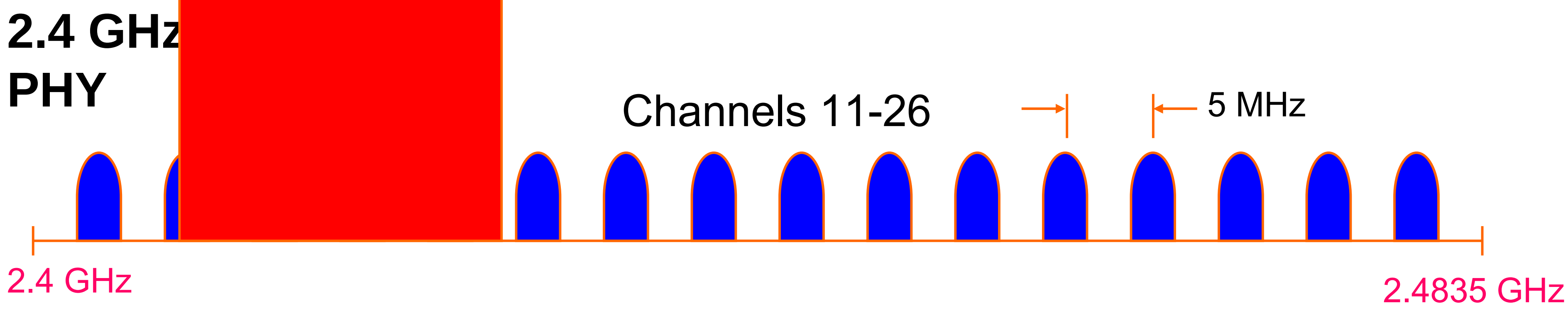
First Challenge: External Interference



First ... nge: External Interference

Typical Tx p...

- IEEE802. ... nW
- IEEE802. ... W



First Challenge: External Interference

868 MHz

433 MHz

2.4 GHz

5 GHz

Wi Fi

IEEE802.11b/g/n

Bluetooth

wibree

Wi Fi

IEEE802.11a/n

Z wave the wireless language

io homecontrol

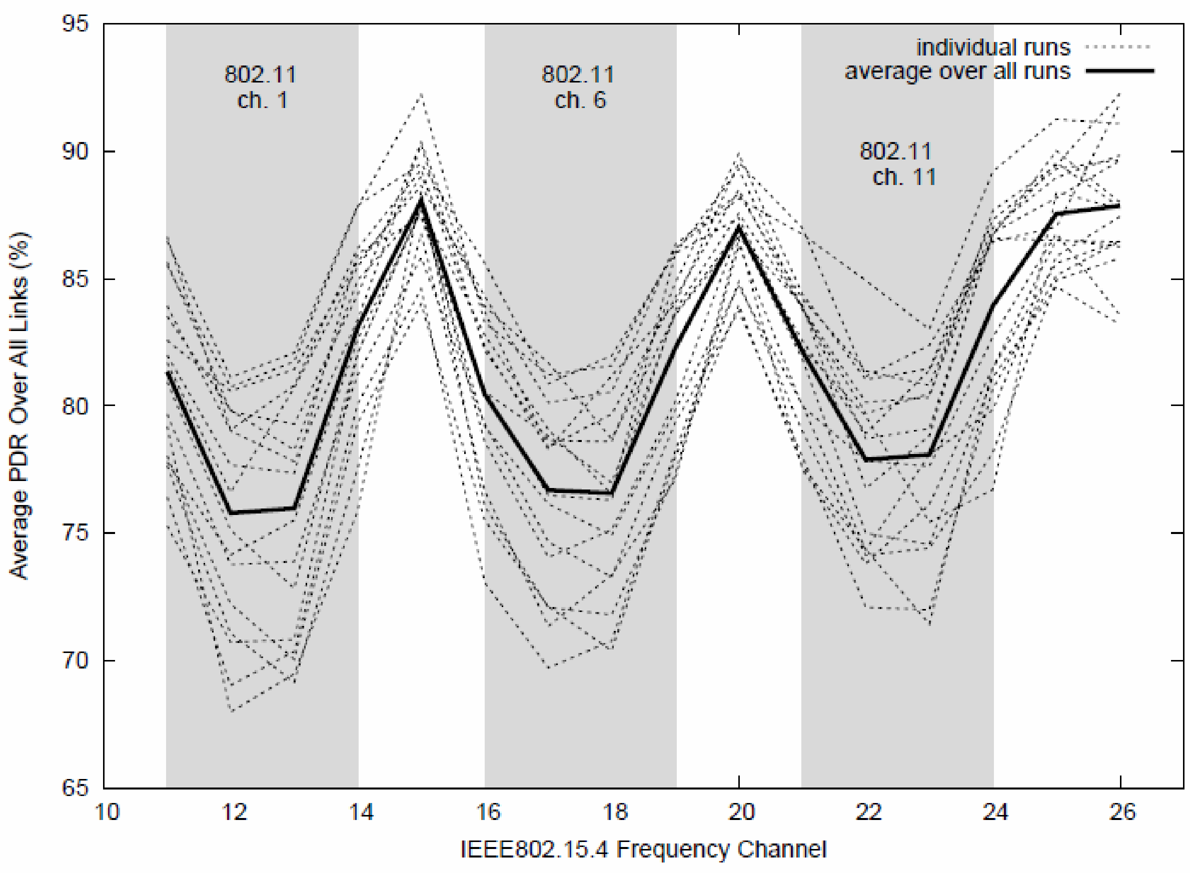
wavenis more than wireless

ZigBee Alliance
Wireless Control That Simply Works

IEEE802.15.4

nanotron TECHNOLOGIES

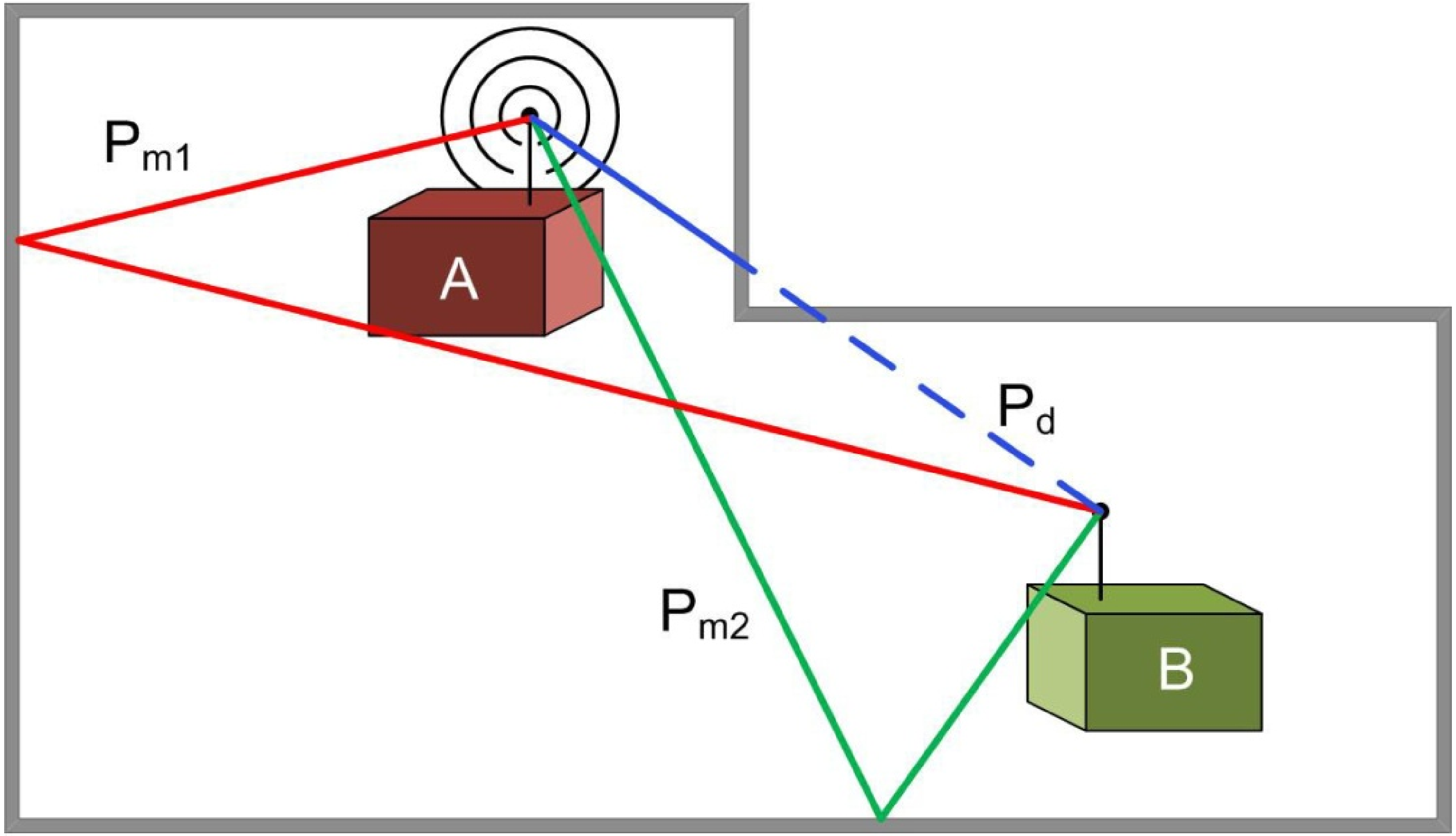
First Challenge: External Interference



- 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

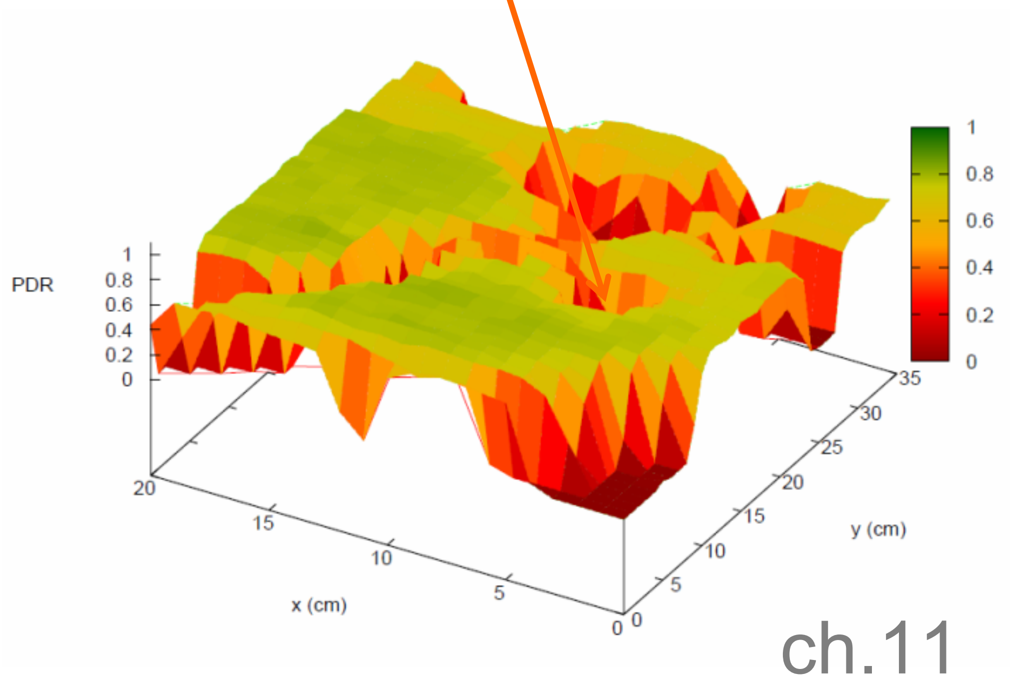
Second Challenge: Multipath Fading

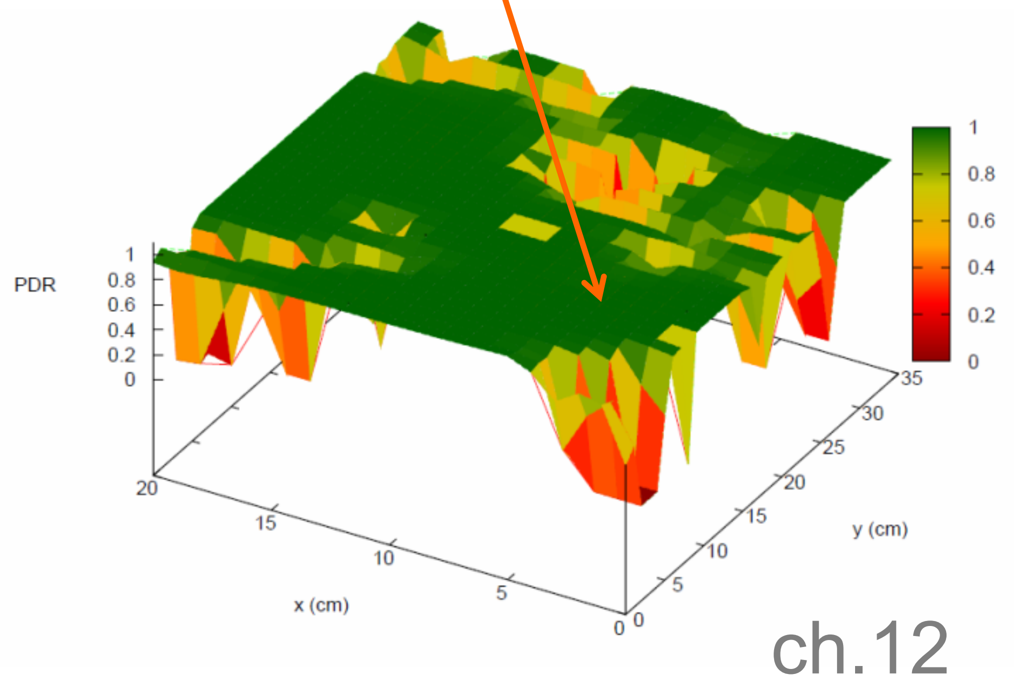


Second Challenge: Multipath Fading

0% reliability

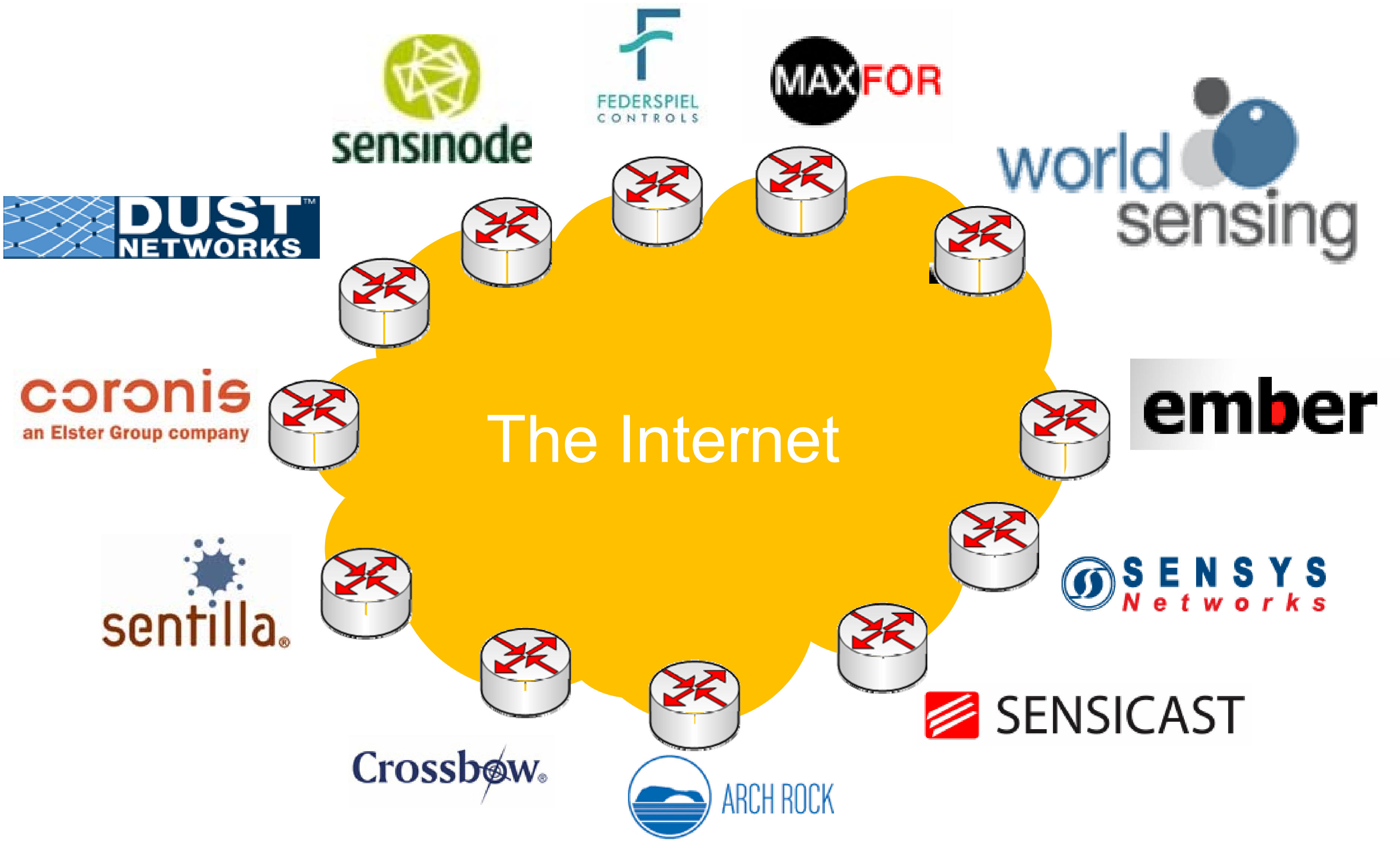
100% reliability





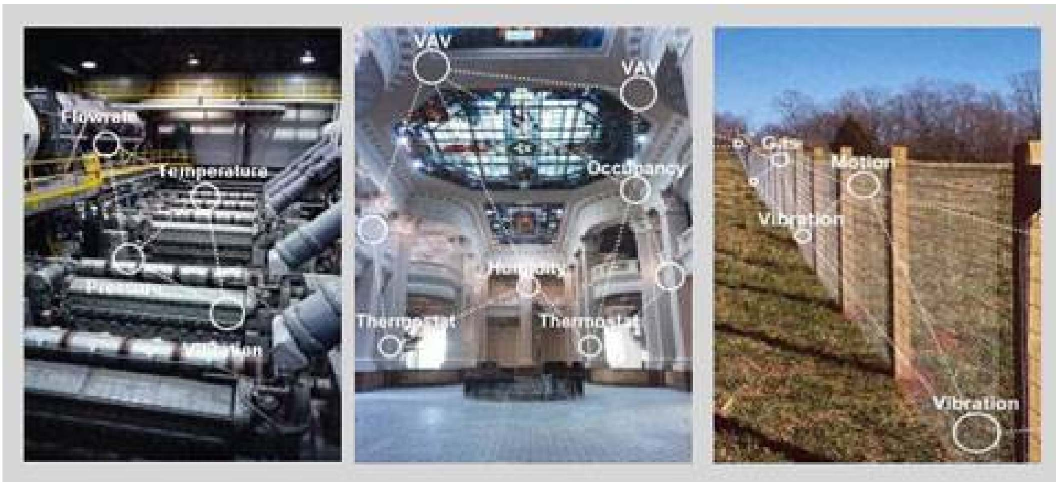
3.3
Proprietary M2M Solutions

Key Embedded M2M Companies



Dust Networks [US]

- Dust Networks facts:
  - founded in 2002 by industry pioneer Prof. Kris Pister, Berkeley, USA
  - vision of a world of ubiquitous sensing – a world of connected sensors scattered around like specs of dust, or smart dust, gathering information economically and reliably, that had previously been impractical or impossible to acquire
  - inventors of TSMP which are used in ISA100, Wireless HART and IEEE 802.15.4E
  - emphasis on <u>industrial control</u>



Arch Rock [US]

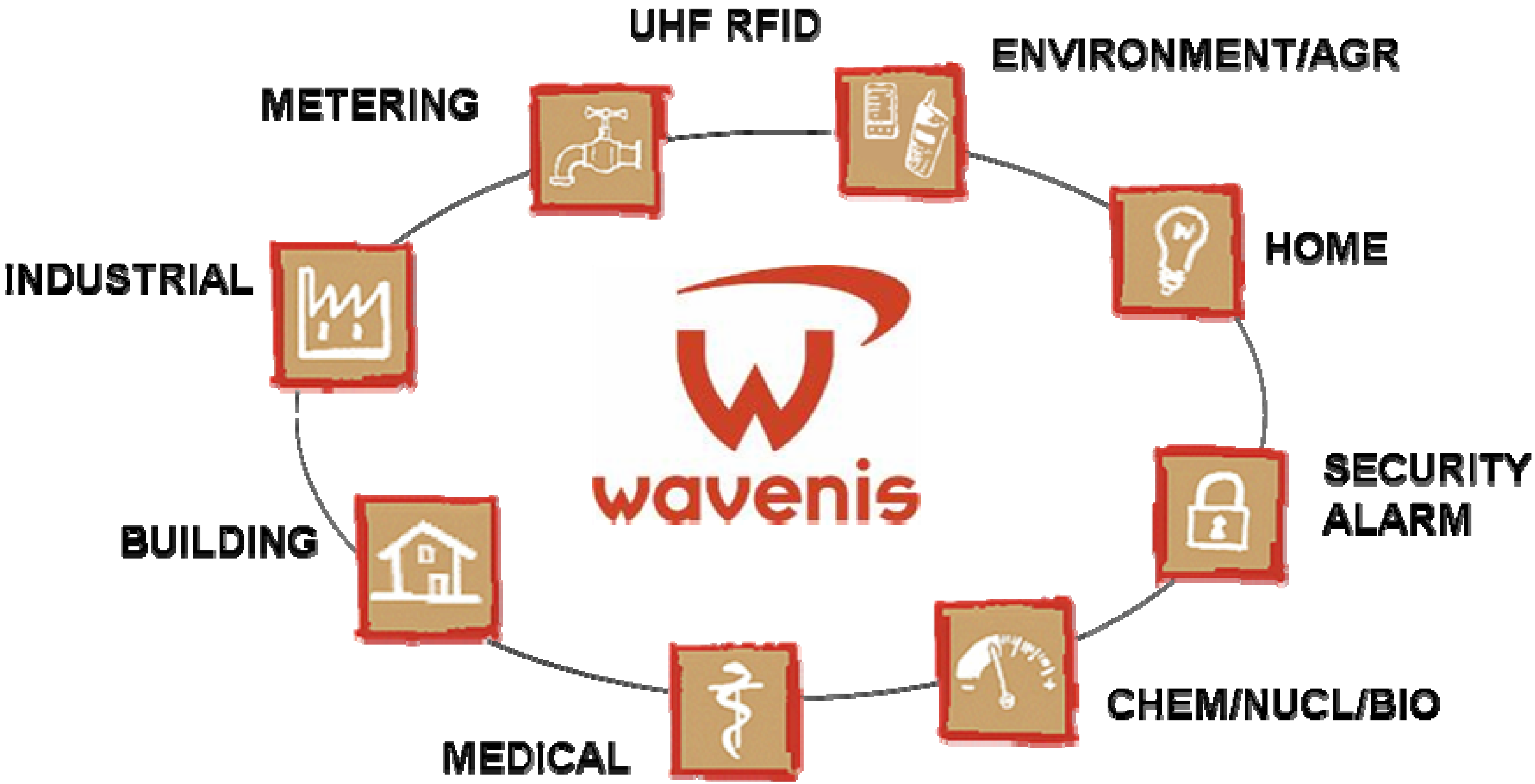
- Arch Rock facts:
  - founded in May 2005 with a vision of providing a high quality, seamless integration of the physical and virtual worlds that would enhance the information awareness of the individual and the enterprise
  - company builds upon a decade of research at the University of California, Berkeley and Intel Research by David Culler et al.
  - founder of a new operating system, TinyOS and Berkeley Mote, for small wirelessly connected computers that sense the physical environment and form vast embedded networks; emphasis on environmental monitoring & ind. control

Crossbow [US]

- Crossbow facts:
  - Global Leader in Sensory Systems; founded in 1995 by Mike Horton
  - Products MEMS-Based Inertial Systems & Wireless Sensor Networking
  - World-Wide Employee Base; Headquartered in San Jose, CA
  - $25M in Venture Capital
  - Cisco Systems, Intel Corporation, Morgenthaler Ventures, Paladin Capital
  - emphasis on asset management & tracking

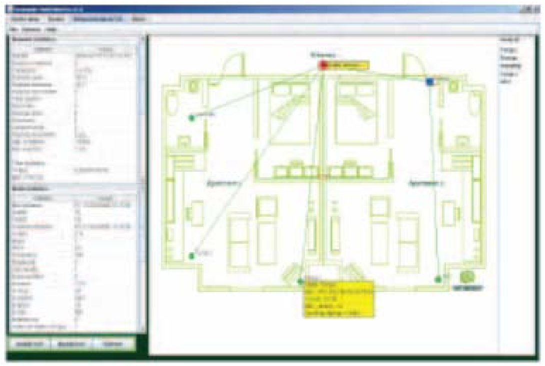
Coronis/Elster [FR, US]

- Coronis, France, (now bought by Elster, USA) in short:



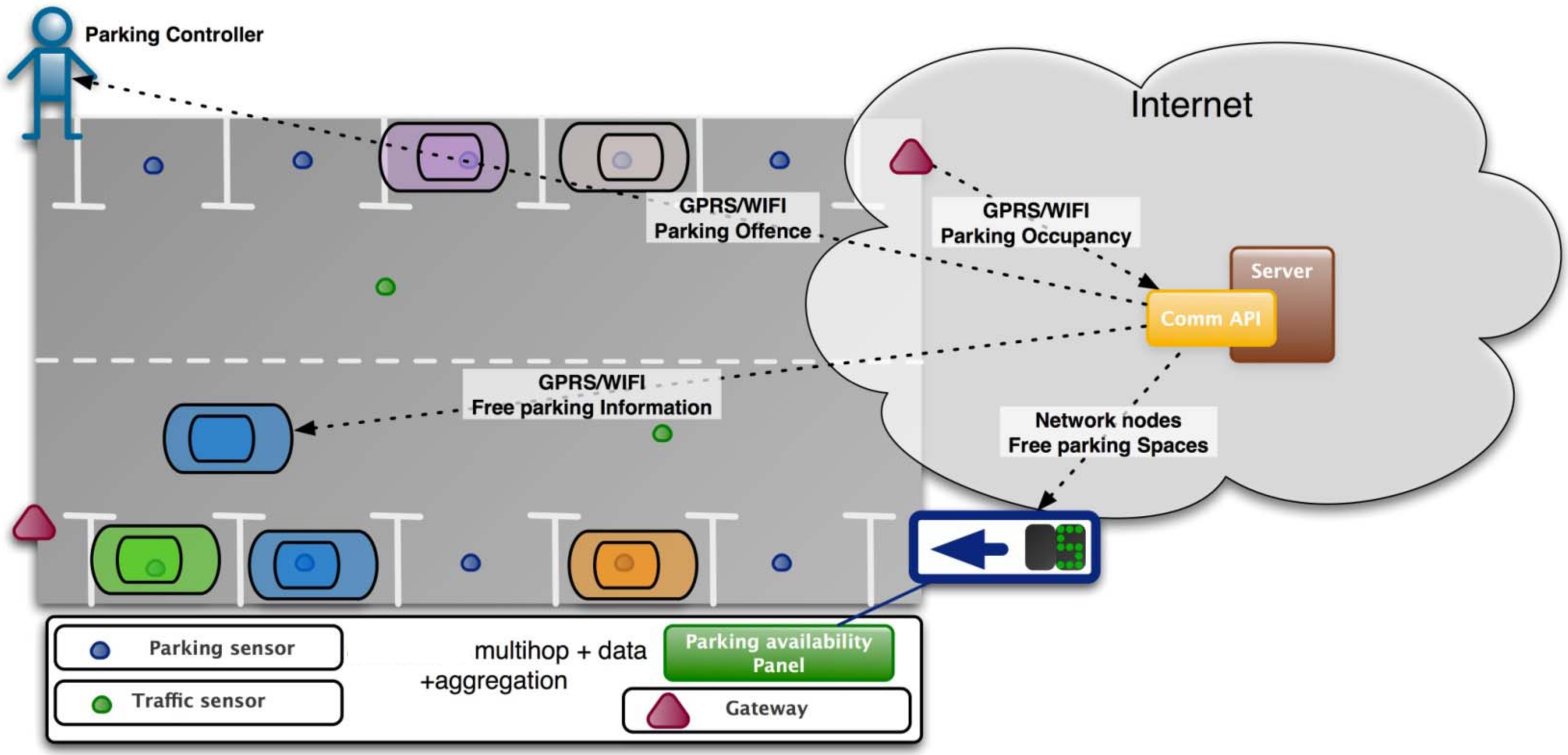
Sensinode [FI]

- Sensinode facts:
  - leader in IP-based wireless sensor network (WSN) technology
  - 1st on the market with a 6lowpan stack
  - 6lowpan products and services: 6lowpan Devkits, Network Products, NanoStack 6lowpan Stack
  - Engineering Services
  - Sensinode is headquartered in Finland
  - A 2005 spin-off of the University of Oulu, Finland based on a decade of research



Worldsensing [ES]

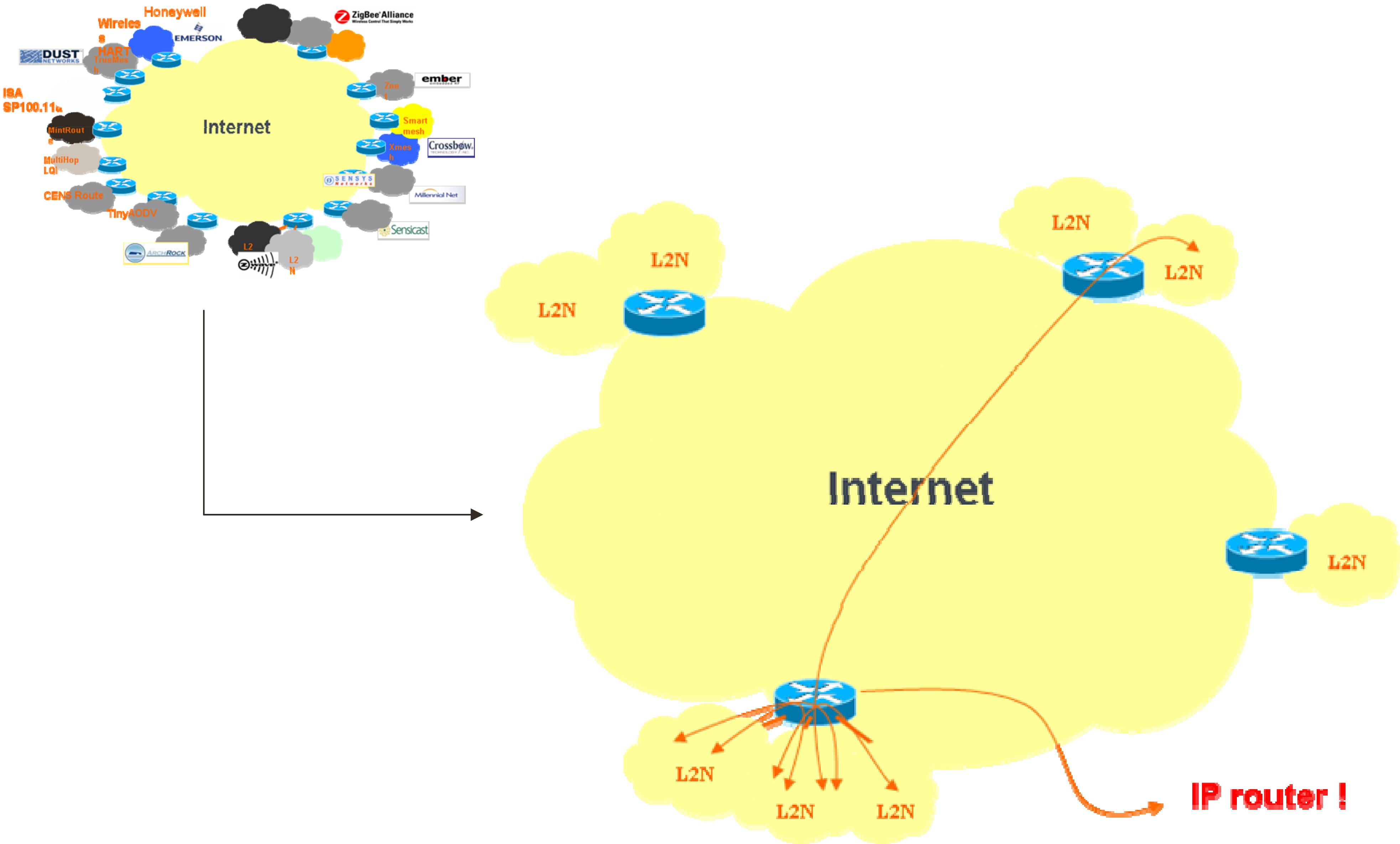
- Worldsensing facts:
  - addressing Smart Parking/City, Smart Construction, Smart-* markets
  - winner of IBM Smart Camp London 2010 competition
  - intelligent technology and software providing end-to-end solutions



3.4

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

	Application	OpenADR, XML
IETF	Transport	TCP, UDP
IETF	Networking	IETF RPL (routing)
IETF		IETF 6LoWPAN (adaptation)
IEEE	MAC	IEEE 802.15.4E
IEEE	PHY	IEEE 802.15.4-2006

3.4.1

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)

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

IEEE802.15.4 - PHY

- Emphasis of IEEE 802.15.4 is on power-constrained application:
  - Low-rate communication @ **250kbps**:
    - high data-rate communication (up to 2Mbps) is possible, but not standard-compliant
  - Output power of 0dBm (1mW) is typical; higher possible:
    - 10s of meters indoors typical, 100m outdoors
    - very dependent on environment
  - low-power:
    - currently available chips: >14mA in Tx @0Bm
    - announced chips: 3mA in Tx @0Bm
  - **2.400-2.485GHz** is band used in most applications
    - Other PHY available e.g. 868-868.8 MHz (Europe), 902-928 MHz (North America)
  - **16 frequency channels**, 2MHz wide, separated by 5MHz (non-overlapping)
  - link quality and **received signal strength** indicators available in most chips
  - **secure communications** built in (128-bit AES engine in most chips)
  - Short packets: PHY payload limited to **127 bytes**

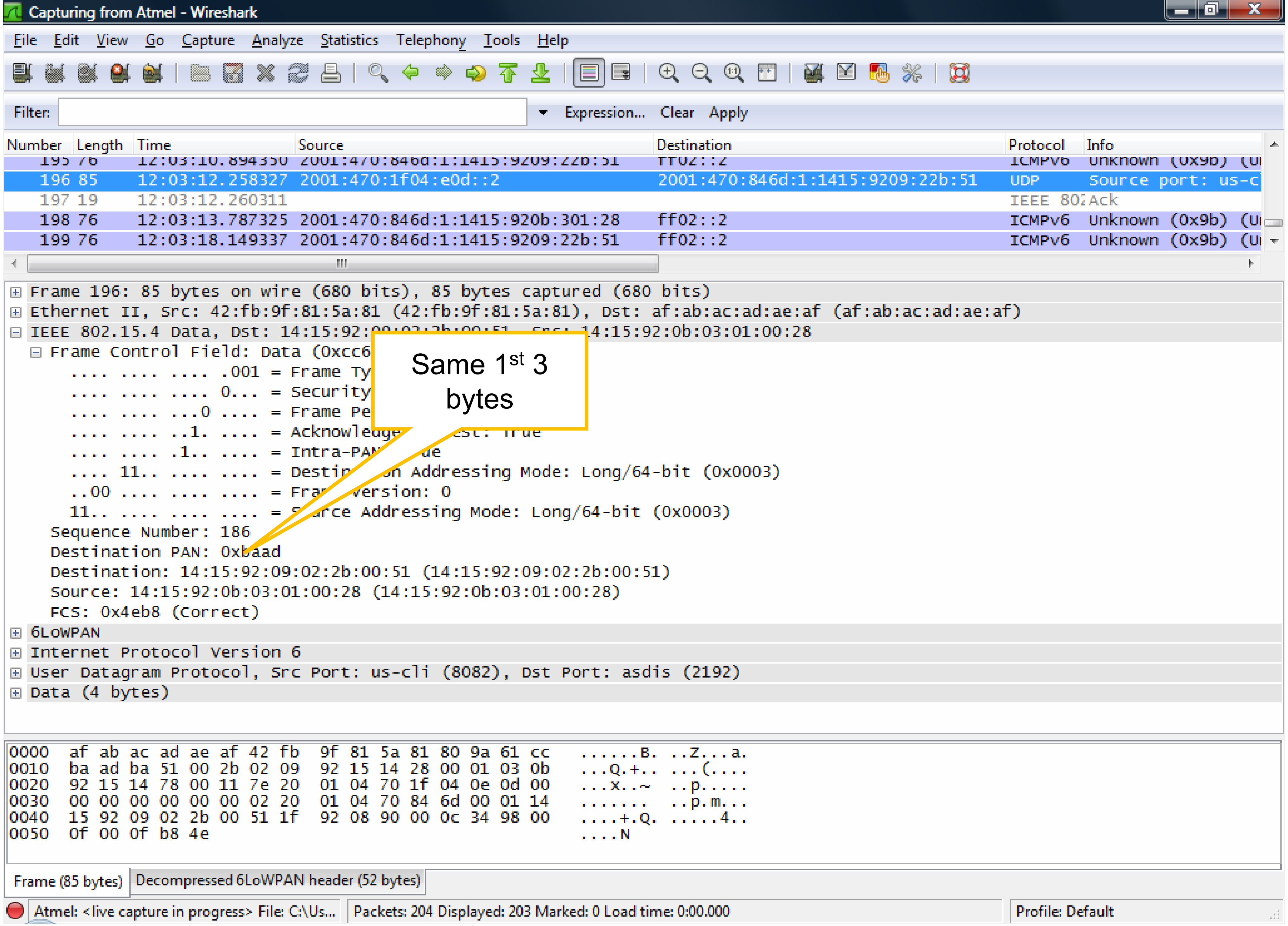
- IEEE802.15.4-2006 includes Medium Access Control:
  - Powered-on routers
  - Single channel operation

IEEE802.15.4 - Addressing

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

- Each node contains a 64-bit Extended Unique Identifier (EUI64):
  - First 3 bytes Organizational Unique Identifier (OUI)
    - http://standards.ieee.org/regauth/oui/
    - e.g. 0x00170D for Dust Networks
    - 17 million vendors identifiers available
  - Last 5 bytes identify the chip
    - 1000 billion chips identifiers available, per vendor

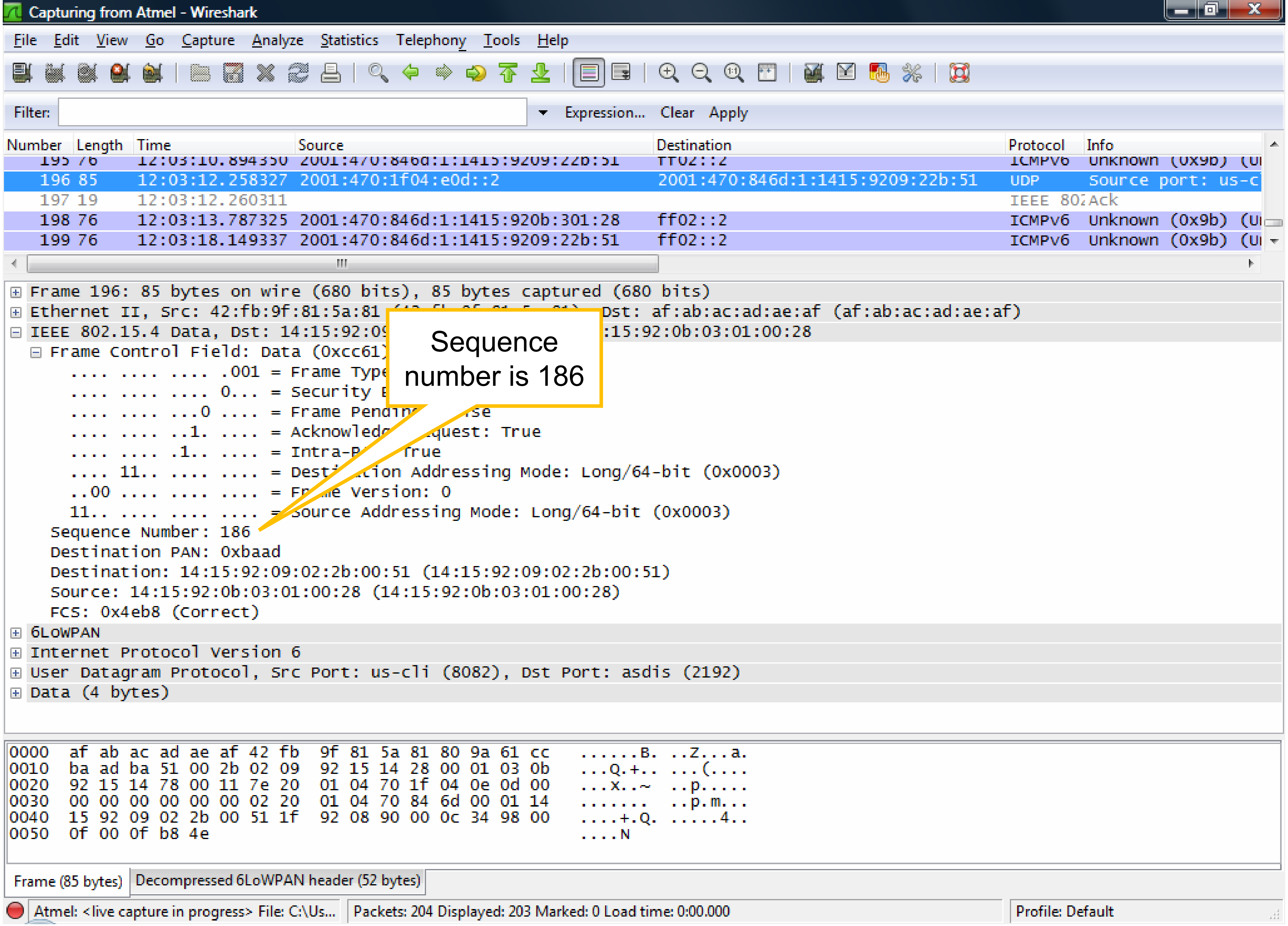
- Under some circumstances, nodes can acquire a 16-bit short identifier
  - By registering with the PAN coordinator in a ZigBee network
  - By registering with the coordinator in a ISA100.11a network

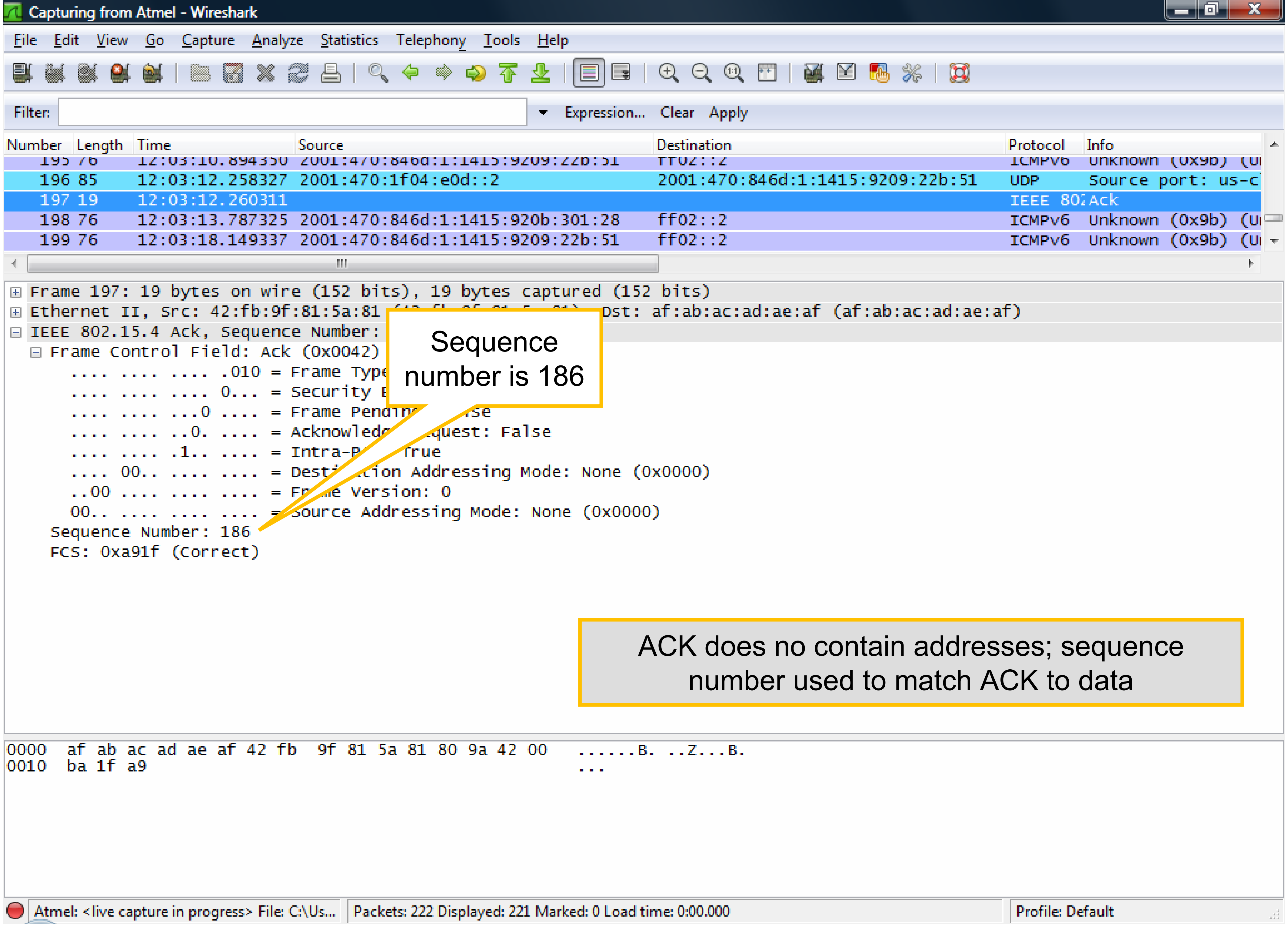

Capturing from Atmel - Wireshark
File Edit View Go Capture Analyze Statistics Telephony Tools Help
Filter:
Expression... Clear Apply
Number Length Time Source Destination Protocol Info
196 85 12:03:12.258327 2001:470:1f04:e0d::2 2001:470:846d:1:1415:9209:22b:51 UDP Source port: us-c
197 19 12:03:12.260311 IEEE 802 Ack
198 76 12:03:13.787325 2001:470:846d:1:1415:920b:301:28 ff02::2 ICMPv6 Unknown (0x9b) (U
199 76 12:03:18.149337 2001:470:846d:1:1415:9209:22b:51 ff02::2 ICMPv6 Unknown (0x9b) (U
Frame 196: 85 bytes on wire (680 bits), 85 bytes captured (680 bits)
Ethernet II, Src: 42:fb:9f:81:5a:81 (42:fb:9f:81:5a:81), Dst: af:ab:ac:ad:ae:af (af:ab:ac:ad:ae:af)
IEEE 802.15.4 Data, Dst: 14:15:92:
Src: 14:15:92:0b:03:01:00:28
Frame Control Field: Data (0xcc6
.... .001 = Frame Ty
.... 0... = Security
....0 .... = Frame Pe
....1. .... = Acknowledge
.... .1.. .... = Intra-PAN
.... 11.. .... = Destin
..00 .... = Fra
11.. .... =
Addressing Mode: Long/64-bit (0x0003)
version: 0
Source Addressing Mode: Long/64-bit (0x0003)
Sequence Number: 186
Destination PAN: 0xbaad
Destination: 14:15:92:09:02:2b:00:51 (14:15:92:09:02:2b:00:51)
Source: 14:15:92:0b:03:01:00:28 (14:15:92:0b:03:01:00:28)
FCS: 0x4eb8 (Correct)
6LoWPAN
Internet Protocol Version 6
User Datagram Protocol, Src Port: us-cli (8082), Dst Port: asdis (2192)
Data (4 bytes)
Same 1st 3 bytes
0000 af ab ac ad ae af 42 fb 9f 81 5a 81 80 9a 61 cc ......B. ..Z...a.
0010 ba ad ba 51 00 2b 02 09 92 15 14 28 00 01 03 0b ...Q.+.. ...(....
0020 92 15 14 78 00 11 7e 20 01 04 70 1f 04 0e 0d 00 ...x..~ ..p.....
0030 00 00 00 00 00 00 02 20 01 04 70 84 6d 00 01 14 ....p.m...
0040 15 92 09 02 2b 00 51 1f 92 08 90 00 0c 34 98 00 ....+.Q. .....4..
0050 0f 00 0f b8 4e ....N
Frame (85 bytes) Decompressed 6LoWPAN header (52 bytes)
Atmel: <live capture in progress> File: C:\Us... Packets: 204 Displayed: 203 Marked: 0 Load time: 0:00.000 Profile: Default

IEEE802.15.4 - Packet Format

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

- IEEE802.15.4 header
  - 2B Frame Control Field
    - set of flags which indicate how the header is built
  - 1B sequence number
    - increases for every packet sent (for ACKing)
  - 2B Personal Area Network (PAN) identifier
    - Preset, common to all nodes
  - 8B destination address
    - EUI64
  - 8B source address
    - EUI64
- IEEE802.15.4 footer
  - 2B Frame Control Sequence
    - 16 bit Cyclic Redundancy Check over the PHY payload by the transmitter
    - packet rejected when CRC fails at the receiver


Capturing from Atmel - Wireshark
File Edit View Go Capture Analyze Statistics Telephony Tools Help
Filter:
Expression... Clear Apply
Number Length Time Source Destination Protocol Info
196 85 12:03:12.258327 2001:470:1f04:e0d::2 2001:470:846d:1:1415:9209:22b:51 UDP Source port: us-c
197 19 12:03:12.260311 IEEE 802 Ack
198 76 12:03:13.787325 2001:470:846d:1:1415:920b:301:28 ff02::2 ICMPv6 Unknown (0x9b) (Ui
199 76 12:03:18.149337 2001:470:846d:1:1415:9209:22b:51 ff02::2 ICMPv6 Unknown (0x9b) (Ui
Frame 196: 85 bytes on wire (680 bits), 85 bytes captured (680 bits)
Ethernet II, Src: 42:fb:9f:81:5a:81 Dst: af:ab:ac:ad:ae:af (af:ab:ac:ad:ae:af)
IEEE 802.15.4 Data, Dst: 14:15:92:09 :15:92:0b:03:01:00:28
Frame Control Field: Data (0xcc61)
.... .001 = Frame Type
.... 0... = Security E
....0 .... = Frame Pendin se
....1. .... = Acknowled quest: True
.... .1.. .... = Intra-P True
.... 11.. .... = Desti tion Addressing Mode: Long/64-bit (0x0003)
..00 .... = Fr e Version: 0
11.. .... = Source Addressing Mode: Long/64-bit (0x0003)
Sequence Number: 186
Destination PAN: 0xbaad
Destination: 14:15:92:09:02:2b:00:51 (14:15:92:09:02:2b:00:51)
Source: 14:15:92:0b:03:01:00:28 (14:15:92:0b:03:01:00:28)
FCS: 0x4eb8 (Correct)
6LoWPAN
Internet Protocol Version 6
User Datagram Protocol, Src Port: us-cli (8082), Dst Port: asdis (2192)
Data (4 bytes)
Sequence number is 186
0000 af ab ac ad ae af 42 fb 9f 81 5a 81 80 9a 61 cc ......B. ..Z...a.
0010 ba ad ba 51 00 2b 02 09 92 15 14 28 00 01 03 0b ...Q.+.. ...(....
0020 92 15 14 78 00 11 7e 20 01 04 70 1f 04 0e 0d 00 ...x..~ ..p.....
0030 00 00 00 00 00 00 02 20 01 04 70 84 6d 00 01 14 ....p.m...
0040 15 92 09 02 2b 00 51 1f 92 08 90 00 0c 34 98 00 ....+.Q. .....4..
0050 0f 00 0f b8 4e ....N
Frame (85 bytes) Decompressed 6LoWPAN header (52 bytes)
Atmel: <live capture in progress> File: C:\Us... Packets: 204 Displayed: 203 Marked: 0 Load time: 0:00.000 Profile: Default


Capturing from Atmel - Wireshark
File Edit View Go Capture Analyze Statistics Telephony Tools Help
Filter: Expression... Clear Apply
Number Length Time Source Destination Protocol Info
196 85 12:03:12.258327 2001:470:1f04:e0d::2 2001:470:846d:1:1415:9209:22b:51 UDP Source port: us-c
197 19 12:03:12.260311 IEEE 802 Ack
198 76 12:03:13.787325 2001:470:846d:1:1415:920b:301:28 ff02::2 ICMPv6 Unknown (0x9b) (U
199 76 12:03:18.149337 2001:470:846d:1:1415:9209:22b:51 ff02::2 ICMPv6 Unknown (0x9b) (U
Frame 197: 19 bytes on wire (152 bits), 19 bytes captured (152 bits)
Ethernet II, Src: 42:fb:9f:81:5a:81 Dst: af:ab:ac:ad:ae:af (af:ab:ac:ad:ae:af)
IEEE 802.15.4 Ack, Sequence Number:
Frame Control Field: Ack (0x0042)
.... .010 = Frame Type
.... 0... = Security E
....0 .... = Frame Pendin
....0. .... = Acknowled
.... .1.. .... = Intra-P True
.... 00.. .... = Destination Addressing Mode: None (0x0000)
..00 .... = Frame Version: 0
00.. .... = Source Addressing Mode: None (0x0000)
Sequence Number: 186
FCS: 0xa91f (Correct)
Sequence number is 186
ACK does no contain addresses; sequence number used to match ACK to data
0000 af ab ac ad ae af 42 fb 9f 81 5a 81 80 9a 42 00 ......B. ..Z...B.
0010 ba 1f a9 ...
Atmel: <live capture in progress> File: C:\Us...
Packets: 222 Displayed: 221 Marked: 0 Load time: 0:00.000
Profile: Default

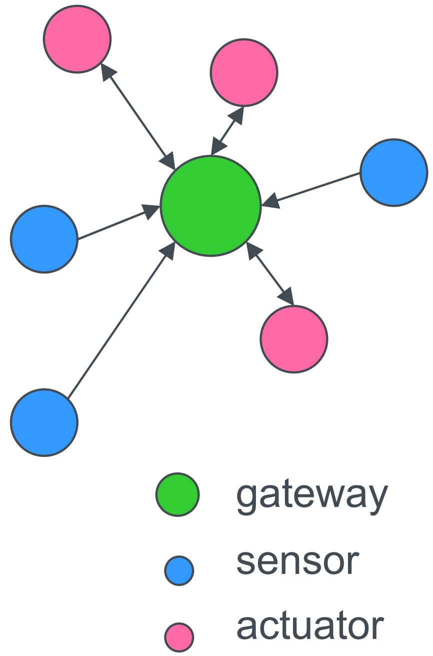
IEEE 802.15.4e – Overview

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

- Standards history:
  - latest draft standard: April 2010
  - likely ratification: December 2010
- 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**

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

LL - Low Latency

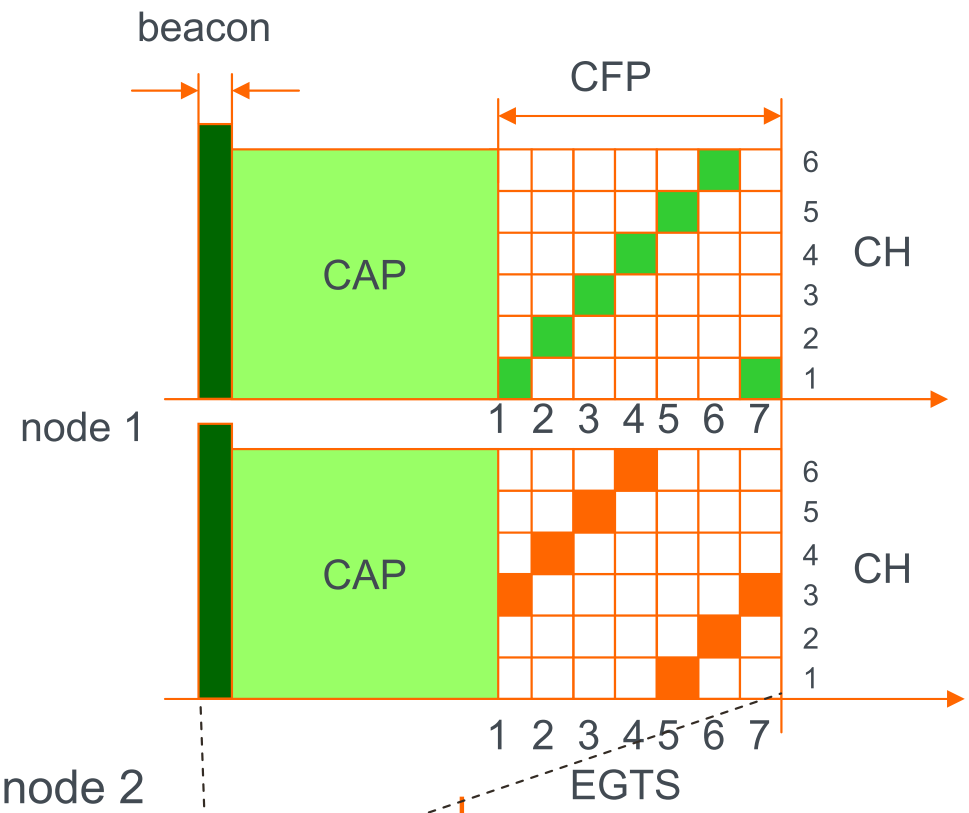


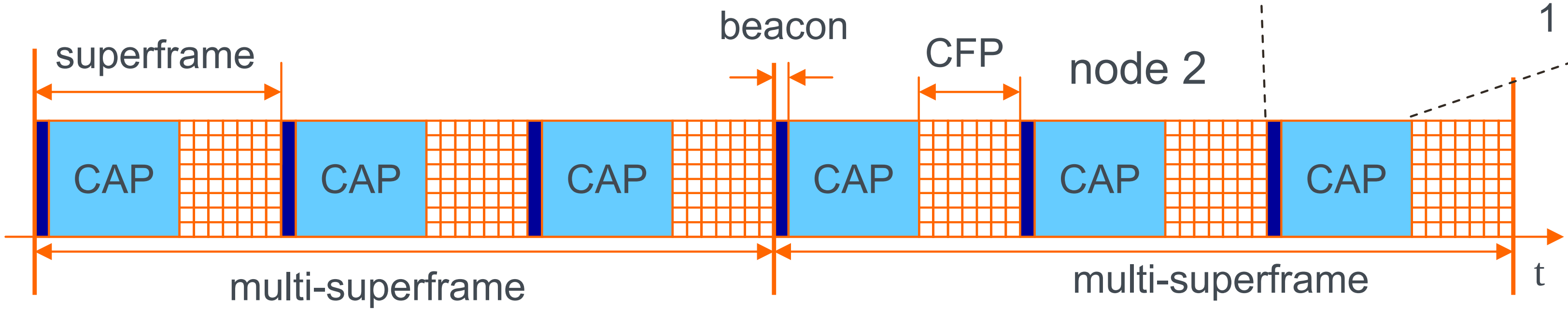
- Star network topology:
  - single gateway + sensor/actuator devices
  - unidirectional links between sensors and the gateway
  - bidirectional links between actuators and the gateway
- TDMA Access - superframe structure:
  - simplified version of slotted CSMA/CA
  - dedicated time slot (deterministic access)
  - shared Group Time slot (multiple access)
  - single time slot allows the transmission of exactly one packet
- No channel hopping:
  - ensure coexistence with other RF technologies in 2.4GHz ISM band
- Short MAC frames with 1 byte MAC header

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

CA - Commercial Application

- Multisuperframe = cycle of repeated superframes, consisting of:
  - beacon frame
  - contention access period (CAP)
  - contention free period (CFP)
- Enhanced Guaranteed Time Slot (EGTS)
  - portion of a superframe dedicated exclusively to a given device
  - single EGTS may extend over one or more superframe slots (max = 7).

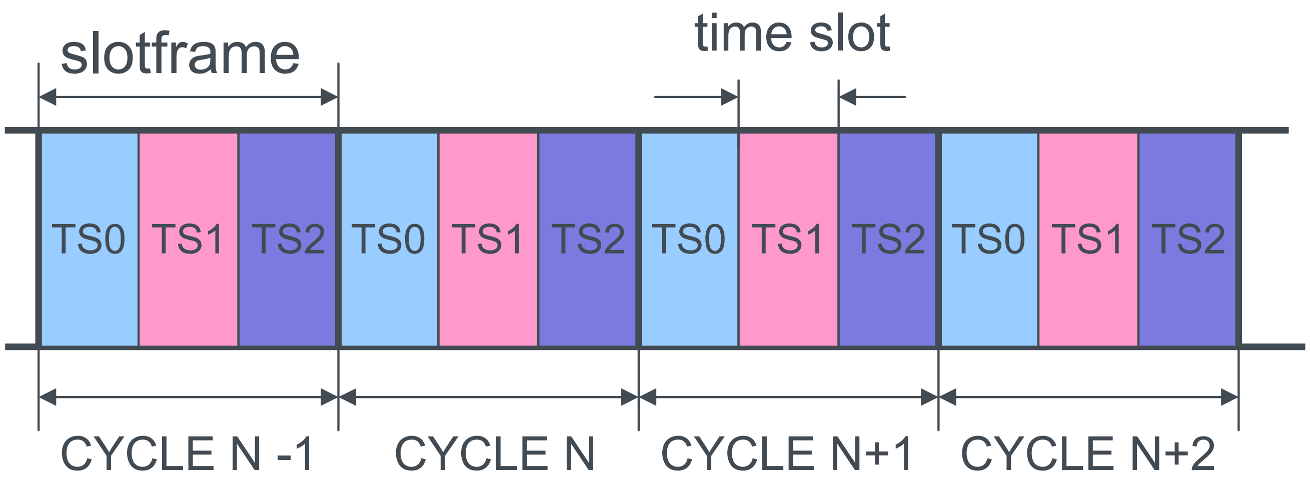




TRAN	UDP, TCP
routing	RPL
NET	IPv6
adaptation	6LoWPAN
MAC	IEEE802.15.4e
PHY	IEEE802.15.4

PA - Process Automation [1/2]

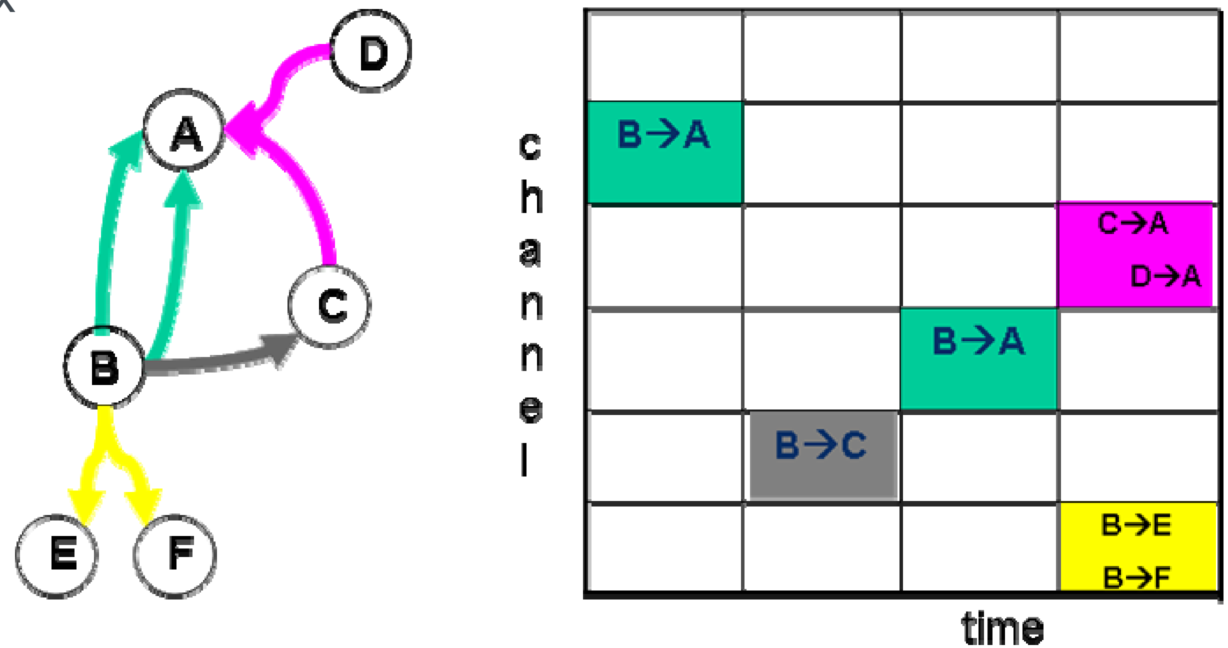
- Slotframe structure = sequence of repeated time slots:
  - time slot can be used by one/multiple devices (dedicated/shared link) or empty
  - multiple slotframes with different lengths can operate at the same time
  - SlotframeCycle: every new slotframe instance in time
  - Slotframe size: # slots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

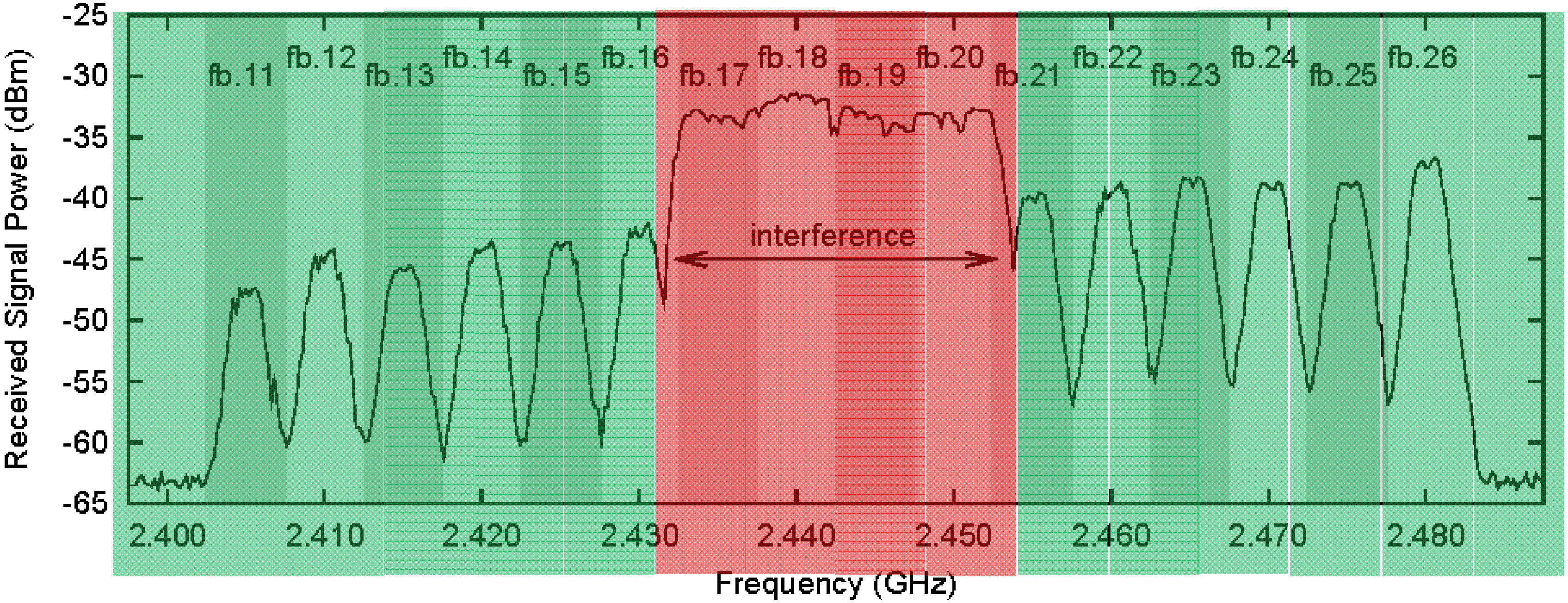
- Link = (time slot, channel offset) → **CHANNEL HOPPING**
- Dedicated link assigned to:
  - dedicated link: 1 node for Tx; 1 or more for Rx
  - shared link: 1 or more for Tx
- Prime aim to help:
  - channel impairments
  - system capacity



✓ 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

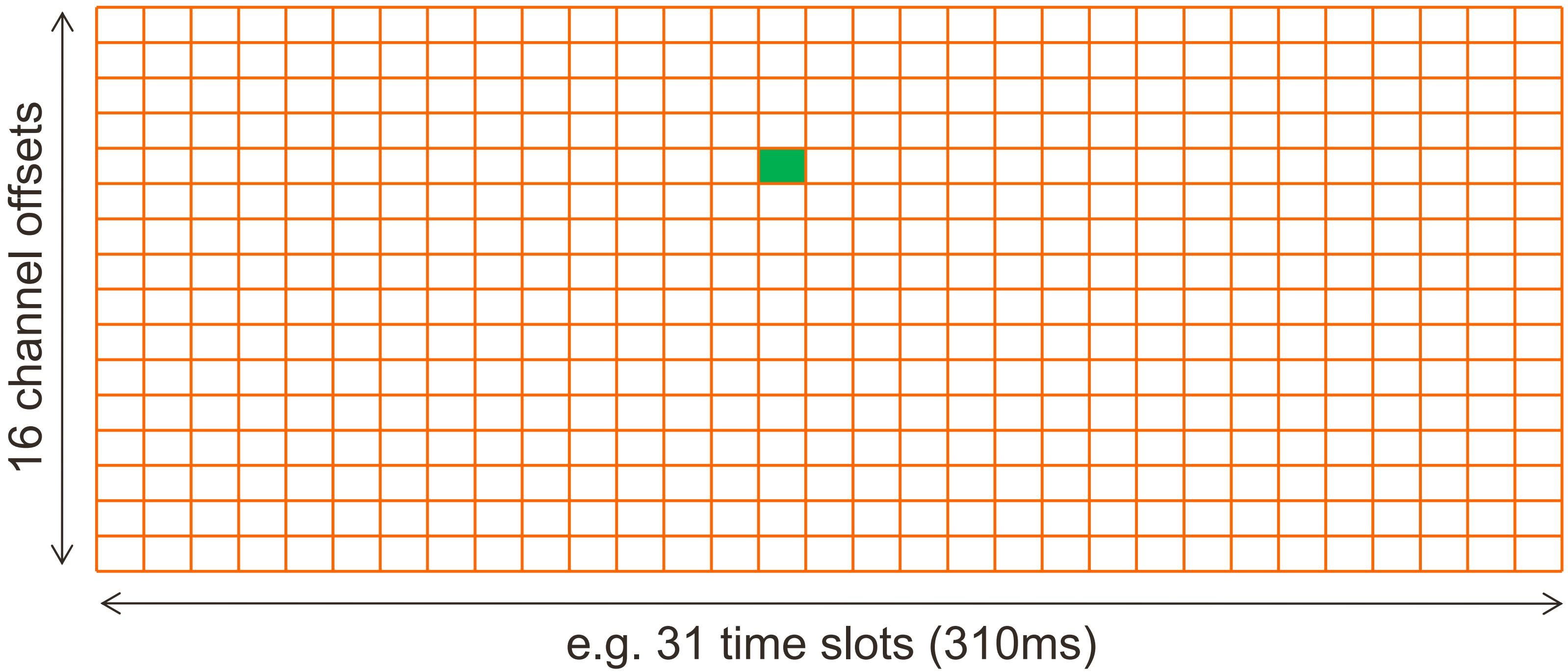
TRAN	UDP, TCP
routing	RPL
NET	IPv6
adaptation	6LoWPAN
MAC	IEEE802.15.4e
PHY	IEEE802.15.4

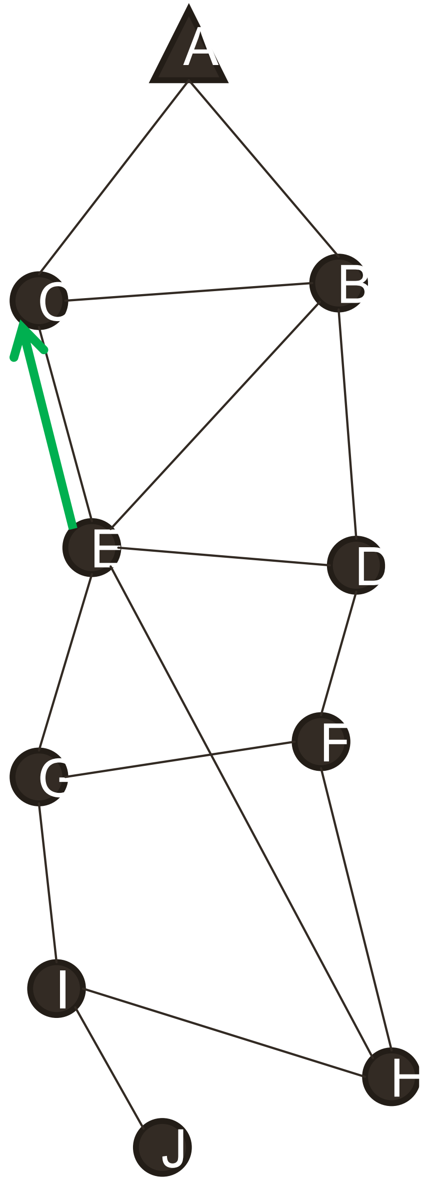


TRAN	UDP, TCP
routing	RPL
NET	IPv6
adaptation	6LoWPAN
MAC	IEEE802.15.4e
PHY	IEEE802.15.4

PA - Slotted Structure

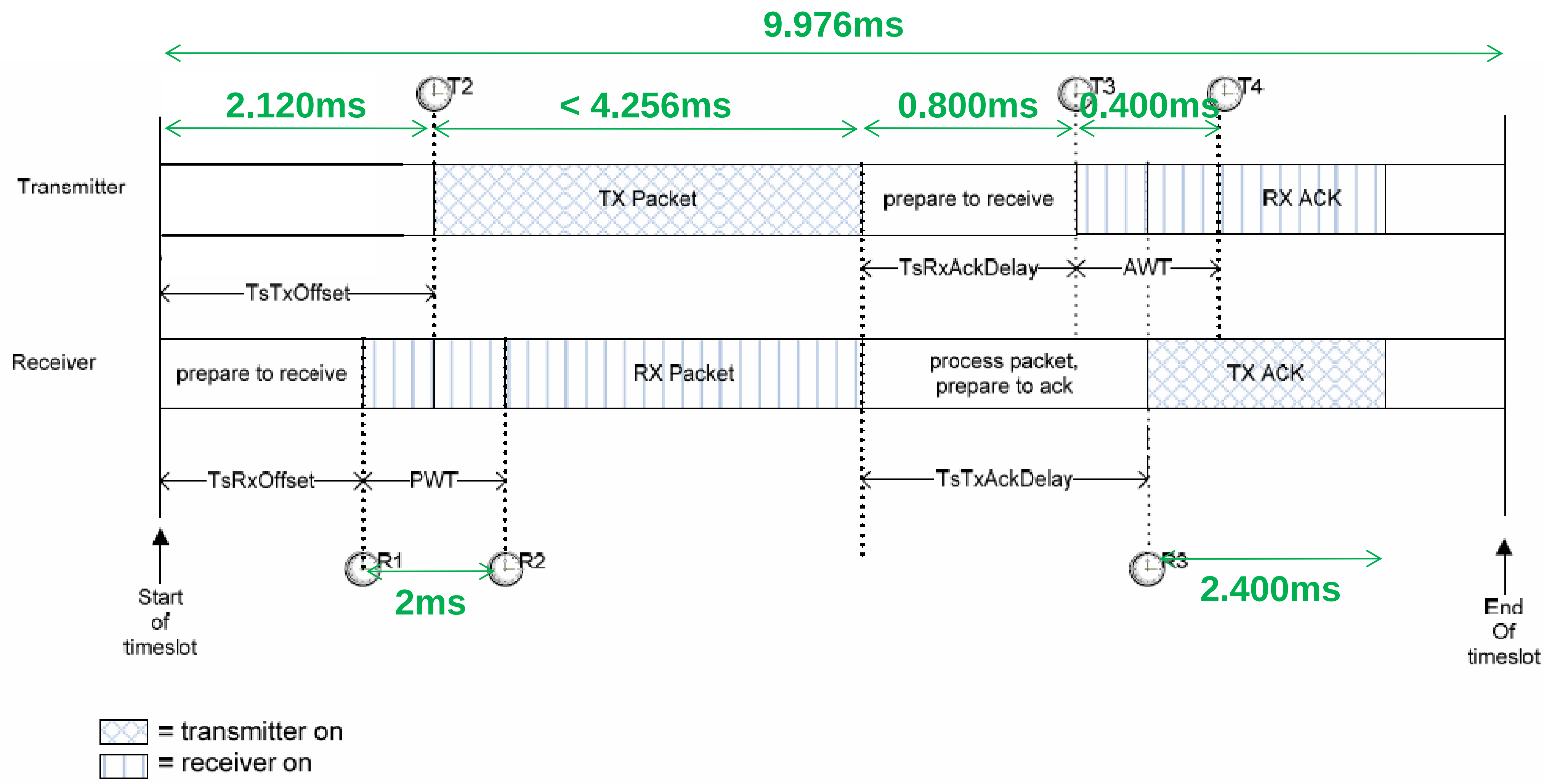
- A super-frame repeats over time
  - Number of slots in a superframe is tunable
  - Each cell can be assigned to a pair of motes, in a given direction





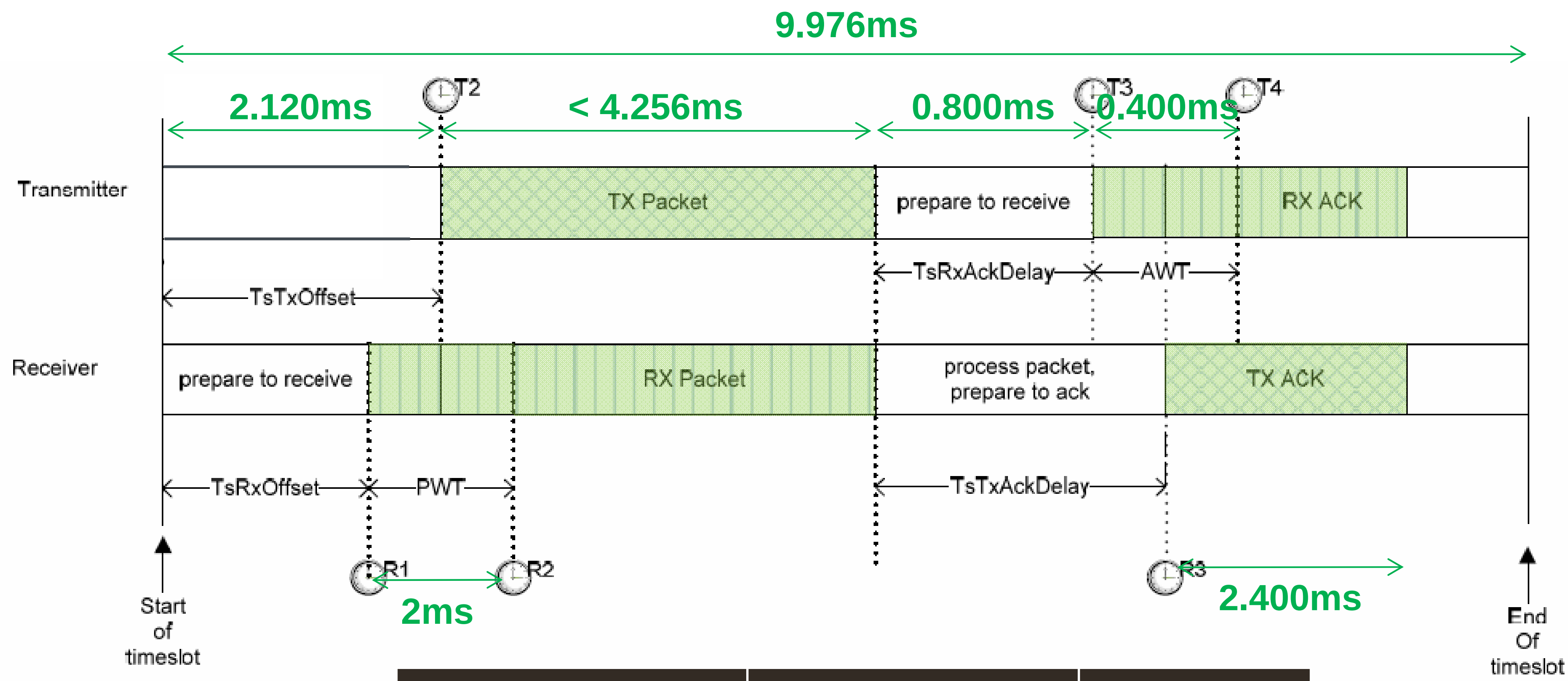
PA - Slot Structure

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

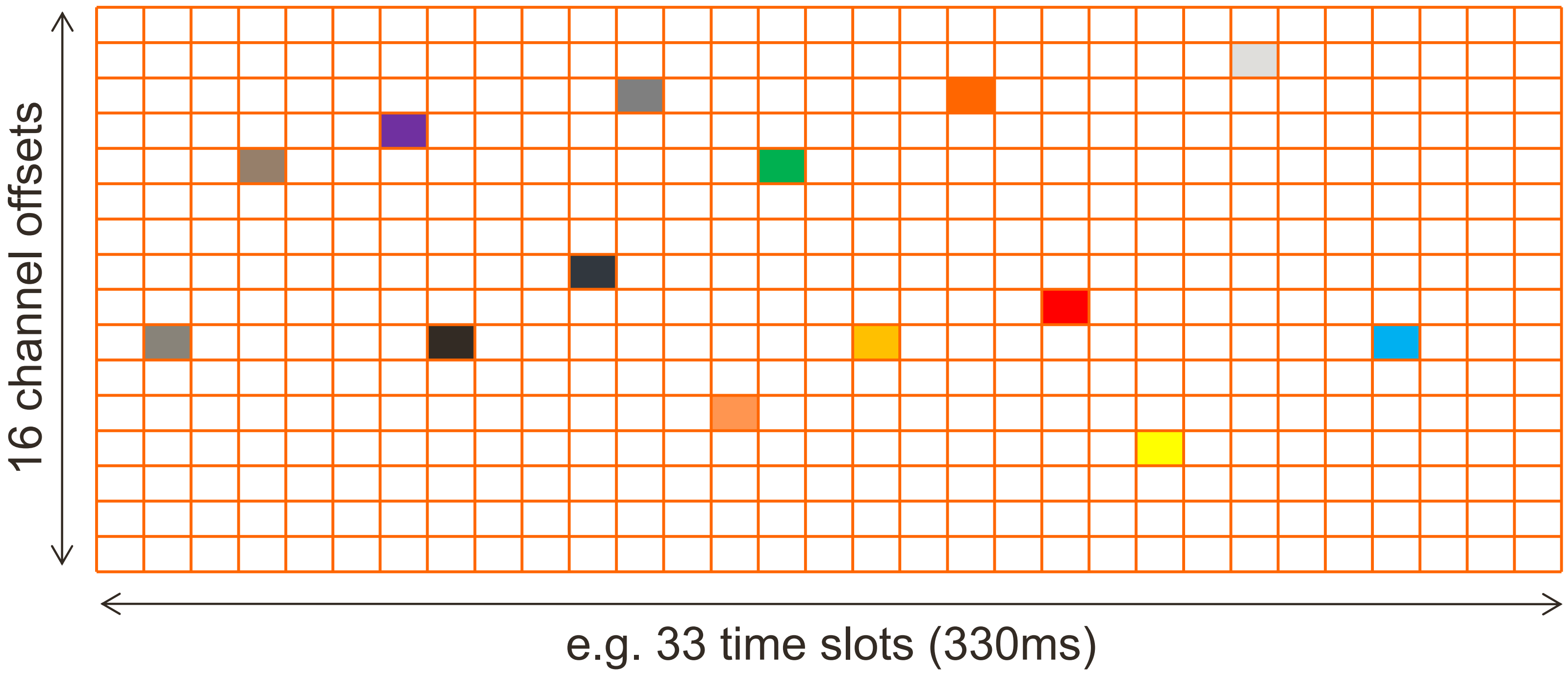
= transmitter on

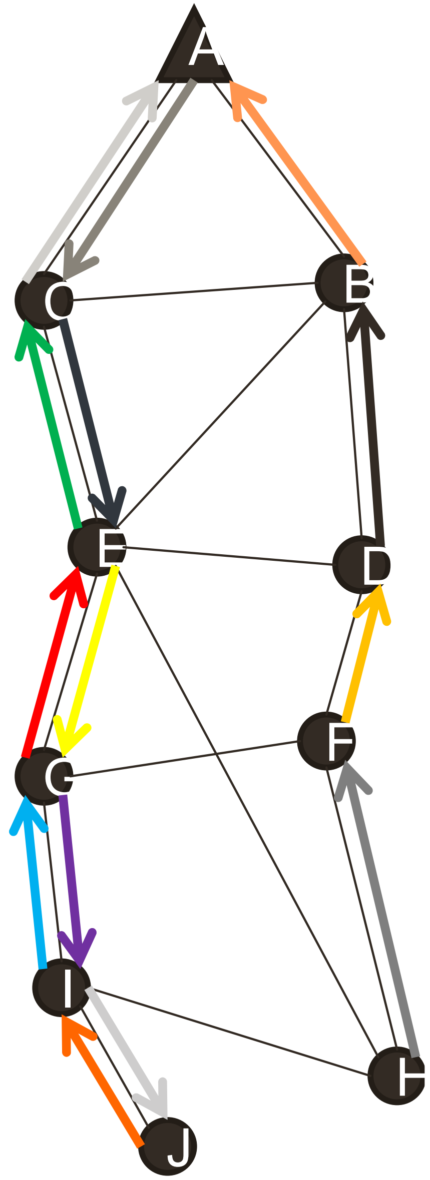
= receiver on

PA - Slotted Structure

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

- Cells are assigned according to application requirements



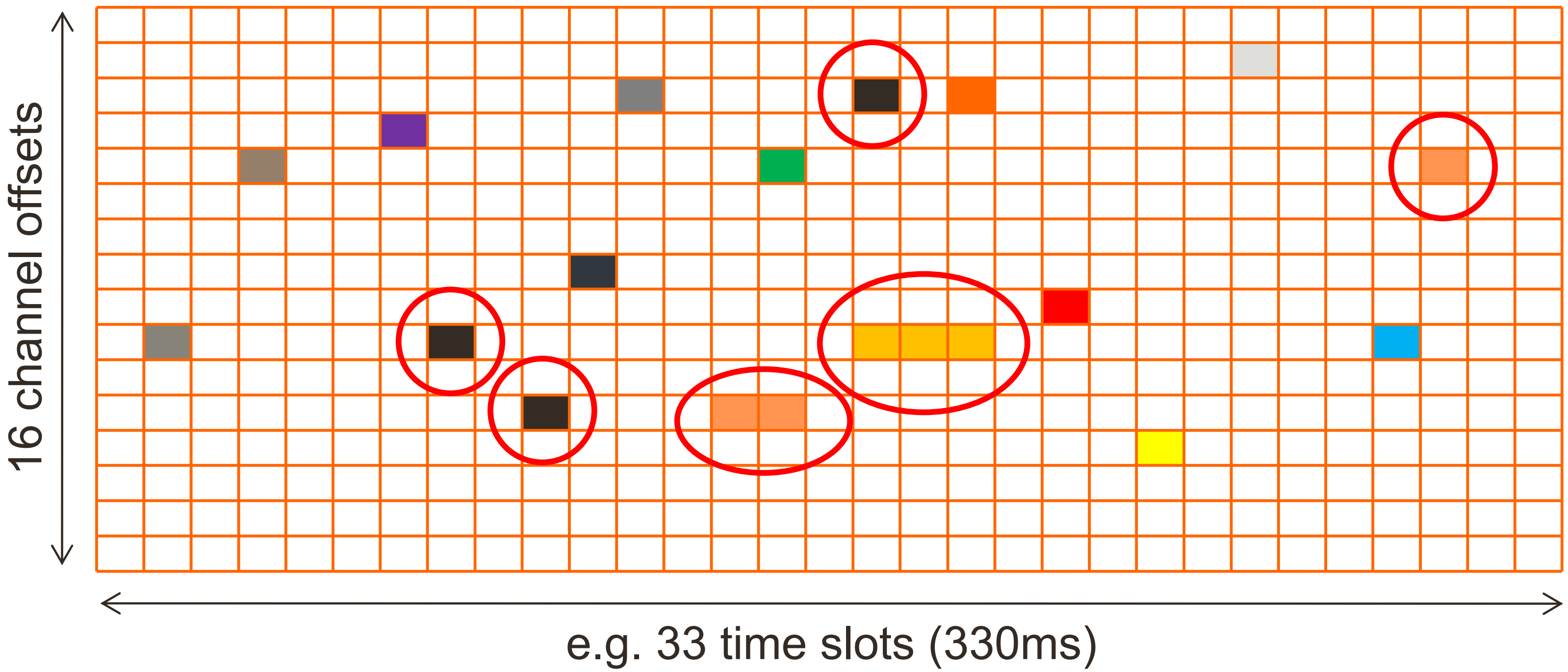


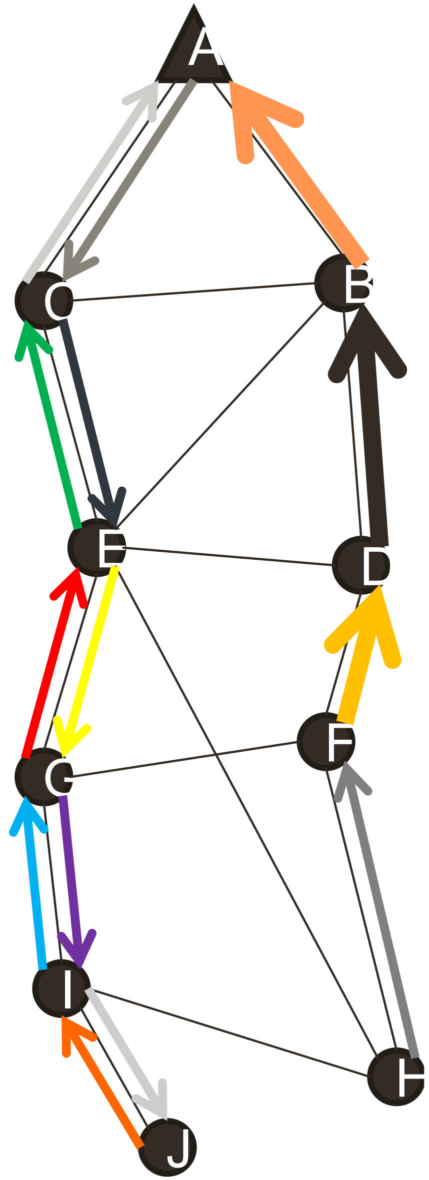
TRAN	UDP, TCP
routing	RPL
NET	IPv6
adaptation	6LoWPAN
MAC	IEEE802.15.4e
PHY	IEEE802.15.4

PA - Trade-Off [1/3]

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

  …and energy consumption



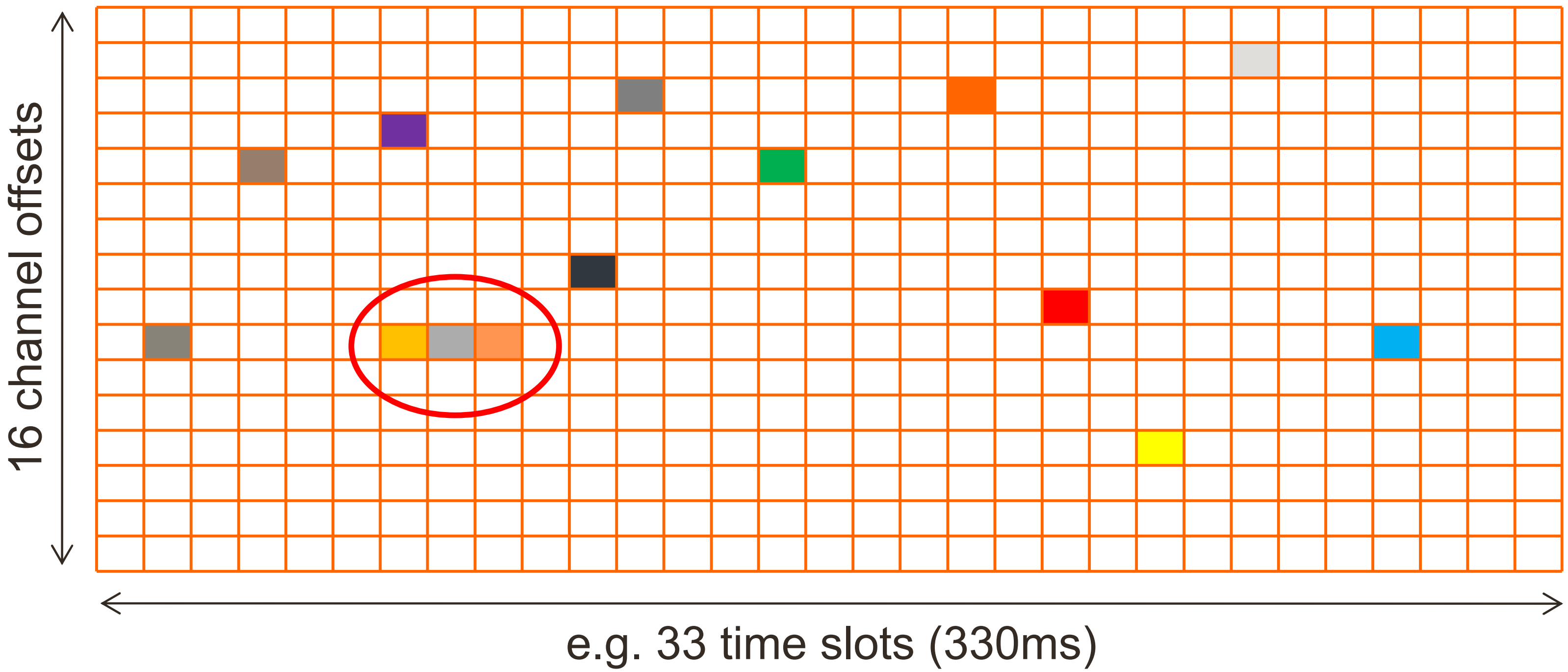


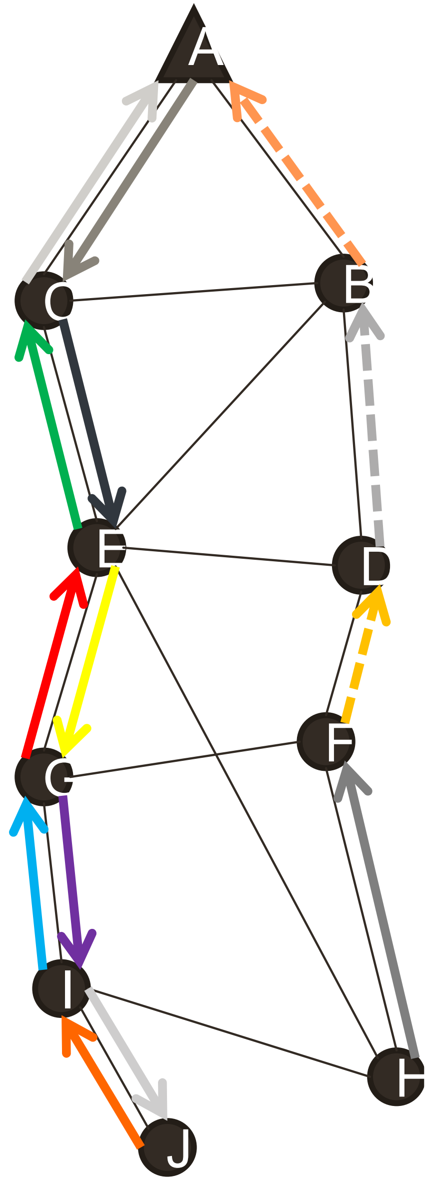
TRAN	UDP, TCP
routing	RPL
NET	IPv6
adaptation	6LoWPAN
MAC	IEEE802.15.4e
PHY	IEEE802.15.4

PA - Trade-Off [2/3]

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

  …and energy consumption



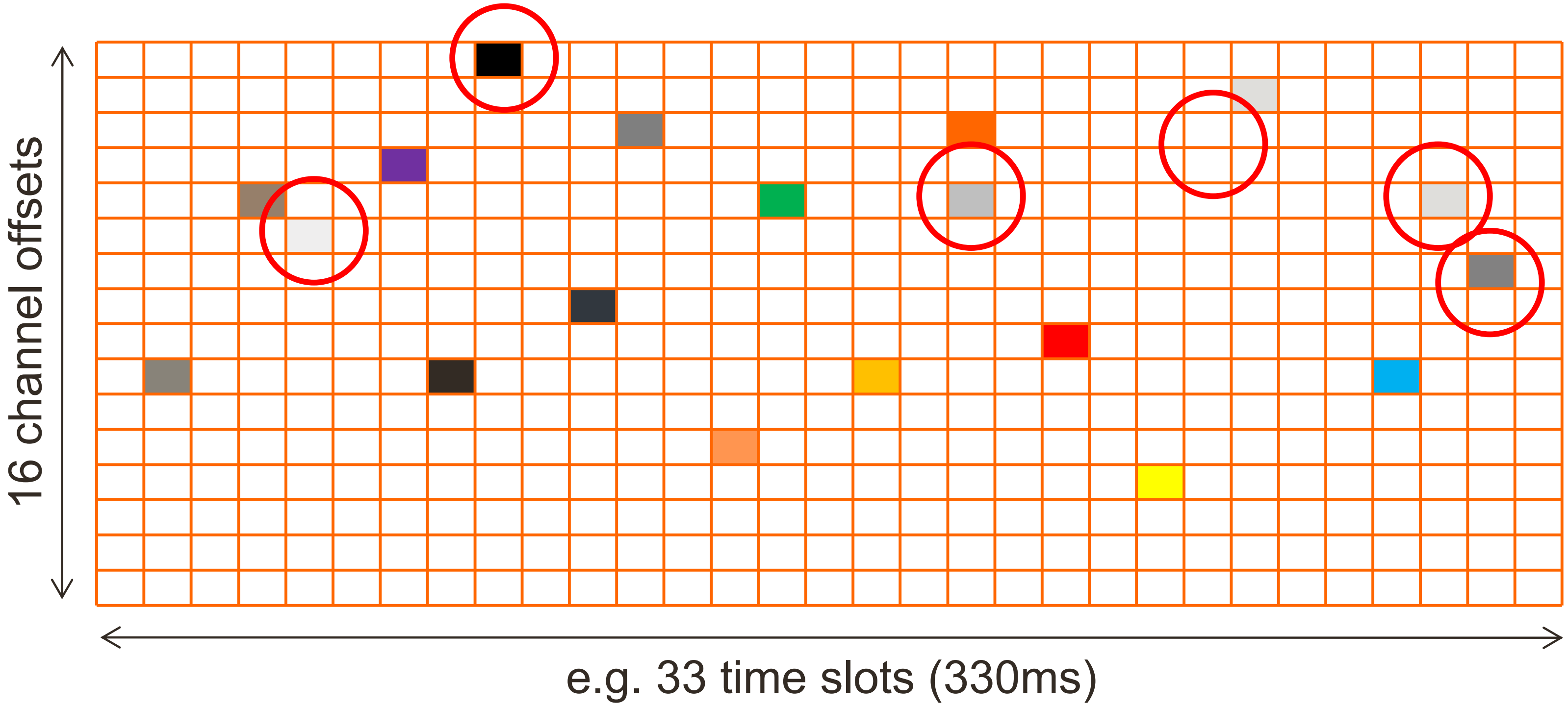


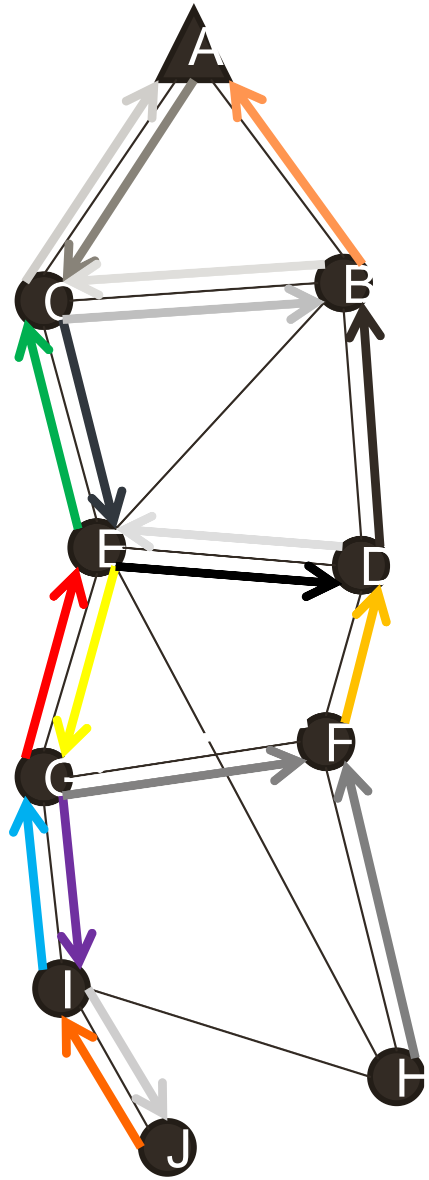
TRAN	UDP, TCP
routing	RPL
NET	IPv6
adaptation	6LoWPAN
MAC	IEEE802.15.4e
PHY	IEEE802.15.4

PA - Trade-Off [3/3]

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

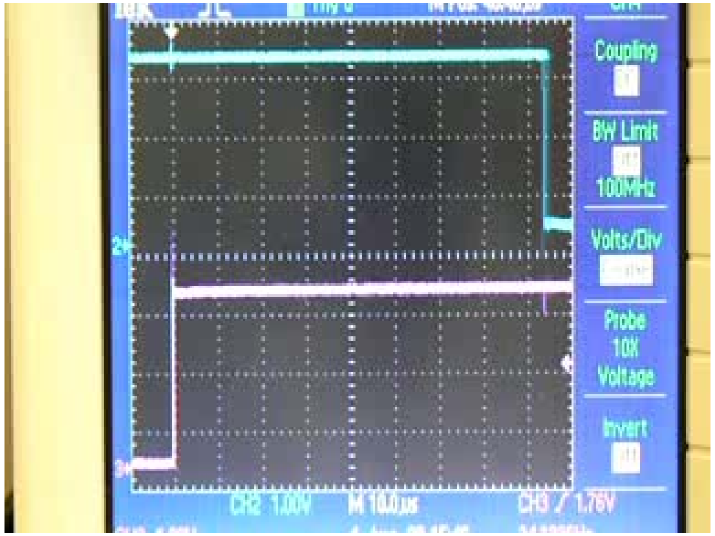
  …and energy consumption





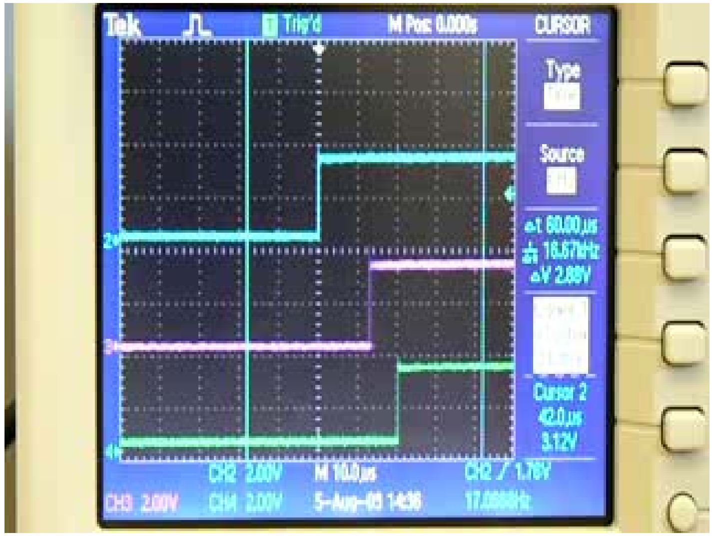
PA - Synchronization

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



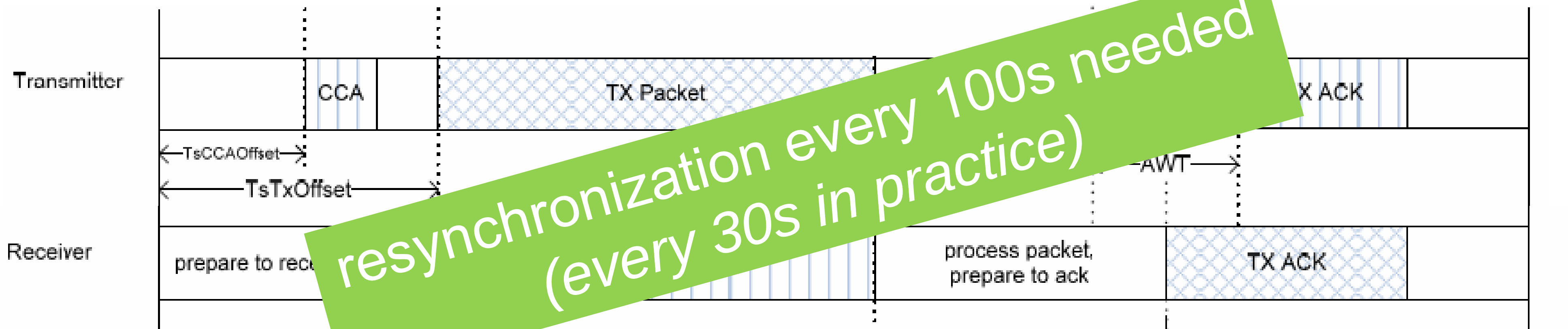
clocks drift

(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)

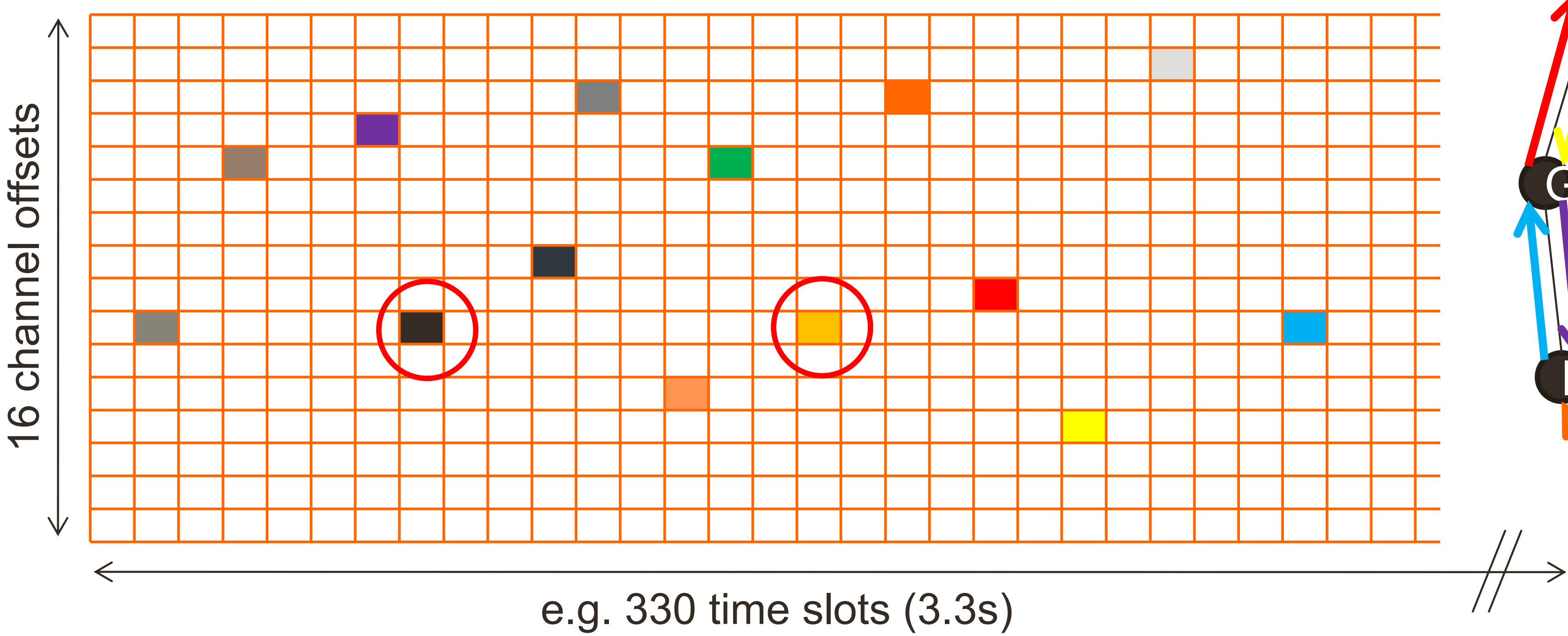
- If I only want to keep synchronization *(theoretical lower limit)*
  - 7.656ms from a time budget of 171 hours→ I can resync. 80×10^6 times
  - 76 years of lifetime (» battery shelf-life)

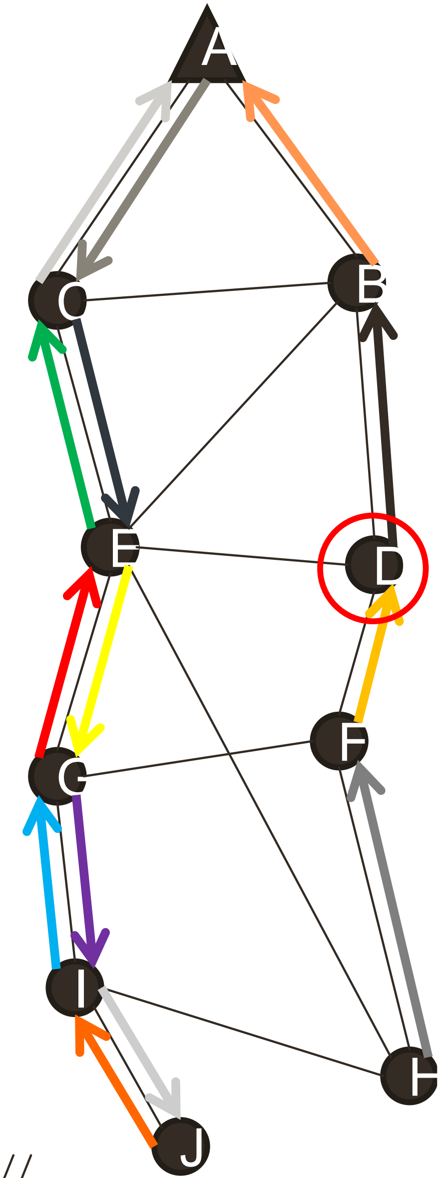
- A duty cycle of 1% → 2 years of lifetime

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

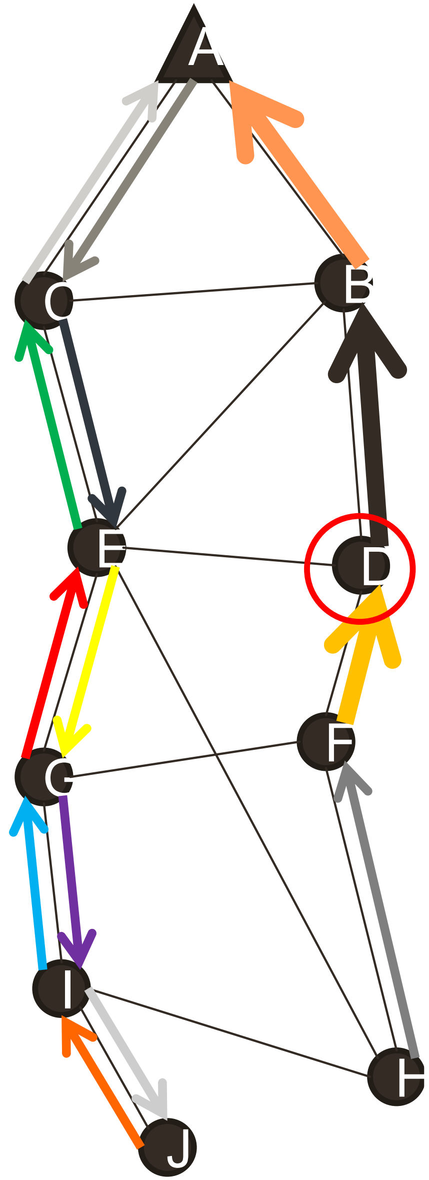


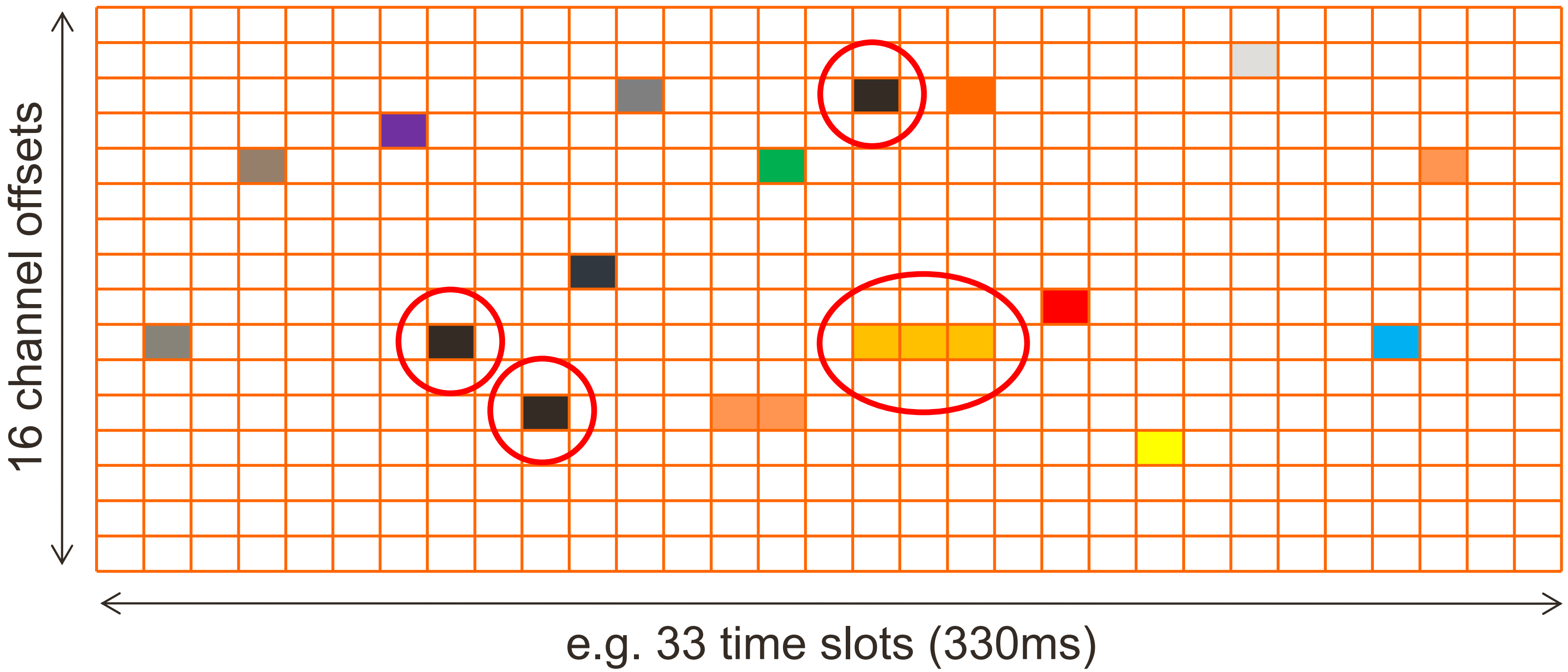


TRAN	UDP, TCP
routing	RPL
NET	IPv6
adaptation	6LoWPAN
MAC	IEEE802.15.4e
PHY	IEEE802.15.4

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

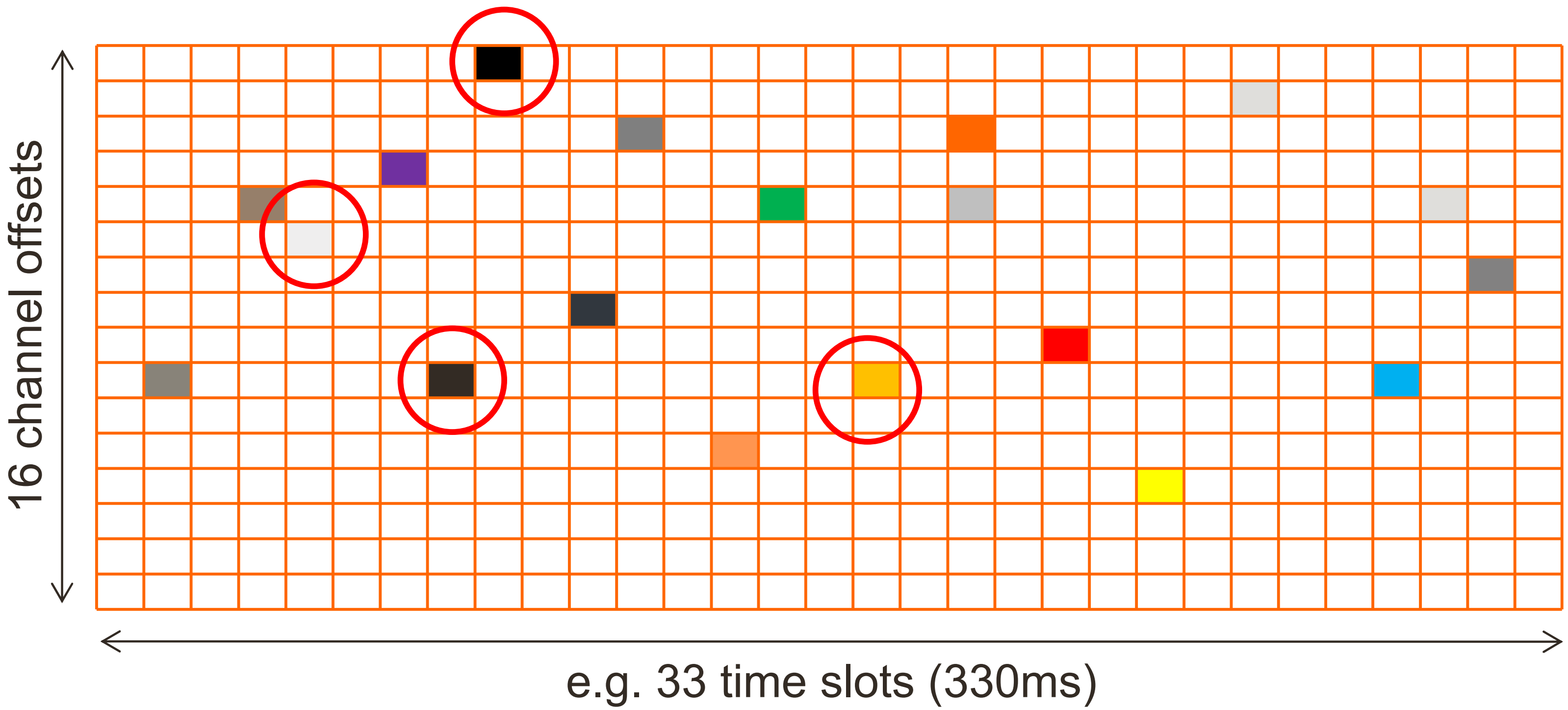


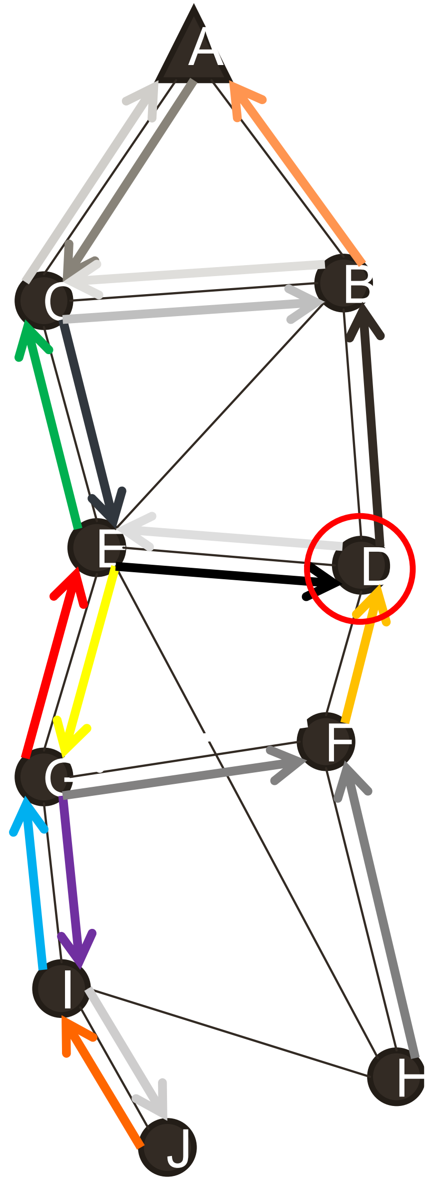


TRAN	UDP, TCP
routing	RPL
NET	IPv6
adaptation	6LoWPAN
MAC	IEEE802.15.4e
PHY	IEEE802.15.4

PA – Lifetime

- Looking at node D
  - “normal” case
  - Triple data rate
  - Double every link
    - 2 receptions, 2 transmissions (30ms) every 3.3 seconds
    - .9% duty cycle → 2 years lifetime





3.4.2

IETF-Pertinent M2M Standards

IETF – Overview

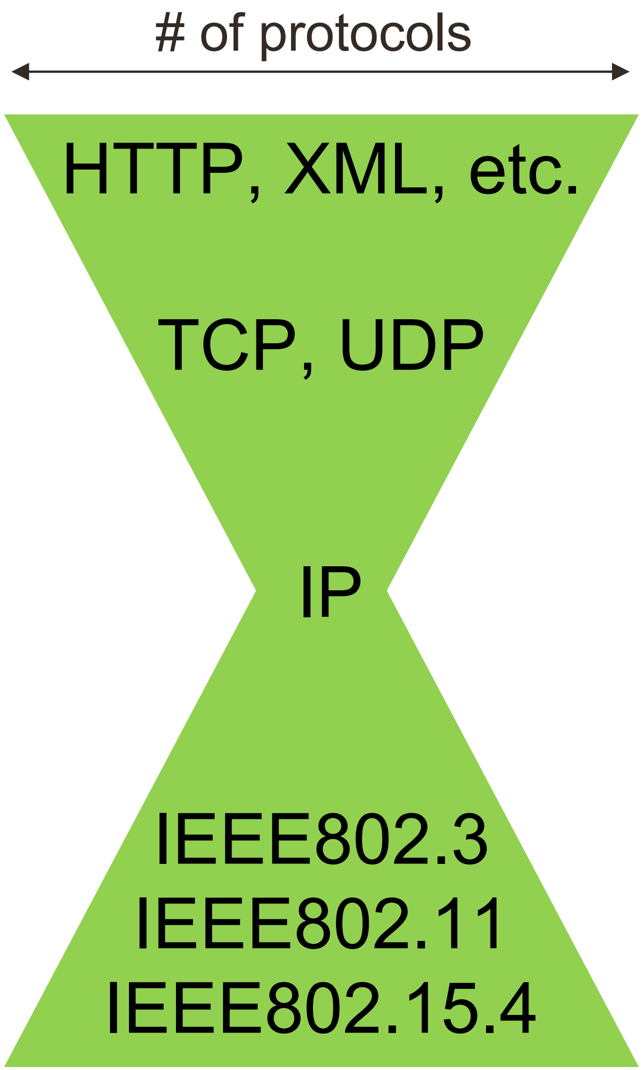
- Internet Engineering Task Force:
  - not approved by the US government; composed of individuals, not companies
  - quoting the spirit: “We reject kings, presidents and voting. We believe in rough consensus and running code.” D. Clark, 1992
  - meets 3 times a year, and gathers an average of 1,300 individuals
  - 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 M2M:
  - 6LoWPAN (IPv6 over Low power WPAN)
  - ROLL (Routing Over Low power and Lossy networks)

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

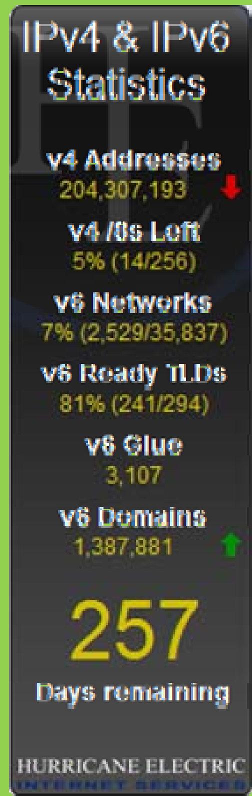
IPv6 address space

$2^{128} = 3.4 \times 10^{38}$ addresses

IPv4 address space

$2^{32} = 4.3 \times 10^{9}$ addresses

(10^{-12} pixels on a side)



Friday, May 27, 2011

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 gets an address with the format:

```
pppp:pppp:pppp:pppp:pppp:pppp:pppp:pppp:iiii:iiii:iiii:iiii:iiii:iiii:iiii:iiii
```

64-bit prefix
(provided by ISP)

64-bit Interface Identifier
(EUI64)

```
⊞ Frame 232: 85 bytes on wire (680 bits), 85 bytes captured (680 bits)
⊞ Ethernet II, Src: 42:fb:9f:81:5a:81 (42:fb:9f:81:5a:81), Dst: af:ab:ac:ad:ae:af (af:ab:ac:ad:ae:af)
⊞ IEEE 802.15.4 Data, Dst: 14:15:92:09:02:2b:00:51, Src: 14:15:92:0b:03:01:00:28
⊞ 6LoWPAN
⊟ Internet Protocol Version 6
  ⊞ 0110 .... = Version: 6
  ⊞ .... 0000 0000 .... .... .... .... .... = Traffic class: 0x00000000
    .... .... .... 0000 0000 0000 0000 0000 = Flowlabel: 0x00000000
    Payload length: 12
    Next header: UDP (0x11)
    Hop limit: 126
    Source: 2001:470:1f04:e0d::2 (2001:470:1f04:e0d::2)
    Destination: 2001:470:846d:1:1415:9209:22b:51 (2001:470:846d:1:1415:9209:22b:51)
⊞ User Datagram Protocol, Src Port: us-cli (8082), Dst Port: asdis (2192)
⊞ Data (4 bytes)
```

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

Internet Protocol (IP) version 6

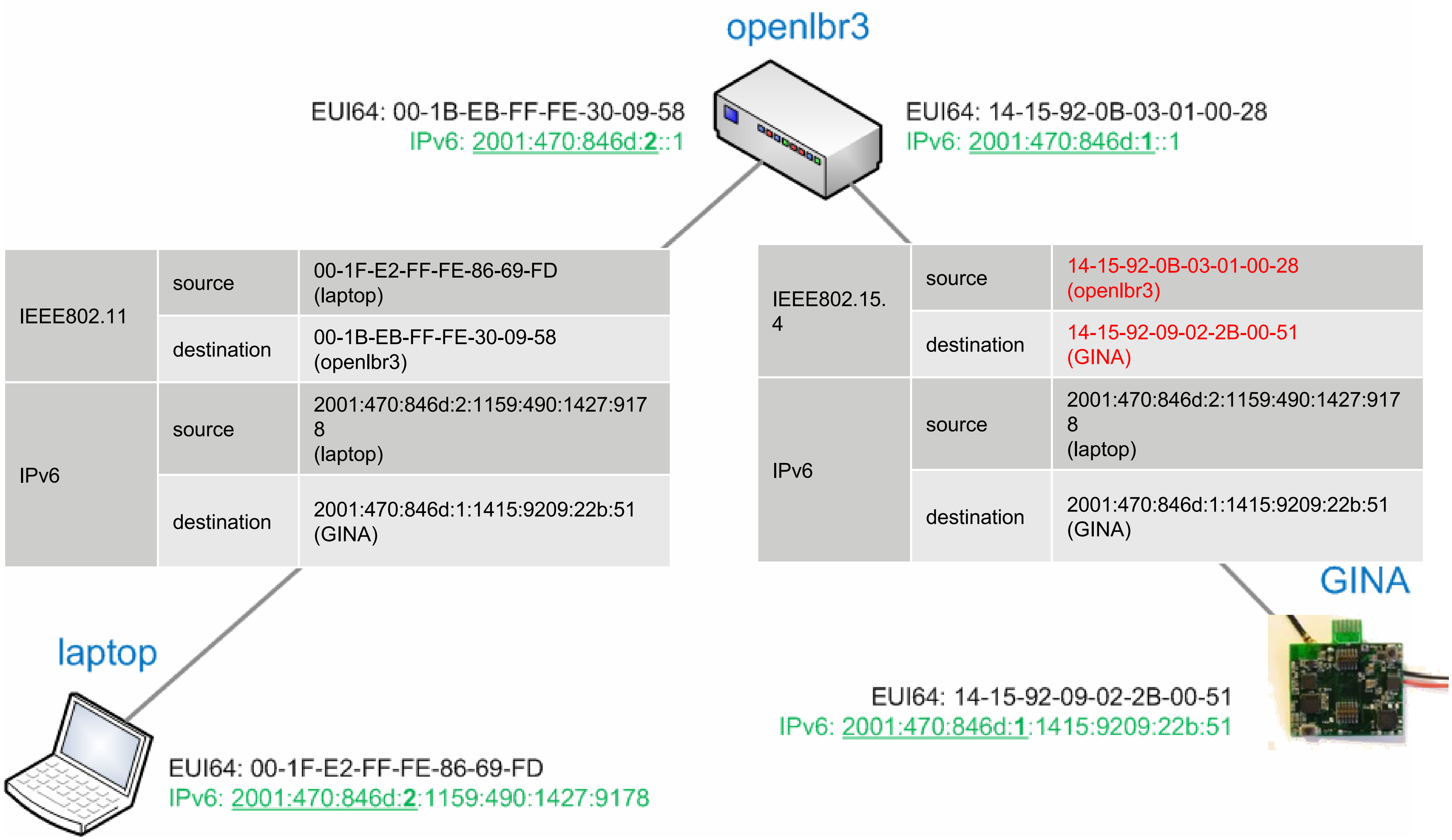
- Header Format

```
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|Version| Traffic Class |           Flow Label                  |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|         Payload Length        |  Next Header  |   Hop Limit   |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
+                                                               +
|                                                               |
+                         Source Address                        +
|                                                               |
+                                                               +
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
+                                                               +
|                                                               |
+                      Destination Address                      +
|                                                               |
+                                                               +
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

- Source and destination addresses… again?
  - Yes, because packets are sent over multiple hops
  - IEEE802.15.4 are changed at every hop
    - source address: identifies previous hop
    - destination address: identifies next hop
  - IPv6 are never changed as a packet travels over a multi-hop path
    - source address: initial sender
    - Destination address: final destination

Internet Protocol (IP) version 6

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

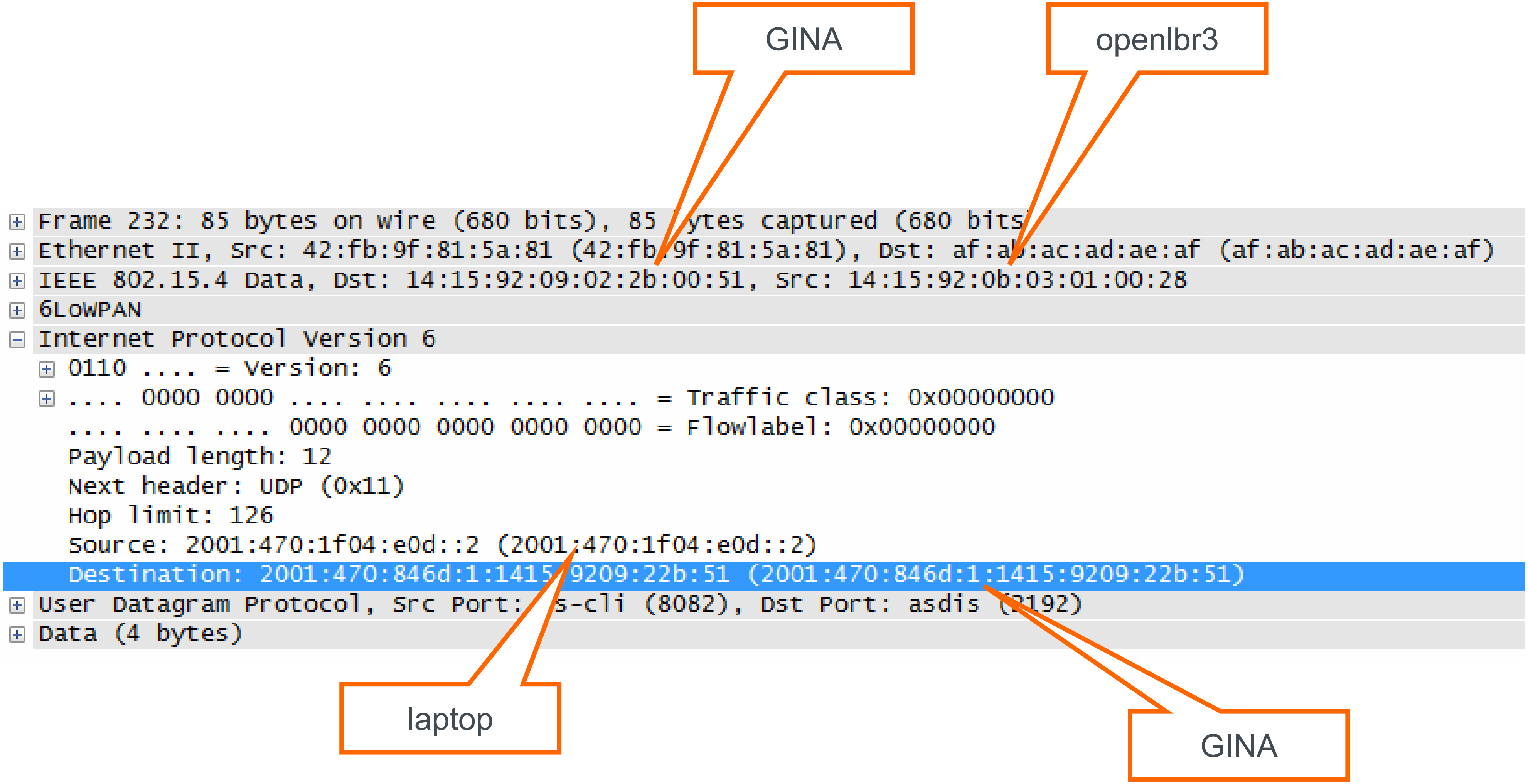


IEEE802.11	source	00-1F-E2-FF-FE-86-69-FD (laptop)
	destination	00-1B-EB-FF-FE-30-09-58 (openlbr3)
IPv6	source	2001:470:846d:2:1159:490:1427:9178 (laptop)
	destination	2001:470:846d:1:1415:9209:22b:51 (GINA)

IEEE802.15.4	source	14-15-92-0B-03-01-00-28 (openlbr3)
	destination	14-15-92-09-02-2B-00-51 (GINA)
IPv6	source	2001:470:846d:2:1159:490:1427:9178 (laptop)
	destination	2001:470:846d:1:1415:9209:22b:51 (GINA)

Internet Protocol (IP) version 6

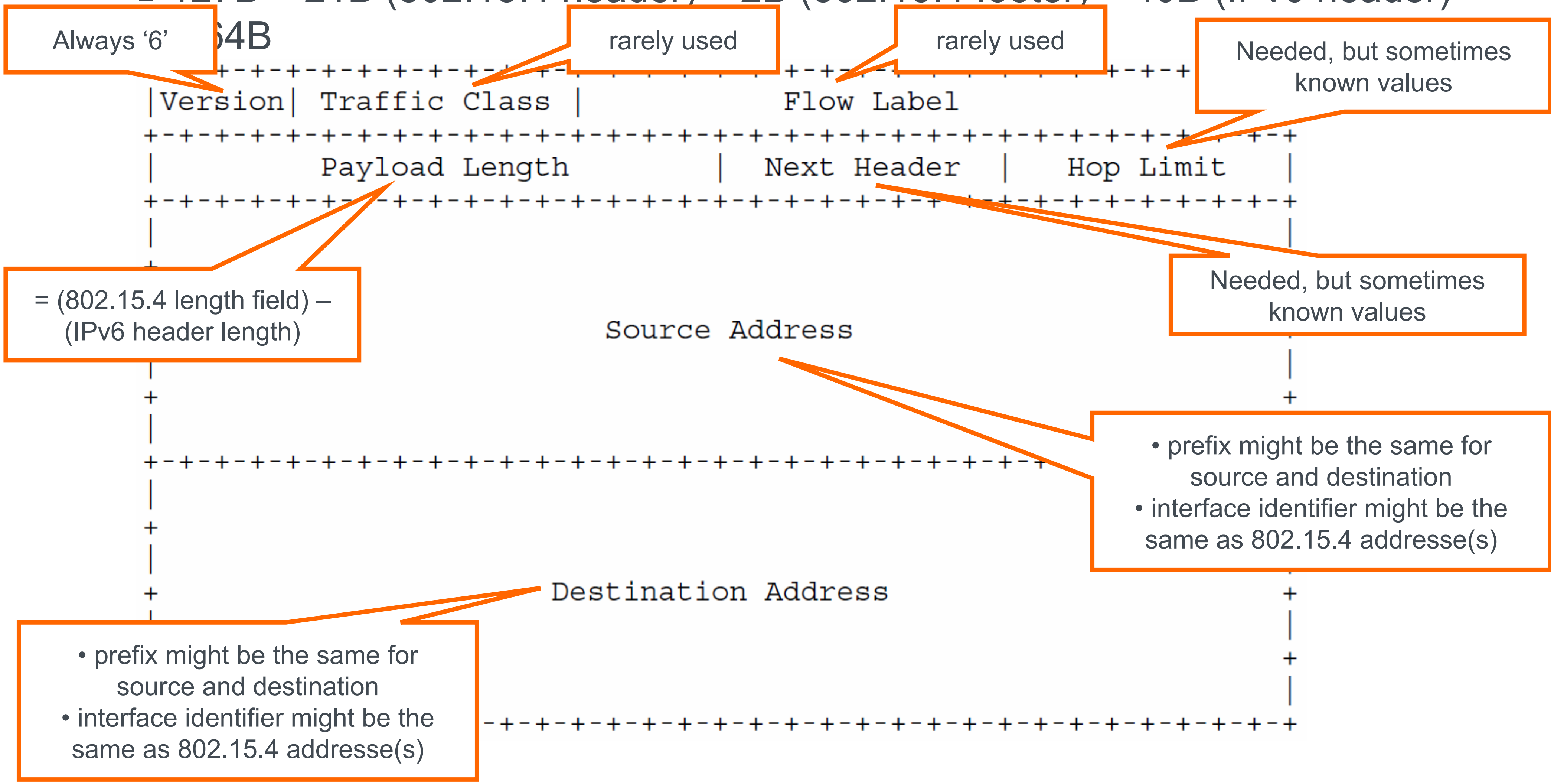
TRAN	UDP, TCP
routing	RPL
NET	IPv6
adaptation	6LoWPAN
MAC	IEEE802.15.4e
PHY	IEEE802.15.4



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

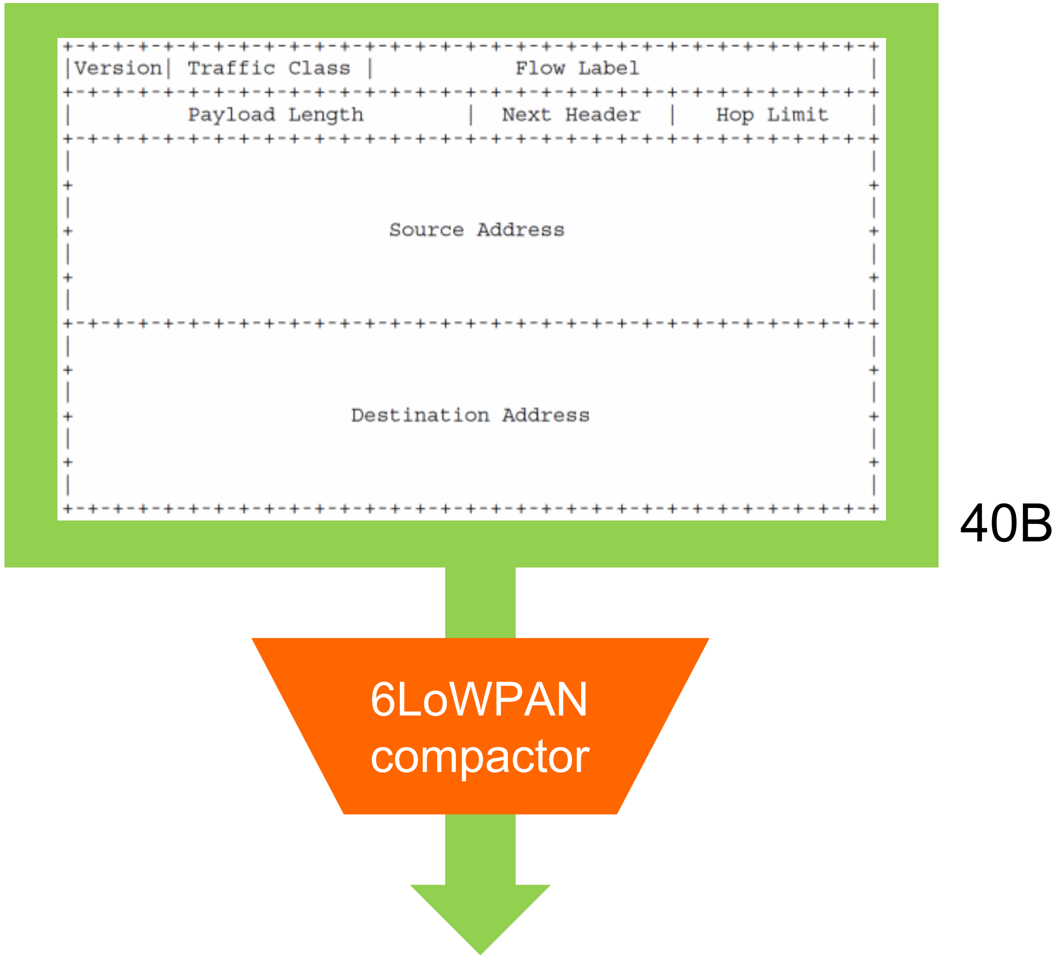
Internet Protocol (IP) version 6

- Header Format
  - 127B – 21B (802.15.4 header) – 2B (802.15.4 footer) – 40B (IPv6 header) 64B



IETF 6LoWPAN

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



flags indicating what was compressed +
compressed fields +
uncompressible fields

4 to 36 bytes

IETF 6LoWPAN

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

```
⊟ IEEE 802.15.4 Data, Dst: 14:15:92:09:02:2b:00:51, Src: 14:15:92:0b:03:01:00:83
  ⊞ Frame Control Field: Data (0xcc61)
    Sequence Number: 13
    Destination PAN: 0xbaad
    Destination: 14:15:92:09:02:2b:00:51 (14:15:92:09:02:2b:00:51)
    Source: 14:15:92:0b:03:01:00:83 (14:15:92:0b:03:01:00:83)
    FCS: 0xe43d (Correct)
⊟ 6LoWPAN
  ⊟ IPHC Header
      011. .... = Pattern: IP header compression (3)
      ...1 1... .... .... = Traffic class and flow label: Version, traffic class, and flow label compressed (0x0003)
      .... .0.. .... .... = Next header: Inline
      .... ..00 .... .... = Hop limit: Inline (0x0000)
      .... .... 0... .... = Context identifier extension: False
      .... .... .0.. .... = Source address compression: Stateless
      .... .... ..11 .... = Source address mode: Compressed (0x0003)
      .... .... .... 0... = Multicast address compression: False
      .... .... .... .0.. = Destination address compression: Stateless
      .... .... .... ..11 = Destination address mode: Compressed (0x0003)
    Next header: UDP (0x11)
    Hop limit: 1
    Source: fe80::1615:920b:301:83 (fe80::1615:920b:301:83)
    Destination: fe80::1615:9209:22b:51 (fe80::1615:9209:22b:51)
⊟ Internet Protocol Version 6
  ⊞ 0110 .... = Version: 6
  ⊞ .... 0000 0000 .... .... .... .... .... = Traffic class: 0x000
    .... .... .... 0000 0000 0000 0000 0000 = Flowlabel: 0x0000000
    Payload length: 9
    Next header: UDP (0x11)
    Hop limit: 1
    Source: fe80::1615:920b:301:83 (fe80::1615:920b:301:83)
    Destination: fe80::1615:9209:22b:51 (fe80::1615:9209:22b:51)
```

Favorable case: single hop between neighbors

- source and destination prefixes are the same
- IPv6 source interface identifier is the same as IEEE802.15.4 source
- IPv6 destinatoin interface identifier is the same as IEEE802.15.4 destination

➔ Header compacted from 40B to 4B

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

IETF 6LoWPAN

```
⊟ IEEE 802.15.4 Data, Dst: 14:15:92:09:02:2b:00:51, Src: 14:15:92:0b:03:01:00:28
  ⊞ Frame Control Field: Data (0xcc61)
    Sequence Number: 62
    Destination PAN: 0xbaad
    Destination: 14:15:92:09:02:2b:00:51 (14:15:92:09:02:2b:00:51)
    Source: 14:15:92:0b:03:01:00:28 (14:15:92:0b:03:01:00:28)
    FCS: 0x3ba6 (Correct)
⊟ 6LoWPAN
  ⊞ IPHC Header
    Next header: UDP (0x11)
    Hop limit: 126
    Source: 2001:470:1f04:e0d::2 (2001:470:1f04:e0d::2)
    Destination: 2001:470:846d:1:1415:9209:22b:51 (2001:470:846d:1:1415:9209:22b:51)
⊟ Internet Protocol Version 6
  ⊞ 0110 .... = Version: 6
  ⊞ .... 0000 0000 .... .... .... .... .... = Traffic class: 0x00000000
    .... .... .... 0000 0000 0000 0000 0000 = Flowlabel: 0x00000000
    Payload length: 12
    Next header: UDP (0x11)
    Hop limit: 126
    Source: 2001:470:1f04:e0d::2 (2001:470:1f04:e0d::2)
    Destination: 2001:470:846d:1:1415:9209:22b:51 (2001:470:846d:1:1415:9209:22b:51)
```

Unfavorable case: multi-hop packet from Internet
• source and destination prefixes are the different
• IPv6 source interface identifier is different from IEEE802.15.4 source
• IPv6 destination interface identifier is different from IEEE802.15.4 destination
➔ Header compacted from 40B to 36B

IETF 6LoWPAN

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

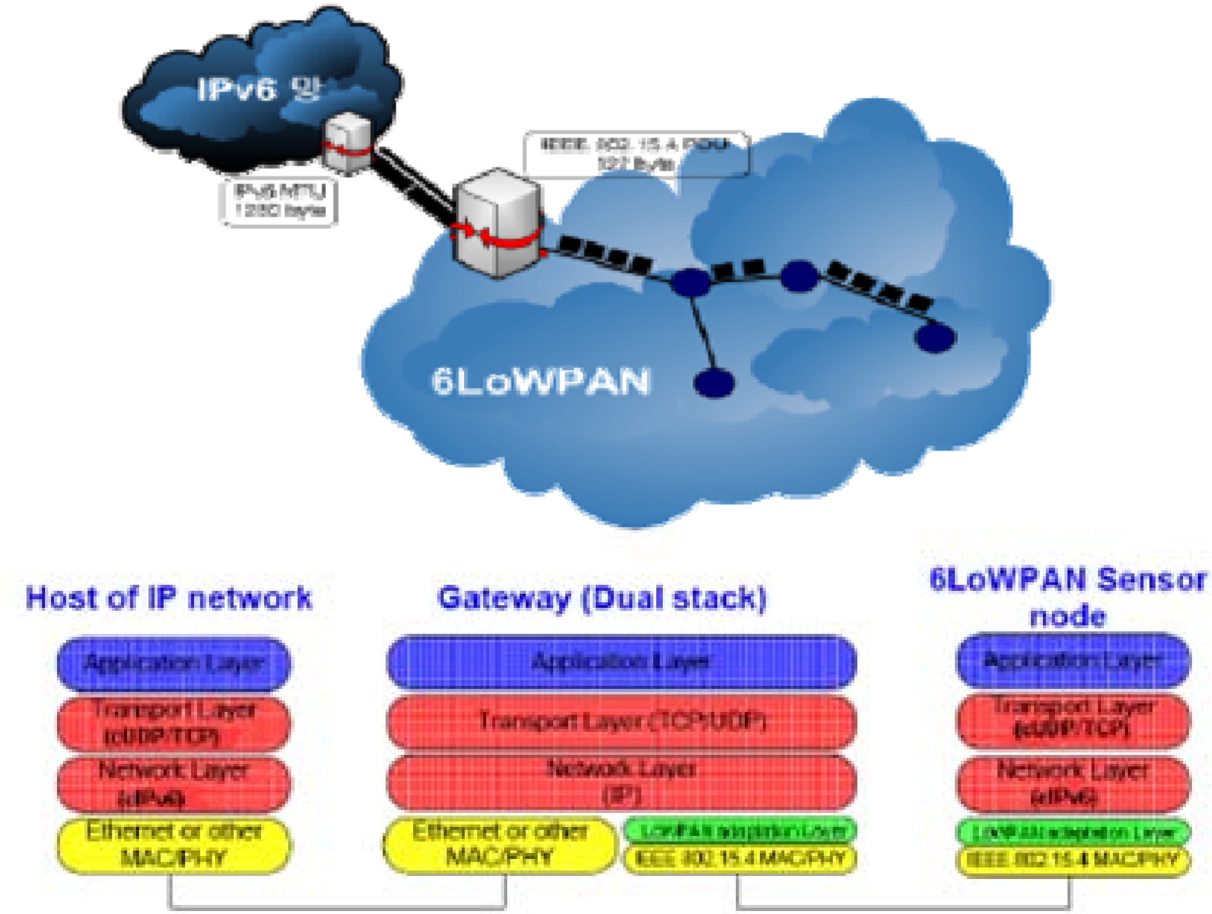
- 6LoWPAN has thus the following key properties:
  - IPv6 for very low power embedded devices using IEEE 802.15.4
  - provision of neighborhood discovery protocol
  - header compression with up to 80% compression rate
  - packet fragmentation (1260 byte IPv6 frames -> 127 byte 802.15.4 frames)
  - direct 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

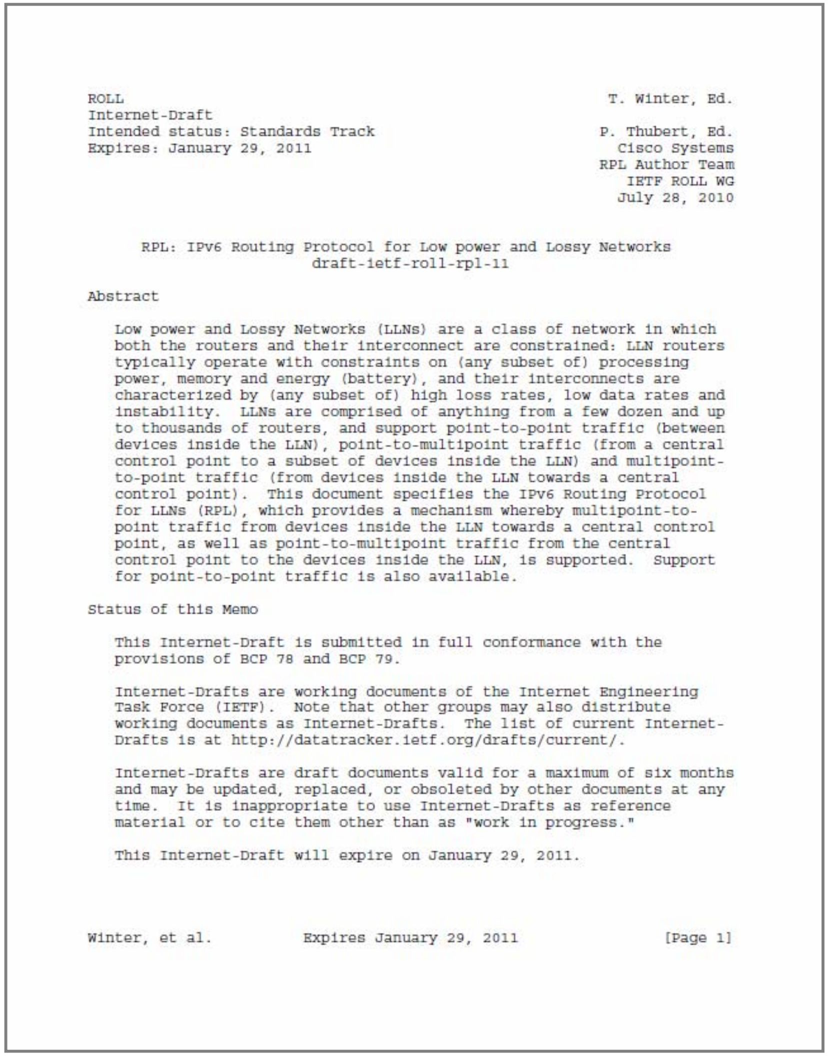
- Typical architecture:



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

IETF RPL – Status

- IETF WG “Routing Over Low power and Lossy networks”
  - Design a routing protocol for Wireless Mesh Network
  - Revision 11 dated 07/28/2010
  - Final stage of standardization



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."

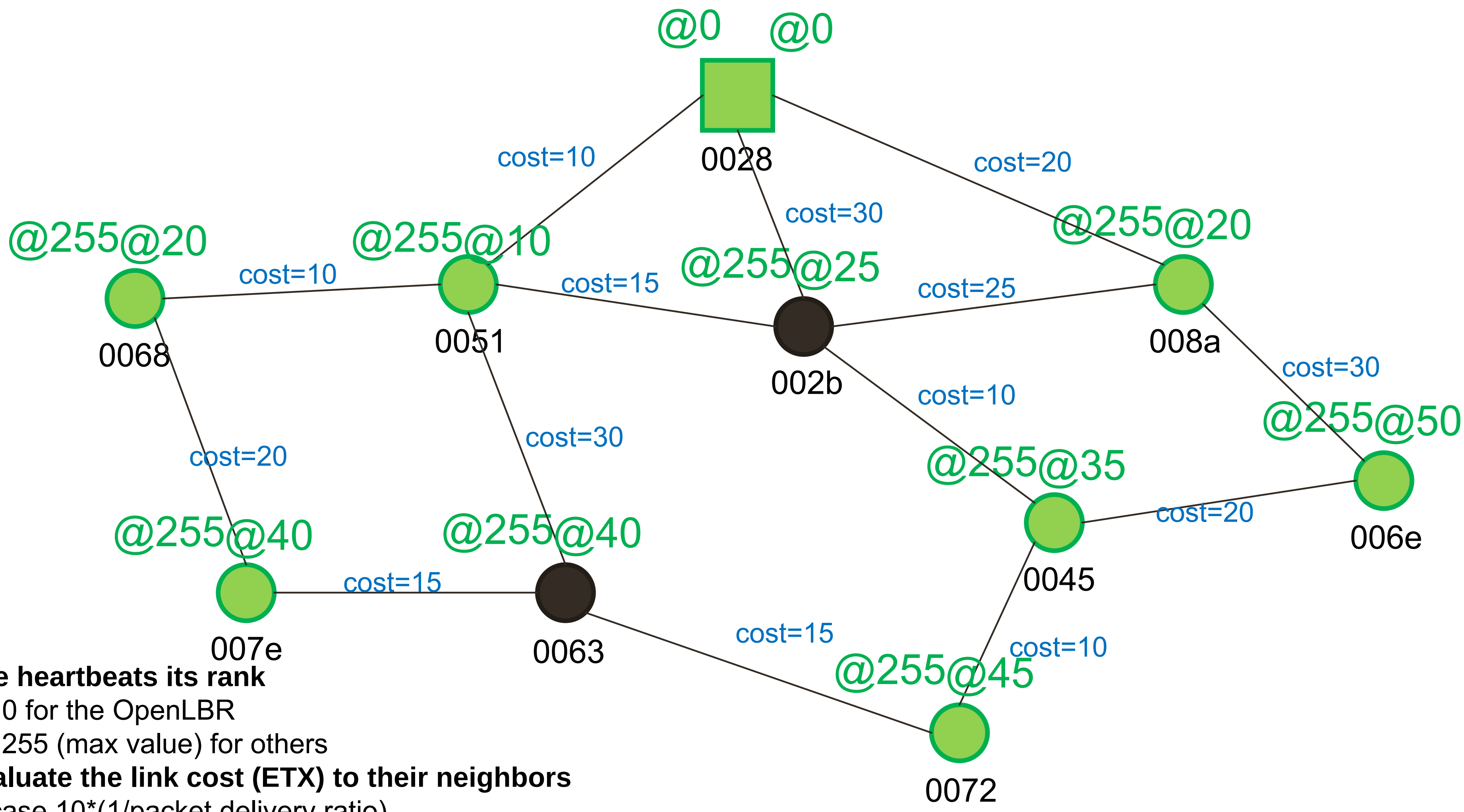
This Internet-Draft will expire on January 29, 2011.

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

- Gradient Routing
  - Nodes acquire a “rank” based on the distance to the collecting node
  - Message follow the gradient of ranks

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

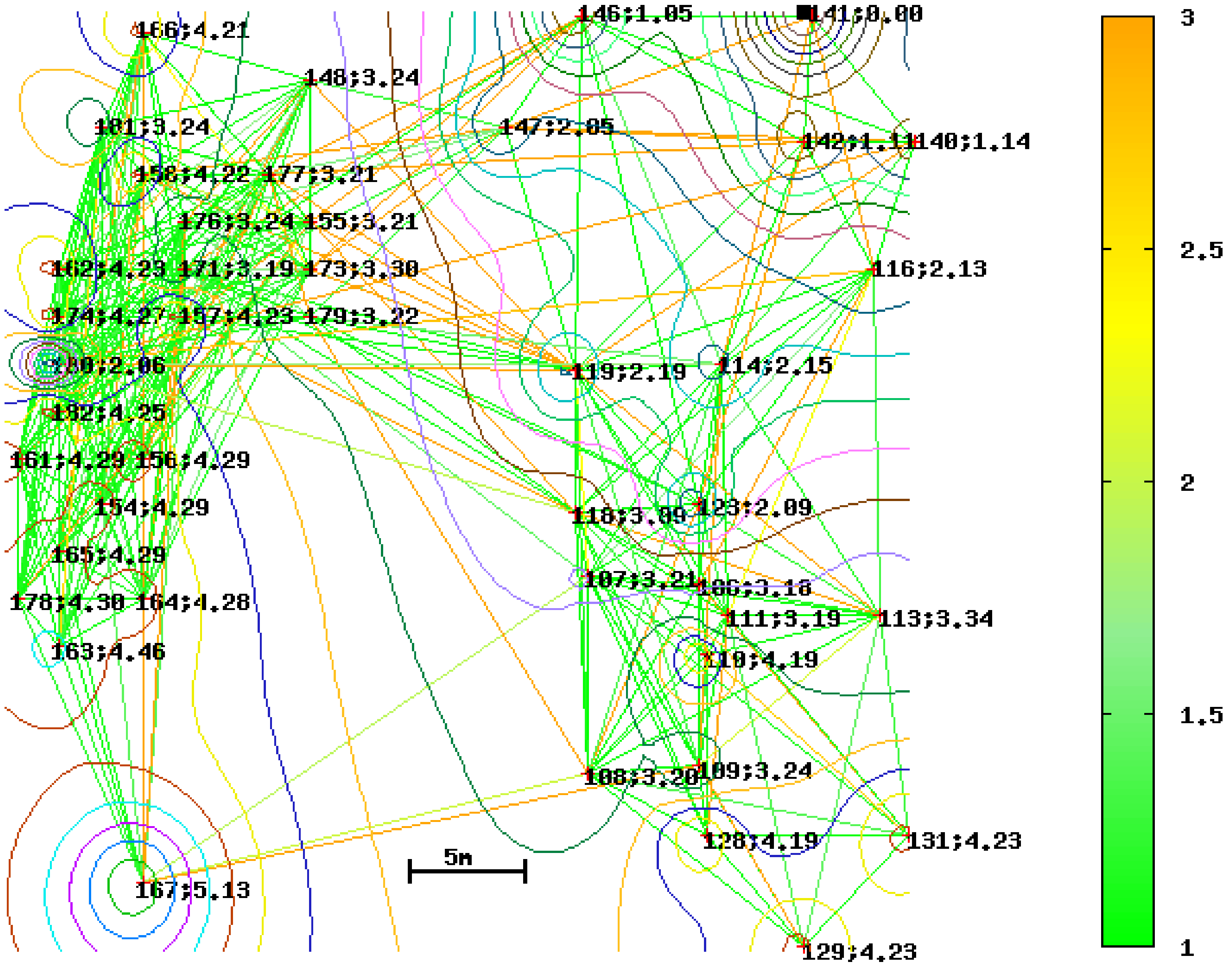
2. Nodes evaluate the link cost (ETX) to their neighbors
- In our case 10*(1/packet delivery ratio)
- Perfect link: cost=10
- Link with 50% loss: cost=20

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

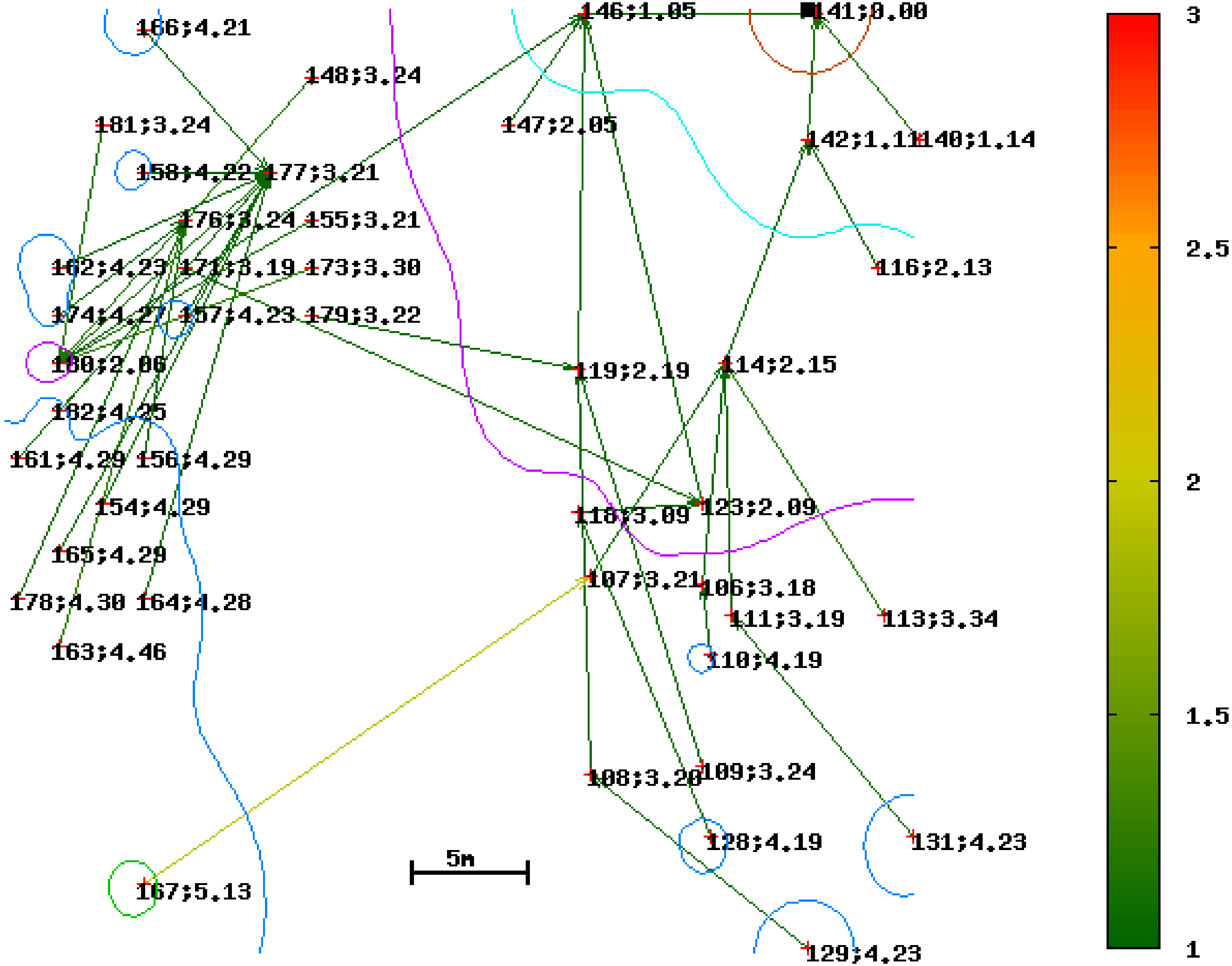
IETF RPL – Gradient Routing

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



IETF RPL – Gradient Routing

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

IETF RPL – Packet Format

- Not complete implementation
- RPL payload as ICMPv6 type 155

For all neighbors to hear

All nodes send RPL packets

```
⊞ IEEE 802.15.4 Data, Dst: Broadcast, Src: 14:15:92:0b:03:01:00:29

⊟ Internet Protocol Version 6
  ⊞ 0110 .... = Version: 6
  ⊞ .... 0000 0000 .... .... .... .... .... = Traffic class: 0x00000000
    .... .... .... 0000 0000 0000 0000 0000 = Flowlabel: 0x00000000
    Payload length: 9
    Next header: ICMPv6 (0x3a)
    Hop limit: 64
    Source: 2001:470:846d:1:1415:920b:301:29 (2001:470:846d:1:1415:920b:301:29)
    Destination: ff02::2 (ff02::2)
⊟ Internet Control Message Protocol v6
    Type: 155 (Unknown)
    Code: 1 (Unknown)
    Checksum: 0xf24f [correct]
⊟ Data (1 byte)
    Data: 0f
    [Length: 1]
```

"All routers" IPv6 multicast address

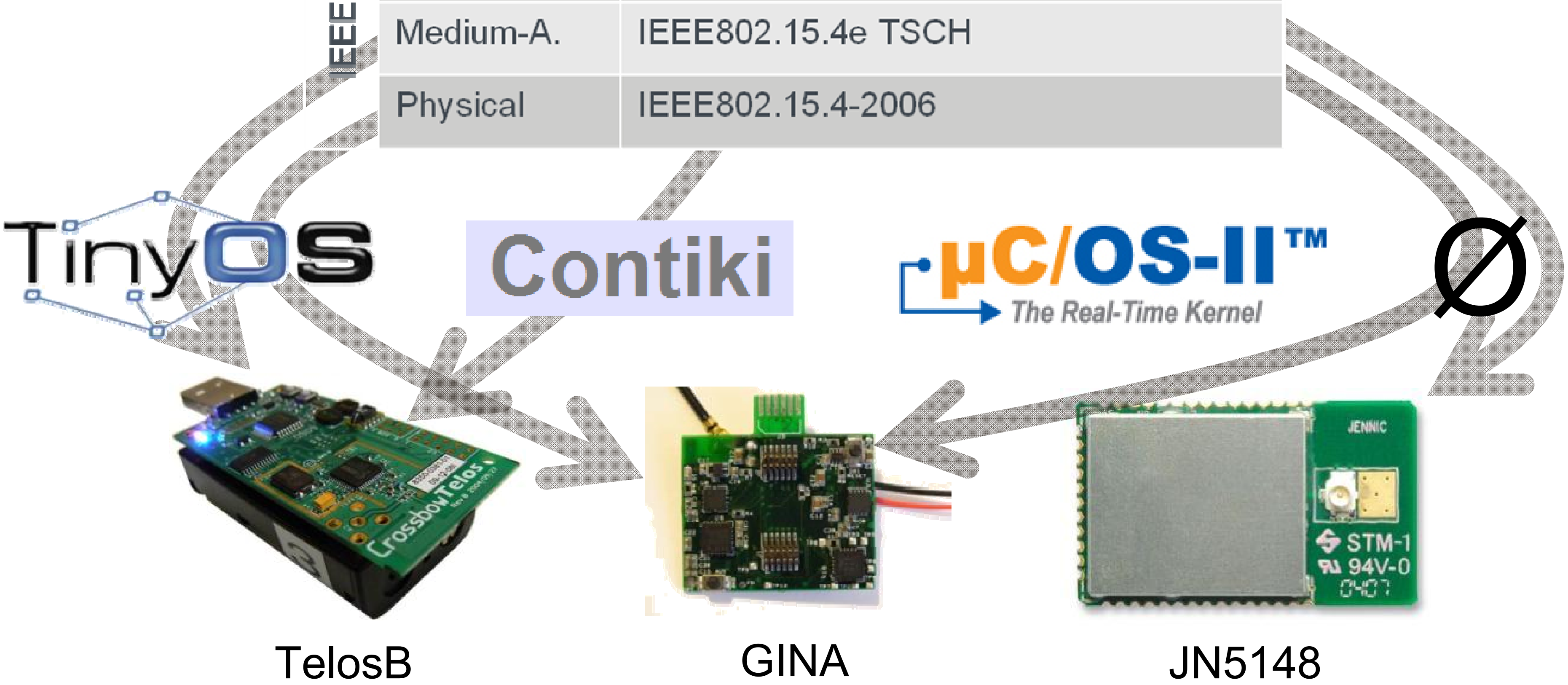
This node is at rank 0x0f=15

3.4.3

Implementation – Berkeley OpenWSN

OpenWSN - Motivation

IETF	Application	HTTP, XML, sensor.network.com, etc.
	Transport	UDP, TCP
	Network	RPL
	Adaptation	6LoWPAN IPHC-7
IEEE	Reservation	nRES / uRES
	Medium-A.	IEEE802.15.4e TSCH
	Physical	IEEE802.15.4-2006



Berkeley's OpenWSN Proj...

openwsn.berkeley.edu

OpenWSN

Implementing the Internet of Things

Search

Login | About Trac | Preferences | Help/Guide

Wiki | Timeline | Roadmap | Browse Source | View Tickets | Search

Start Page | Index | History | Last Change

OpenWSN

*The OpenWSN project serves as a repository for **open-source implementations** of **protocol stacks** based on Internet of Things **standards**, using a **variety of hardware and software platforms**.*

Motivation

The Internet of Things enables great applications, such as energy-aware homes or real-time asset tracking. With these networks gaining maturity, standardization bodies have started to work on standardizing how these networks of tiny devices communicate.

The goal of the OpenWSN project is to provide open-source implementations of a complete protocol stack based on the to-be-finalized Internet of Things standards, on a variety of software and hardware platforms. This implementation can then help academia and industry verify the applicability of these standards to the Internet of Things, for those networks to become truly ubiquitous.

Protocol stack

The standards under development most applicable for the Internet of Things are:

- The IEEE802.15.4e working group is defining MAC amendment to the existing IEEE802.15.4-2006 standard. The proposal being standardized, called Time Synchronized Channel Hopping, significantly increases robustness against external interference and persistent multi-path fading, while running on legacy IEEE802.15.4-2006 hardware.
- The IETF 6LoWPAN working group standardizes a mechanism for an IPv6 packet to travel over networks of devices communicating using IEEE802.15.4 radios; this includes header compression techniques in order to increase data space in IEEE802.15.4 packets.
- The IETF ROLL working group standardizes the routing protocol, i.e. the distributed algorithm which finds the multi-hop path connecting the nodes in the network with a small number of destination nodes. The current proposal, called RPL, finds optimal routes according a set of constraints.
- OpenADR describes an open standards-based communications data model designed to promote common information exchange between the utility and electric customers using demand response price and reliability signals. OpenADR is one element of the Smart Grid information and communications technologies that are being developed to improve optimization between electric supply and demand.

These standards can be layered one on top of another, forming the following protocol stack:

application	openADR, HTTP, sensor.network

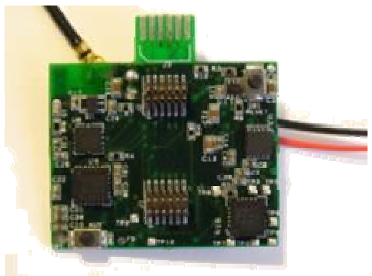
Table of Contents

Current Status

TelosB

- Commercially available mote
  - MSP430 µ-controller, CC2420 radio
  - light, humidity, temperature sensors
- Programmed using TinyOS
  - nesC pre-compiler, msp-gcc GNU toolchain
  - non-preemtive scheduling
  - 38kB ROM, 2.8kB RAM

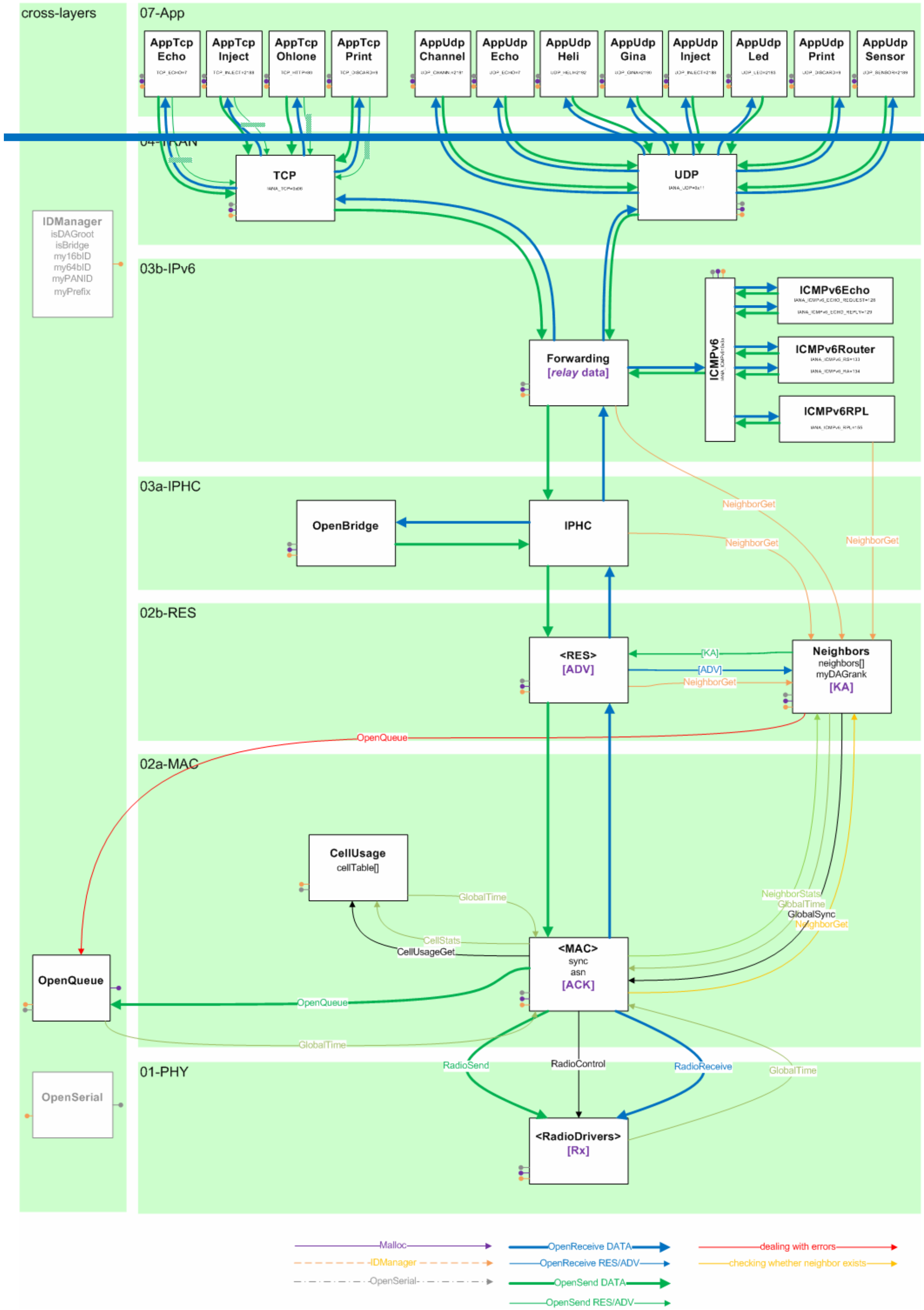
GINA-basestation



GINA

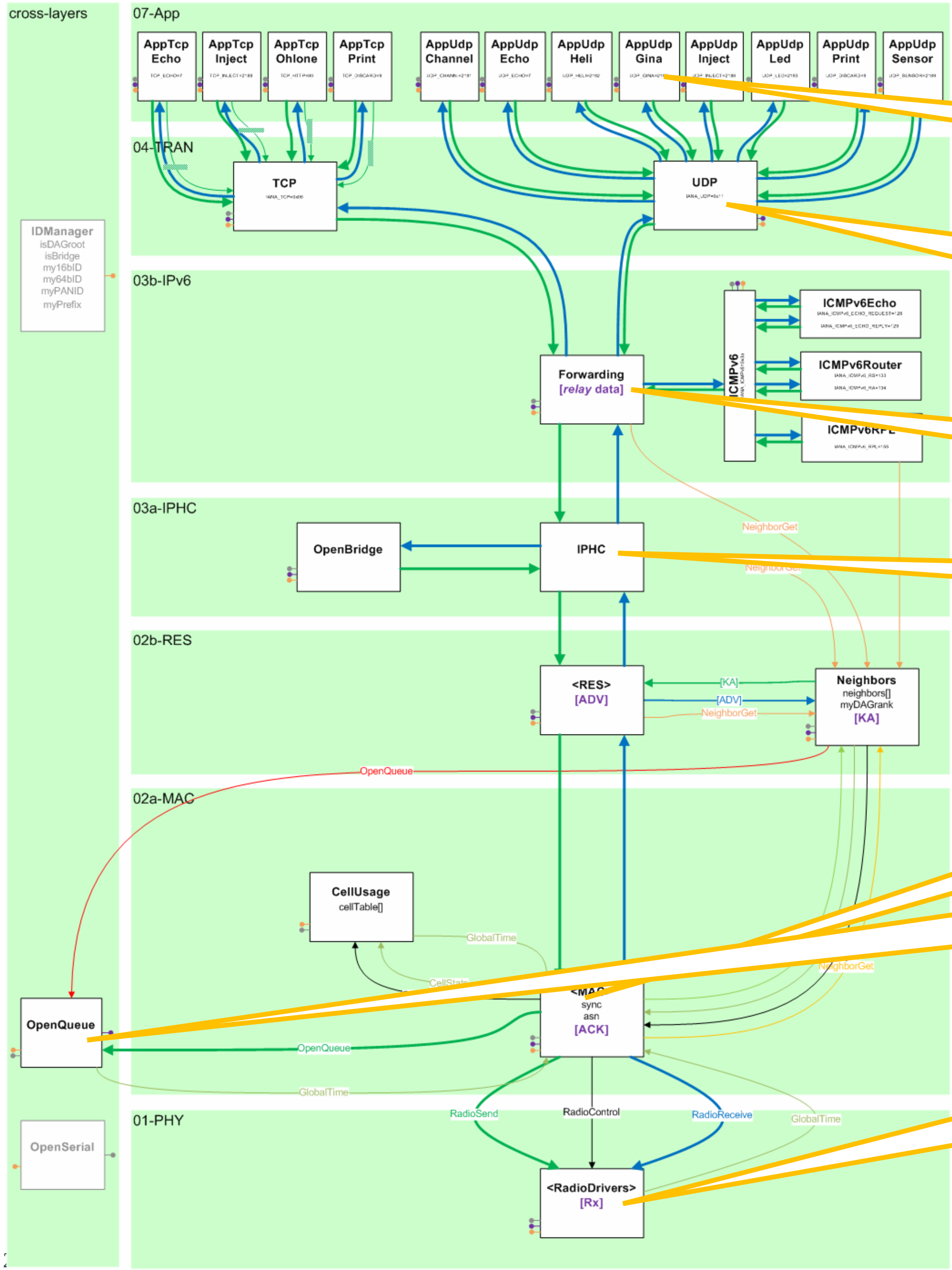
- In-house platforms
  - MSP430 µ-controller, AT86RF231 radio
  - 12-axis inertial sensor, weighs 1.6g
- Programmed in C
  - IAR toolchain
  - non-preemtive scheduling (~TinyOS)
  - 19kB ROM, 2.3kB RAM

Berkeley Socket Abstraction



AppUdpGina

```
void appudpgina_send() {
   OpenQueueEntry_t* packetToSend;
   packetToSend = openqueue_getFreePacketBuffer();
   packetToSend->creator                        = COMPONENT_APPUDPGINA;
   packetToSend->owner                          = COMPONENT_APPUDPGINA;
   packetToSend->l4_protocol                    = IANA_UDP;
   packetToSend->l4_sourcePortORicmpv6Type   = appudpgina_pktReceived->l4_destination_port;
   packetToSend->l4_destination_port         = appudpgina_pktReceived->l4_sourcePortORicmpv6Type;
   packetToSend->l3_destinationORsource.type = ADDR_128B;
   memcpy(&(packetToSend->l3_destinationORsource.addr_128b[0]),
         &(appudpgina_pktReceived->l3_destinationORsource.addr_128b[0]),
         16);
   //payload, gyro data
   packetfunctions_reserveHeaderSize(packetToSend,8);
   gyro_get_measurement(&(packetToSend->payload[0]));
   //payload, large_range_accel data
   packetfunctions_reserveHeaderSize(packetToSend,6);
   large_range_accel_get_measurement(&(packetToSend->payload[0]));
   //payload, magnetometer data
   packetfunctions_reserveHeaderSize(packetToSend,6);
   magnetometer_get_measurement(&(packetToSend->payload[0]));
   //payload, sensitive_accel_temperature data
   packetfunctions_reserveHeaderSize(packetToSend,10);
   sensitive_accel_temperature_get_measurement(&(packetToSend->payload[0]));
   //send packet
   udp_send(packetToSend);
}
```



Packet is created, IMU data is added

UDP header added, specifying the port of AppUdpGina as source

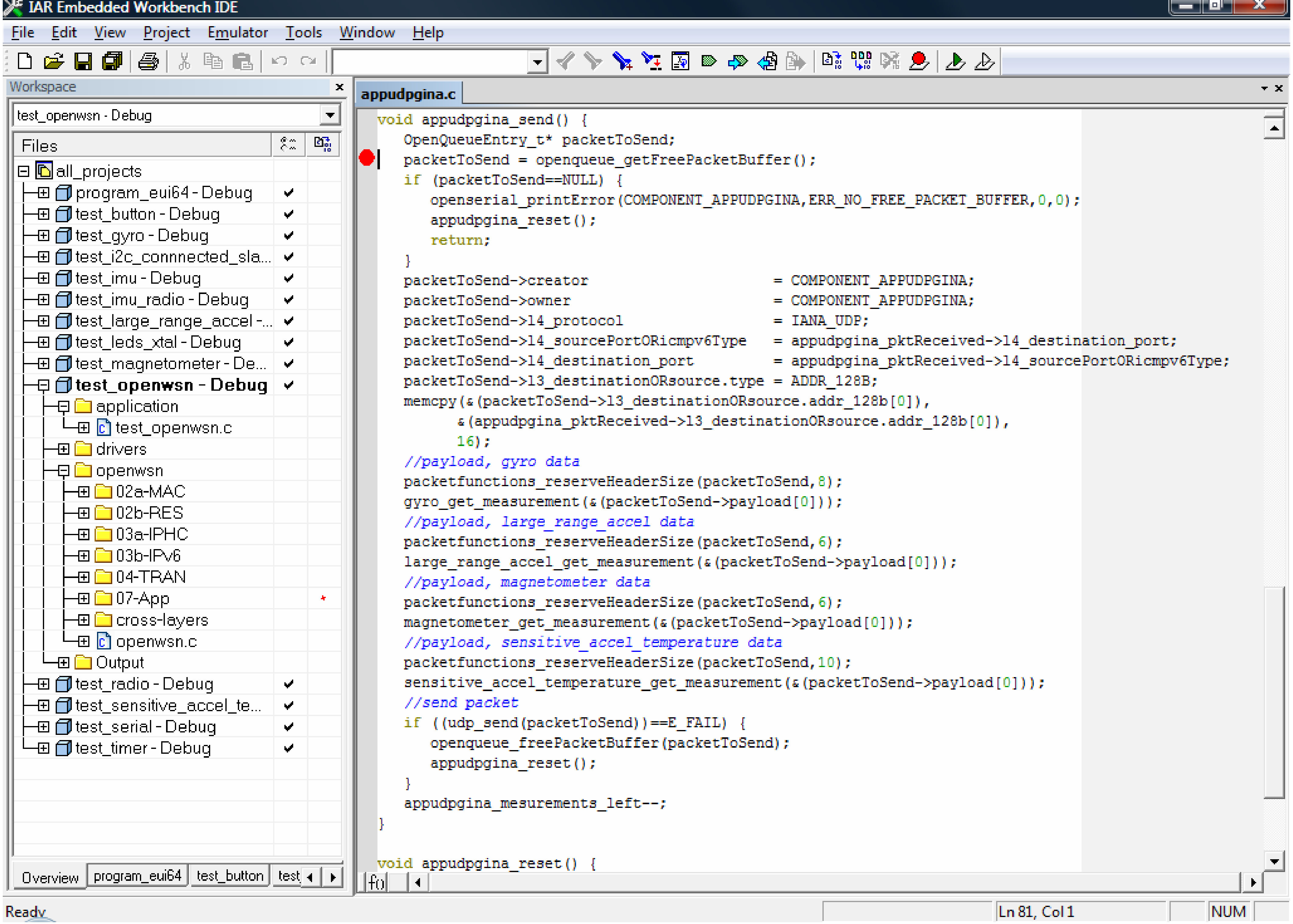
Routing decision to choose next hop

Compacted IPv6 header added

IEEE802.15.4 header added

Packet stored until medium access control ready to send

When ready, packet transferred to radio chip, which sends it


IAR Embedded Workbench IDE
File Edit View Project Emulator Tools Window Help
Workspace
test_openwsn - Debug
Files
all_projects
program_eui64 - Debug
test_button - Debug
test_gyro - Debug
test_i2c_connnected_sla...
test_imu - Debug
test_imu_radio - Debug
test_large_range_accel -...
test_leds_xtal - Debug
test_magnetometer - De...
test_openwsn - Debug
application
test_openwsn.c
drivers
openwsn
02a-MAC
02b-RES
03a-IPHC
03b-IPv6
04-TRAN
07-App
cross-layers
openwsn.c
Output
test_radio - Debug
test_sensitive_accel_te...
test_serial - Debug
test_timer - Debug
Overview
program_eui64
test_button
test
appudpgina.c
void appudpgina_send() {
OpenQueueEntry_t* packetToSend;
packetToSend = openqueue_getFreePacketBuffer();
if (packetToSend==NULL) {
openserial_printError(COMPONENT_APPUDPGINA,ERR_NO_FREE_PACKET_BUFFER,0,0);
appudpgina_reset();
return;
}
packetToSend->creator = COMPONENT_APPUDPGINA;
packetToSend->owner = COMPONENT_APPUDPGINA;
packetToSend->l4_protocol = IANA_UDP;
packetToSend->l4_sourcePortORicmpv6Type = appudpgina_pktReceived->l4_destination_port;
packetToSend->l4_destination_port = appudpgina_pktReceived->l4_sourcePortORicmpv6Type;
packetToSend->l3_destinationORsource.type = ADDR_128B;
memcpy(&(packetToSend->l3_destinationORsource.addr_128b[0]),
&(appudpgina_pktReceived->l3_destinationORsource.addr_128b[0]),
16);
//payload, gyro data
packetfunctions_reserveHeaderSize(packetToSend,8);
gyro_get_measurement(&(packetToSend->payload[0]));
//payload, large_range_accel data
packetfunctions_reserveHeaderSize(packetToSend,6);
large_range_accel_get_measurement(&(packetToSend->payload[0]));
//payload, magnetometer data
packetfunctions_reserveHeaderSize(packetToSend,6);
magnetometer_get_measurement(&(packetToSend->payload[0]));
//payload, sensitive_accel_temperature data
packetfunctions_reserveHeaderSize(packetToSend,10);
sensitive_accel_temperature_get_measurement(&(packetToSend->payload[0]));
//send packet
if ((udp_send(packetToSend))==E_FAIL) {
openqueue_freePacketBuffer(packetToSend);
appudpgina_reset();
}
appudpgina_mesurements_left--;
}
void appudpgina_reset() {
Ready
Ln 81, Col 1
NUM

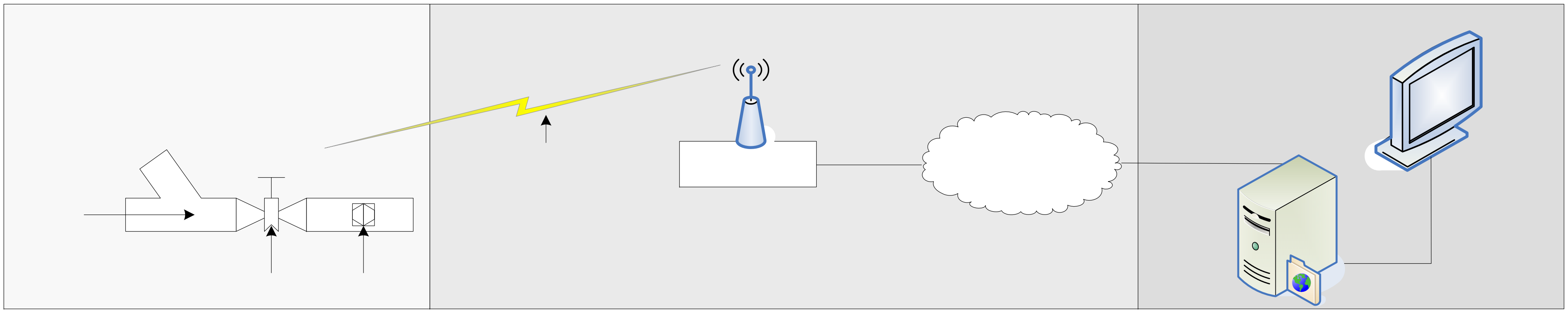
```
⊟ IEEE 802.15.4 Data, Dst: 14:15:92:0b:03:01:00:29, Src: 14:15:92:09:02:2b:00:51
  ⊞ Frame Control Field: Data (0xcc61)
    Sequence Number: 5
    Destination PAN: 0xbaad
    Destination: 14:15:92:0b:03:01:00:29 (14:15:92:0b:03:01:00:29)
    Source: 14:15:92:09:02:2b:00:51 (14:15:92:09:02:2b:00:51)
    FCS: 0x6c4a (Correct)
⊟ 6LoWPAN
  ⊞ IPHC Header
    Next header: UDP (0x11)
    Hop limit: 64
    Source: fe80::1615:9209:22b:51 (fe80::1615:9209:22b:51)
    Destination: fe80::1615:920b:301:29 (fe80::1615:920b:301:29)
⊟ Internet Protocol Version 6
  ⊞ 0110 .... = Version: 6
  ⊞ .... 0000 0000 .... .... .... .... .... = Traffic class: 0x00000000
    .... .... .... 0000 0000 0000 0000 0000 = Flowlabel: 0x00000000
    Payload length: 38
    Next header: UDP (0x11)
    Hop limit: 64
    Source: fe80::1615:9209:22b:51 (fe80::1615:9209:22b:51)
    Destination: fe80::1615:920b:301:29 (fe80::1615:920b:301:29)
⊟ User Datagram Protocol, Src Port: tivoconnect (2190), Dst Port: http-alt (8080)
    Source port: tivoconnect (2190)
    Destination port: http-alt (8080)
    Length: 38
  ⊞ Checksum: 0x06e3 [incorrect, should be 0x02e3 (maybe caused by "UDP checksum offload"?)]
⊟ Data (30 bytes)
    Data: 06ed07f7050d050f0835ffe2ffc6fe4584fc870091c0c500...
    [Length: 30]
```

```
                                                61 cc
05 ad ba 29 00 01 03 0b  92 15 14 51 00 2b 02 09
92 15 14 78 33 11 40 08  8e 1f 90 00 26 06 e3 06
ed 07 f7 05 0d 05 0f 08  35 ff e2 ff c6 fe 45 84
fc 87 00 91 c0 c5 00 ff  fc ff d7 00 02 4a 6c
```

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

- **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]

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

Challenges for Capillary M2M

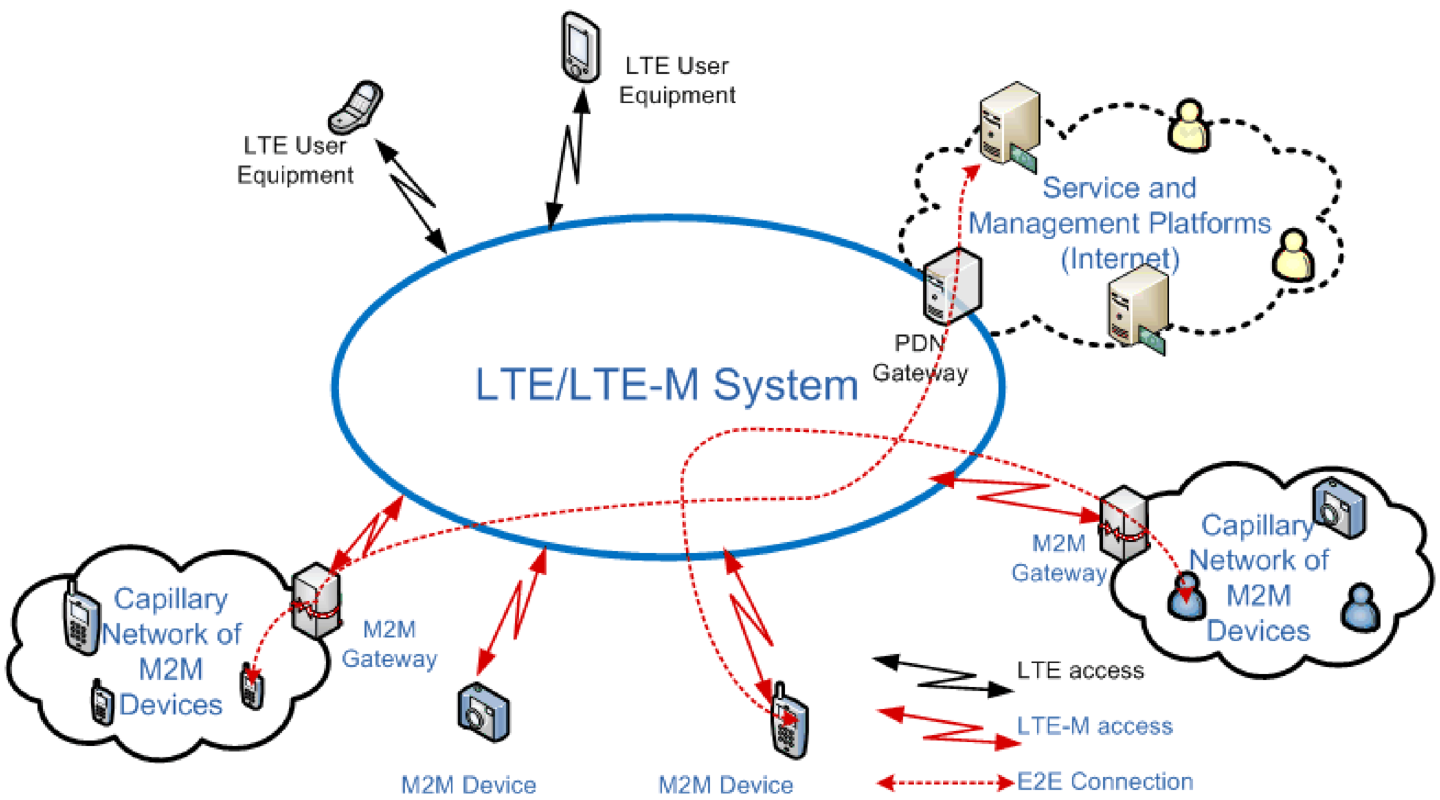
- Core Challenge #1 – **Delays:**
  - Connection Delay: optimize L2/L3 node discovery protocols
  - Communication Delay: ultra reliable & time-critical MAC urgently needed
- Core Challenge #2 – **Security:**
  - Requirements: room for efficient end-to-end security solution
  - Extras: fit security into 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

Conclusions

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

ICT EXALTED

Expanding LTE for Devices



At A Glance: EXALTED

Expanding LTE for Devices

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

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

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

Contract Number: INFSO-ICT-258512