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INVENTORS FOR THE DIGITAL WORLD



FIT IoT-lab

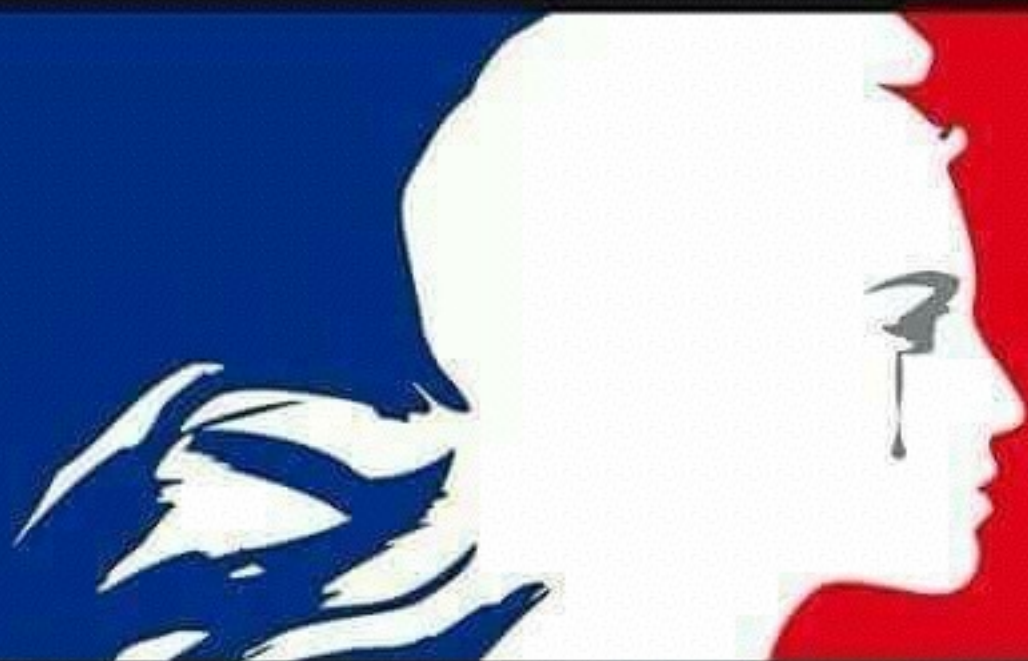
FIT IoT-LAB

First Class IoT Open Experimental Testbed

E. Fleury, ENS de Lyon / Inria

26th Asian School — Asian Institute of Technology, Thailand

intERLab, AIT — Bangkok, Thailand. November 16-17, 2015



PARIS, 13 NOVEMBRE 2015

WORDS FROM A. PETIT, PRESIDENT AND CEO OF INRIA

- ▶ The barbarians responsible for these horrors should not hope that they are going to frighten us or succeed in getting us to abandon our values of freedom and democracy. Accordingly, the institute will pursue its activities "normally" respecting the Law and the measures taken by the President of the Republic.
In particular, for the moment, we plan no cancellation of meetings, seminars, or scientific conferences.

Agenda

1. Vanilla Flavour of IoT
2. Promise/Challenge of Wireless
3. Deep Dive into the Layers
4. Experiment with IoT-LAB
5. Demo of IoT-LAB
6. **Tutorial and LAB on IoT-LAB**
 - <https://www.iot-lab.info/aintec-2015>

Special thanks to :

- ▶ Kanchana Kanchanasut
- ▶ Sukumal Kitisin
- ▶ Sweet Mae Monteclaro



Thanks to :

- ▶ C. Adjih, Inria
- ▶ E. Baccelli, Inria
- ▶ C. Chaudet, Institut Mines-Télécom
- ▶ N. Mitton, Inria
- ▶ T. Noel, University of Strasbourg



Special thanks to:

- ▶ Pascal Thubert, CISCO
- ▶ Laurent Toutain, Telecom Bretagne
- ▶ Thomas Watteyne, Inria

1

Vanilla flavour of IoT

Agenda

1. Vanilla flavour of IoT

1. Global picture & challenges

2. Industrial Internet

The Internet of Everything — P2P/M2P/M2M

- Challenge: harness innovation
- \$14.4 trillion in IoE “Value at Stake”
 - Asset utilization (reduced costs)
 - Employee productivity (greater labor efficiencies)
 - Supply chain and logistics (eliminating waste)
 - Customer experience (addition of more customers)
 - Innovation (reducing time to market)

Internet of Everything (IoE) Value Index
How Much Value Are Private-Sector Firms Capturing from IoE in 2013?
White Paper — cisco — http://internetofeverything.cisco.com/sites/default/files/docs/en/ioe-value-index_Whitepaper.pdf

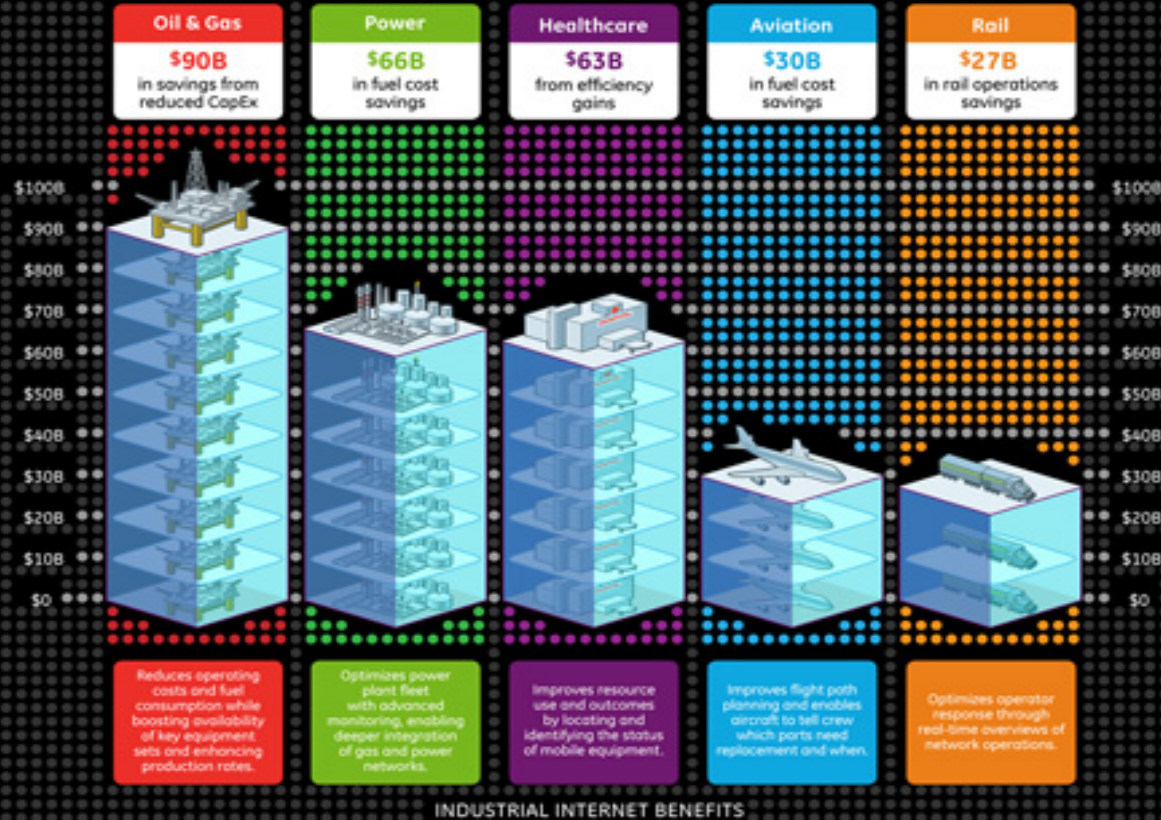
The Internet of Everything — P2P/M2P/M2M

- More efficient operation
- New/Improve experience
- Beyond Control and Automation
 - Optimise process (by 1%?)
 - Leveraging IT, Live Big Data Analysis

Internet of Everything (IoE) Value Index
How Much Value Are Private-Sector Firms Capturing from IoE in 2013?
White Paper — cisco — http://internetofeverything.cisco.com/sites/default/files/docs/en/ioe-value-index_Whitepaper.pdf

INDUSTRIAL INTERNET: THE POWER OF 1%

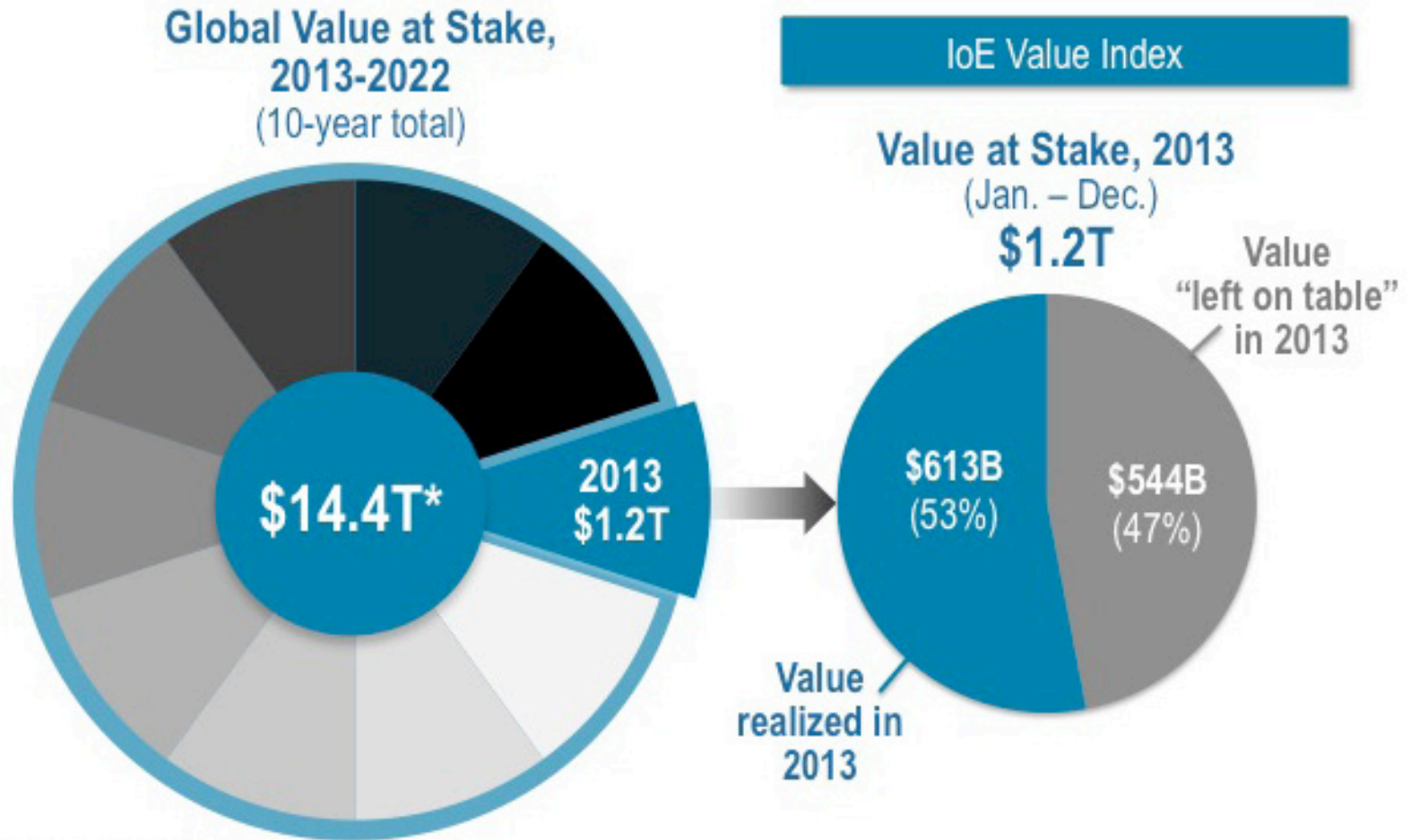
Efficiency gains as small as 1% could have sizable benefits over 15 years when scaled up across the economic system.



Source: GE estimates

Internet of Everything (IoE) Value Index
 How Much Value Are Private-Sector Firms Capturing from IoE in 2013?
 White Paper — cisco — http://internetofeverything.cisco.com/sites/default/files/docs/en/ioe-value-index_Whitepaper.pdf

The Internet of Everything — P2P/M2P/M2M



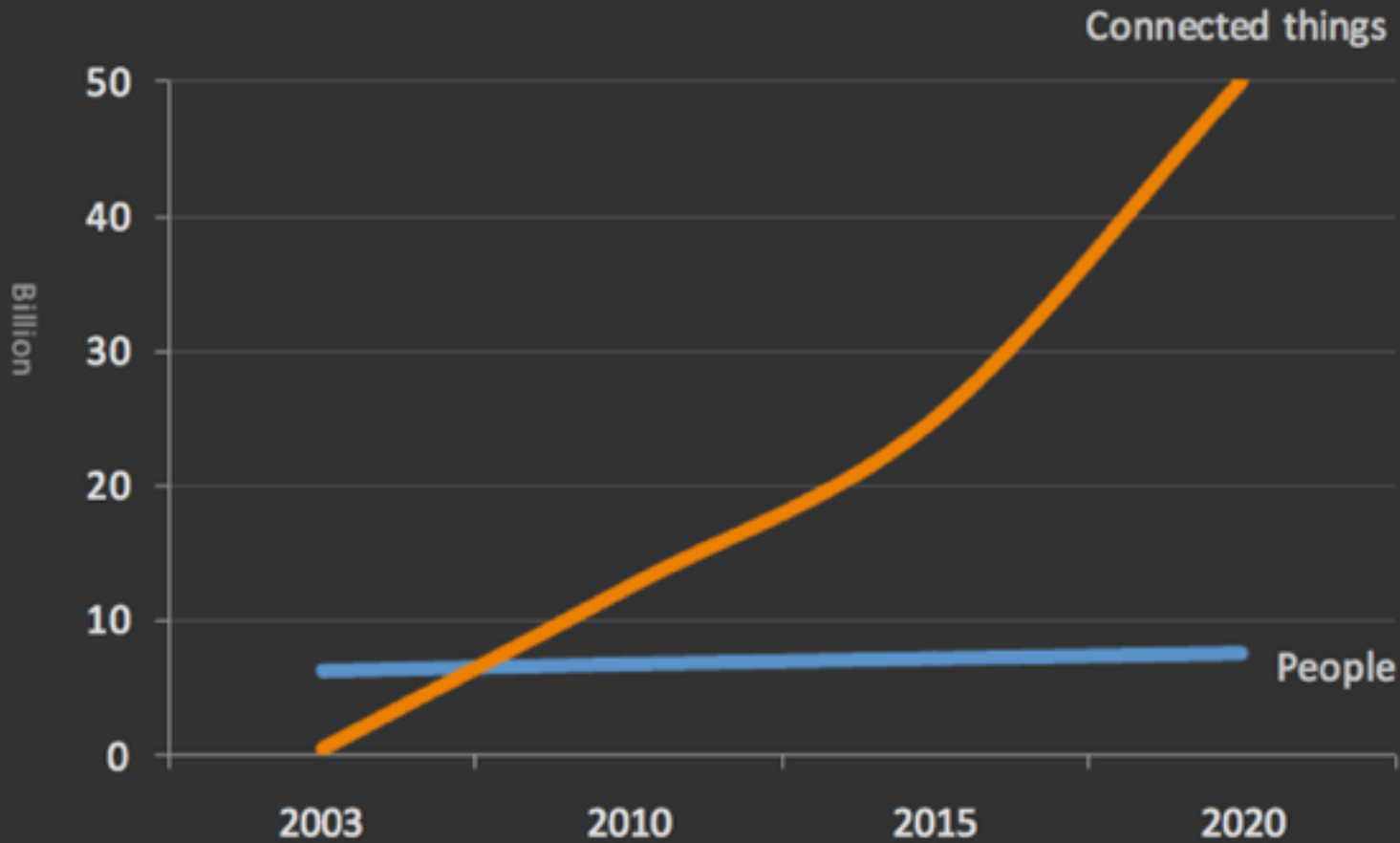
Note: chart is not to scale

* \$14.4T is conservative because it is based on a set number (21) of private-sector use cases and discounts future cash flows due to uncertainty around privacy and regulatory issues.

Source: Cisco, 2013

$$2^{128} =$$

340.282.366.920.938.463.463.374.607.431.768.211.456



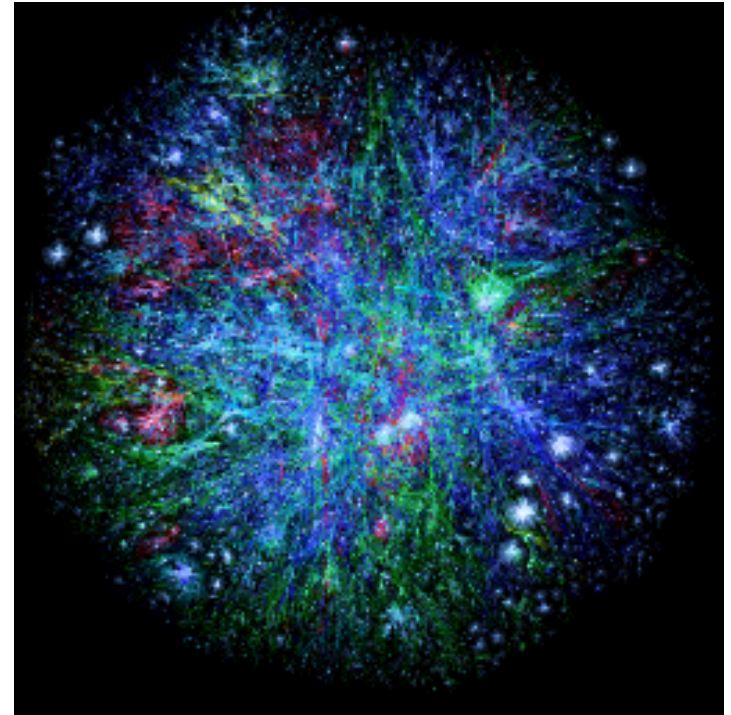
Scaling to Pervasive IoE/T

1000*^{scale} => No leak in the Internet
=> Opaque Fringe operations

Reachability => Radio

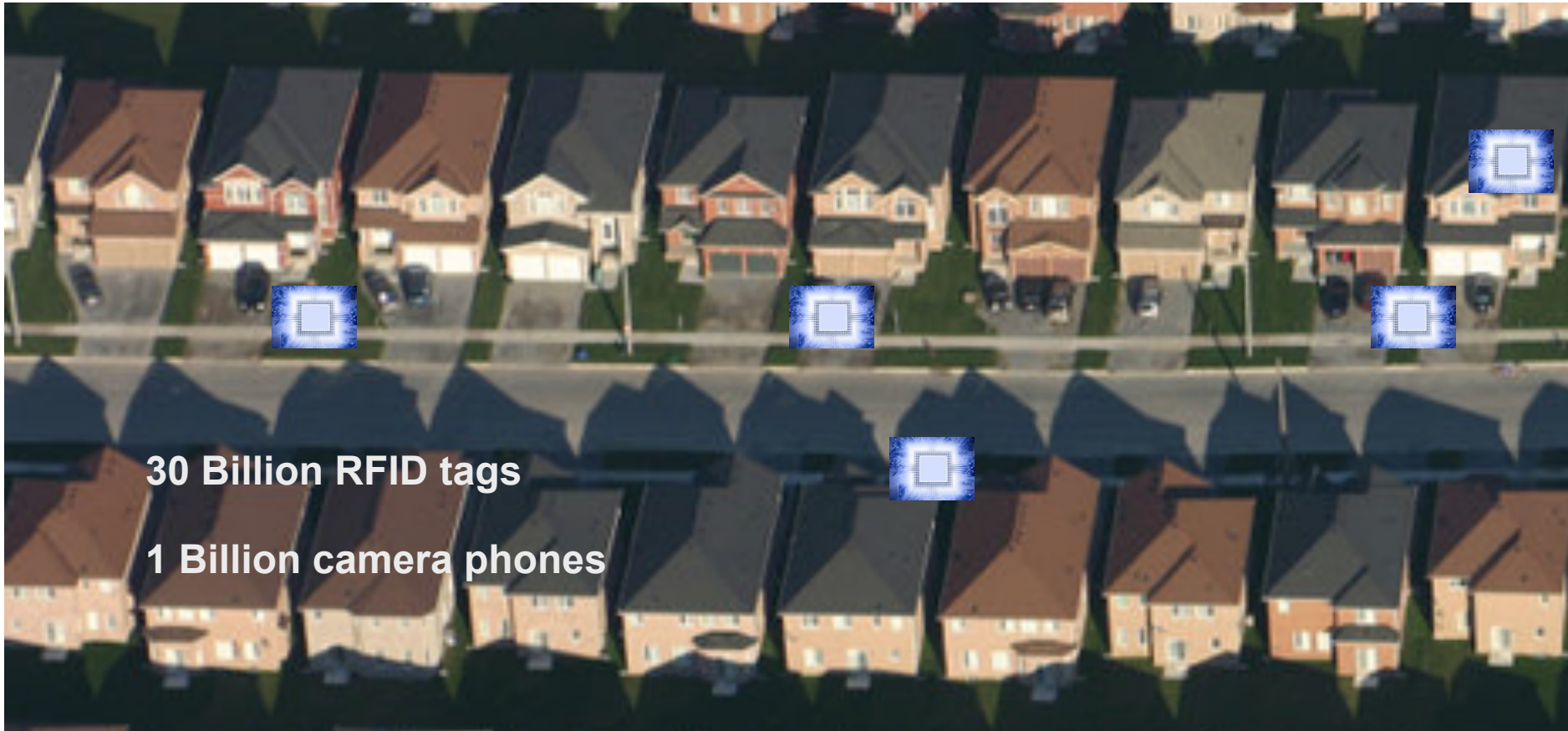
Addressing => IPv6

Density => spatial reuse



© Pascal Thubert / cisoc

Instrumented



30 Billion RFID tags

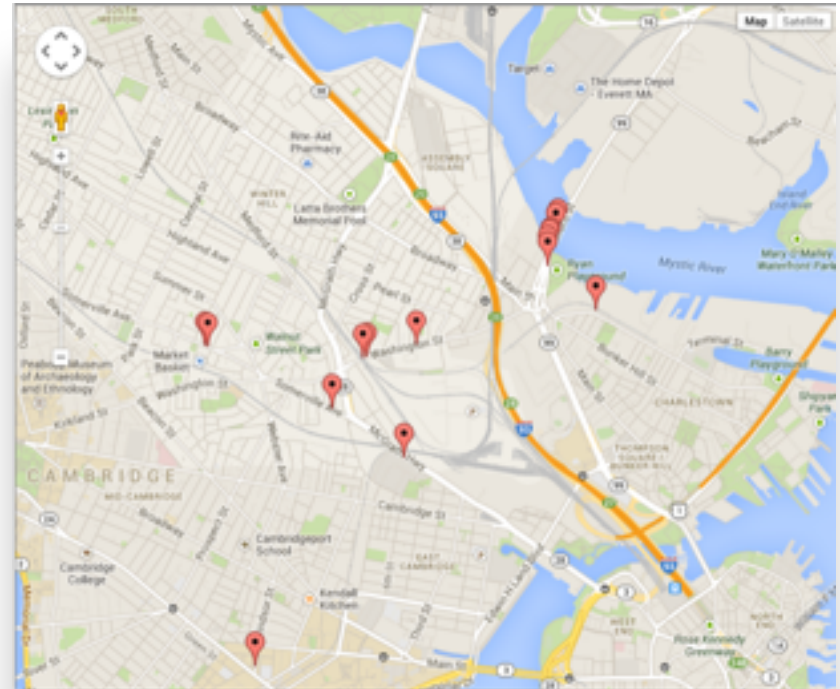
1 Billion camera phones

source: Kim Escherich , Executive Innovation Architect sur Pan-European Chief Technology Officer Team, IBM SWG

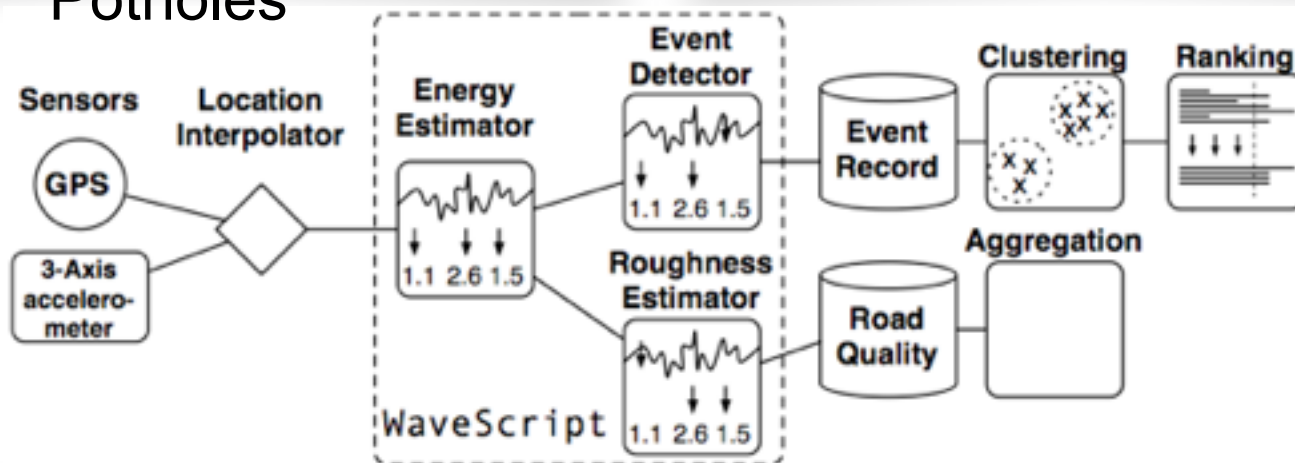


How google traffic is working?

How to monitor road condition « for free »?



Potholes



Interconnected



+2 Billions Internet subscribers

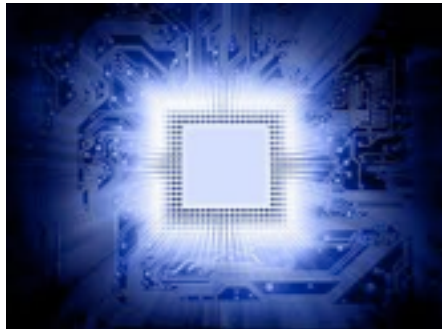
+20 Billion connected device

source: Kim Escherich , Executive Innovation Architect sur Pan-European Chief Technology Officer Team, IBM SWG

Intelligent



Every systems is becoming



+



+



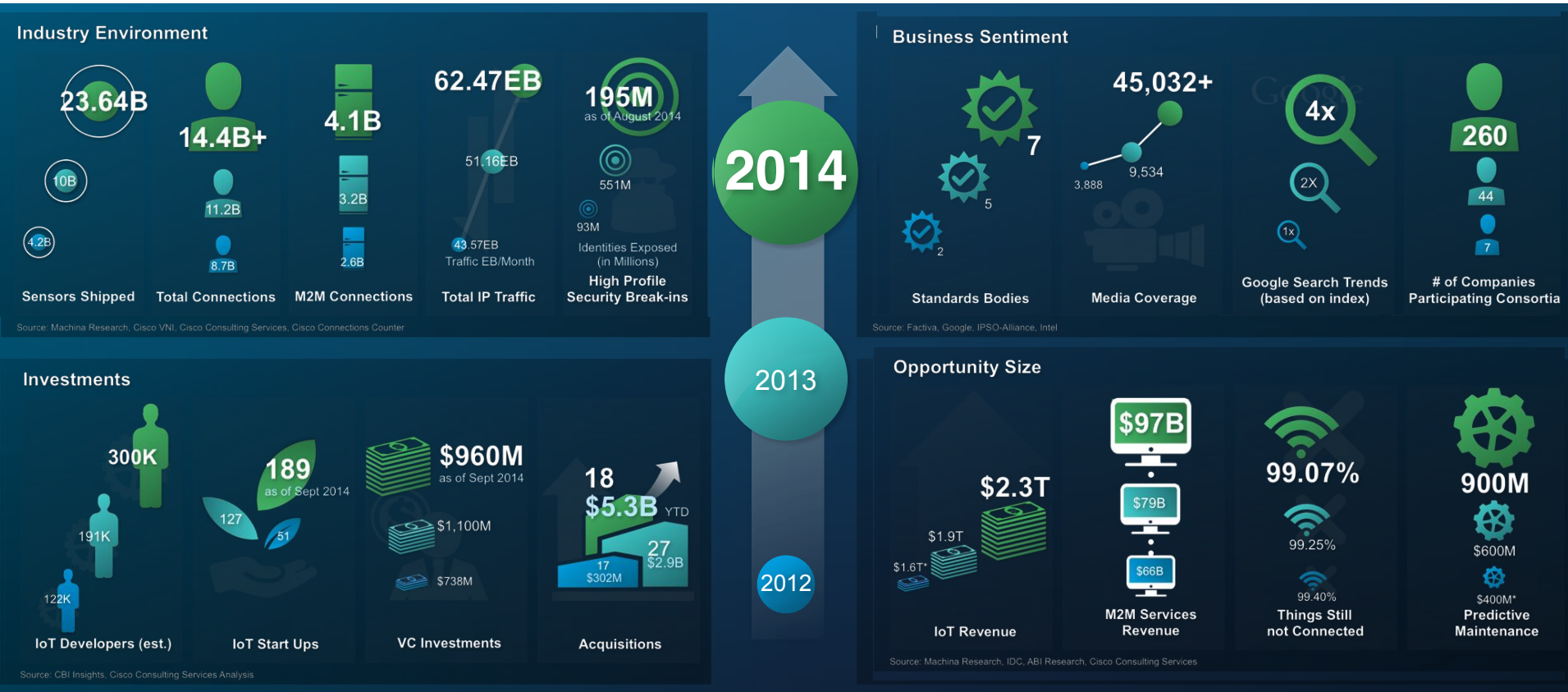
**NEW
INTELLIGENCE**

**SMART
WORK**

GREEN

**DYNAMIC
INFRASTRUCTURE**

IoT Acceleration Dashboard 2012-2014



Source: CBI Insights, Cisco Consulting Services Analysis

Health

Home

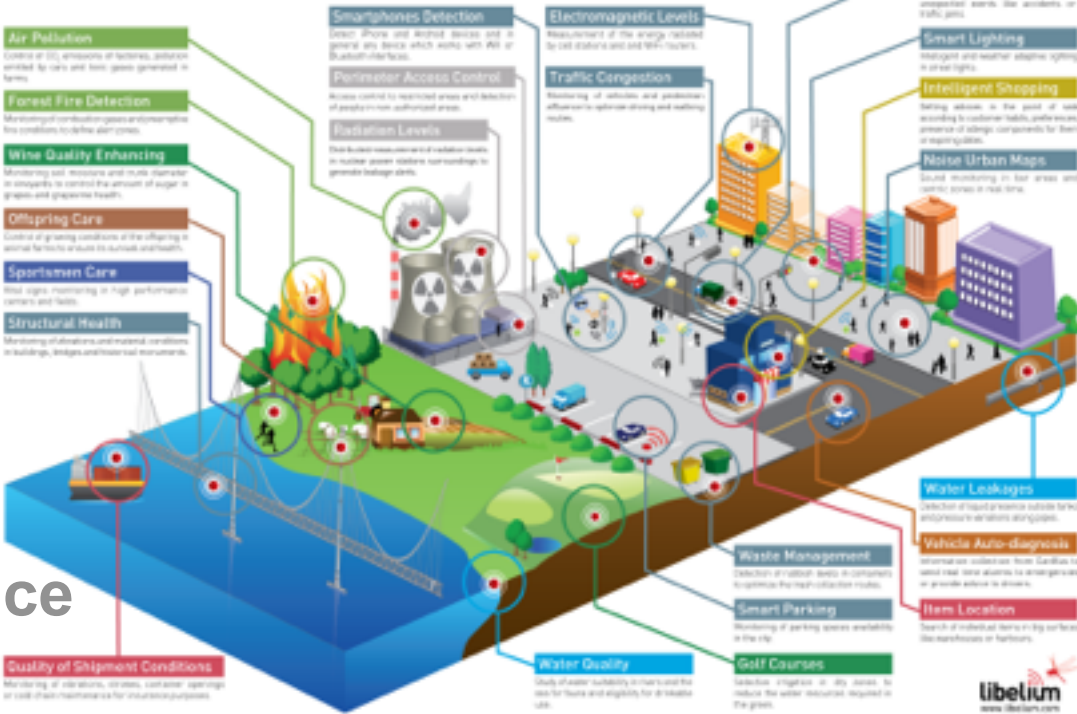
Ecology

Security

Transport

Maintenance

Libelium Smart World



HiKoB



Mosar

HiKoB



First takeaways

1. IoT Is Here. Now. And It's Big

The Internet of Everything is not the Internet of tomorrow, it's the Internet of today.

3. IoT is Accelerating

Technology infrastructure and tools are essential, but it's the innovative application of technology that will separate winners from losers in the IoE Economy.

5. Huge Opportunity for Ecosystem

Data is ubiquitous and no longer a differentiator.

Agenda

1. Vanilla flavour of IoT

1. Global picture & challenges

2. Industrial Internet

Wireless Industrial

- Better process optimization and more accurate predictive maintenance increase profit; 1% improvement in a refinery with a \$1.5B annual profit leads to \$40k/day (\$15M/yr) more profit
- Thus more and different sensors can be justified economically, if they can be connected
- But wire buried in conduit has a high installation and maintenance cost, with long lead times to change, and is difficult to repair
- The solution: wireless sensors in non-critical applications, designed for the industrial environment: temperature, corrosion, intrinsic safety, lack of power sources (particularly when there is no wire)
- For critical control loops, use wireless control room links with controllers located in the field, possibly connected over local wiring



Converging ICT and OT

Operational Technology (OT) is hardware and software that detects or causes a change through the direct monitoring and/or control of physical devices, processes and events in the enterprise.

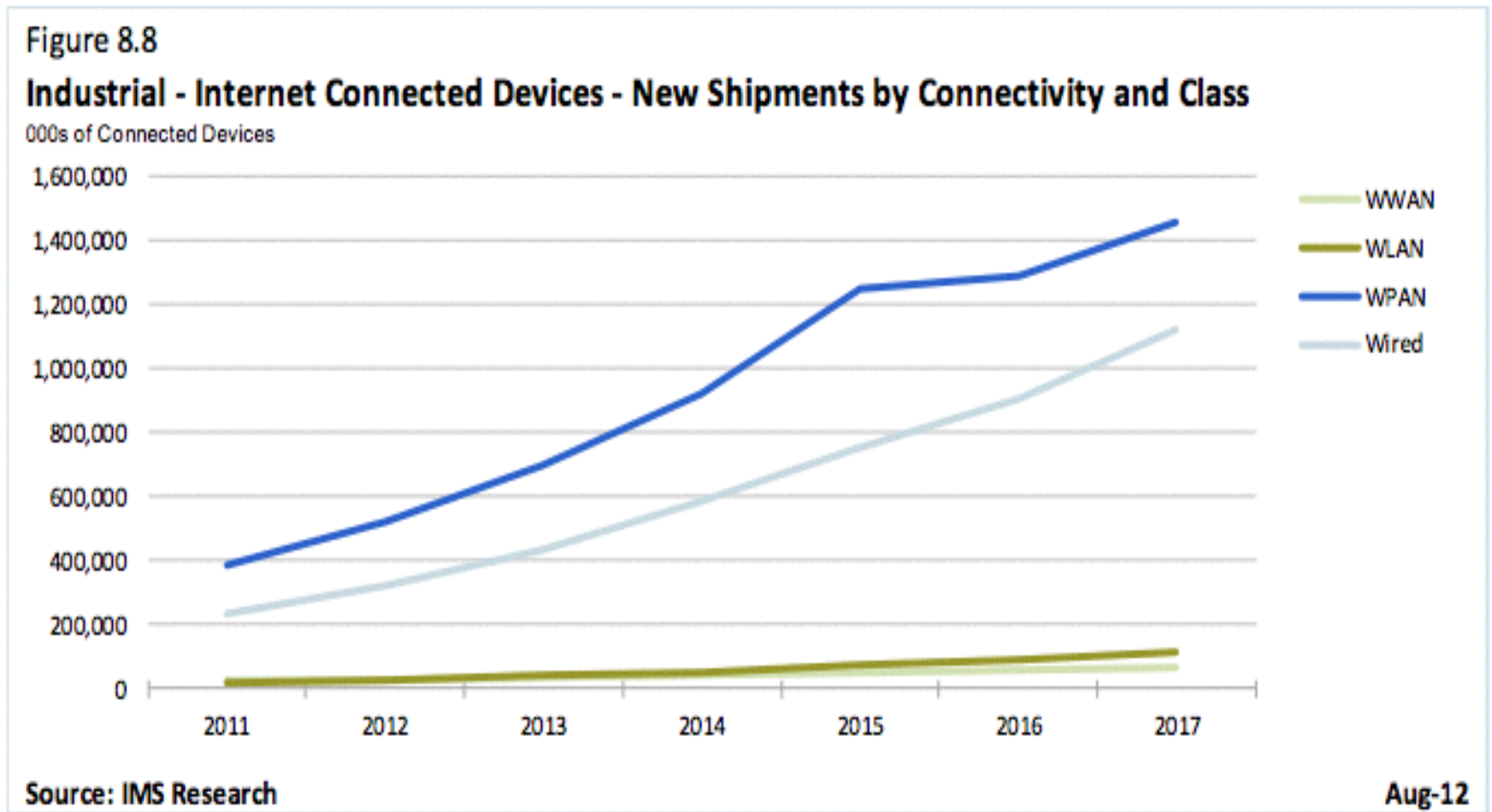
Convergence of IT and OT technologies, aka the **Industrial Internet**, represents a multibillion opportunity for IT vendors and long term job creation.

Deterministic Wireless Networking is one of the key elements.

For each 'critical' wired measurement there are hundreds missing ones that could be addressed through wireless (Industrial Internet)

Architecture and Standards are necessary for Industry adoption

Industrial connected device growth



WWAN: GSM – LTE WLAN: 802.11 WPAN: 802.15.4, ISA100.11a, WirelessHART

What's the question?

1. **How to Engineer cities**
2. « data acquisition systems »
3. such that cities become smart(er)...



CAPTURE



COLLECT

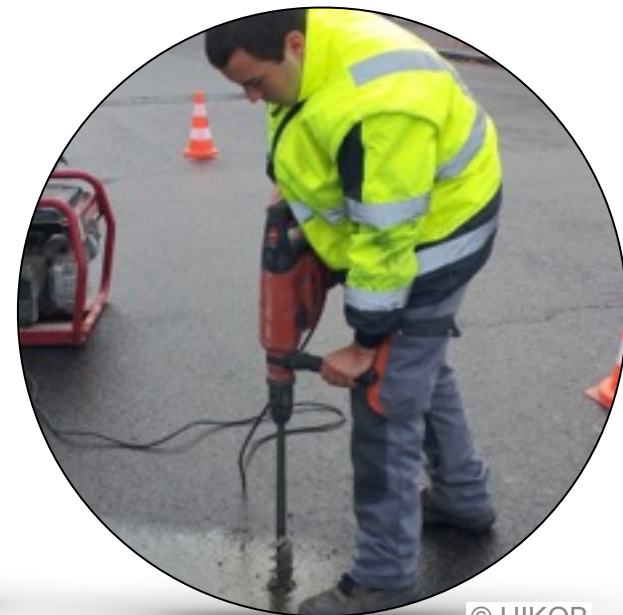
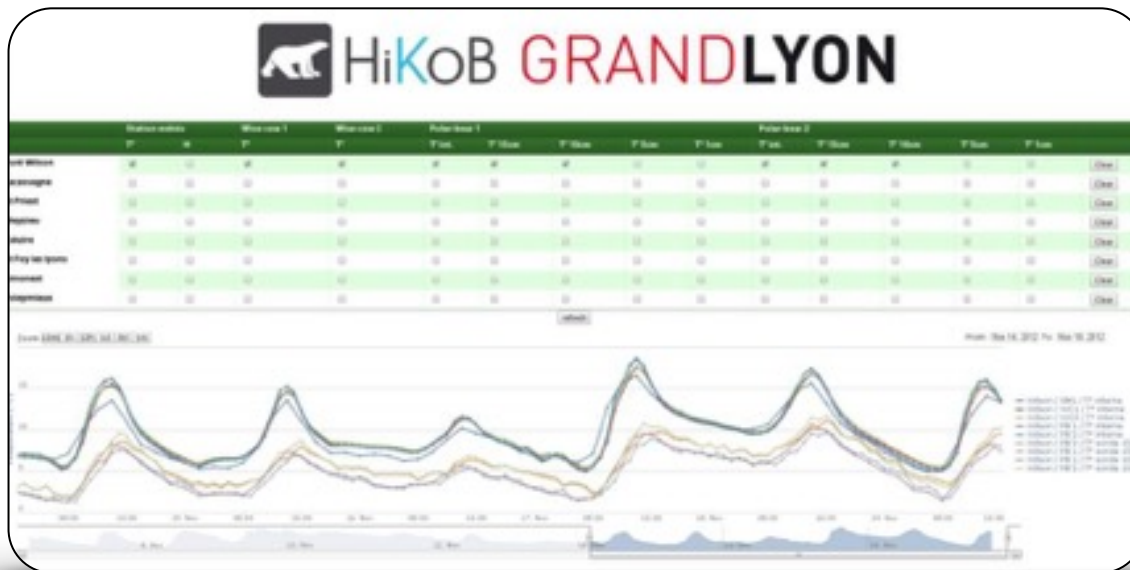
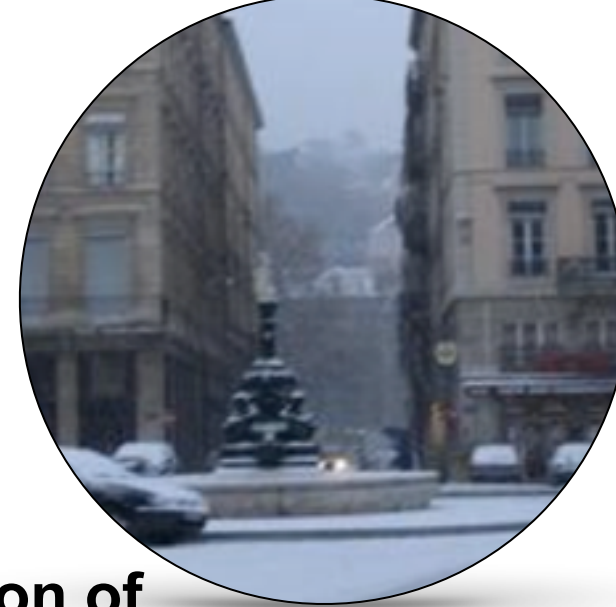


REPORT

Example from HiKoB

• Infrastructure Management

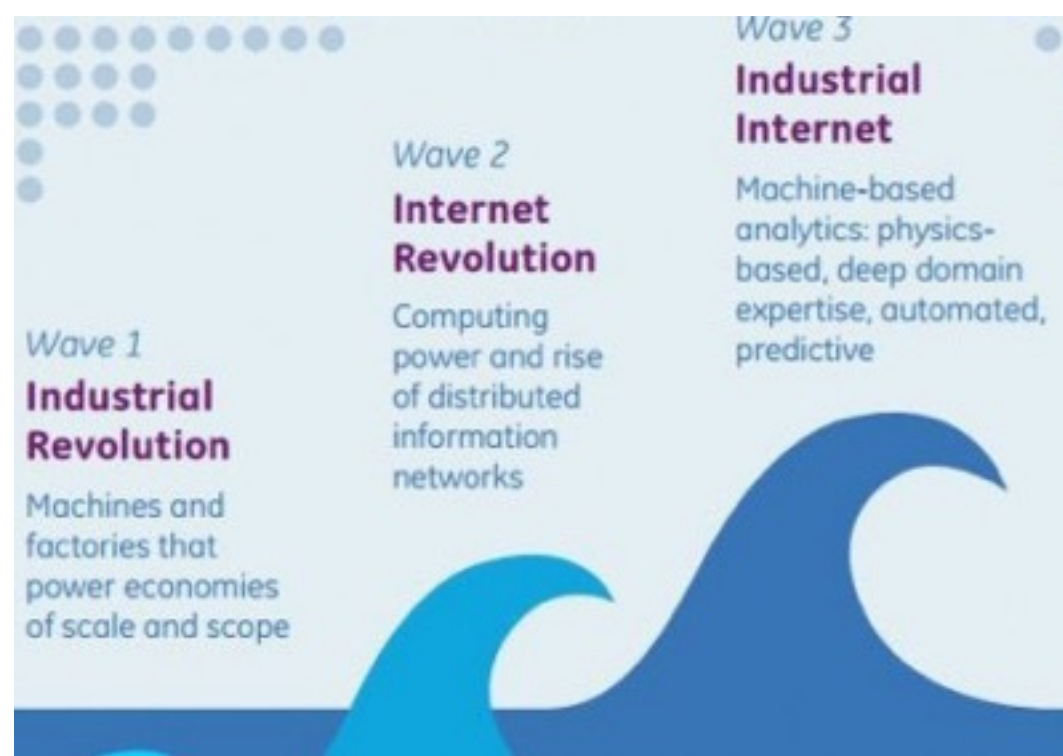
- Real-time road surface and moisture measurement
- Optimisation of management and reduction of cost and resource



© HIKOB

The revolution

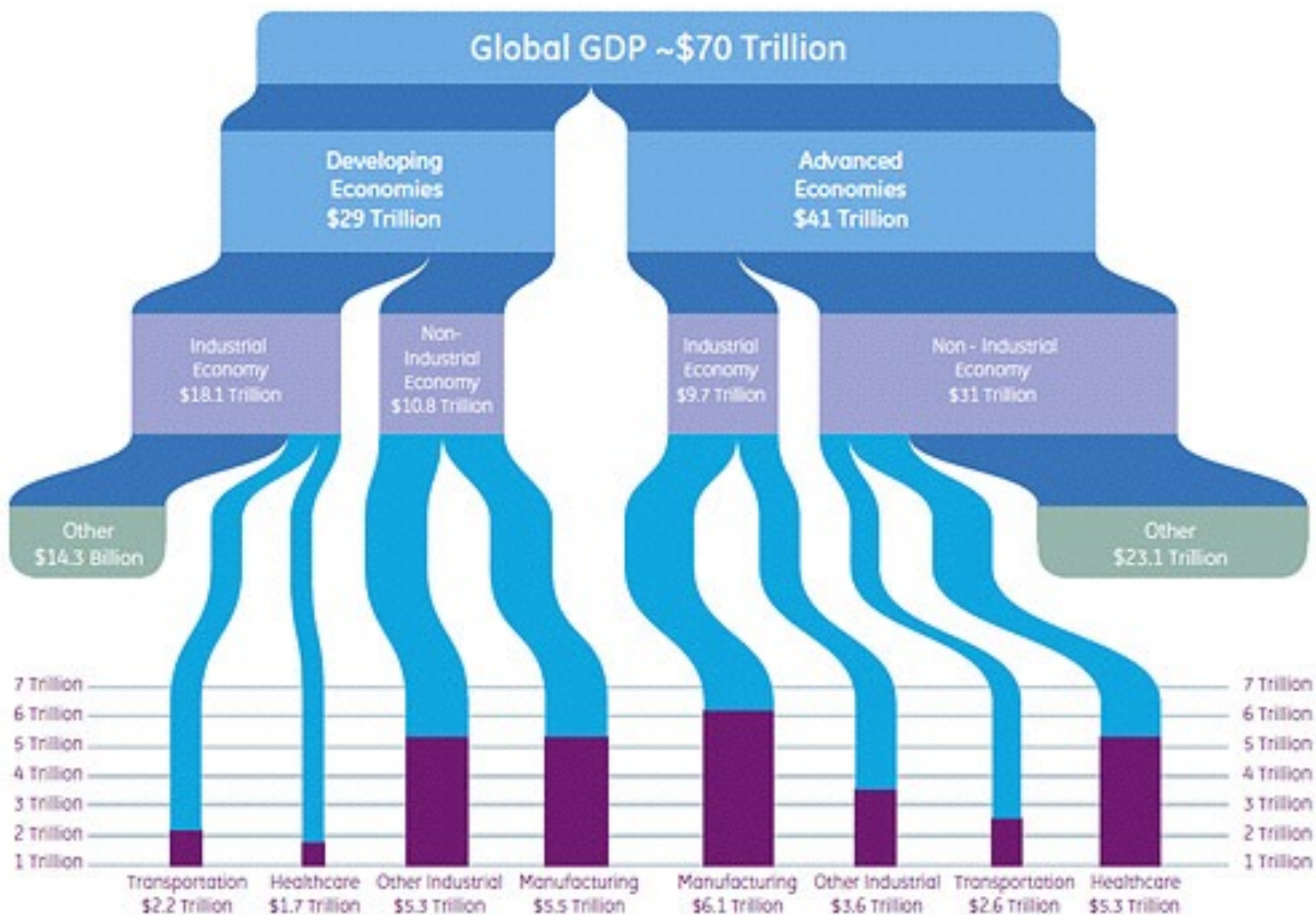
- **IoT Revolution**
 - Smart objects
 - IoT
 - Big Data Analysis
- **Industrial Internet**
 - Intelligent Machine
 - Advanced Analytics
 - People at work



*That which is measured improves. That which is measured and reported **improves exponentially** » (Pearson's law)*

© HIKOB

Revolution of process, not application



Traditional industries vs native IoT players

Most of the Industrial Internet Market belong to traditional players.

IoT technologies are **not disruptive** for the industries but instead they operate as an **enabler**:

- they open **new perspectives** to **existing industries**
- give **existing players** the opportunity to **leap across the frontiers of their current exercise.**

For more information



▶ FIT IoT-LAB

▶ <https://www.iot-lab.info>

▶ HiKoB

▶ <http://www.hikob.com>



2

Promise/Challenge of wireless

Agenda

2. Promise/Challenge of wireless

1. Background

2. Low Power Lossy Networks

We said...

- RFI (Radio Frequency Identification)
- NFC (Near Field Communication)
- Wireless Sensor (and Actuator) Networks
- Smart Grids
- Cars

Internet of Things

- Internet Protocols
- Simplified Internet Protocols
- Interoperability with Internet (e2e, URI, ...)
- Open Standards
- Always on

The routing Infrastructure today

- The Internet

- Fully engineered
 - Hierarchical, Aggregations, ASs, Wire links
- Fully distributed States
 - Shows limits (BGP tables, addr. depletion)

⇒ Reached adult size, mature to aging

⇒ Conceptually unchanged by IPv6

- IPv4 Intranets

- Same structure as the Internet
- Yet decoupled from the Internet
 - NAT, Socks, Proxies

⇒ First model for Internet extension



© Pascal Thubert / cisoc

History repeating?

- 80's: IP as a word wide protocol
 - other alternatives: CLNP, X.25, Frame Relay, ATM
 - IP: Best Effort, no reservation, fixed address size, ...
- 80's: IP in entreprise network
 - Other alternatives: IPX, NetBios
 - IP: no auto-configuration, no service discovery
- 90's 00 IP in telephony & IPinTV
 - Other alternatives: IEEE 1394/ATM/Hiperlan
- **Conclusion**
 - Network value comes from **Interconnexion**
 - Interconnections i based on **Open Protocols**

Why IP ?

Open Standards vs. proprietary

- COTS* suppliers drive costs down but
- Reliability, Availability and Security up

IP abstraction vs. per MAC/App

- 802.11, 802.15.4 (e), Sat, 3G, UWB
- Keep L2 topology simple

To Infinity and Beyond... But End-to-End.

- No intermediate gateway, tunnel, middle boxes & other trick
- * *Commercial, off-the-shelf*



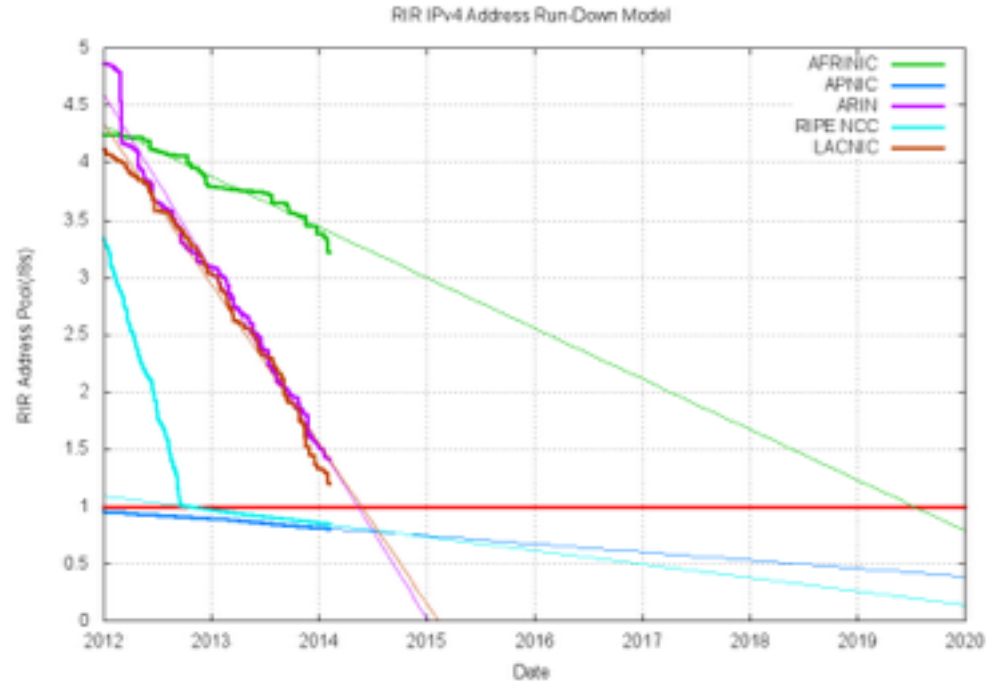


Which IP version ?

The current Internet comprises several billion devices

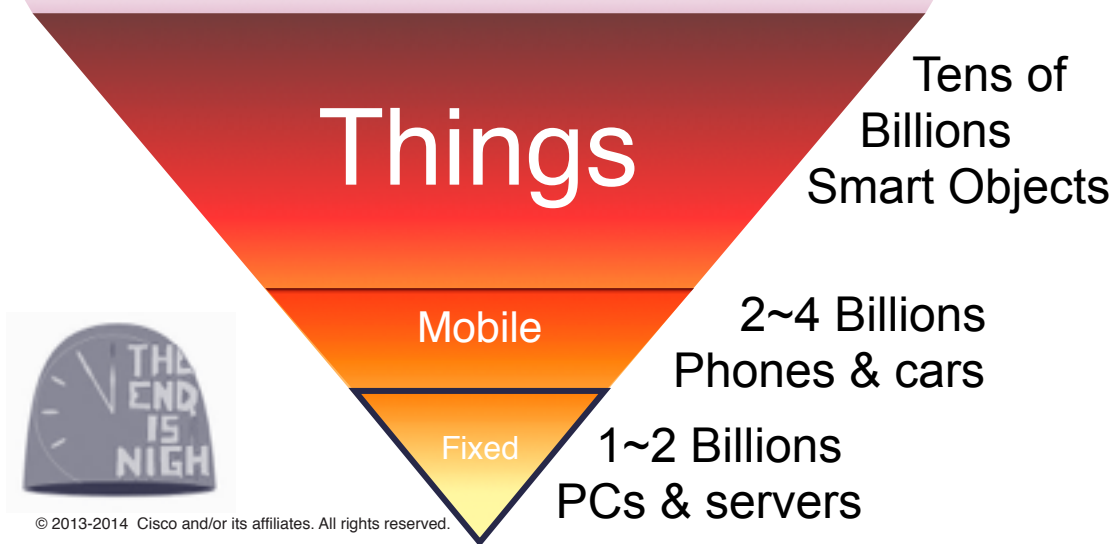
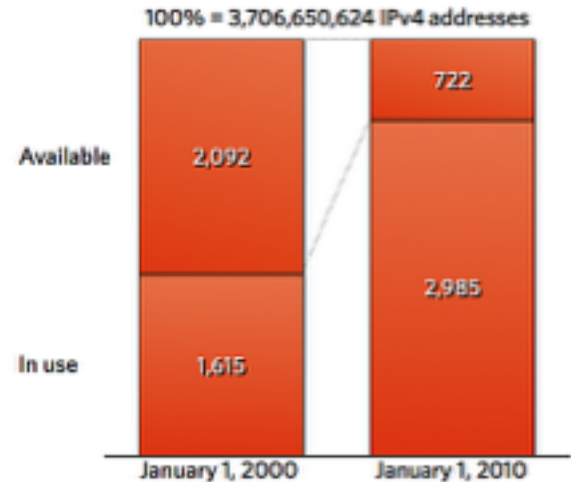
Smart Objects will add tens of billions of additional devices

IPv6 is the only viable way forward



IPv4 Unallocated pool exhausted March 2011 !
RIPE NCC: Sept 2012; ARIN March 2015 (last /8)

IPv4 address utilization: 2000 vs. 2010
 Millions



Agenda

2. Promise/Challenge of wireless

1. Background

2. Low Power Lossy Networks

Wireless: the evolution trait

New level of cost effectiveness

Deploying wire is slow and costly

Low incremental cost per device



Reaching farther out

New types of devices (Internet Of Things)

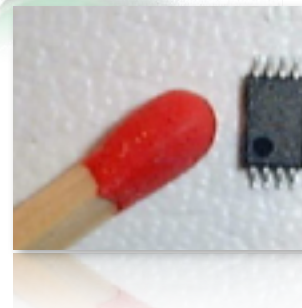
New usages (widespread monitoring, IoE)

Global Coverage from Near Field to Satellite via 3/4G



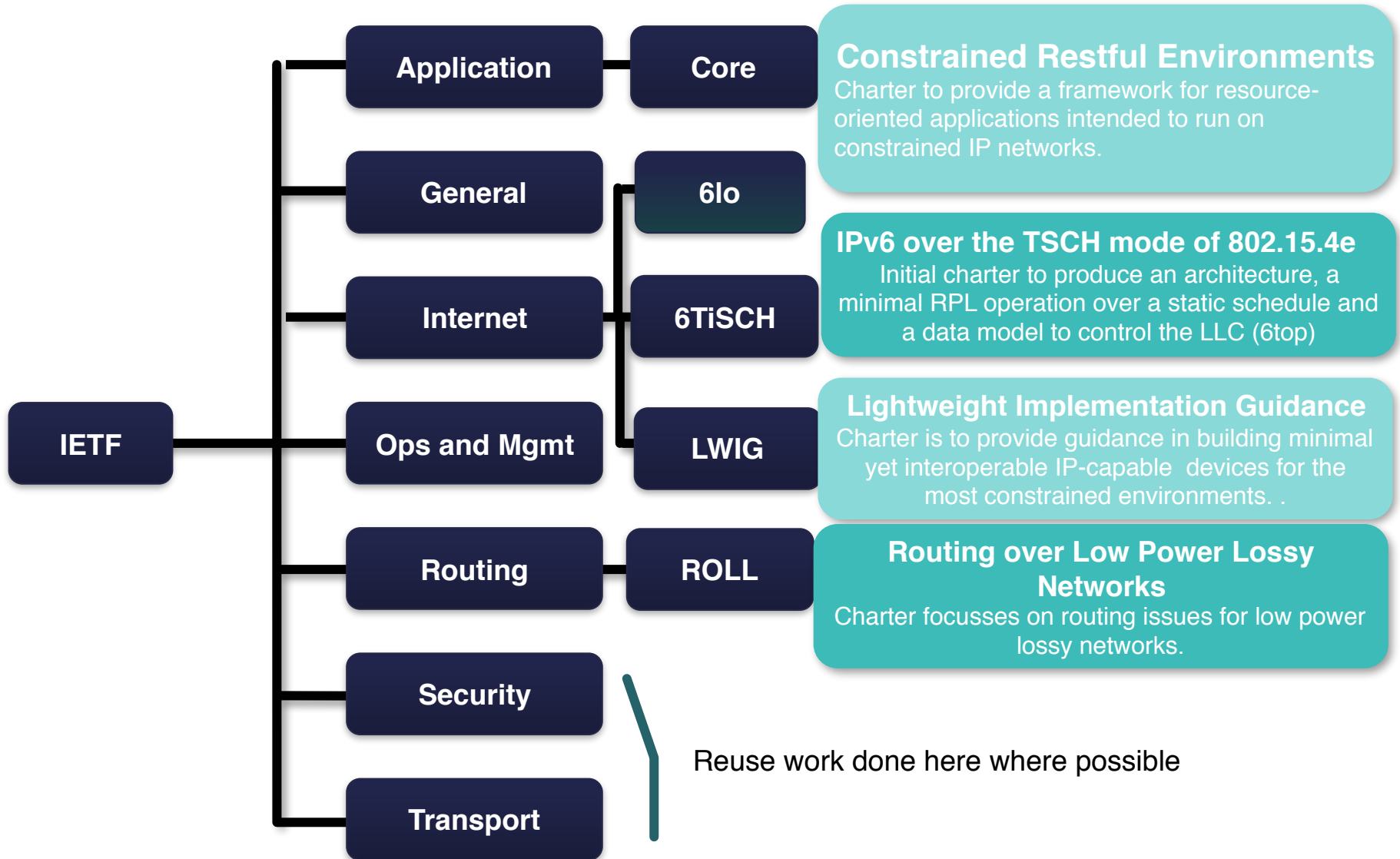
Low Power Lossy Networks

- LLNs comprise a large number of highly constrained devices (smart objects) interconnected by predominantly wireless links of unpredictable quality
- LLNs cover a wide scope of applications
 - Industrial Monitoring, Building Automation, Connected Home, Healthcare, Environmental Monitoring, Urban Sensor Networks, Energy Management, Asset Tracking, Refrigeration
- Several IETF working groups and Industry Alliance addressing LLNs
 - IETF - CoRE, 6Lowpan, ROLL
 - Alliances - IP for Smart Objects Alliance (IPSO)



World's smallest web server

IETF LLN Related Workgroups



Characteristics of LLNs

- LLNs operate with a hard, very small bound on state
- LLNs are optimised for saving energy in the majority of cases
- Traffic patterns can be MP2P, P2P and P2MP flows
- Typically LLNs deployed over link layers with restricted frame-sizes
 - Minimise the time a packet is enroute (in the air/on the wire) hence the small frame size
 - The routing protocol for LLNs should be adapted for such links
- LLN routing protocols must consider efficiency versus generality
 - LLN nodes are typically very conservative in resources

Challenges

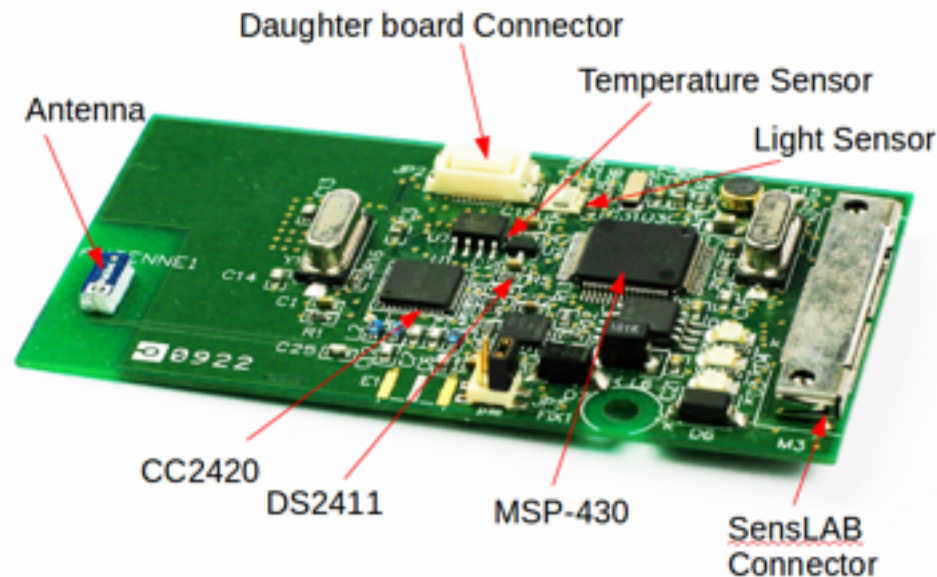
- **Reduce IP impact in term of:**
 - Code size / Energy consumption
 - Collapsed OSI stack.
 - Moore's Law lead to reduce costs not increase capacities.

- **Network topology**
 - Star topology / Meshed

- **Interoperability**

Hardware and physical layers requirements

- Both hardware and Physical Layer should be designed to minimize energy consumption
 - Low-consumption processor (RISC, low frequency)
 - Favor non-volatile memory (e.g. Flash) over RAM
 - Radio coding / modulation not very efficient but interference-resilient to simplify MAC protocol



Hardware and physical layers requirements

Data sheet

	WSN430 v1.3b	WSN430 v1.4
MCU	16-bit Ultra-Low-Power, 48kB Flash, 10kB RAM – MSP430F1611	
sensors	<ul style="list-style-type: none">• Ambient sensor light – TSL2550• Temperature – DS1722	
radio communication	860 MHz, highly configurable – TI CC1101	2.4 GHz, more high level – TI CC2420
external memory	1MB external flash memory ST M25P80	
LEDs	green, red, blue	
EEPROM serial number	allowing unique identifier DS2411	
power	3,7V battery (830mAh)	
Operating-System	FreeRTOS, Contiki, Riot, TinyOS, OpenWSN	

What is the most expensive operation?

Energy:

- Consumption (Tx): 19.5 mA
- Consumption (Rx): 21.8 mA
- Consumption (μ C): 1.8 mA
- Consumption (sens): 54.5 μ A
- Consumption (idle): 5.1 μ A
- Flash reading: 4 mA
- Flash writing: 20 mA

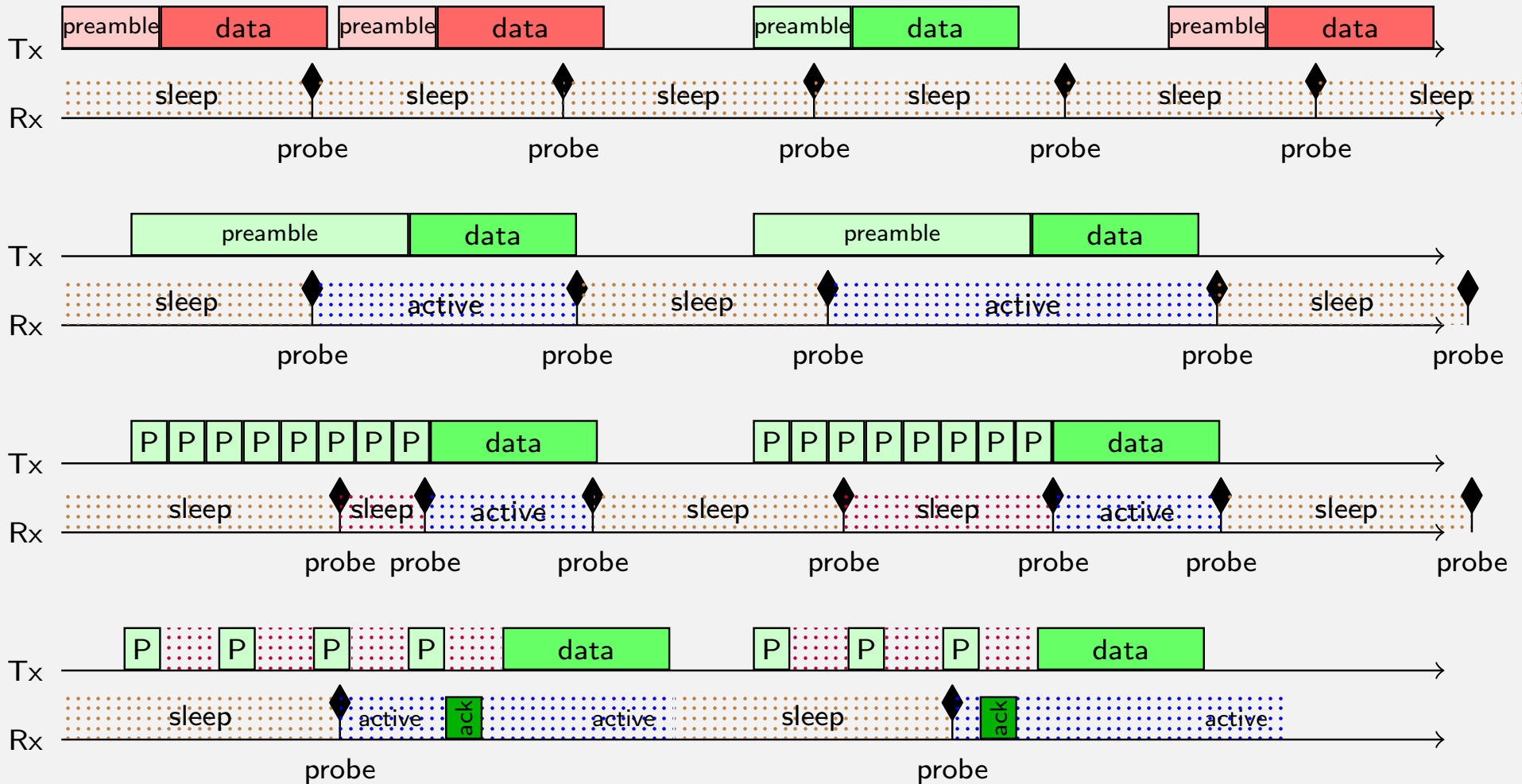
Minimize energy!

- **Asynchronous: Transmit when needed**
 - Can be protected by a CSMA/CA algorithm
 - Minimize delays, but receivers **MUST** listen
- **Synchronous**
 - A Master send Beacon Frame with active and idle times.
 - Each node may also send their schedules to synchronize between themselves.
- **Multi-Channel**
 - Pre assign slots and frequencies for transmissions
 - Not flexible, for deterministic transmissions.

Sleeping receiver.

http://perso.ens-lyon.fr/eric.fleury/Upload/Mosar/mosar_activity_scheduling.swf

Sleeping receiver.



The Evolution of MAC Protocols in Wireless Sensor Networks: A Survey. IEEE COMMUNICATIONS SURVEYS & TUTORIALS, VOL. 15, NO. 1

Low-Power Wireless Challenges

Reliability

Lifetime

T. Watteyne

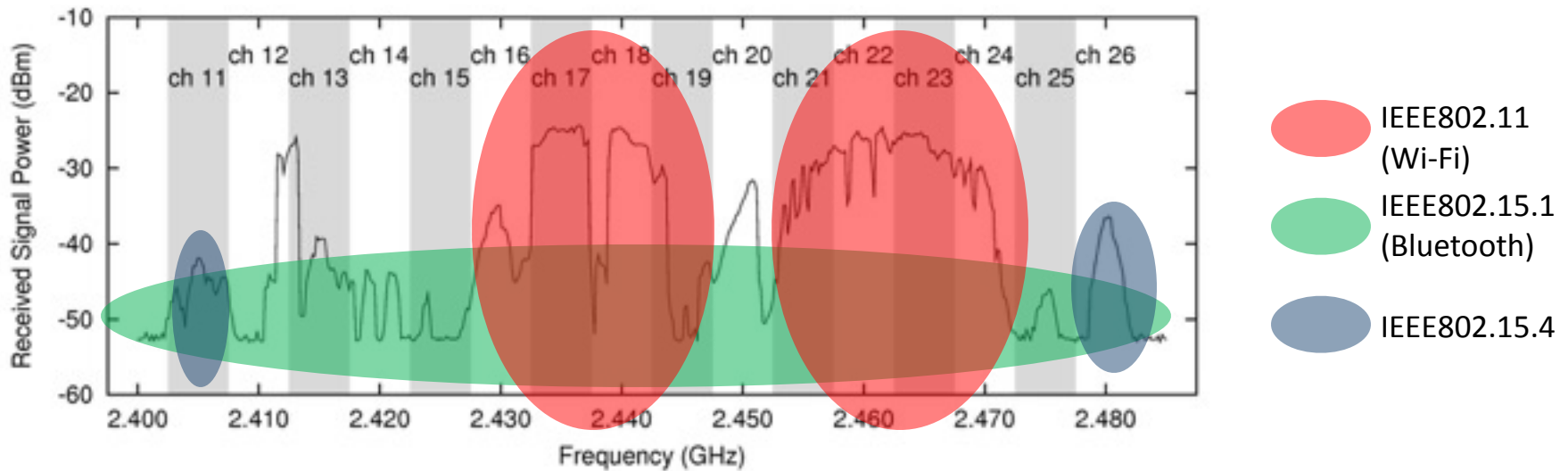
Research Scientist & Innovator, Inria, France

Senior Networking Design Engineer, Dust Networks/Linear Technology, Silicon Valley

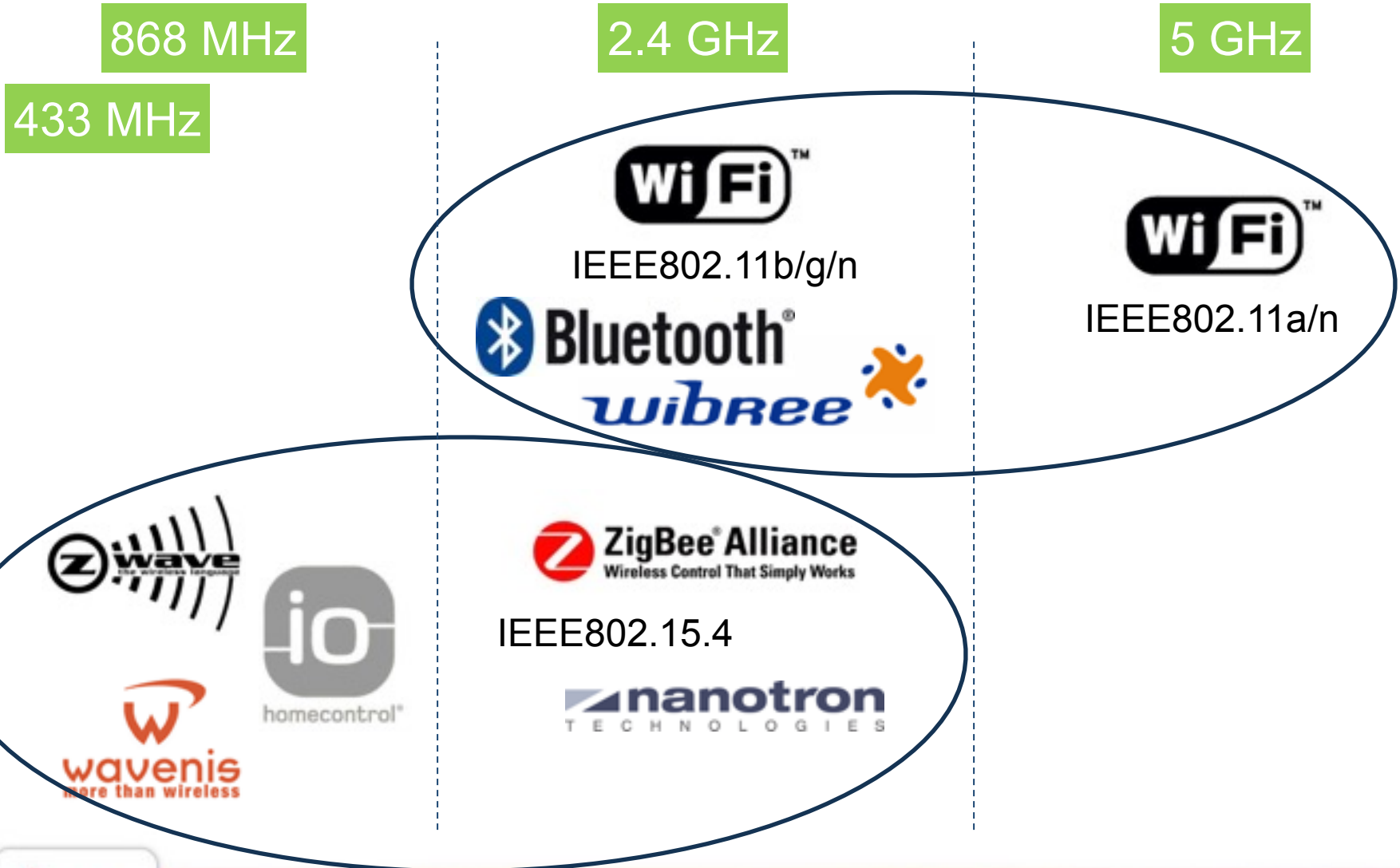
co-chair, IETF 6TiSCH Working Group

IOT360 Summer School September 2015 Rome Italy

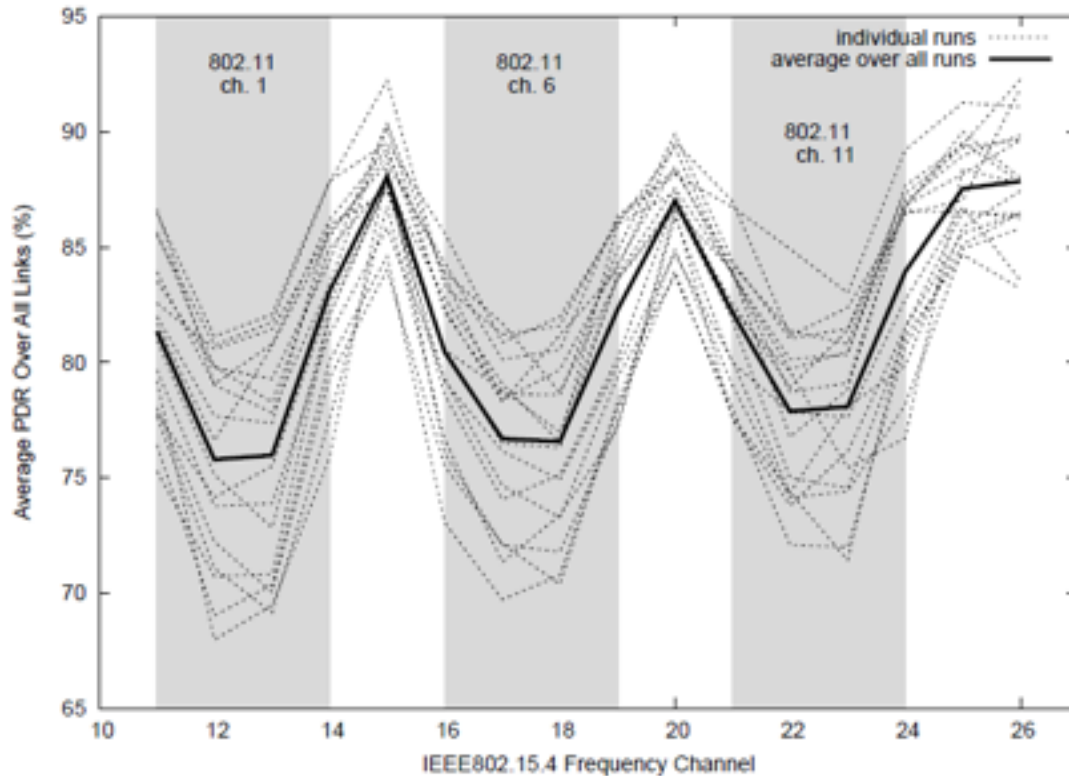
First Challenge: External Interference



First Challenge: External Interference



First Challenge: External Interference

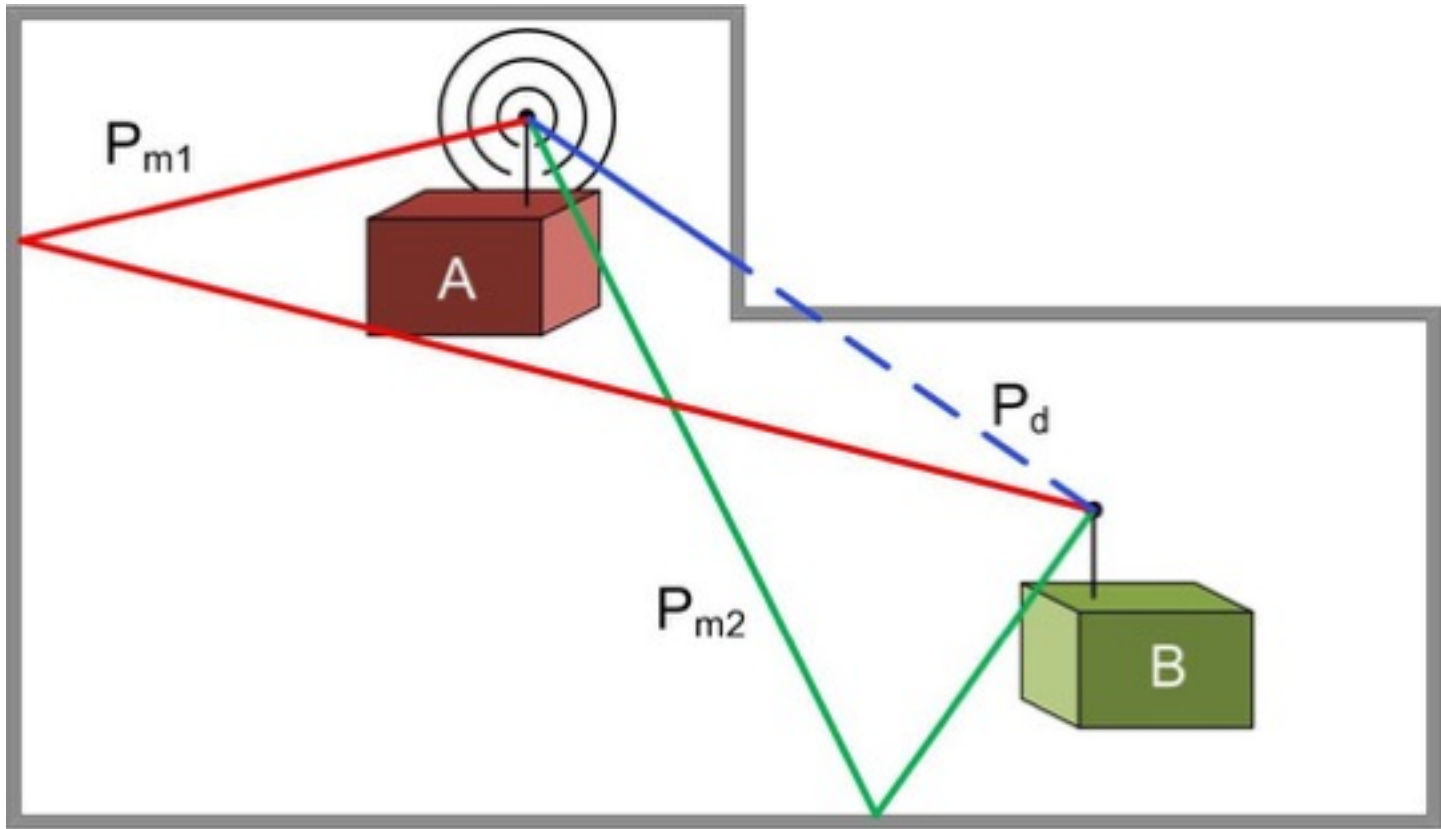


- 45 motes*
- 50x50m office environment
- 12 million packets exchanged, equally over all 16 channels

changing channel improves performance

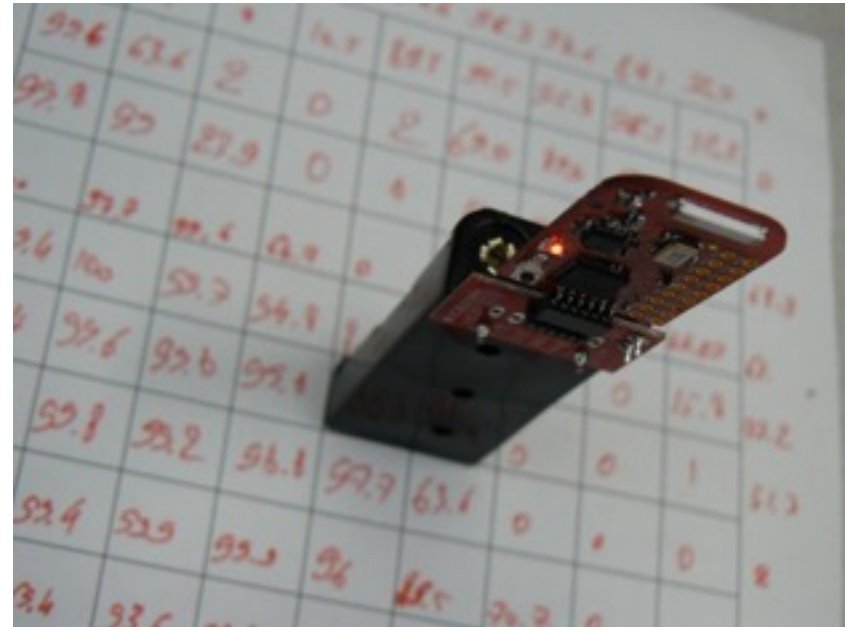
*data collected by Jorge Ortiz and David Culler, UCB

Second Challenge: Multipath Fading

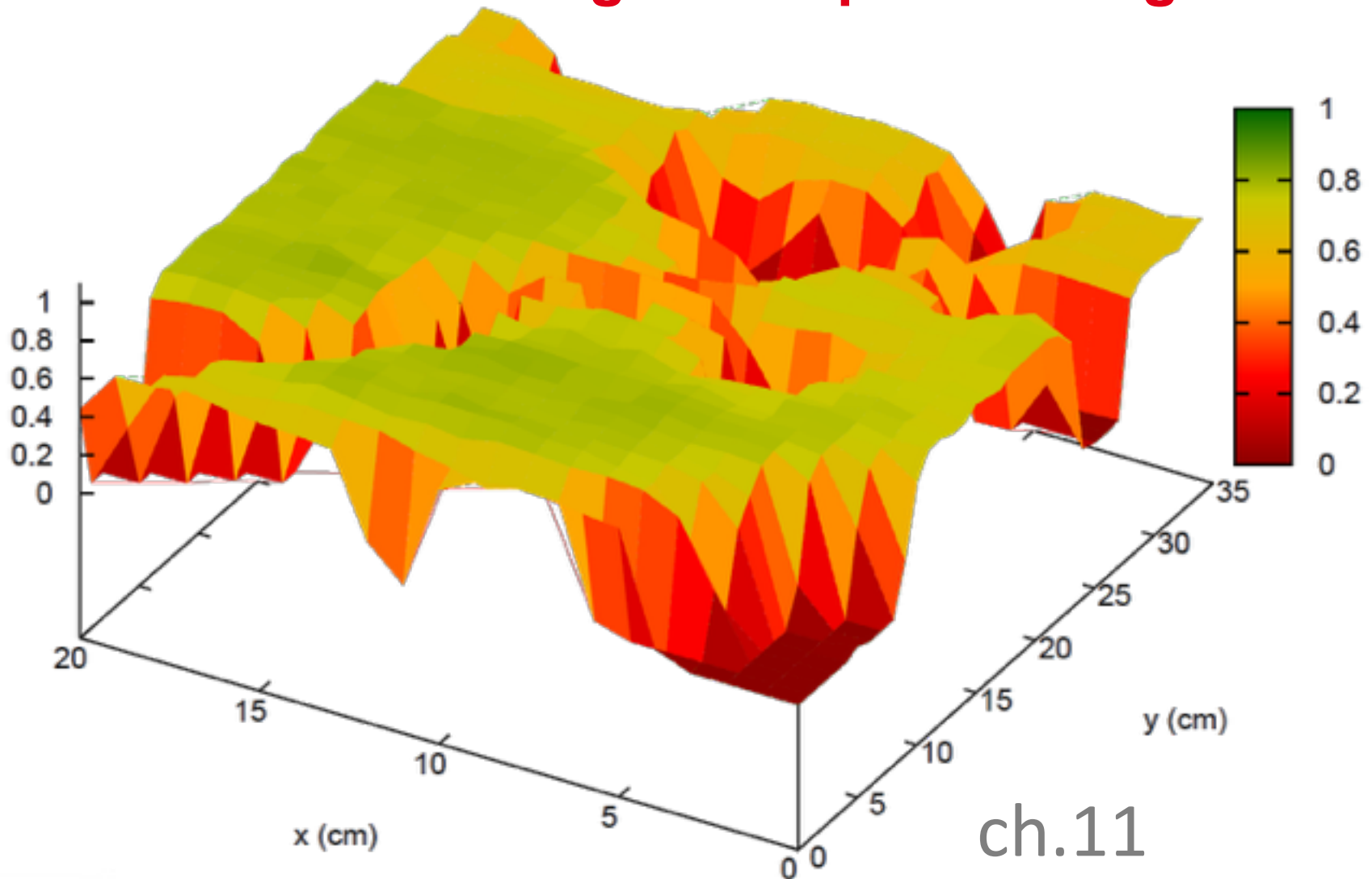


Second Challenge: Multipath Fading

- Separate sender and receiver by 100cm
- Have sender send bursts of 1000 packets
- Have receiver count the number of received packets
- Move transmitter around in a 20cmx35cm square and start over

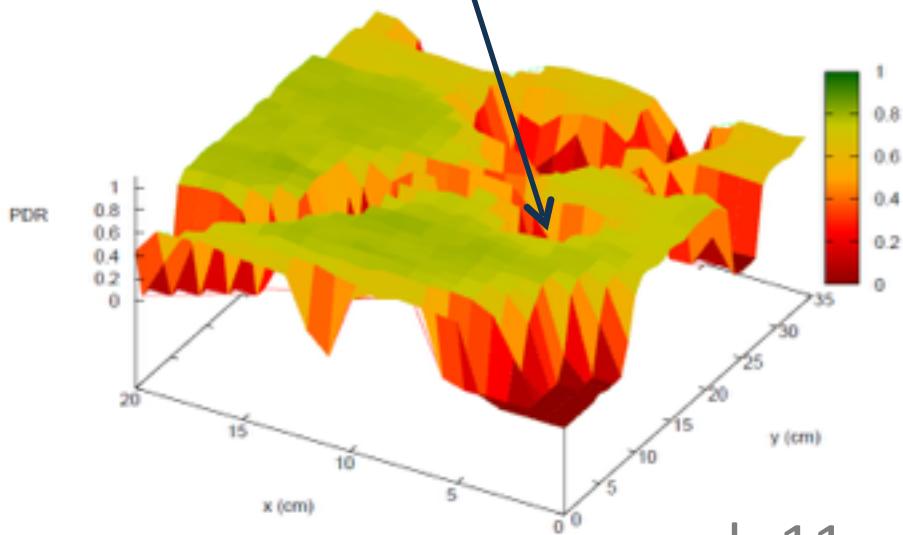


Second Challenge: Multipath Fading



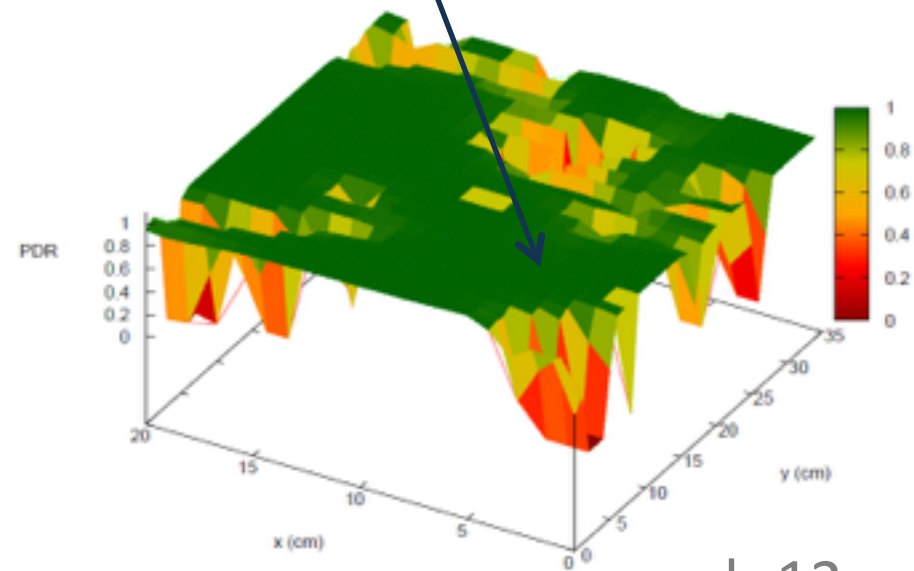
Second Challenge: Multipath Fading

0% reliability



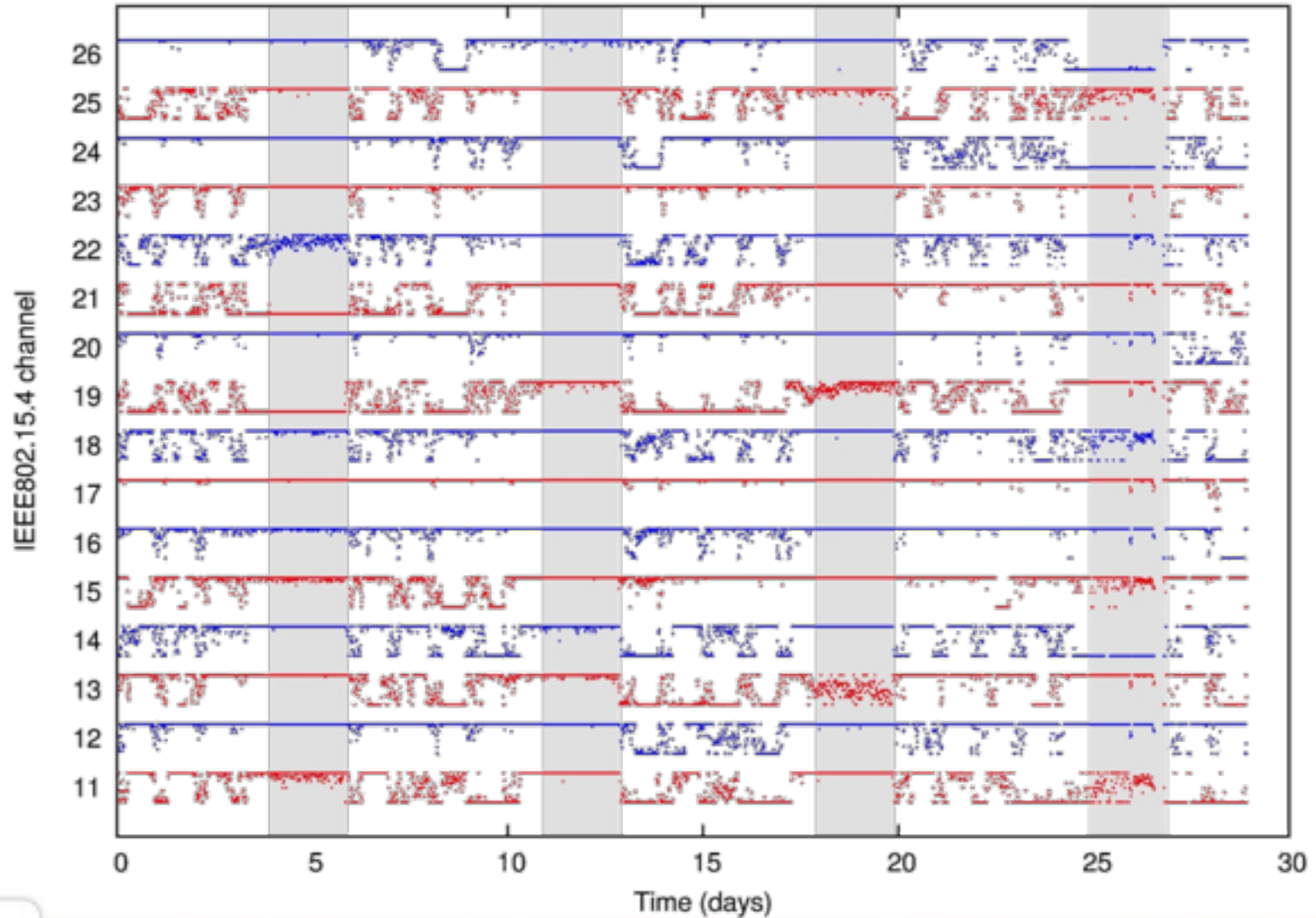
ch.11

100% reliability

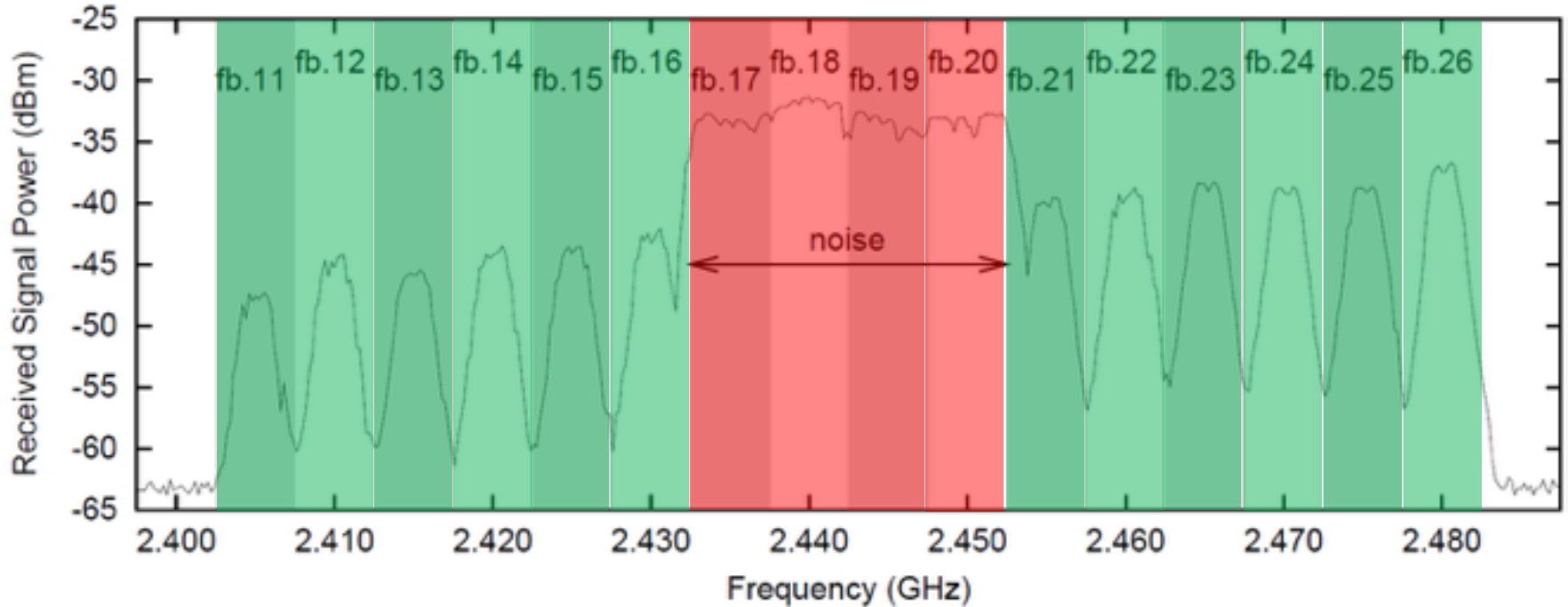


ch.12

16 channels on a single path



Channel Hopping



3

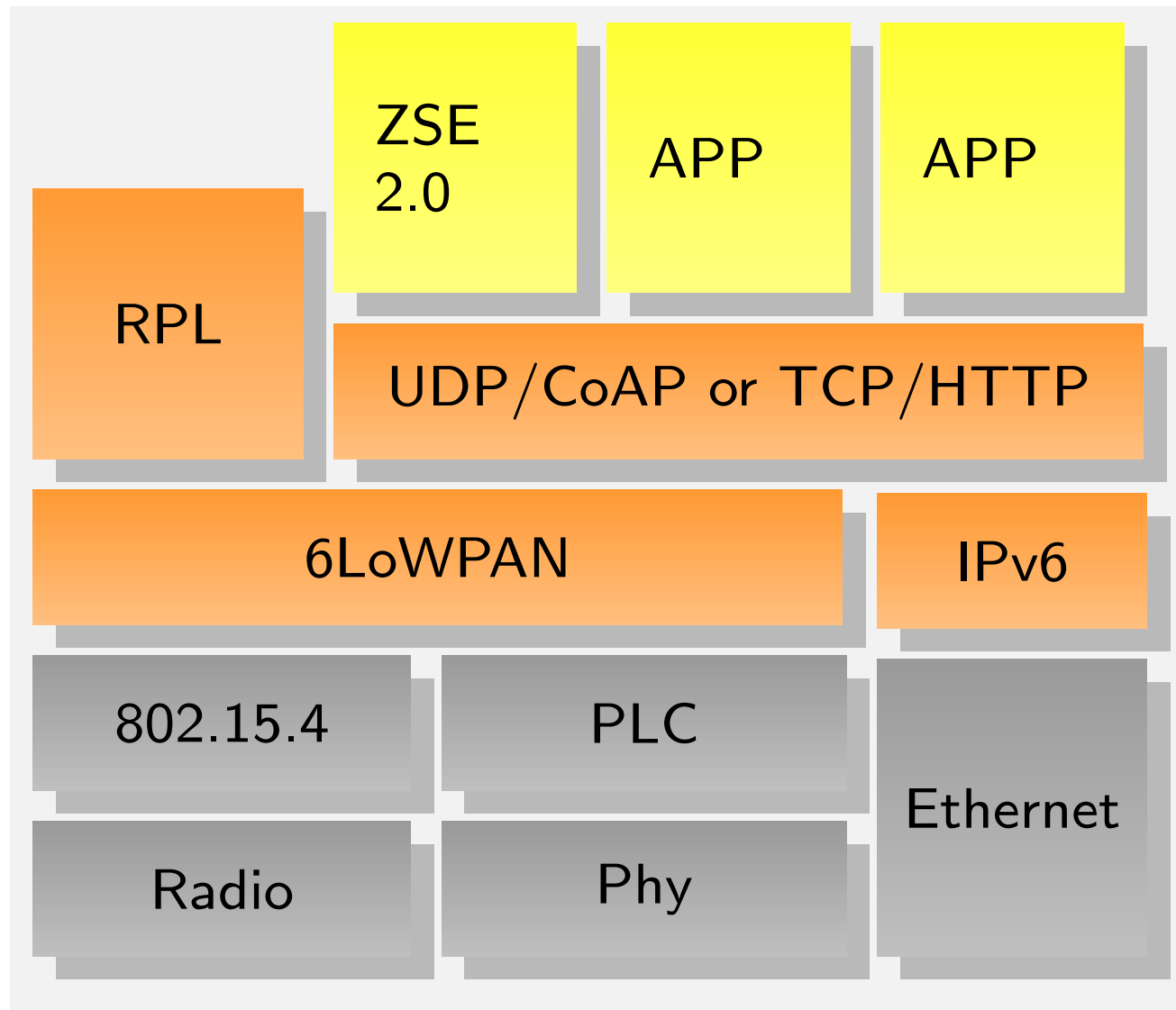
Deep Dive into the layers

Agenda

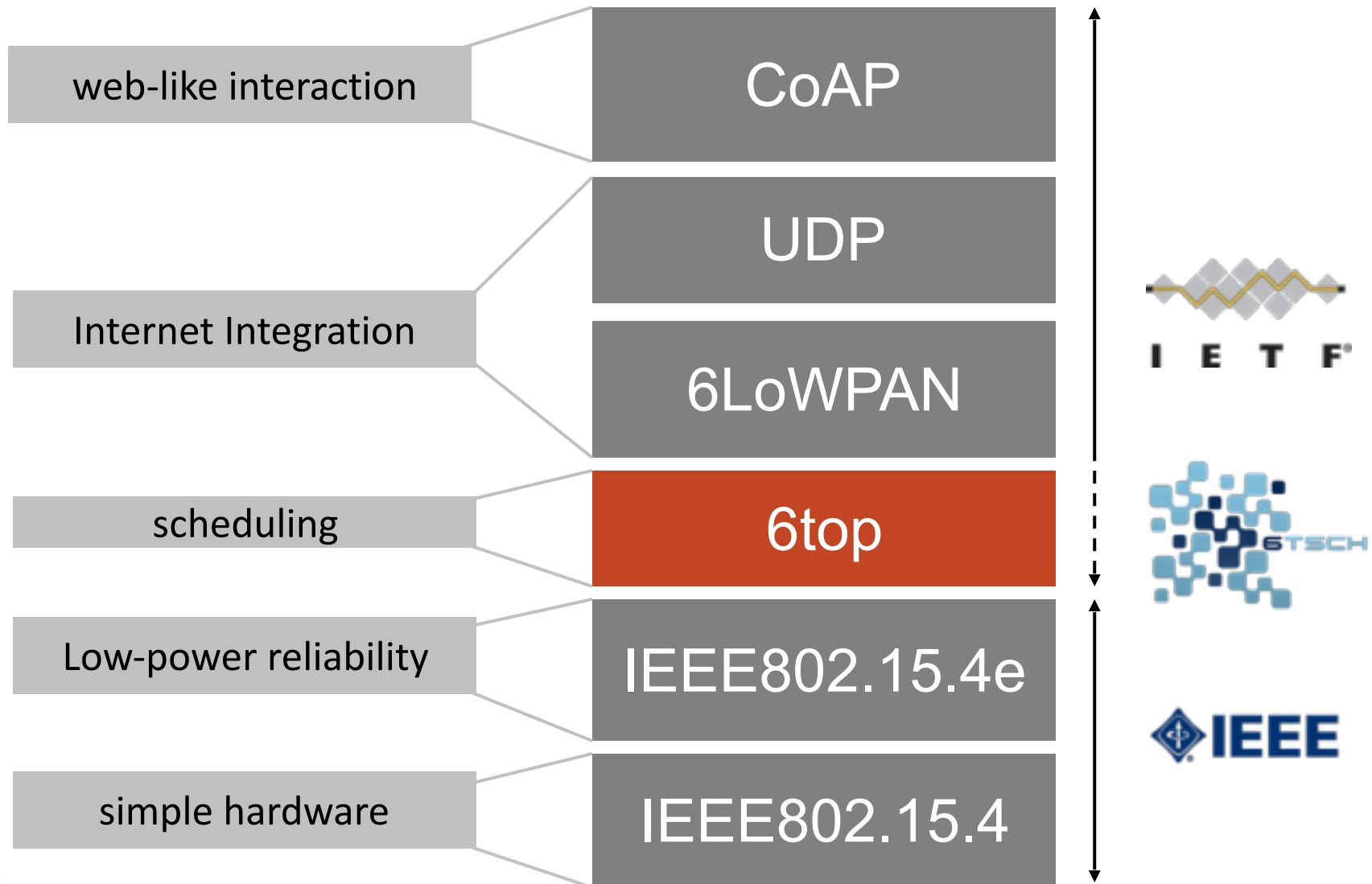
1. Deep Dive into the layers

1. IEEE802.15.4
2. IEEE802.15.4.E
3. 6TSCH
4. 6LOWPAN
5. COAP

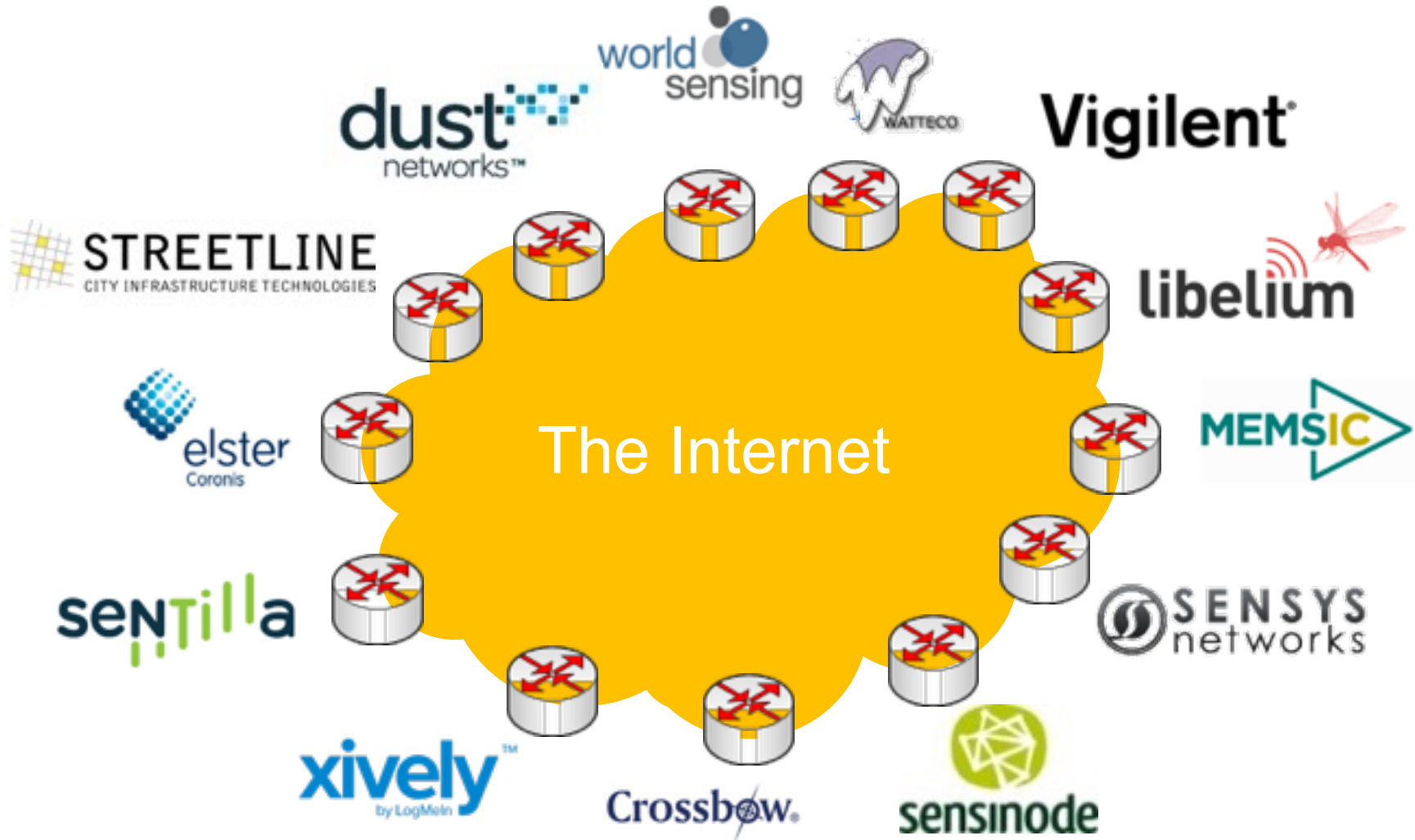
Global overview



The Internet of Things Stack



Why Standardize?



IEEE: Overview

- ~~Institute of Electrical and Electronics Engineers~~
- Standardization through IEEE Standards Association (IEEE-SA)
- IEEE standards affect a wide range of industries:
 - power and energy
 - biomedical and healthcare
 - information technology
 - Telecommunications
 - Transportation
 - nanotechnology, etc.
- IEEE has close to 900 active standards, with 500 standards under development.

IEEE: the 802 “soup”

- 802.1 High Level Interface (HILI) Working Group
- 802.3 CSMA/CD (Ethernet) Working Group
- 802.11 Wireless LAN (WLAN) Working Group
- 802.15 Wireless Personal Area Network (WPAN) Working Group
 - TG1 –WPAN, Bluetooth
 - TG3c – mmWave
 - TG4c - WPAN Alternative PHY for China
 - TG4d - WPAN Alternative PHY for Japan
 - **TG4e - WPAN Enhancements**
 - TG4f – RFID
 - TG4g - Smart Utility Neighborhood
 - TG5 - WPAN Mesh Networking
 - TG6 - Body Area Networks
 - TG7 - Visible Light Communication
- IGthz - Interest Group Terahertz
- WNG - Standing Committee Wireless Next Generation
- 802.16 Broadband Wireless Access (BWA) Working Group
- 802.17 Resilient Packet Ring (RPR) Working Group
- 802.18 Radio Regulatory Technical Advisory Group
- 802.19 Coexistence Technical Advisory Group
- 802.20 Mobile Broadband Wireless Access Working Group
- 802.21 Media Independent Handover Working Group
- 802.22 Wireless Regional Area Networks Working Group



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 WSNs:
 - 6LoWPAN (IPv6 over Low power WPAN)
 - ROLL (Routing Over Low power and Lossy networks)
 - CORE (Constrained RESTful Environments)
 - 6TiSCH (IPv6 over the TSCH mode of IEEE 802.15.4e)

IETF: the RFC “soup”

- RFC760. **1980**. Internet Protocol (IP)
- RFC761. **1980**. Transmission Control Protocol (TCP)
- RFC764. **1980**. Telnet.
- RFC765. **1980**. File Transfer Protocol (FTP)
- RFC768. **1980**. User Datagram Protocol (UDP)
- ...
- RFC1945. **1996**. Hypertext Transfer Protocol (HTTP)
- ...
- RFC2460. **1998**. Internet Protocol version 6 (IPv6)
- ...
- RFC4944. **2007**. Transmission of IPv6 Packets over IEEE 802.15.4 Networks
- RFC6282. **2011**. Compression Format for IPv6 Datagrams over IEEE 802.15.4-Based Networks
- RFC6550. **2012**. RPL: IPv6 Routing Protocol for Low-Power and Lossy Networks
- RFC7252. **2014**. Constrained Application Protocol (CoAP)

IEEE Standard for
Local and metropolitan area networks—

Part 15.4: Low-Rate Wireless Personal Area Networks (LR-WPANs)

Amendment 1: MAC sublayer

IEEE Computer Society

Sponsored by the
LAN/MAN Standards Committee

IEEE
3 Park Avenue
New York, NY 10016-5997
USA

16 April 2012

IEEE Std 802.15.4e™-2012
(Amendment to
IEEE Std 802.15.4™-2011)

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6
7 Internet Engineering Task Force (IETF) ..... J. Bai, Ed.
8 Request for Comments: 6282 ..... Aroh Book Corporation
9 Update: 4944 ..... P. Thibert
10 Category: Standards Track ..... Cisco
11 ISSN: 2070-1721 ..... September 2011
12
13
14 ..... Compression Format for IPv6 Datagrams
15 ..... over IEEE 802.15.4-Based Networks
16
17 Abstract
18
19 --- This document updates RFC 4944, "Transmission of IPv6 Packets over
20 --- IEEE 802.15.4 Networks". This document specifies an IPv6 header
21 --- compression format for IPv6 packet delivery in Low Power Wireless
22 --- Personal Area Networks (6LoWPANs). The compression format relies on
23 --- shared context to allow compression of arbitrary prefixes. How the
24 --- information is maintained in that shared context is out of scope.
25 --- This document specifies compression of multicast addresses and a
26 --- framework for compressing next headers. UDP header compression is
27 --- specified within this framework.
28
29 Status of This Memo
30
31 --- This is an Internet Standards Track document.
32
33 --- This document is a product of the Internet Engineering Task Force
34 --- (IETF). It represents the consensus of the IETF community. It has
35 --- received public review and has been approved for publication by the
36 --- Internet Engineering Steering Group (IESG). Further information on
37 --- Internet Standards is available in Section 2 of RFC 5741.
38
39 --- Information about the current status of this document, any errata,
40 --- and how to provide feedback on it may be obtained at
41 --- http://www.rfc-editor.org/info/rfc6282.
42
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length: 52500  lines: 1340  Ln: 1  Col: 1  Sel: 0:0  UNI  ANSI as UTF-8  IN
  
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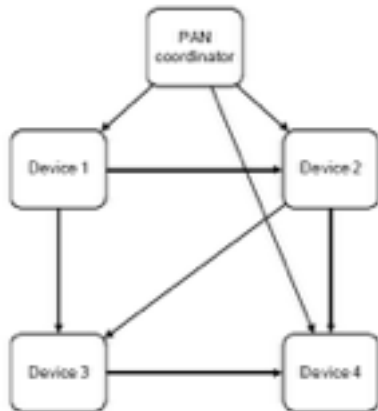


Figure 22a—Example of possible time propagation in a TSCH PAN

As shown in Figure 22a, the coordinator starts at time $T = 0$ from the transmitting device's perspective. The transmitter waits macTxCCAOffset μs , and then performs CCA (if active). At macTxOffset μs , the device begins transmitting the frame. If an acknowledgment is expected, the device waits macTxAckDelay μs , and then enables the receiver to await the acknowledgment. If the acknowledgment does not arrive within macTxAckWait μs , the device may idle the radio and consider the transmission a failure. If an acknowledgment is expected, the transmitter may idle the radio after sending the frame.

On the receiver's side, at its estimate of $T = 0$ it waits macRxOffset μs and then goes into receive mode for macRxWait μs . If the frame has not started by that time, it may idle the receiver. Otherwise, once the frame has been received, the receiver waits macRxAckDelay μs and then sends an acknowledgment.

The transmitter or receiver may synchronize clocks as described in 5.1.4.2a.2.

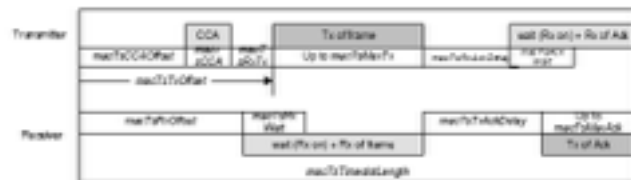


Figure 22b—Timeslot diagram of acknowledged transmission

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draft-thabert-6tsch-architecture-01.tex

294
295 Internet-Draft - 6tsch-architecture - April 2013
296
297
298
299 External Network
300
301
302 Router Router Router
303
304
305
306 Subnet Backbone
307
308
309
310 Backbone Backbone Backbone
311 Router Router Router
312
313
314
315
316
317
318 The main architectural blocks are arranged as follows:
319
320
321 IPCEP CoAP PANA 6LoWPAN RPL
322 PCC DTLS ND
323
324 TCP UDP ICMP RSVP
325
326 IPv6
327
328 6LoWPAN HC
329
330 6TUS
331
332 802.15.4e TSCH
333
334
335 RPL is the routing protocol of choice for LLNs. (TBD RPL) whether
336 there is a need to define a 6TUS OF,
337
338 (TBD NRE) CORAN is working on network Management for LLN. They are

length: 27095 lines: 706 Lx: 270 Cx: 15 Sx: 0 | 0 Macintosh ANSI as UTF-8 PNG

Agenda

1. Deep Dive into the layers

1. IEEE802.15.4

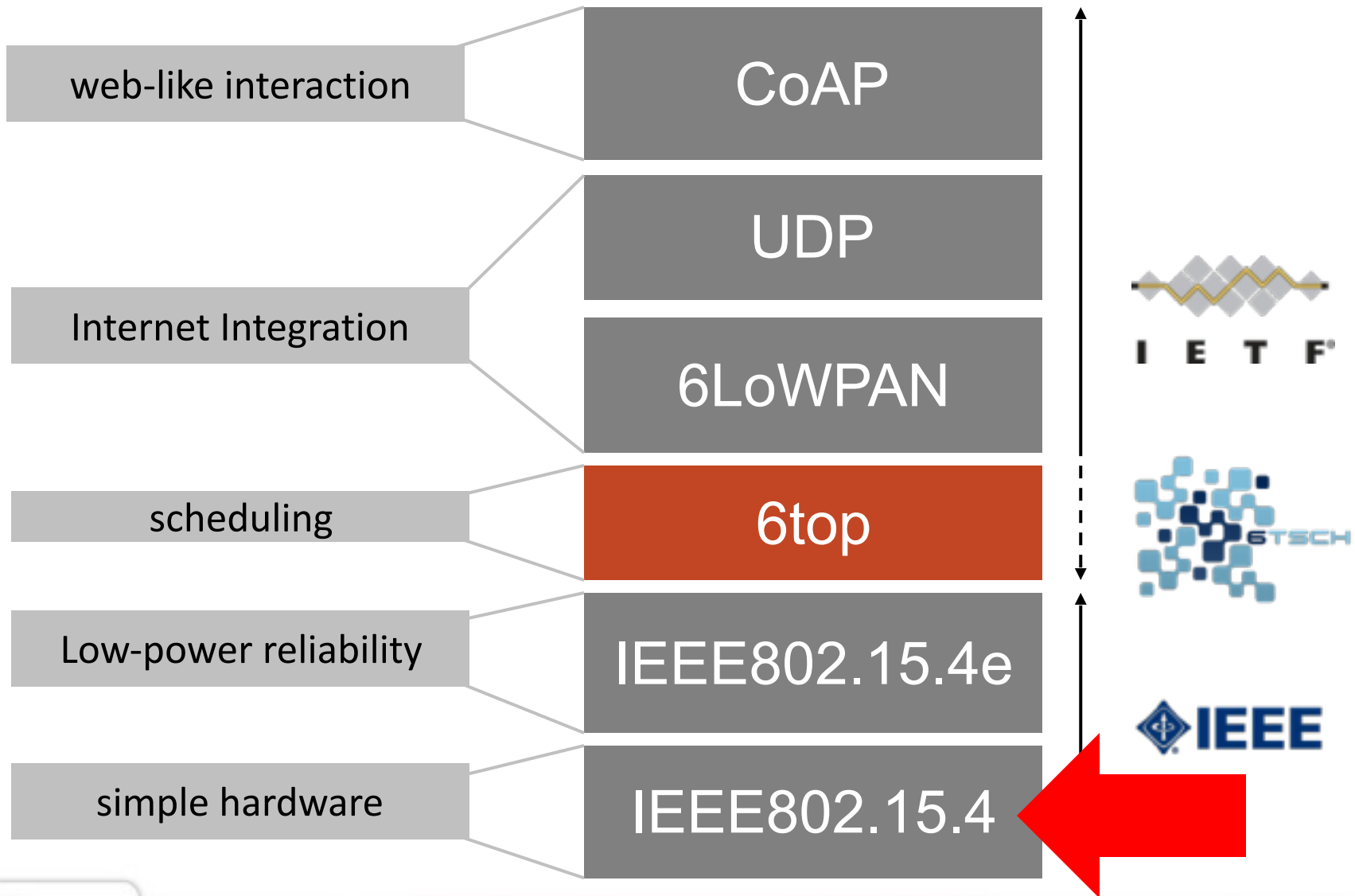
2. IEEE802.15.4.E

3. 6TSCH

4. 6LOWPAN

5. COAP

The Internet of Things Stack



IEEE802.15.4

- Standard by the IEEE:
 - Physical and MAC layer
 - Revisions: 2003, 2006, 2011
 - Typical use:
 - 2.4GHz band
 - 250 kbps (DSSS, O-QPSK)
 - 0dBm to +8dBm typical
 - Indoor range: 10's m
 - **at most 127 bytes per frame**
- Power consumption:
 - TX @ 0dBm: 5mA to 20mA
 - RX: 5mA to 20mA
 - Battery lifetime:
 - From a week to a decade
 - Radio consumption
 - Radio duty cycle

802.15.4 Scope



Initial activities focused on wearable devices
“Personal Area Networks”

Activities have proven to be much more
diverse and varied

- Data rates from Kb/s to Gb/s
- Ranges from tens of metres up to a
Kilometre
- Frequencies from MHz to THz
- Various applications not necessarily
IP based

Focus is on “specialty”, typically short range,
communications

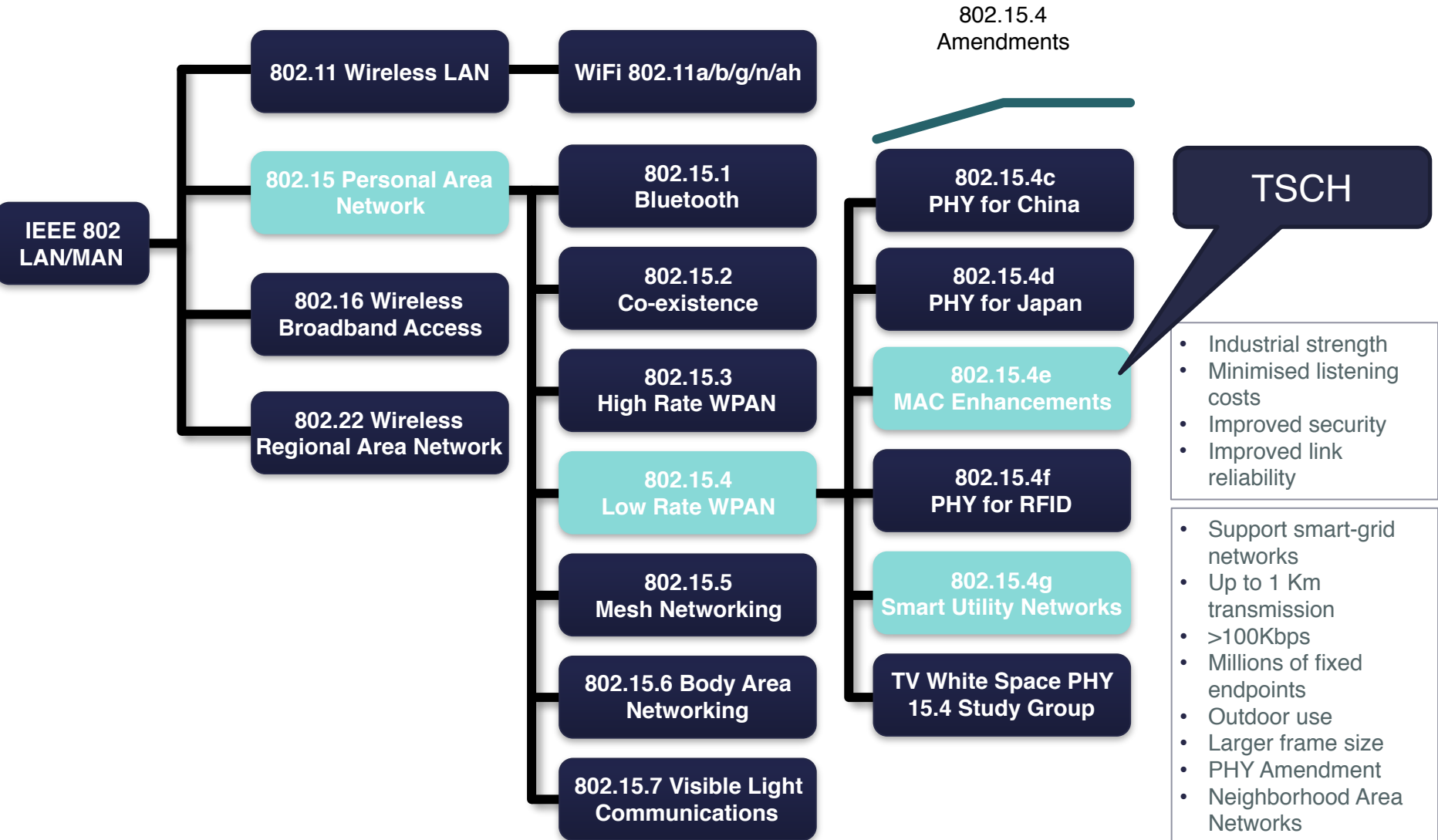
- If it is wireless and not a LAN, MAN,
RAN, or WAN, it is likely to be
802.15 (PAN)

The only IEEE 802 Working Group with
multiple MACs

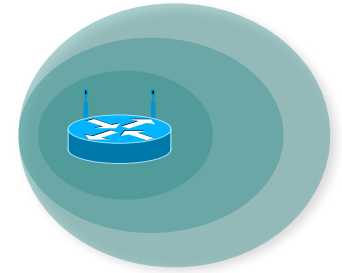
<http://www.ieee802.org/15/pub/TG4.html>
IEEE 802.15 WPAN™ Task Group 4 (TG4) Charter

“The IEEE 802.15 TG4 was chartered to investigate a low data rate solution with multi-month to multi-year battery life and very low complexity. It is operating in an unlicensed, international frequency band. Potential applications are sensors, interactive toys, smart badges, remote controls, and home automation.”

IEEE Wireless Standards



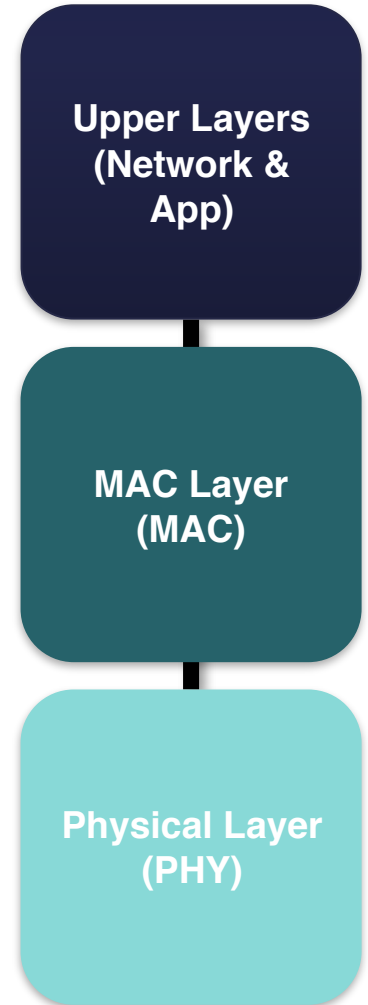
IEEE 802.15.4 Features



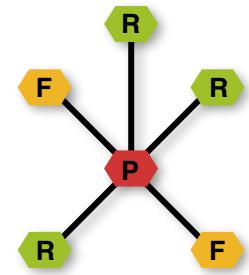
- Designed for low bandwidth, low transmit power, small frame size
 - More limited than other WPAN technologies such as Bluetooth
 - Basic packet size is 127 bytes (802.15.4g is up to 2047 bytes) (Smaller packets, less errors)
 - Transmission Range varies (802.15.4g is up to 1km)
- Fully acknowledged protocol for transfer reliability
- Data rates of 851, 250, 100, 40 and 20 kbps (IEEE 802.15.4-2011 05-Sep-2011)
 - Frequency and coding dependent
- Two addressing modes; 16-bit short (local allocation) and 64-bit IEEE (unique global)
- Several frequency bands (Different PHYs)
 - Europe 868-868.8 MHz – 3 chans , USA 902-928 MHz – 30 chans, World 2400-2483.5 MHz – 16 chans
 - China - 314–316 MHz, 430–434 MHz, and 779–787 MHz Japan - 920 MHz
- Security Modes: None, ACL only, Secured Mode (using AES-CCM mode)
- 802.15.4e multiple modes including **Time Synchronized Channel Hopping (TSCH)**

802.15.4 Protocol Stack

- Specifies PHY and MAC only
- **Medium Access Control Sub-Layer (MAC)**
 - Responsible for reliable communication between two devices
 - Data framing and validation of RX frames
 - Device addressing
 - Channel access management
 - Device association/disassociation
 - Sending ACK frames
- **Physical Layer (PHY)**
 - Provides bit stream air transmission
 - Activation/Deactivation of radio transceiver
 - Frequency channel tuning
 - Carrier sensing
 - Received signal strength indication (RSSI)
 - Link Quality Indicator (LQI)
 - Data coding and modulation, Error correction



IEEE 802.15.4 Node Types

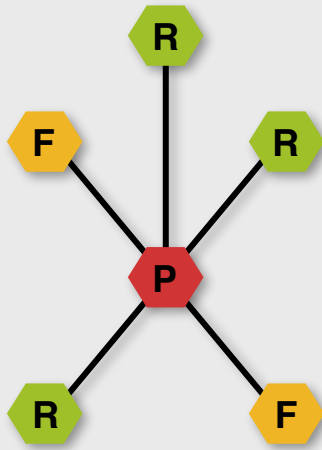


- **Full Function Device (FFD)**
 - Can operate as a PAN co-ordinator (allocates local addresses, gateway to other PANs)
 - Can communicate with any other device (FFD or RFD)
 - Ability to relay messages (PAN co-ordinator)
- **Reduced Function Device (RFD)**
 - Very simple device, modest resource requirements
 - Can only communicate with FFD
 - Intended for extremely simple applications

IEEE 802.15.4 Topologies

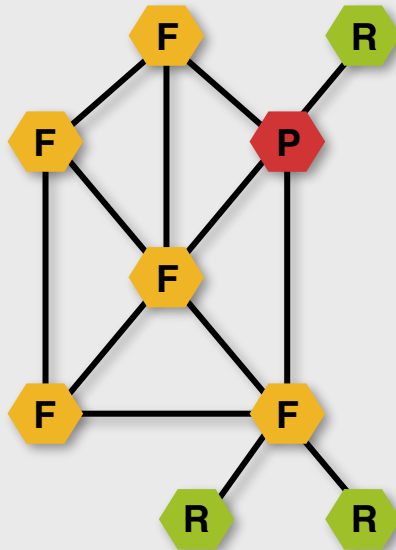
Operates at Layer 2

• Star Topology



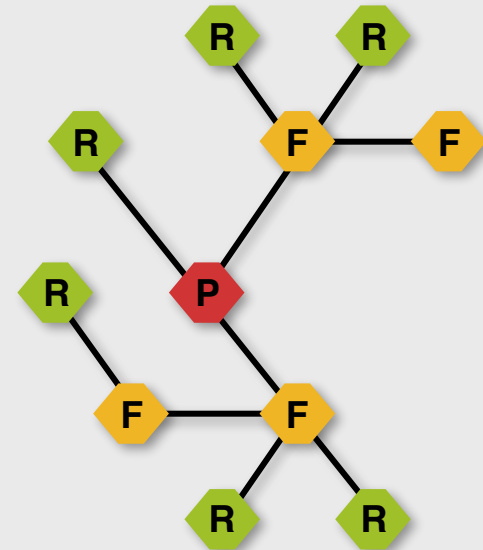
- All devices communicate to PAN co-ordinator which uses mains power
- Other devices can be battery/scavenger

• Mesh Topology



- Devices can communicate directly if within range

• Cluster Tree



- Higher layer protocols like RPL may create their own topology that do not follow 802.15.4 topologies

Single PAN co-ordinator exists for all topologies

Agenda

1. Deep Dive into the layers

1. IEEE802.15.4

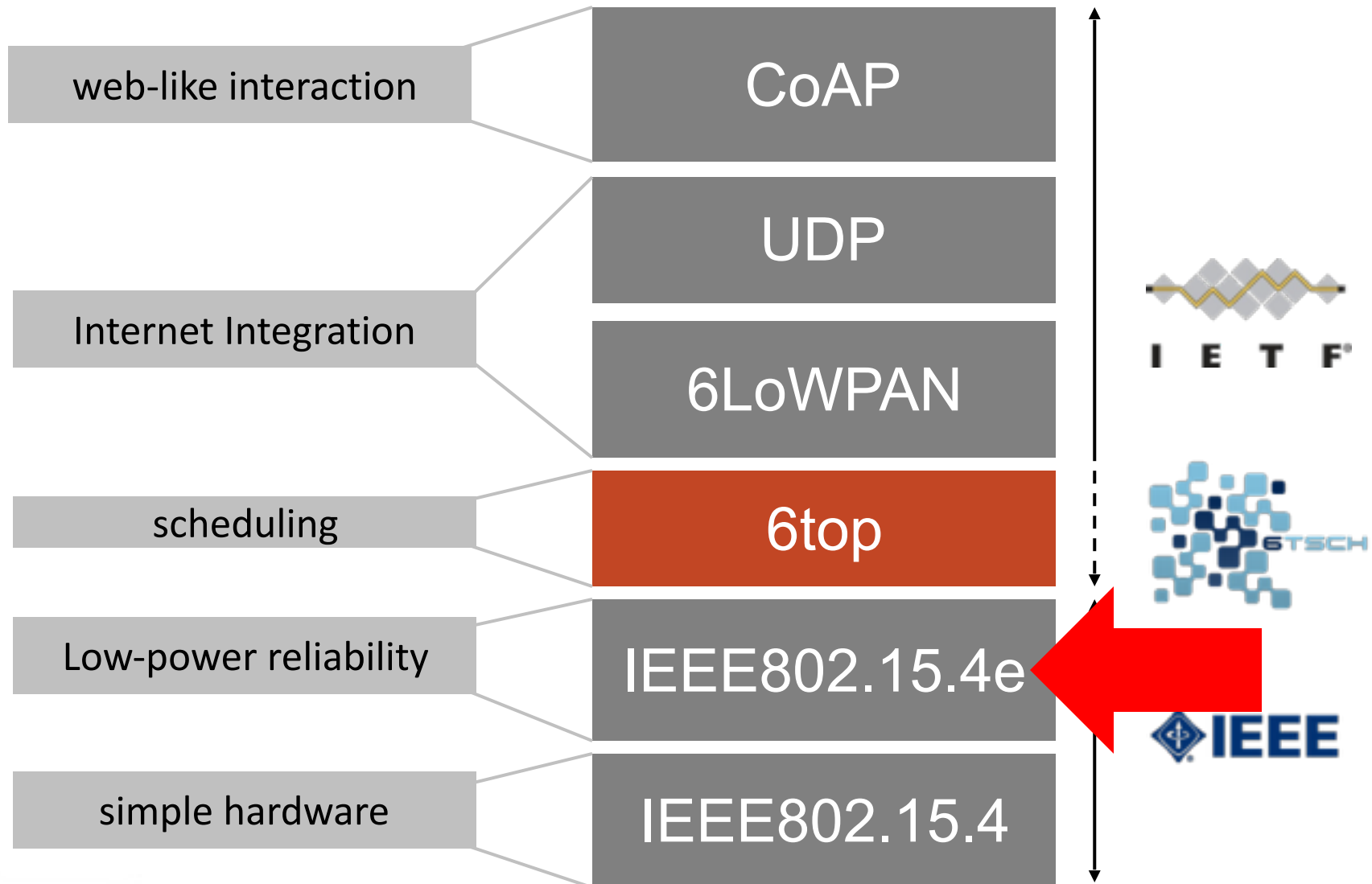
2. IEEE802.15.4.E

3. 6TSCH

4. 6LOWPAN

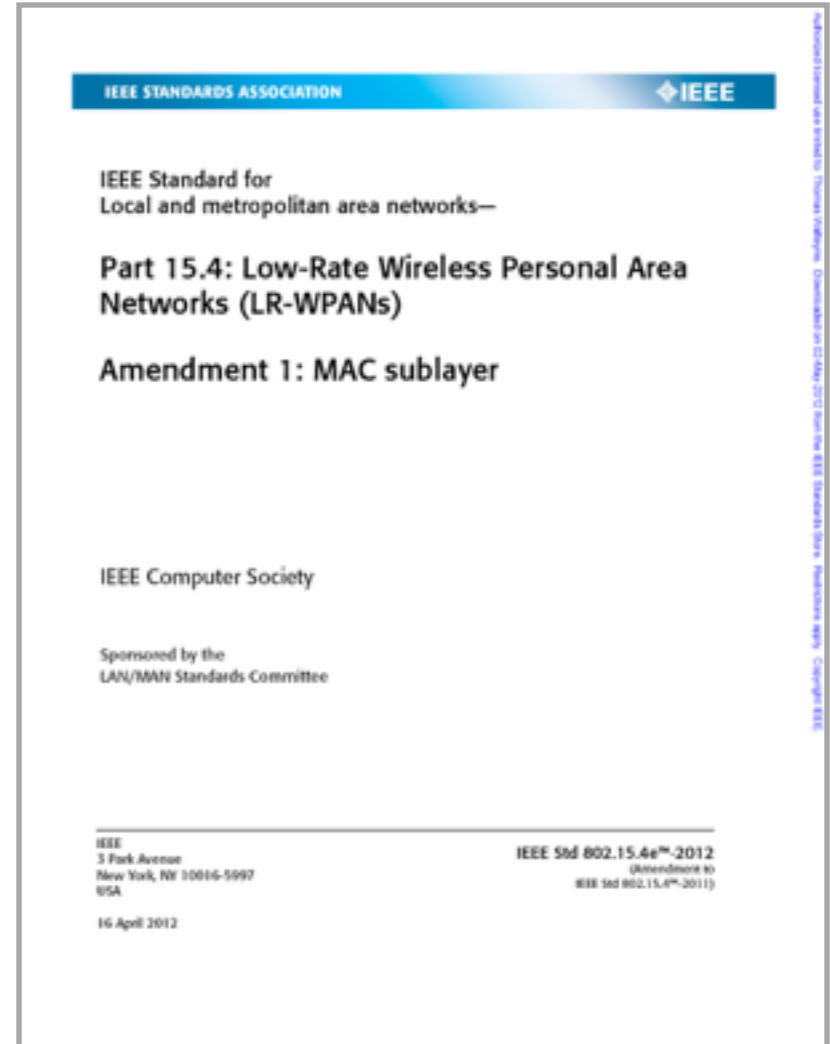
5. COAP

The Internet of Things Stack



IEEE802.15.4e: Status

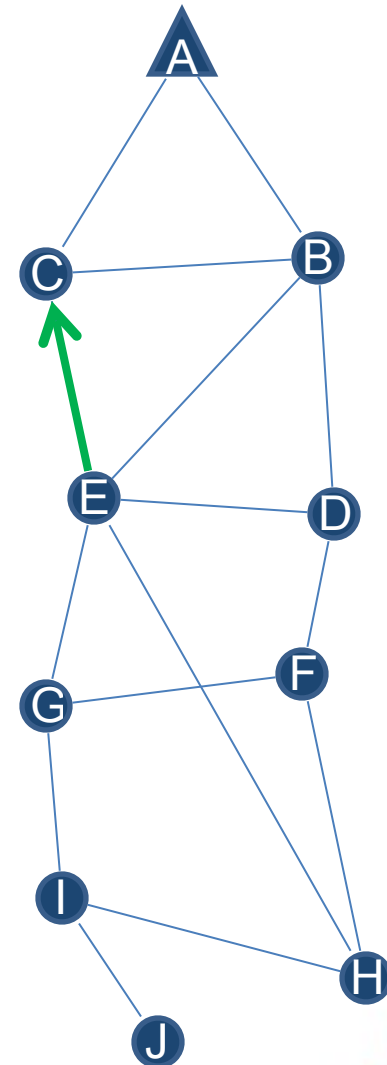
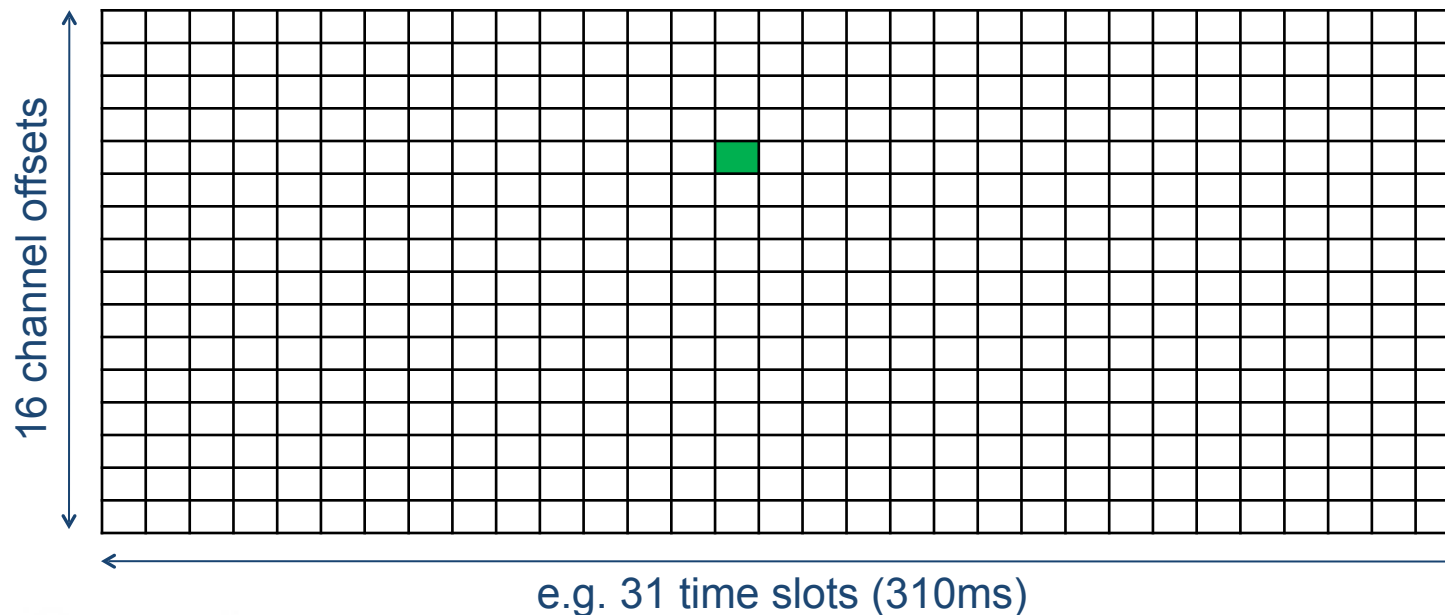
- Published 16 April 2012
- Only amends MAC layer of IEEE 802.15.4-2011:
 - Does not modify PHY layer
 - “Timeslotted Channel Hopping” (TSCH) mode:
 - Ultra low-power operation by synchronizing nodes
 - Ultra high reliability through channel hopping



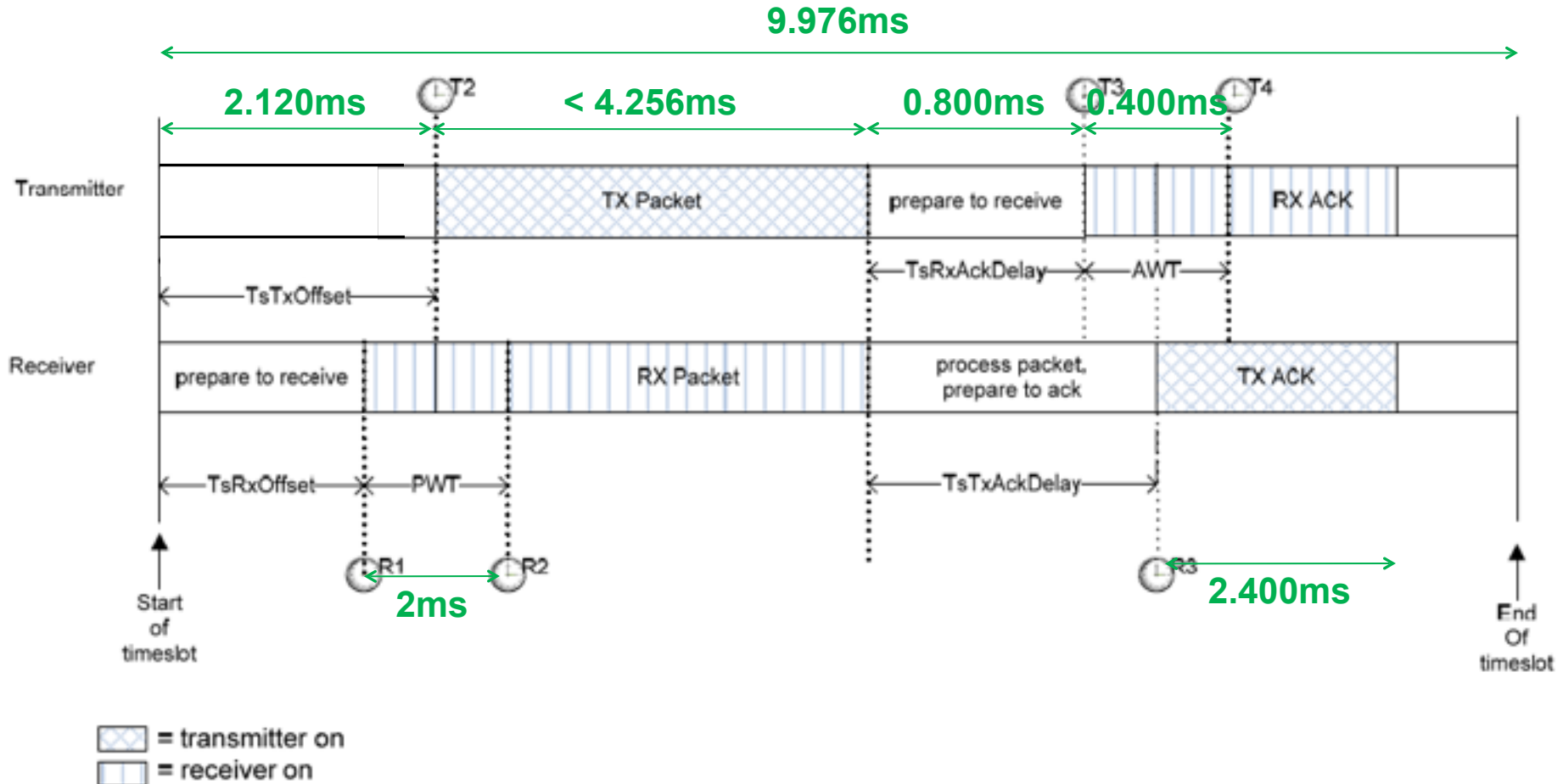
IEEE802.15.4e: Communication Schedule

A super-frame repeats over time

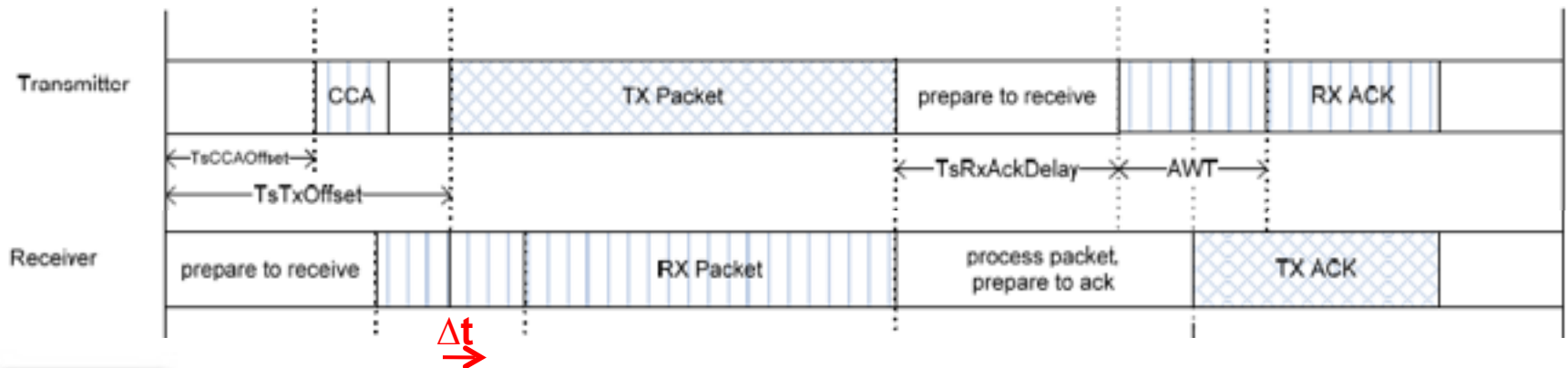
- Number of slots in a superframe is tunable
- Each cell can be assigned to a pair of motes, in a given direction



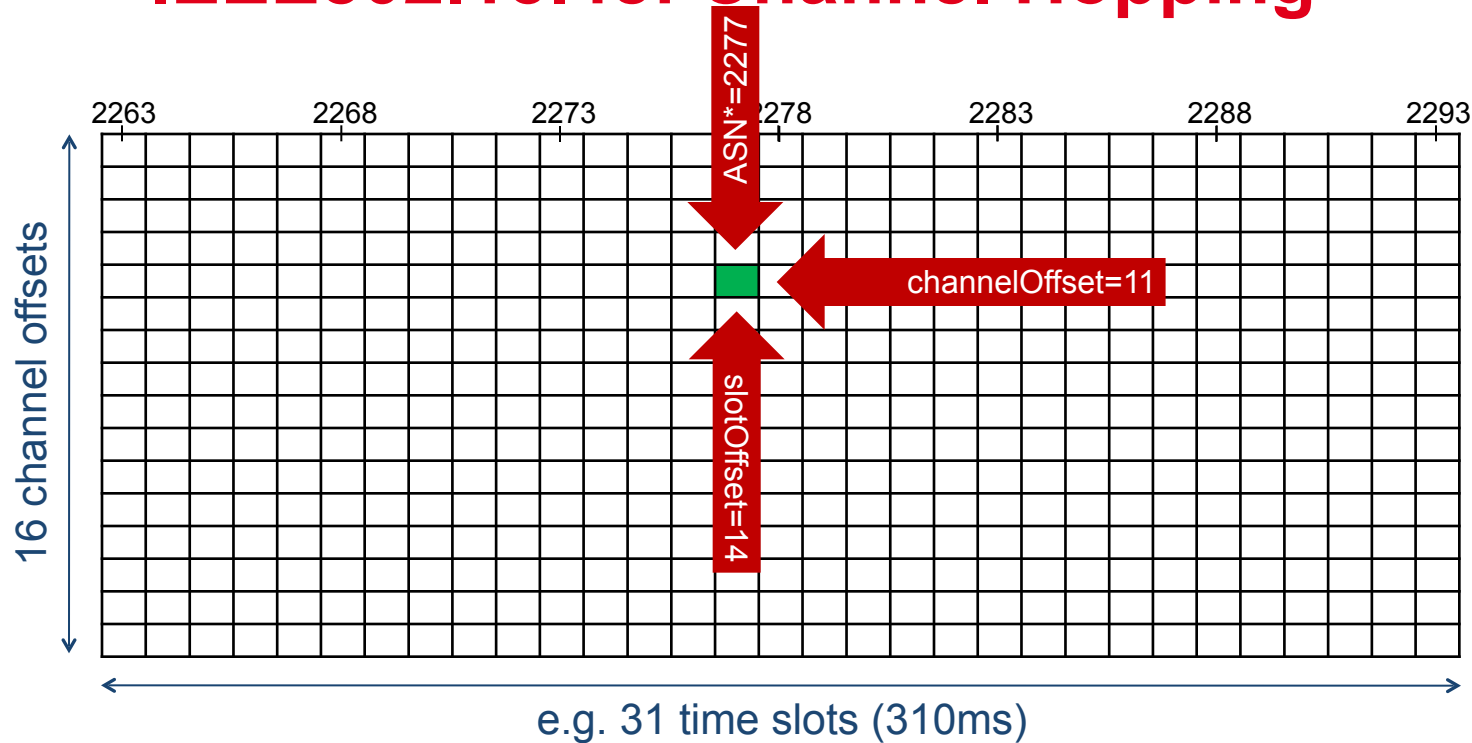
IEEE802.15.4e : a Slot



IEEE802.15.4e: Synchronization



IEEE802.15.4e: Channel Hopping



$$\text{frequencyChannel} = (\text{channelOffset} + \text{ASN}) \% 16 + 11$$

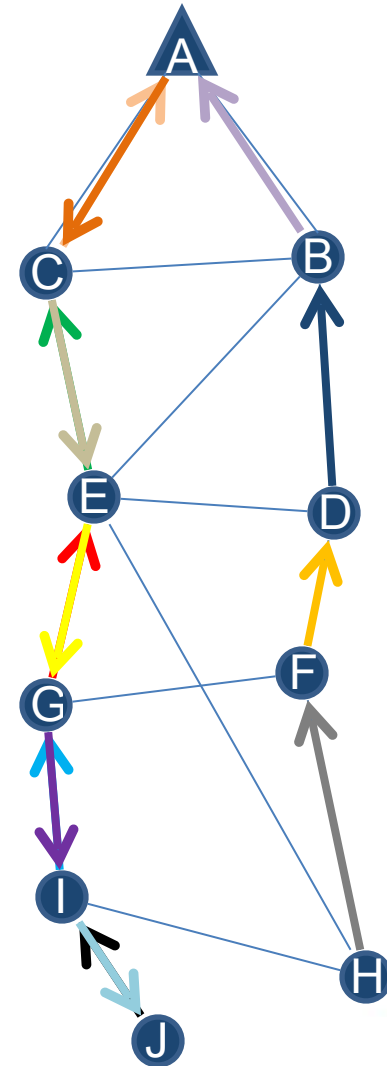
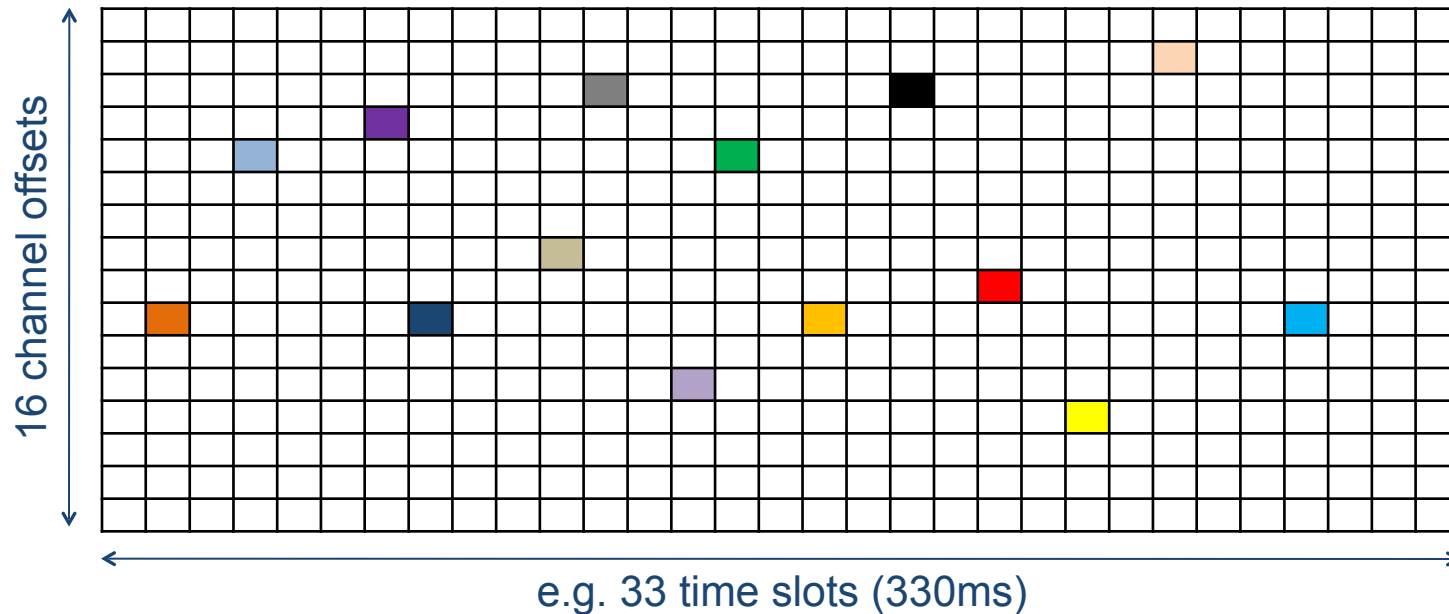
Now:
Ch. 11 (2.405GHz)

Next slotframe:
Ch. 26 (2.480GHz)

*Absolute Slot Number

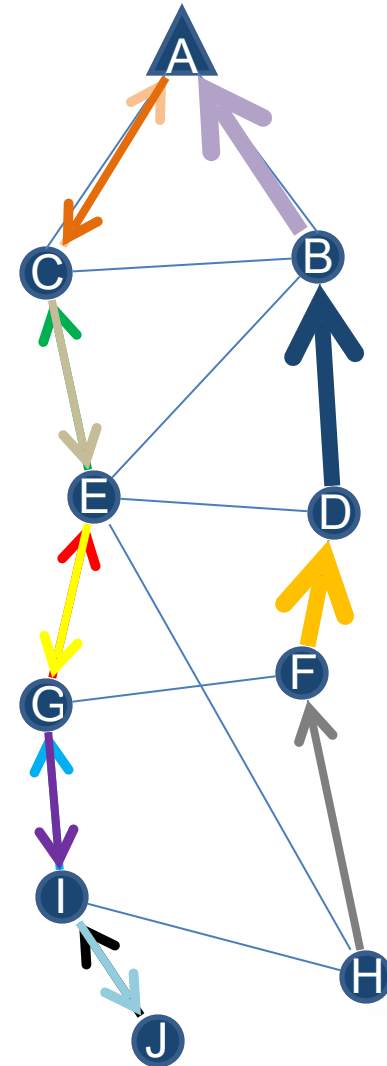
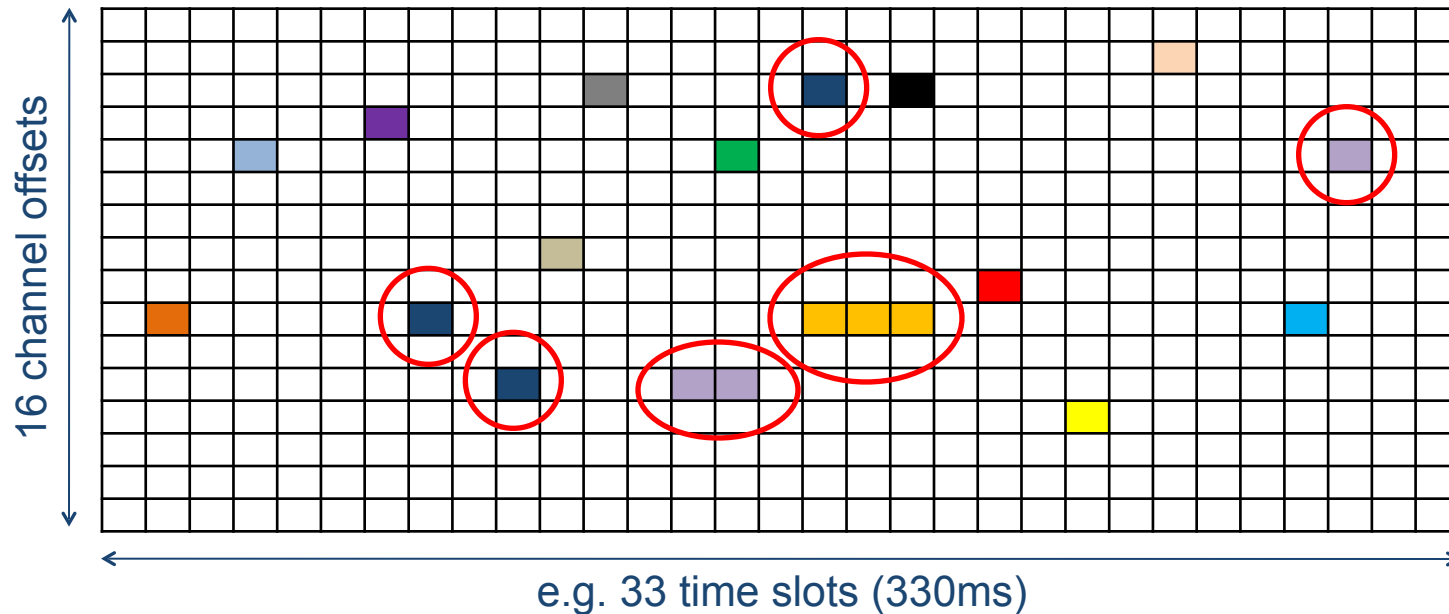
IEEE802.15.4e - Slotted Structure

- Cells are assigned according to application requirements



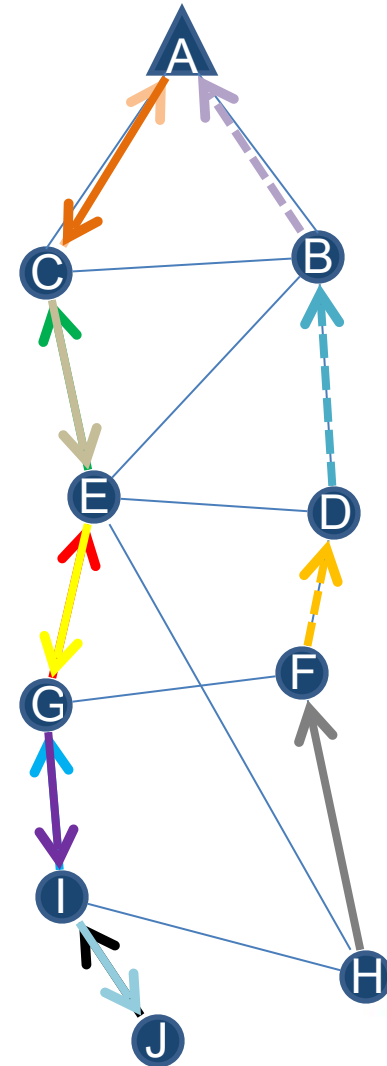
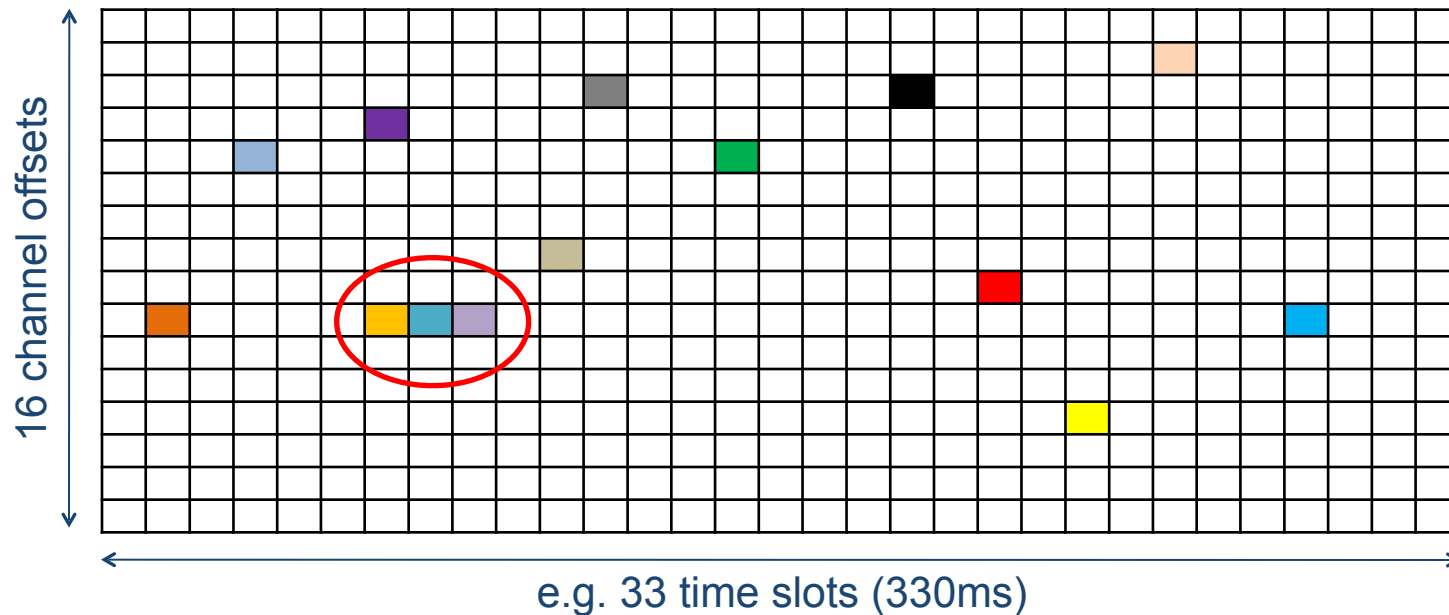
IEEE802.15.4e - Slotted Structure

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



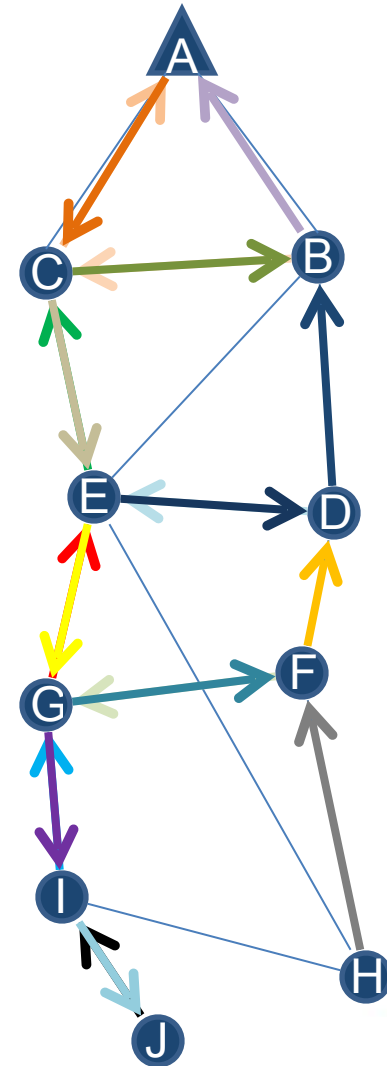
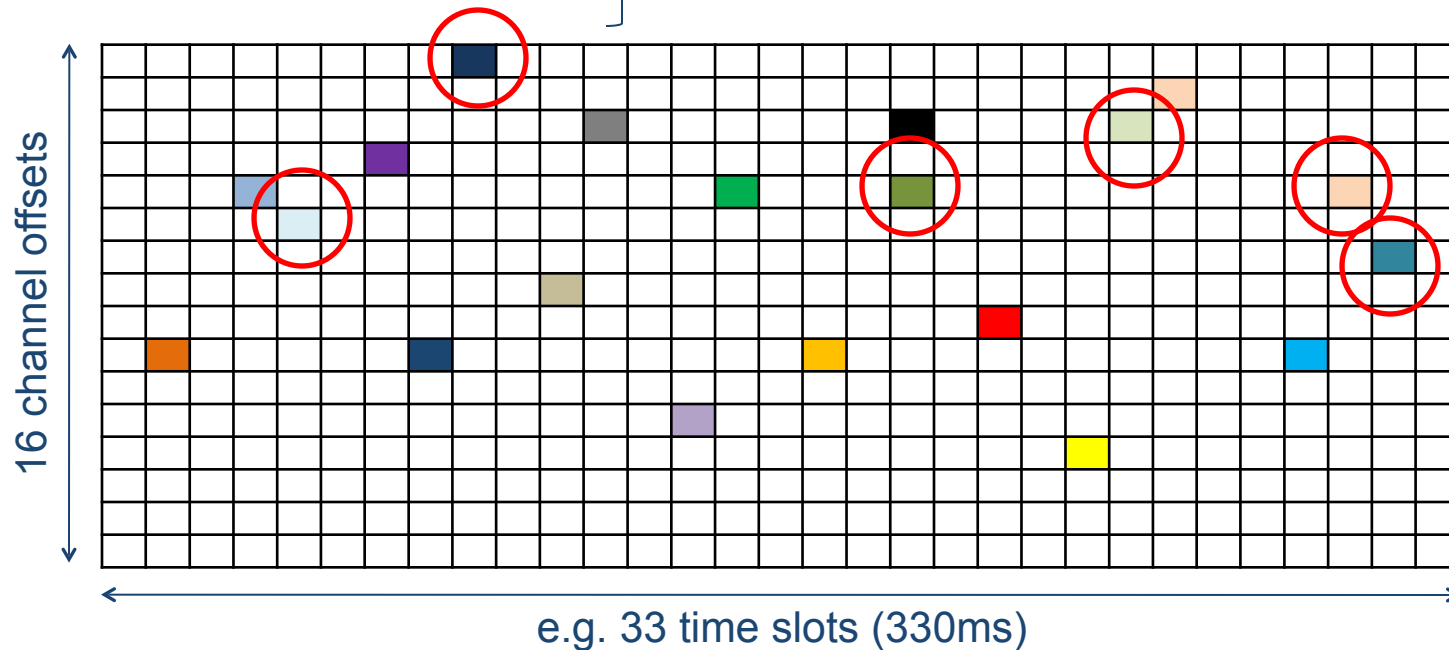
IEEE802.15.4e - Slotted Structure

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

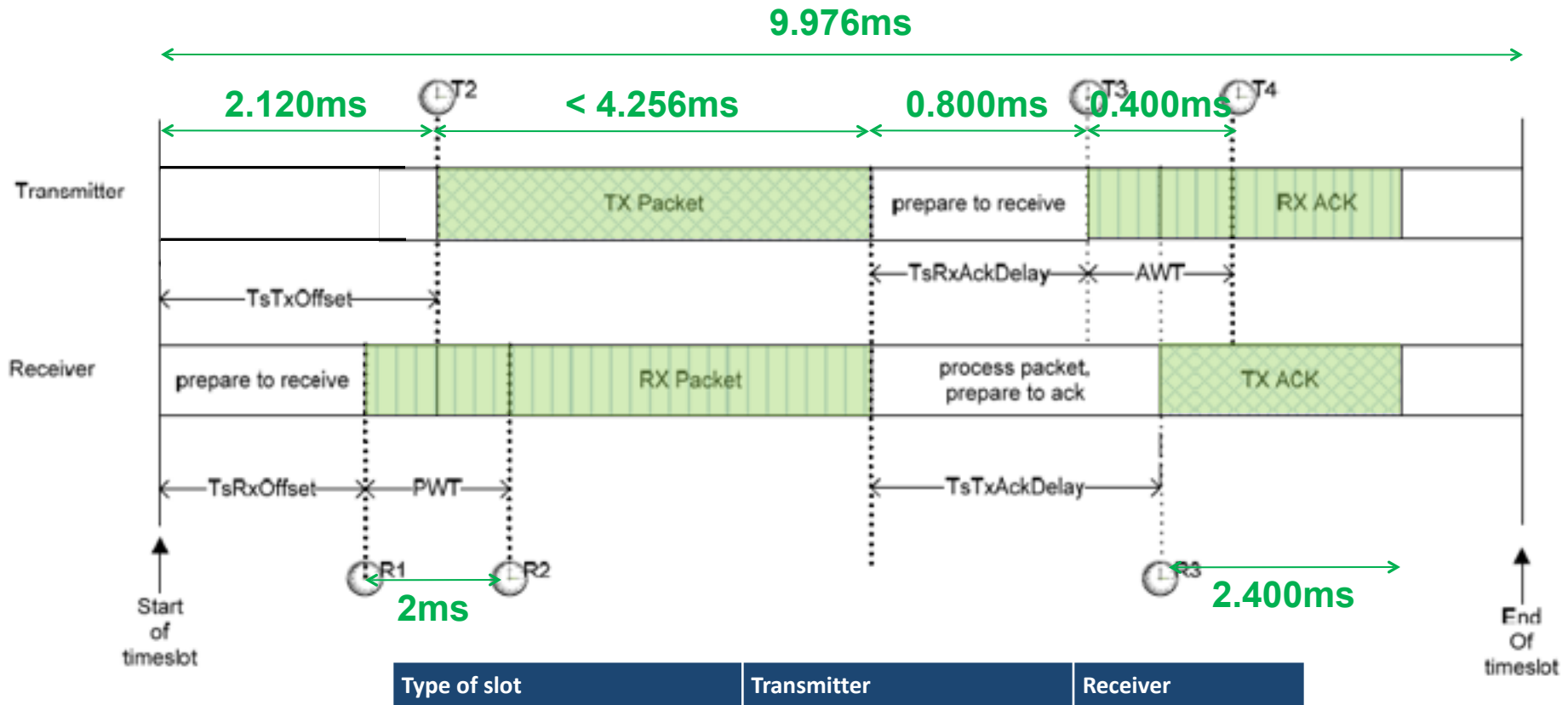




IEEE802.15.4e - Slotted Structure

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



IEEE802.15.4e - Energy Consumption

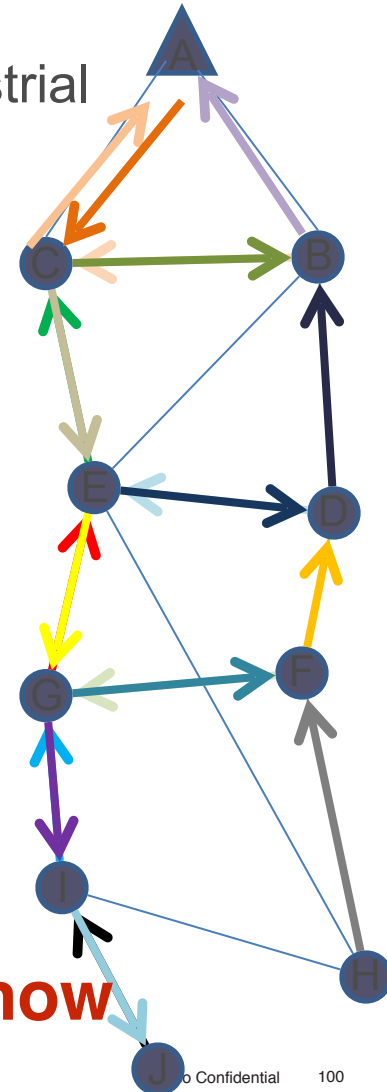
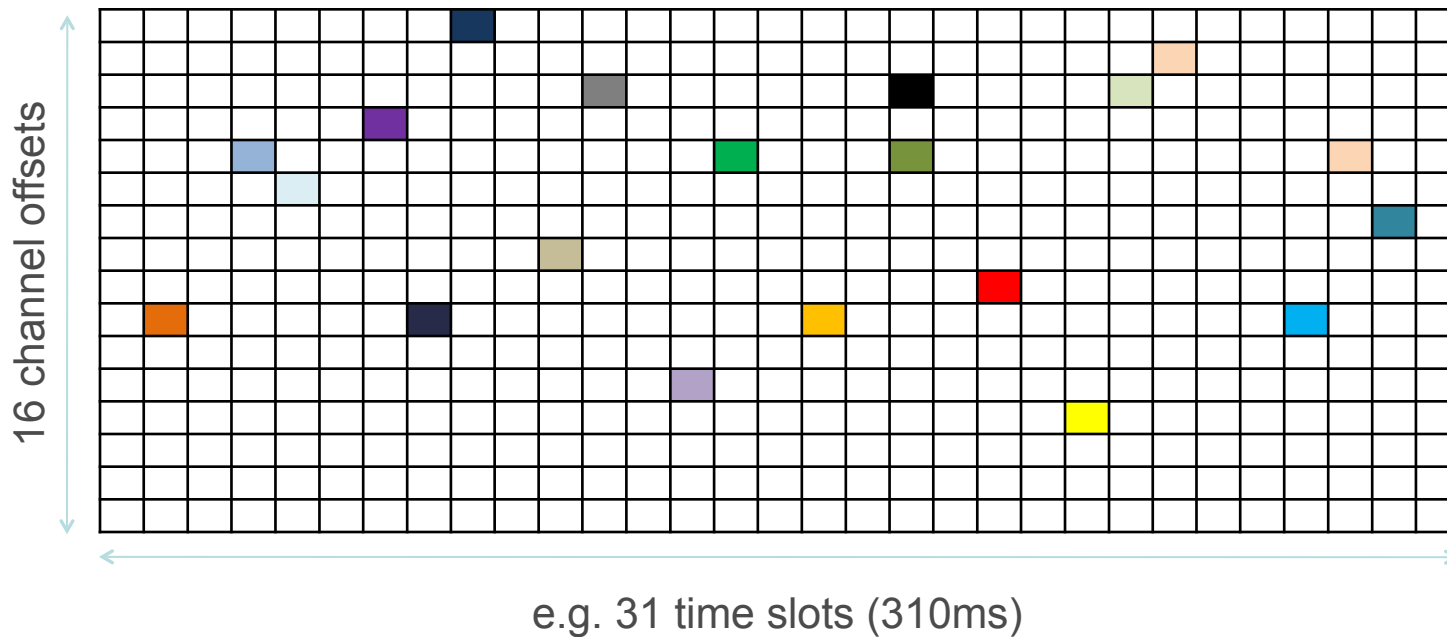


 = transmitter on
 = receiver on

“atomic” operations

IEEE802.15.4e TimeSlotted Channel Hopping

- Schedule => direct **trade-off** between throughput, latency and power consumption.
- A **collision-free** communication schedule is typical in industrial applications.
- IEEE802.15.4e **published** April 2012.



defines how to execute a schedule, but not how to build/maintain it.

Agenda

1. Deep Dive into the layers

1. IEEE802.15.4

2. IEEE802.15.4.E

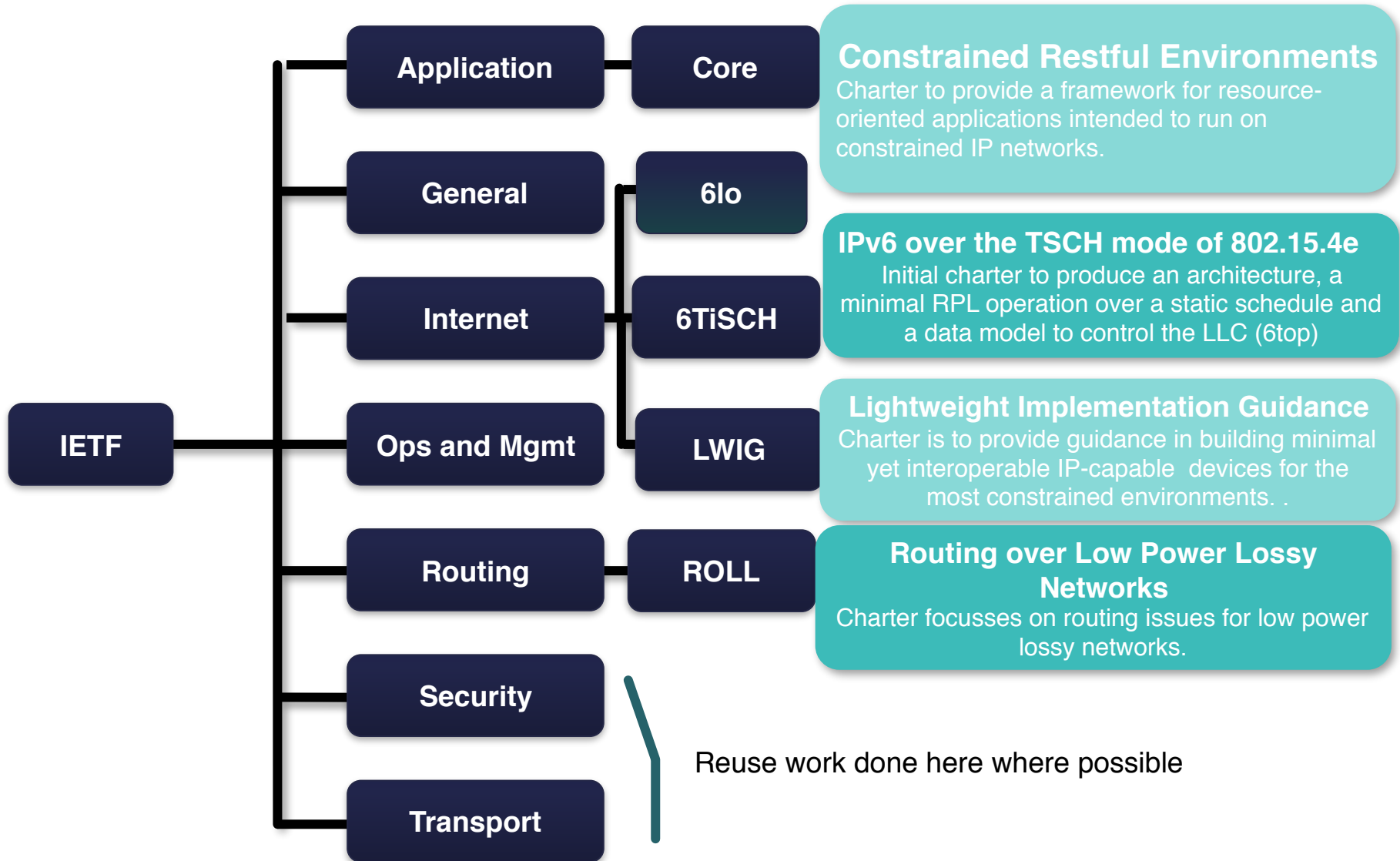
3. 6TSCH

4. 6LOWPAN

5. COAP



IETF LLN Related Workgroups





6TiSCH in a nutshell

IEC 62591



IEC based on HART 7.1.

TDMA

fixed time slots (10ms)

Mesh only

Shipped YE-2008.

Vendor driven

Emerson, E&H, ABB, Siemens

IEC 62734



ISA100.11a

IEC based on 2011 revision

TDMA+CSMA

Var. time slots

Star, mesh and hybrid topology

IPv6, 6LoWPAN, TCP-friendly

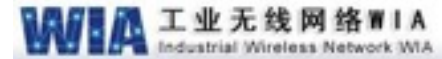
Shipped mid-2010

Mostly user driven

Honeywell, Yokogawa, Invensys

IEC 62601

WIA-PA

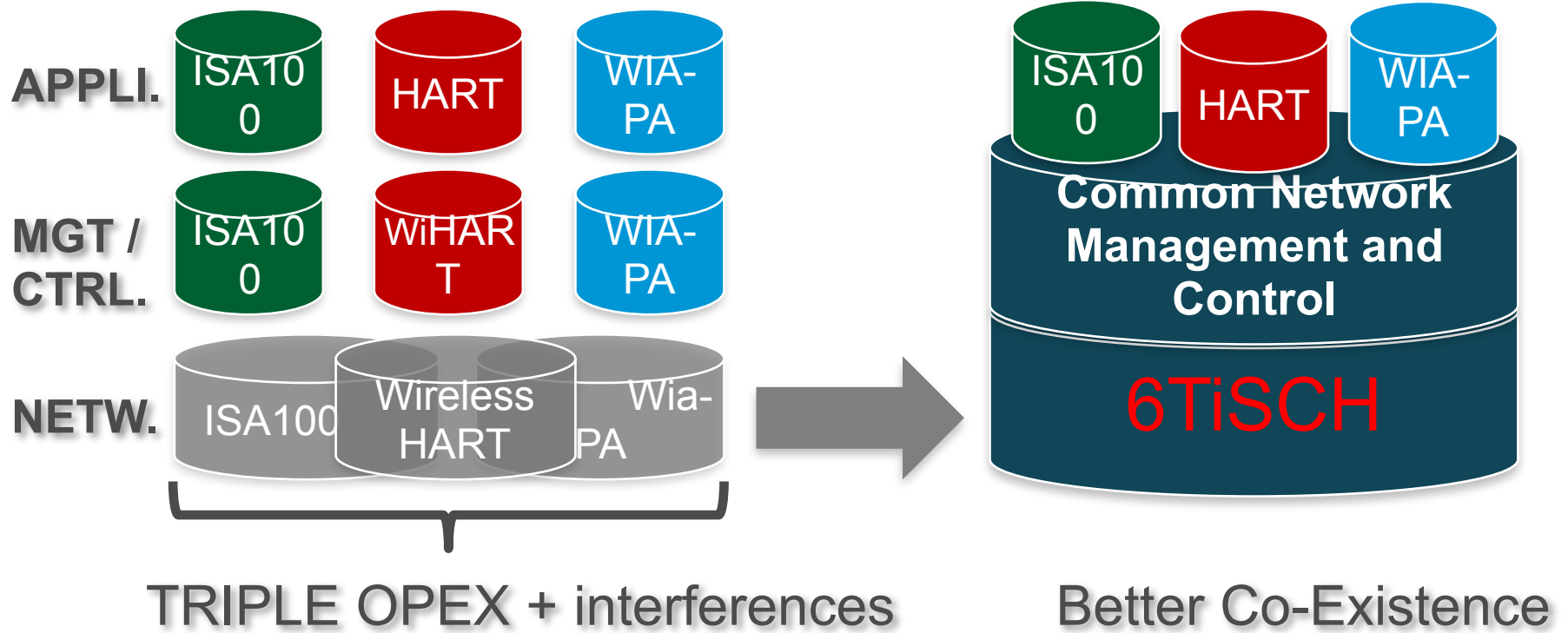


Alternate from China

Star, mesh and hybrid topology

Standardization work started in 2006.

“Single protocol” vs. Converged Network and Control



Requirement for a new standard

- Industrial requires standard-based products
- Must support equivalent features as incumbent protocols
- Must provide added value to justify migration
- 6TiSCH value proposition

Design for same time-sensitive MAC / PHY (802.15.4e TSCH)

Direct IPv6 access to the device (common network mgt)

Distributed routing & scheduling for scalability (for monitoring)

Large scale IPv6 subnet for mobility (50K +)

6TiSCH: IPv6 over TSCH MAC



Active IETF WG, 6 WG docs in or close to last call

Define an Architecture that links it all together

Align existing standards

(RPL, 6LoWPAN, PANA, RSVP, PCEP, MPLS) over 802.15.4e TSCH

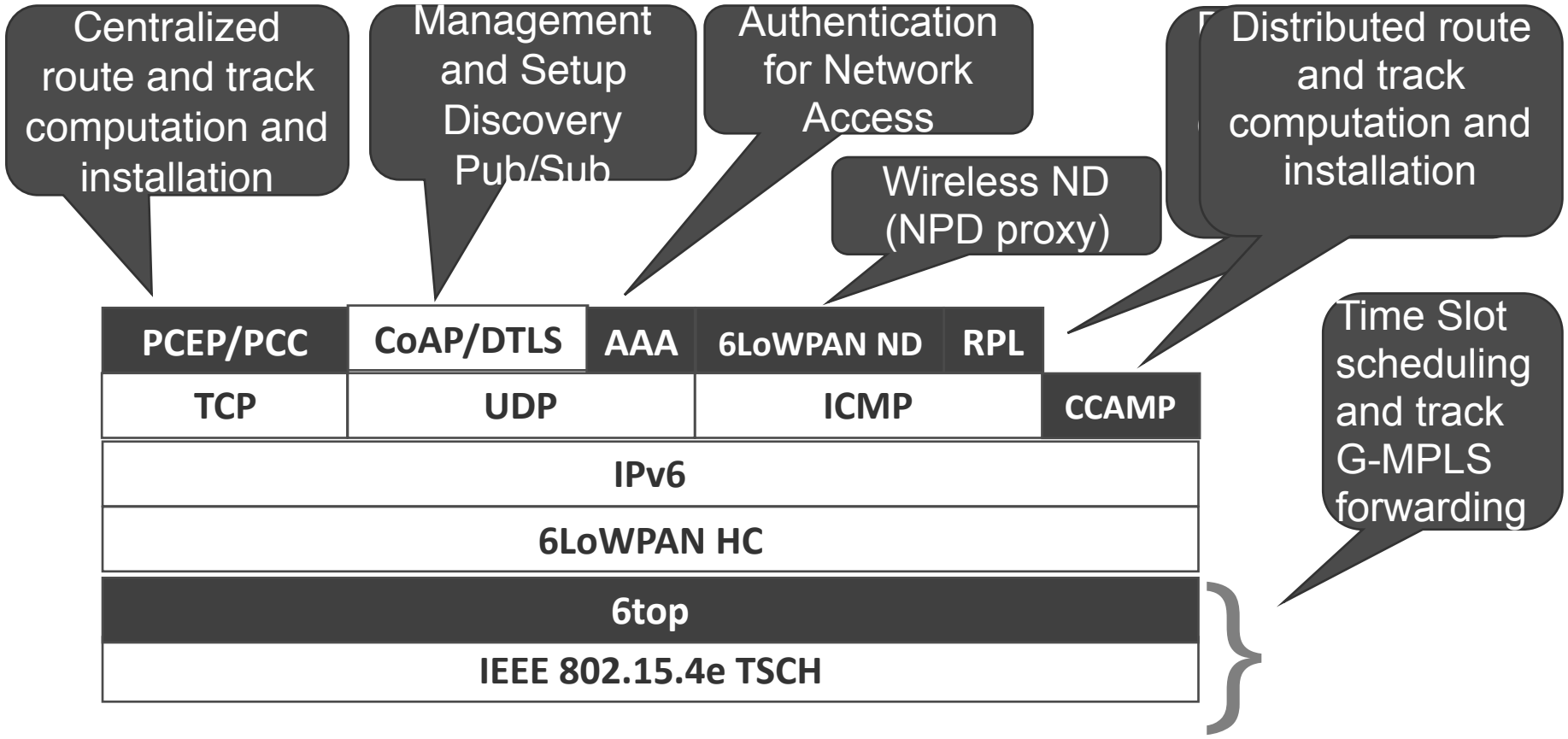
Support Mix of centralized and distributed deterministic routing

Design 6top sublayer for L3 interactions

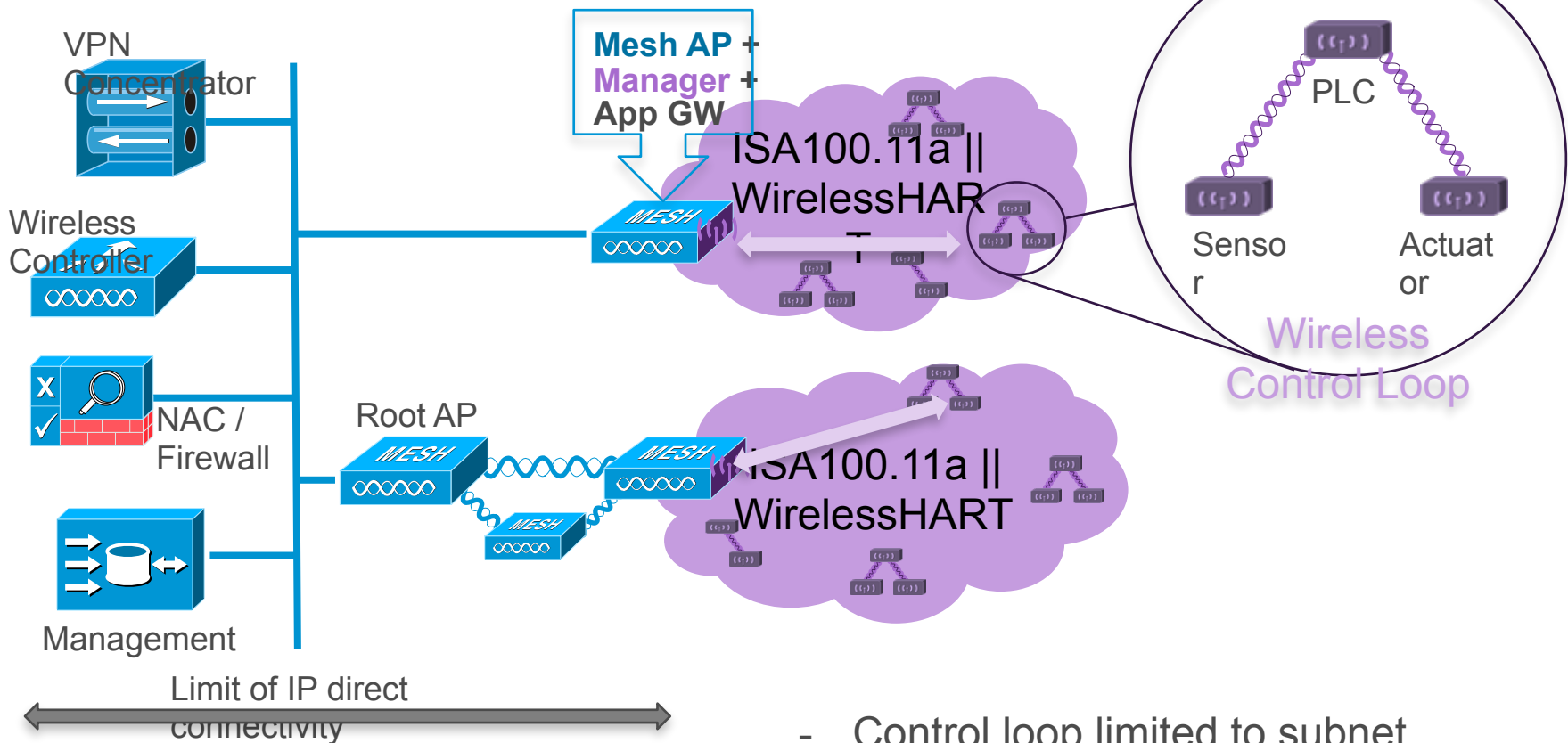
Open source implementations (openWSN...)

Multiple companies and universities participating

6TiSCH Client stack

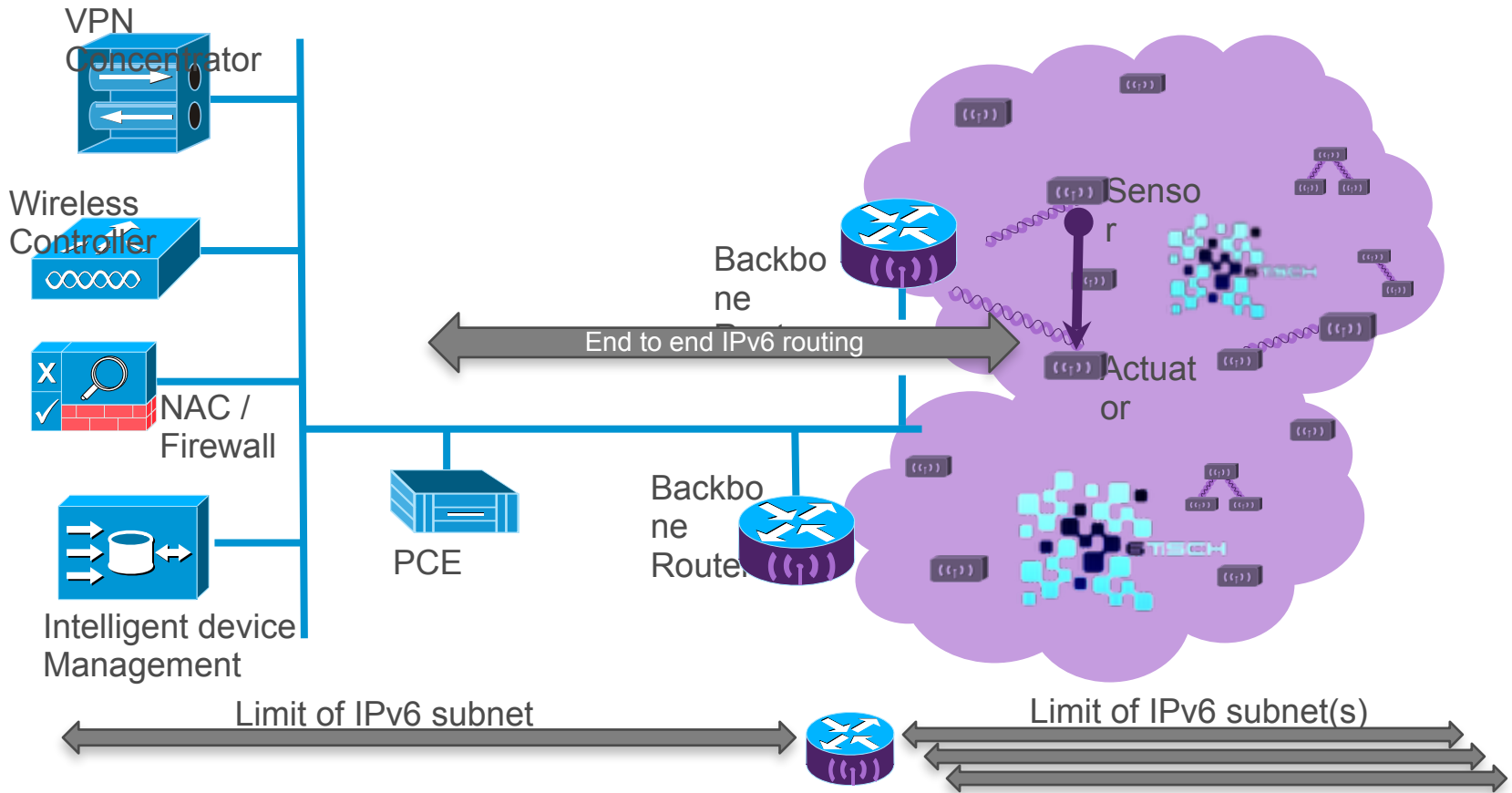


Current architecture: isolated networks

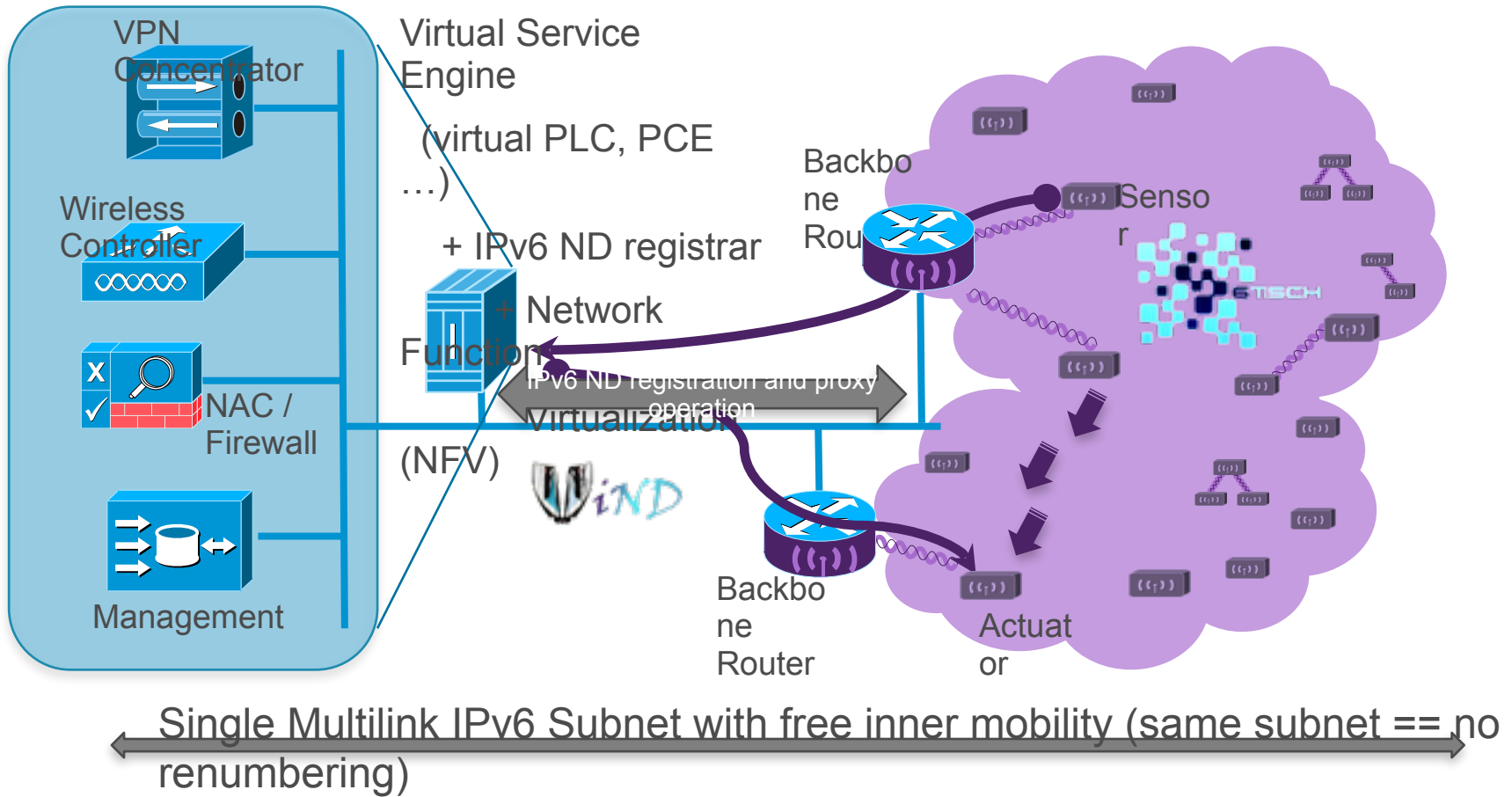


- Control loop limited to subnet
- No end-to-end IP connectivity
- No single view management
- No Cisco presence in control loop

6TiSCH subnets connected to carpeted floor



Step 2, WiND Multilink Subnet for unhindered mobility



So WHY ETISCH ?

- From a technology point of view
 - Scheduled network + PCE
 - Emulate Industrial WSNs including TSN aspects and limitations (mobility, scalability)
 - Peristaltic Scheduling + Distributed routing and scheduling (RPL) + Efficient IPv6 ND (WiND)
 - Large scale monitoring for Industrial Internet in Co-Existence with Industrial WSNs
- From a user point of view
 - Common Network management (over IPv6)
 - Open standards (IETF, IEEE, IEC)
 - Reduced OPEX (though we suggest end-to-end pcpl & multiple apps as opposed to single protocol)
- From a market point of view
 - IPv6 end-to-end → enable control loop virtualization
 - Support dynamic scheduling and deterministic on a same network
 - Single administration, lower OPEX

6TiSCH Charter

Deterministic IPv6 over IEEE802.15.4e TimeSlotted Channel Hopping (6TiSCH)

The Working Group will focus on enabling IPv6 over the TSCH mode of the IEEE802.15.4e standard. The scope of the WG includes one or more LLNs, each one connected to a backbone through one or more LLN Border Routers (LBRs).

Active drafts

<http://tools.ietf.org/html/draft-ietf-6tisch-terminology>

<http://tools.ietf.org/html/draft-ietf-6tisch-tsch>

<http://tools.ietf.org/html/draft-ietf-6tisch-architecture>

<http://tools.ietf.org/html/draft-ietf-6tisch-minimal>

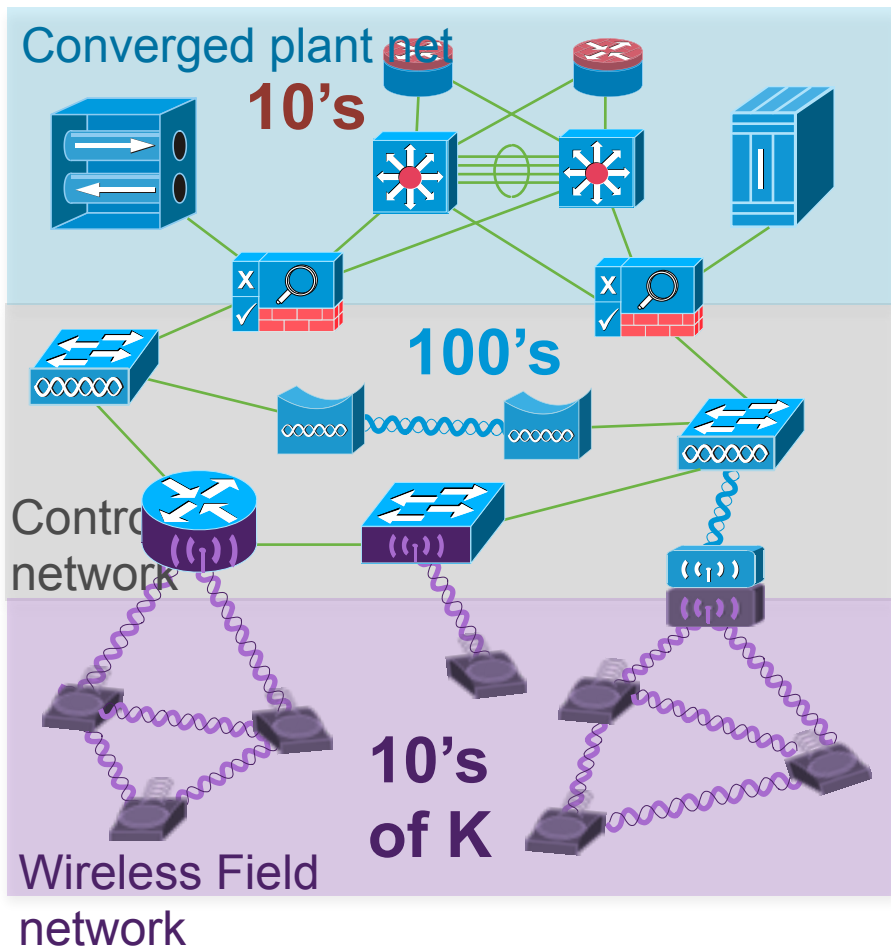
<http://tools.ietf.org/html/draft-ietf-6tisch-6top-interface>

<http://tools.ietf.org/html/draft-ohba-6tisch-security>

<http://tools.ietf.org/html/draft-ietf-6tisch-coap>



Direction: IT/OT Network Convergence



Converged Plant Network

- High availability
- Flow Isolation
- Guaranteed Bandwidth

IP based Control Network

- Autonomic, zero touch commissioning
- Time Sensitive Networking for critical apps
- Packet Reliability

IPv6-based Wireless Field Network

- Deterministic, Autonomic, Secure

RPL Concepts

RPL key concepts

RPL is an extensible proactive IPv6 DV protocol

**Supports MP2P, P2MP and P2P
P2P reactive extension**

RPL specifically designed for LLNs

**Agnostic to underlying link layer technologies
(802.15.4, PLC, Low Power WiFi)**

Minimum topological awareness

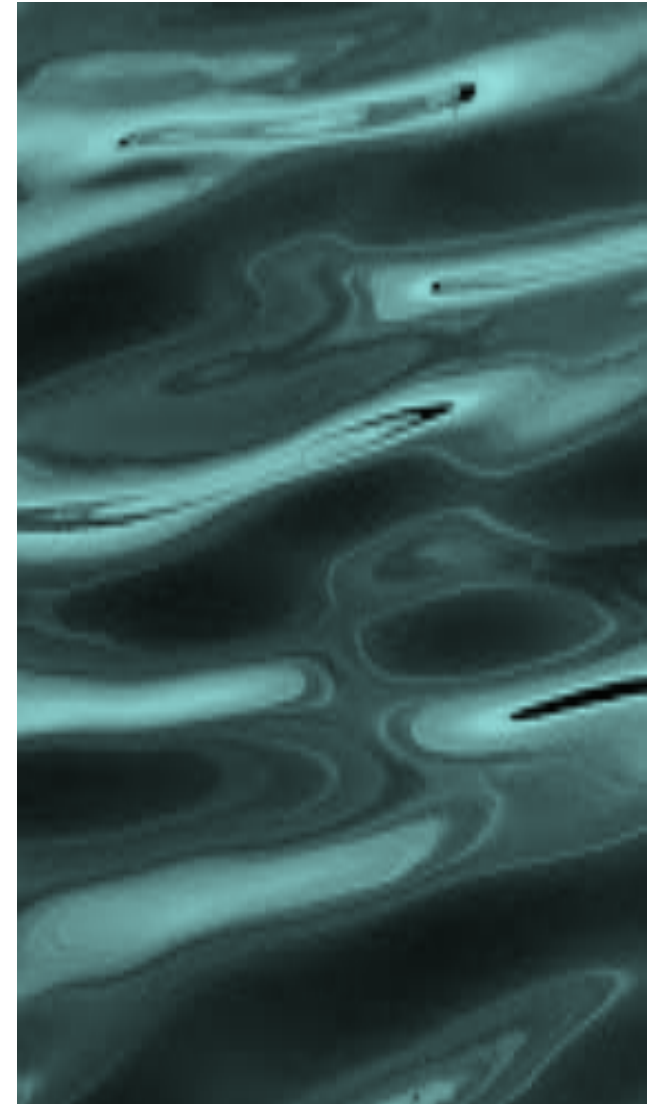
Data Path validation

Non-Equal Cost Multipath Fwd

Instantiation per constraints/metrics

Autonomic Subnet G/W Protocol

Optimized Diffusion over NBMA



Controlling the control ... by design

Distance Vector as opposed to Link State

- Knowledge of SubDAG addresses and children links
- Lesser topology awareness => lesser sensitivity to change
- No database Synchronization => Adapted to movement

Optimized for Edge operation

- Optimized for P2MP / MP2P, stretch for arbitrary P2P
- Least Overhead Routing Approach via common ancestor

Proactive as opposed to Reactive

- Actually both with so-called P2P experimental specification

Datapath validation

Datapath Validation

Control Information in Data Packets:



Hop-By-Hop Header Sender



Instance ID

Rank

Direction (UP/Down)



Errors detected if:

No route further down for packet going down

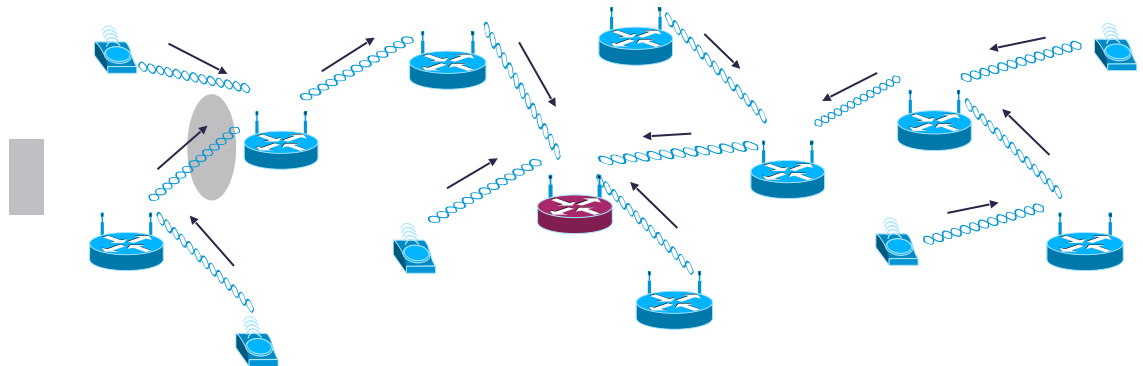
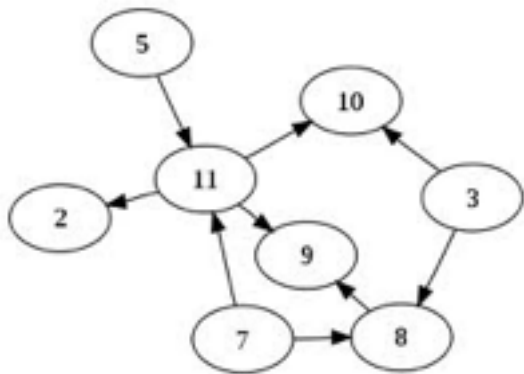
No route for packet going down

Rank and direction do not match

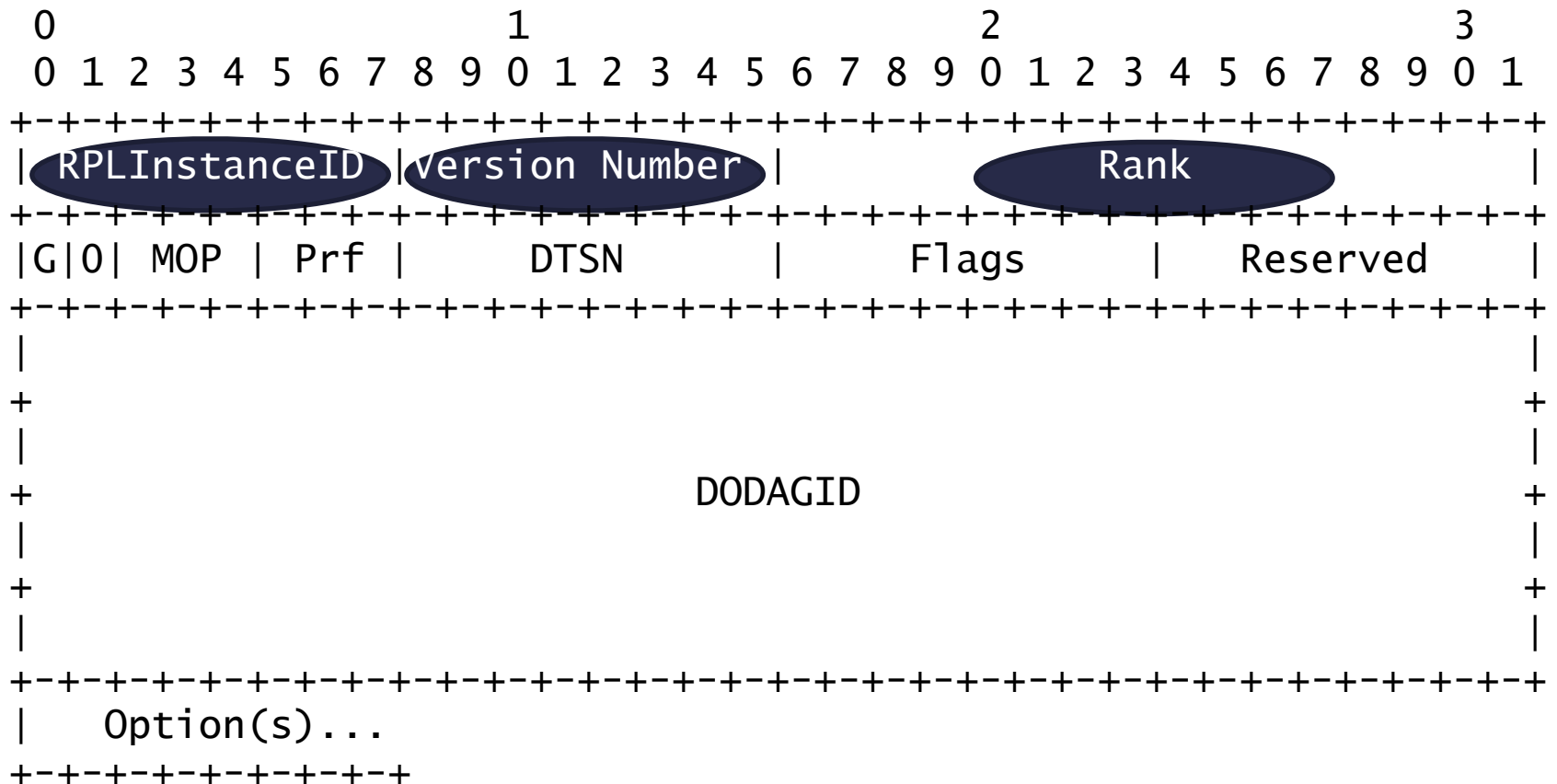


Directed Acyclic Graph

In the context of routing, a DAG is formed by a collection of vertices (nodes) and edges (links), each edge connecting one node to another (directed) in such a way that it is not possible to start at *Node X* and follow a directed path that cycles back to *Node X* (*acyclic*).



DIO Base Object: forming the DODAG



Global versus Local Repair

- **Global repair**: A new DODAG iteration
 - Rebuild the DAG ...
Then repaint the prefixes upon changes
 - A new Sequence number generated by the root
 - A router forwards to a parent or as a host over next iteration
- **Local Repair**: find a “quick” local repair path
 - Only requiring local changes !
 - May not be optimal according to the OF
 - Moving UP and Jumping are cool.
 - Moving Down is risky: Count to Infinity Control

Objective Function

Extend the generic behavior

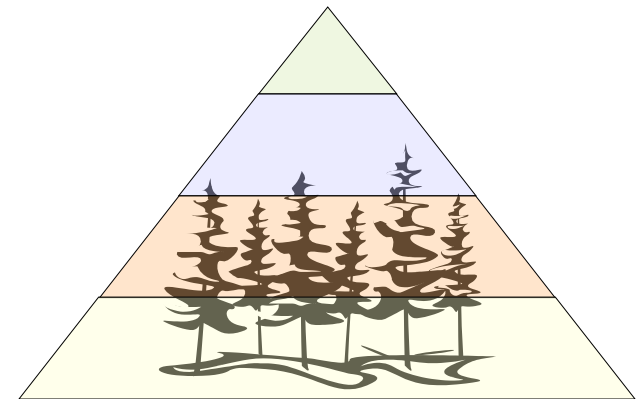
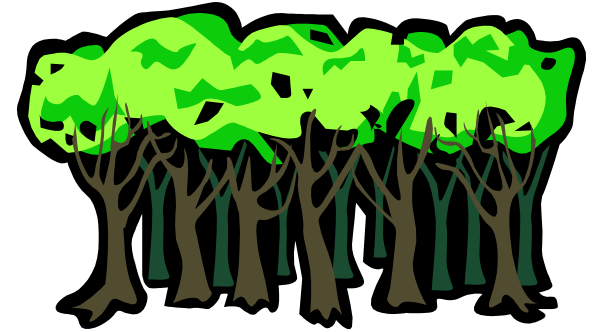
- For a specific need / use case

Used in parent selection

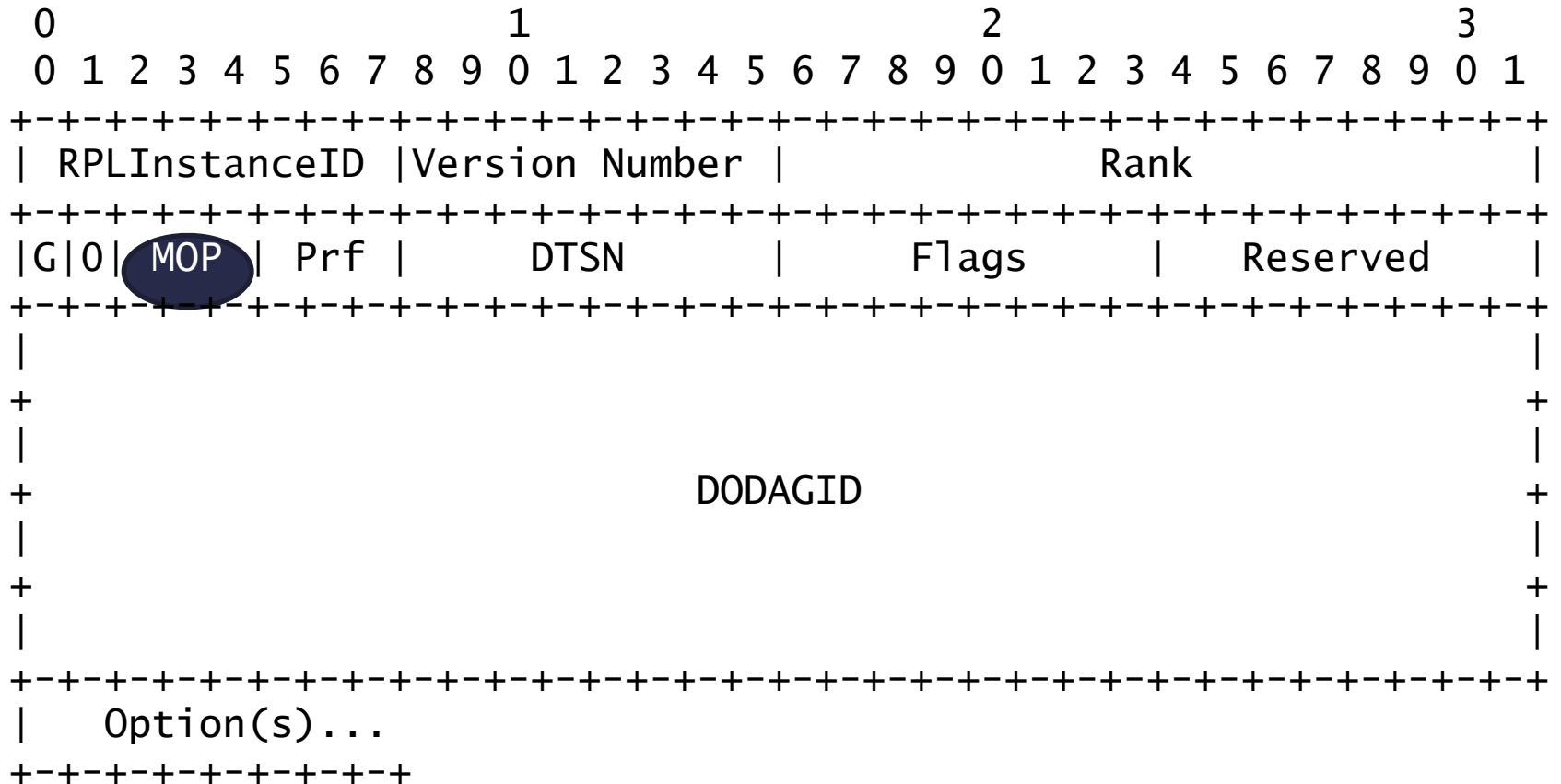
- Constraints
 - Policies
 - Metrics
- } Position in the DAG

Computes the Rank increment

- Based on hop metrics
- Do NOT use OF0 for adhoc radios!
- (OF 0 uses traditional weighted hop count)



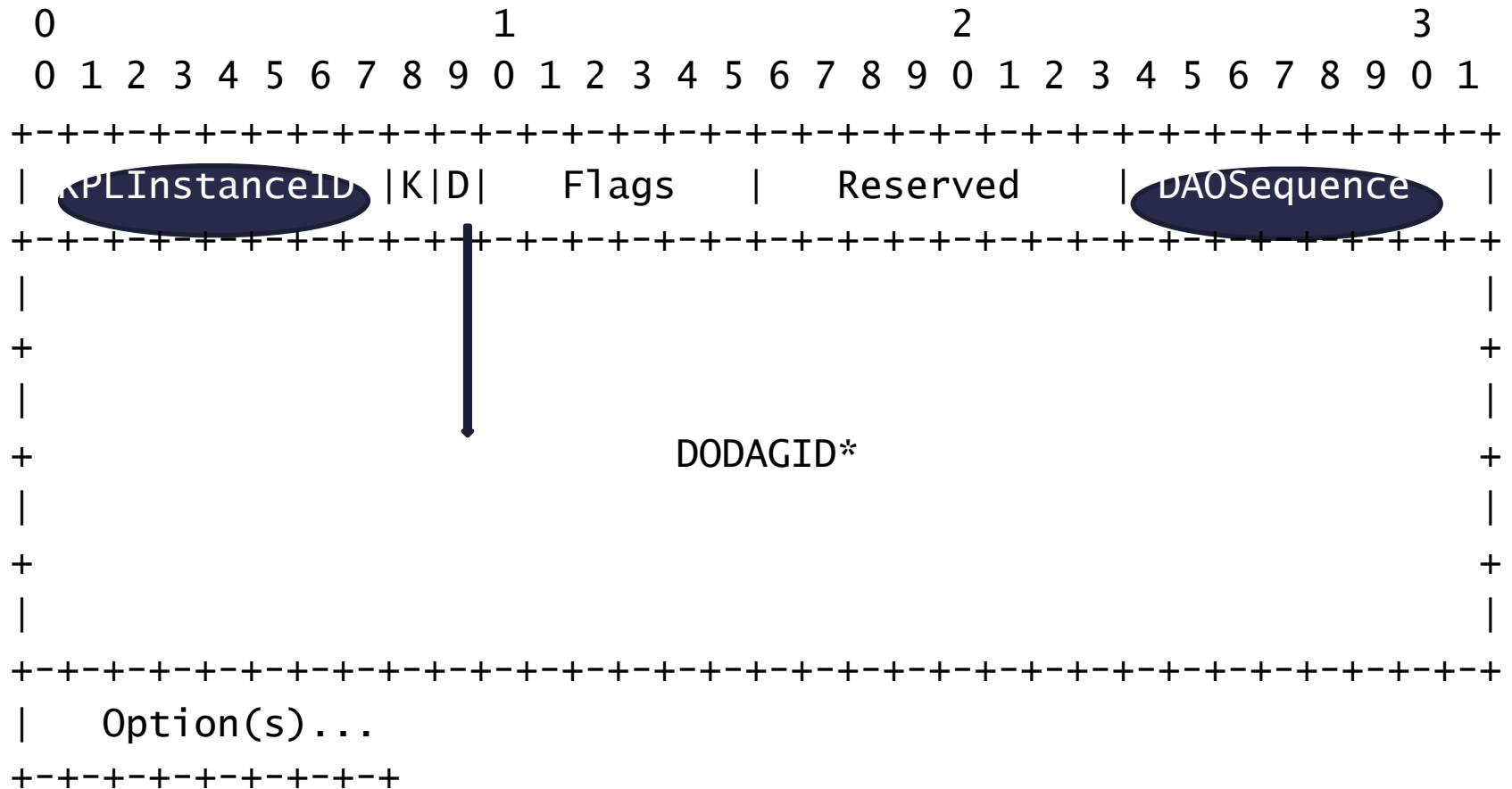
DIO Base Object: route construction rules



Mode of Operation

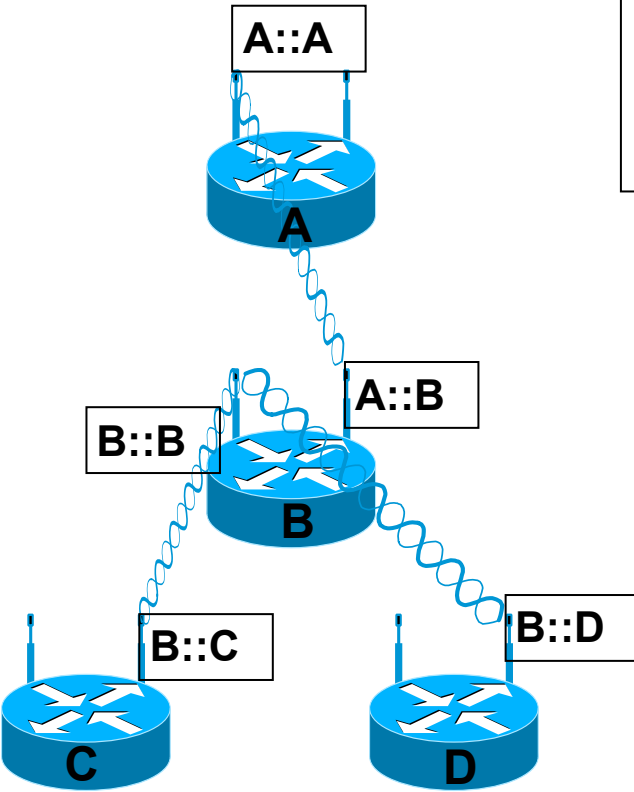
MOP	Description
0	No Downward routes maintained by RPL
1	Non-Storing Mode of Operation
2	Storing Mode of Operation with no multicast support
3	Storing Mode of Operation with multicast support
	All other values are unassigned

DAO Base Object : route construction



Owned prefix routing (storing mode)

Parent is default GW, advertizes owned PIO (L bit on)
 RPL Router autoconfigures Addr from parent PIO
 RPL Router advertises Prefix via self to parent
 RPL Router also advertises children Prefix



C:
 ::/0 via B::B
 B:: connected
 C:: connected

D:
 ::/0 via B::B
 B:: connected
 D:: connected



B:
 ::/0 via A::A
 A:: connected
 B:: connected
 C:: via B::C
 D:: via B::D

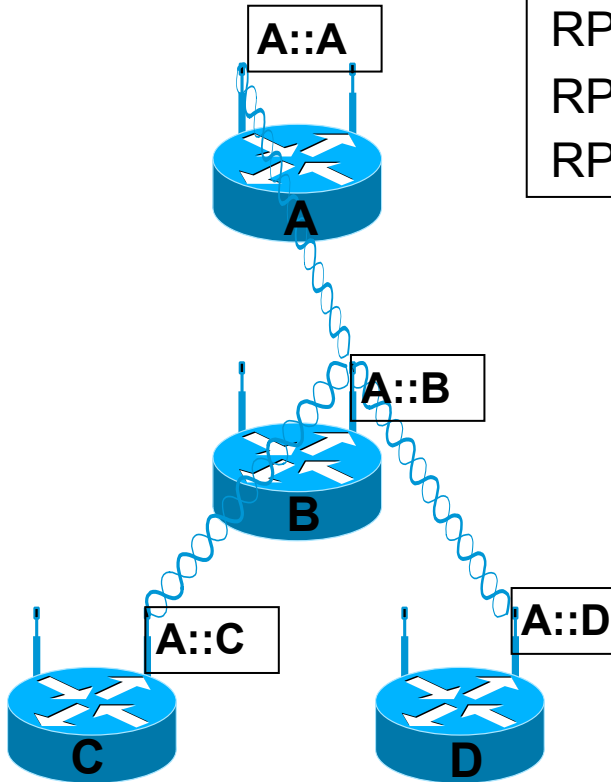


A:
 A:: connected
 B:: via A::B
 C:: via A::B
 D:: via A::B

Subnet Routing (storing mode)



Parent is default GW, propagates root PIO (L-bit off)
Parent Address in the PIO (with R bit)
RPL Router autoconfigures Address from parent PIO
RPL Router advertises Address via self to parent
RPL Router also advertises children Addresses



C:
::/0 via A::B
A::B connected
A::C self
A:: ~onlink

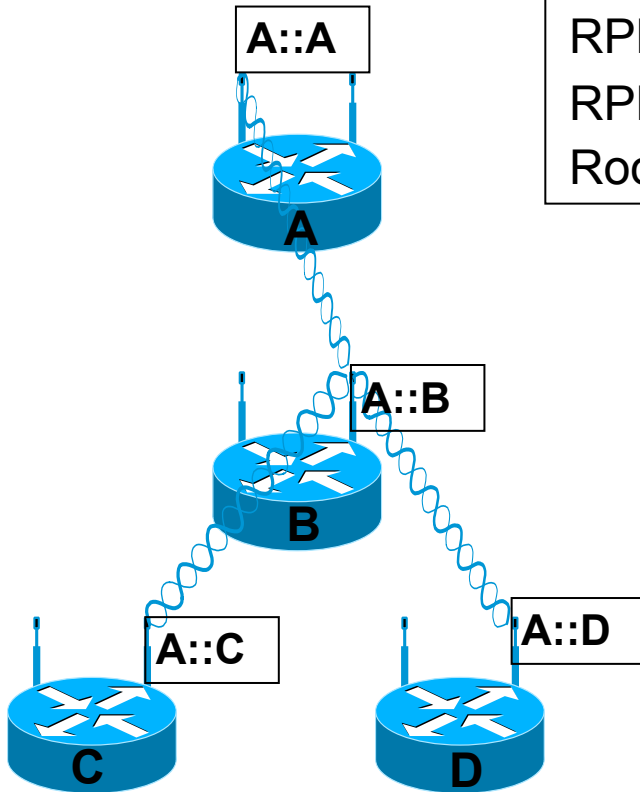
D:
::/0 via A::B
A::B connected
A::D self
A:: ~onlink

B:
::/0 via A::A
A::A connected
A::B self
A::C connected
A::D connected
A:: ~onlink

A:
A::A self
A::B connected
A::C via A::B
A::D via A::B
A:: ~onlink

Subnet Routing (non-storing mode)

Parent is default GW, propagates root PIO (L-bit off)
 Parent Address in the PIO (with R bit)
 RPL Router autoconfigures Address from parent PIO
 RPL Router advertises Address via Parent to Root
 Root recursively builds a Routing Header back



C:
 ::/0 via **A::B**
 A::B connected
 A::C self
 A:: ~onlink

Target A::C via
 Transit A::B

B:
 ::/0 via **A::A**
 A::A connected
 A::B self
 A:: ~onlink

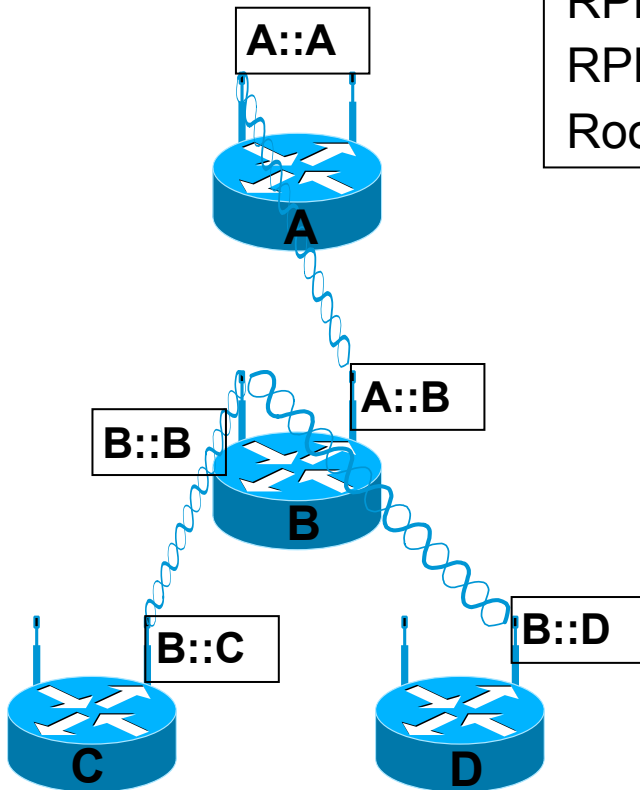
A: (root)
 A::A self
 A::B connected
 A::C via A::B
 A::D via A::B
 A:: ~onlink

D:
 ::/0 via **A::B**
 A::B connected
 A::D self
 A:: ~onlink

RH4: A::D via A::B connected

Owned prefix routing (non-storing mode)

Parent is default GW, advertizes owned PIO (L bit on)
 RPL Router autoconfigures Address from parent PIO
 RPL Router advertises Prefix via Address to Root
 Root recursively builds a Routing Header back



C:
 ::/0 via B::B
 B:: connected
 C:: connected

D:
 ::/0 via B::B
 B:: connected
 D:: connected

Target C::/ via
 Transit B::C

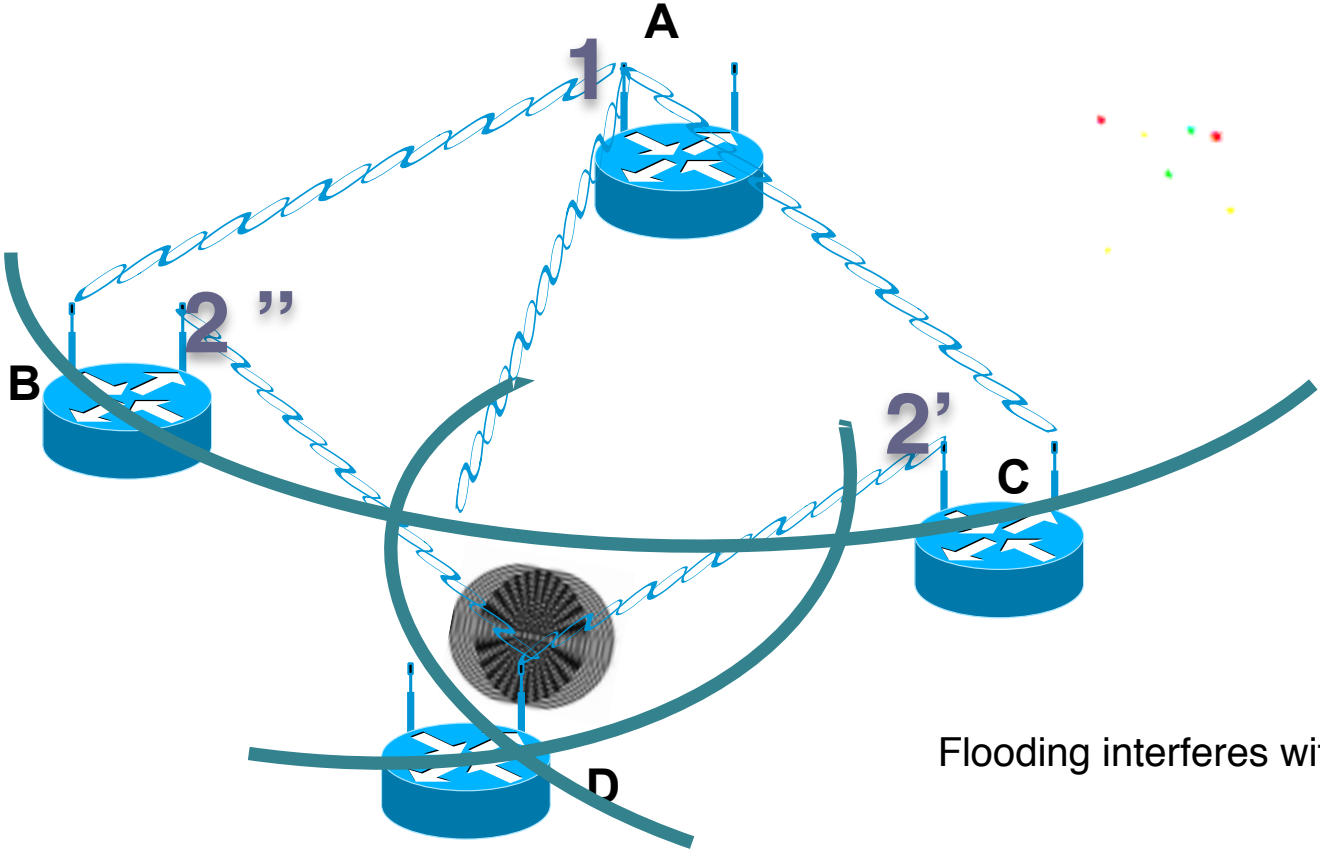
B:
 ::/0 via A::A
 A:: connected
 B:: connected

A: (root)
 A:: connected
 B:: via A::B
 C:: via B::C
 D:: via B::D

RH4: D::3 via B::D via A::B connected

Multicast over radio NBMA

Hidden node/terminal/station



Flooding interferes with itself

Trickle: An Optimized Diffusion

Suppression of redundant copies

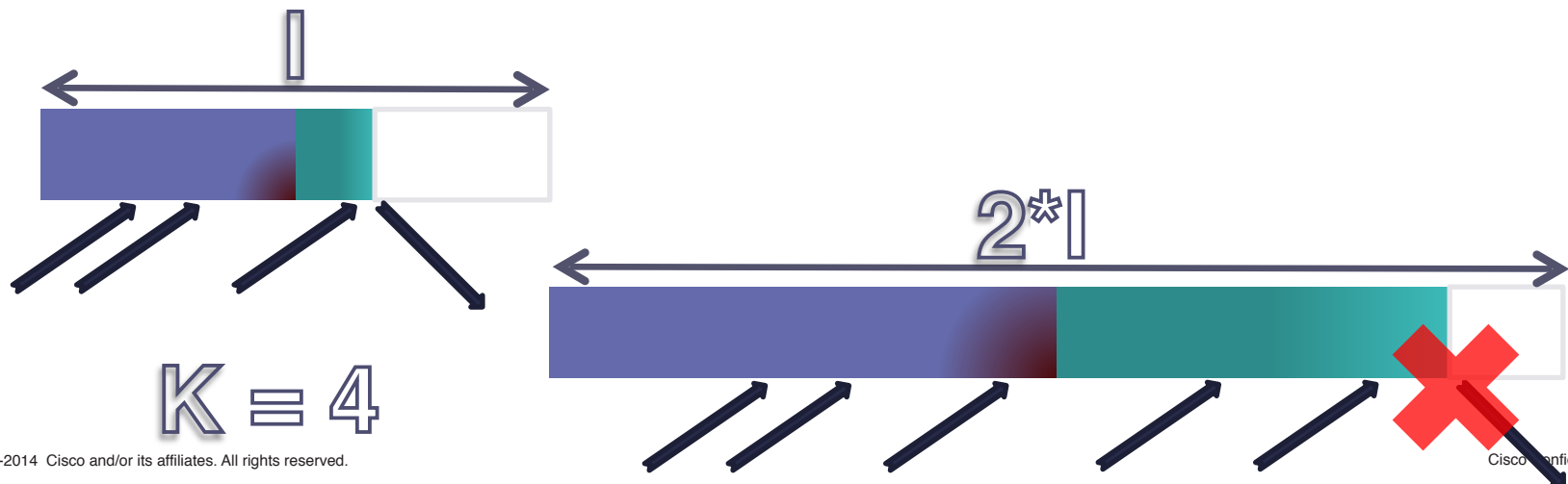
Do not send copy if K copies received

Jitter for Collision Avoidance

First half is mute, second half is jittered

Exponential backoff

Double I after period I, Reset I on inconsistency



Routing Metrics in LLNs

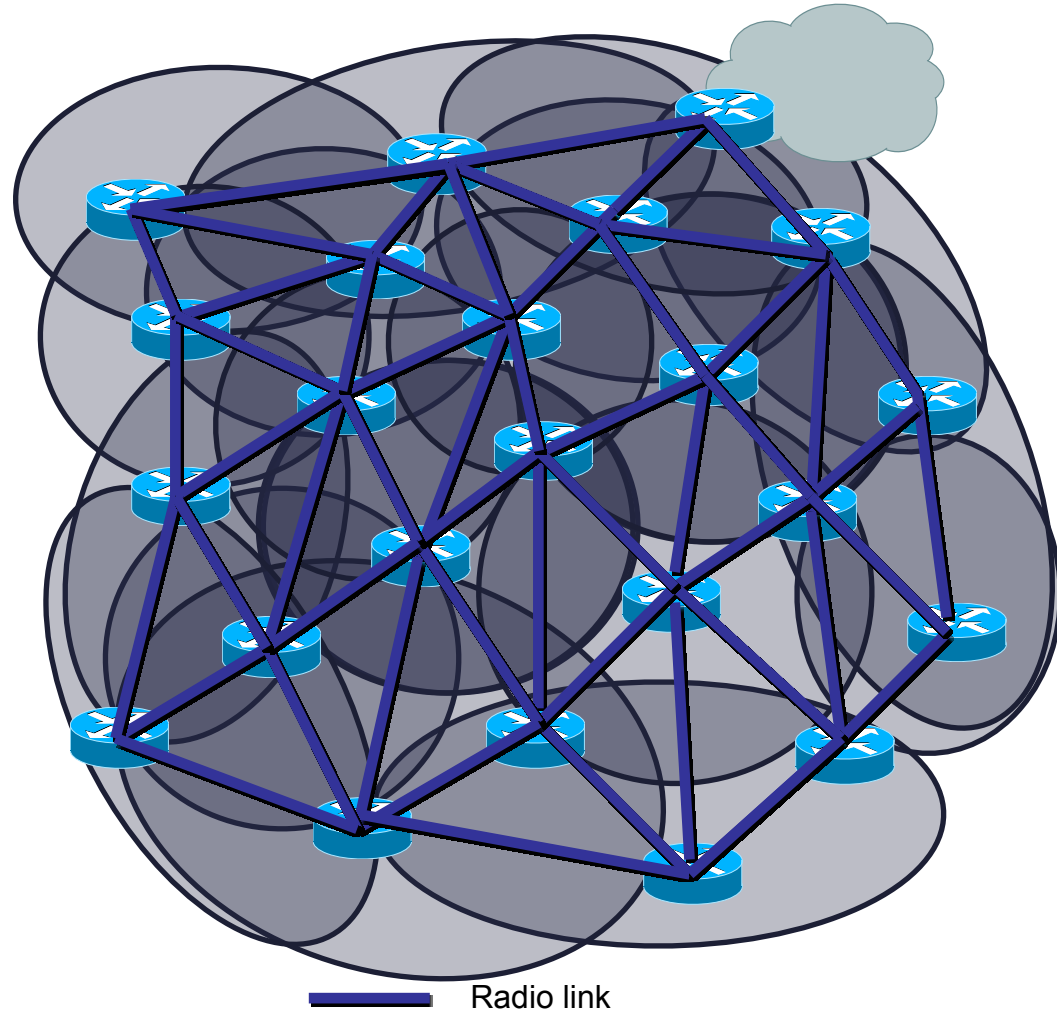


Node Metrics	Link Metrics
<p>Node State and Attributes Object Purpose is to reflect node workload (CPU, Memory...) “O” flag signals overload of resource “A” flag signal node can act as traffic aggregator</p>	<p>Throughput Object Currently available throughput (Bytes per second) Throughput range supported</p>
<p>Node Energy Object “T” flag: Node type: 0 = Mains, 1 = Battery, 2 = Scavenger “I” bit: Use node type as a constraint (include/exclude) “E” flag: Estimated energy remaining</p>	<p>Latency Can be used as a metric or constraint Constraint - max latency allowable on path Metric - additive metric updated along path</p>
<p>Hop Count Object Can be used as a metric or constraint Constraint - max number of hops that can be traversed Metric - total number of hops traversed</p>	<p>Link Reliability Link Quality Level Reliability (LQL) 0=Unknown, 1=High, 2=Medium, 3=Low Expected Transmission Count (ETX) (Average number of TX to deliver a packet)</p>
	<p>Link Colour Metric or constraint, arbitrary admin value</p>

Applying RPL

Example radio connectivity

At a given point of time
connectivity is
(fuzzy)



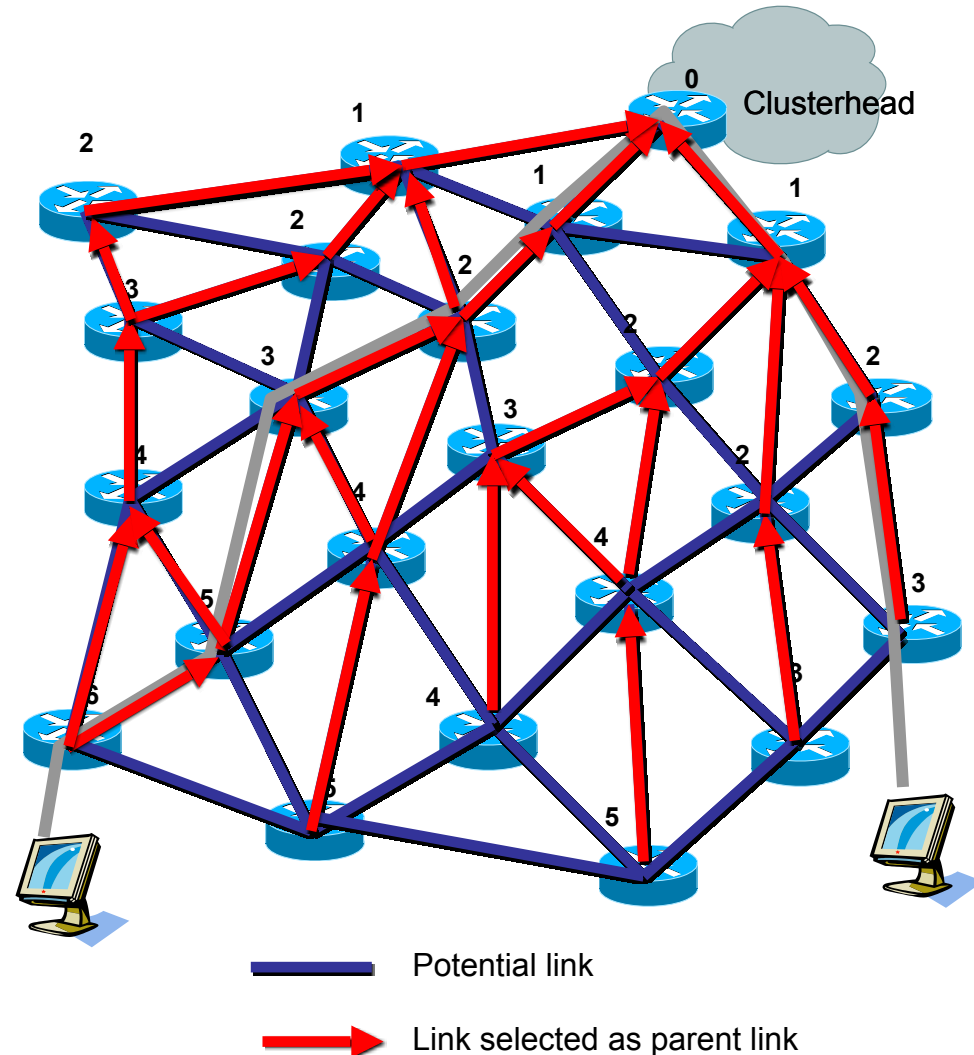
Applying RPL

1st pass (DIO)

- Establishes a logical DAG topology
- Trickle Subnet/config Info
- Sets default route
- Self forming / self healing

2nd pass (DAO)

- paints with addresses and prefixes
- Any to any reachability
- But forwarding over DAG only
- saturates upper links of the DAG
- And does not use the full mesh properly



Local recovery (step 1)

A's link to root fails

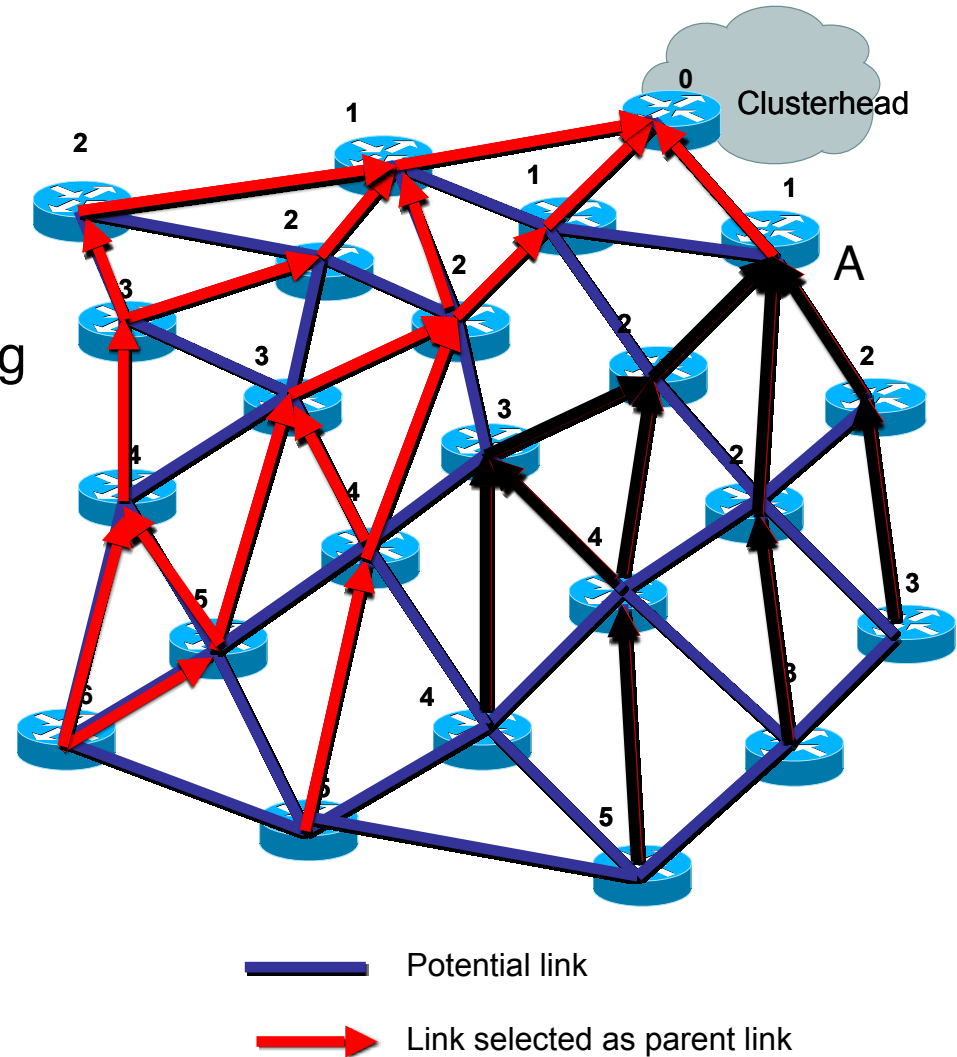
A loses connectivity

Either poisons or detaches a subdag

In black:

the potentially impacted zone

That is A's subDAG



Local recovery (step 2)

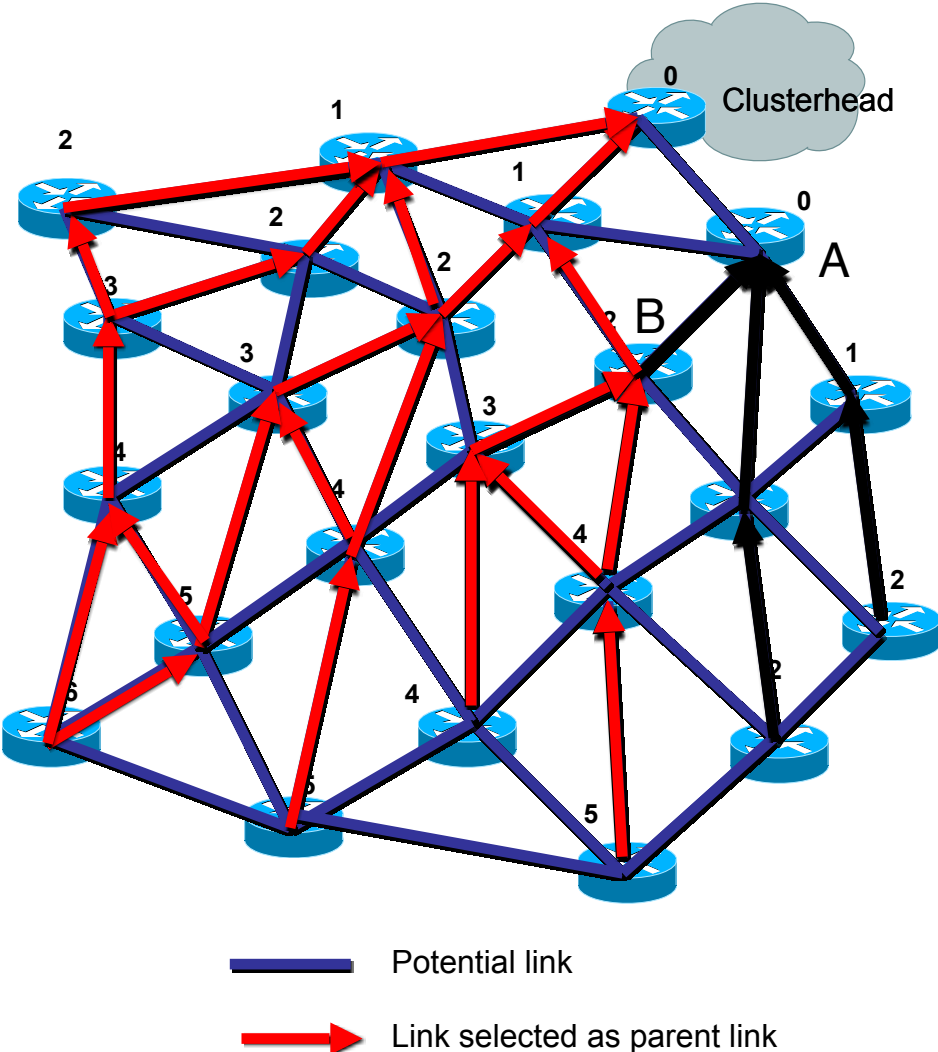
B can reparent a same Rank so B's subDAG is safe

The rest of A's subDAG is isolated

Either poison or build a floating DAG as illustrated

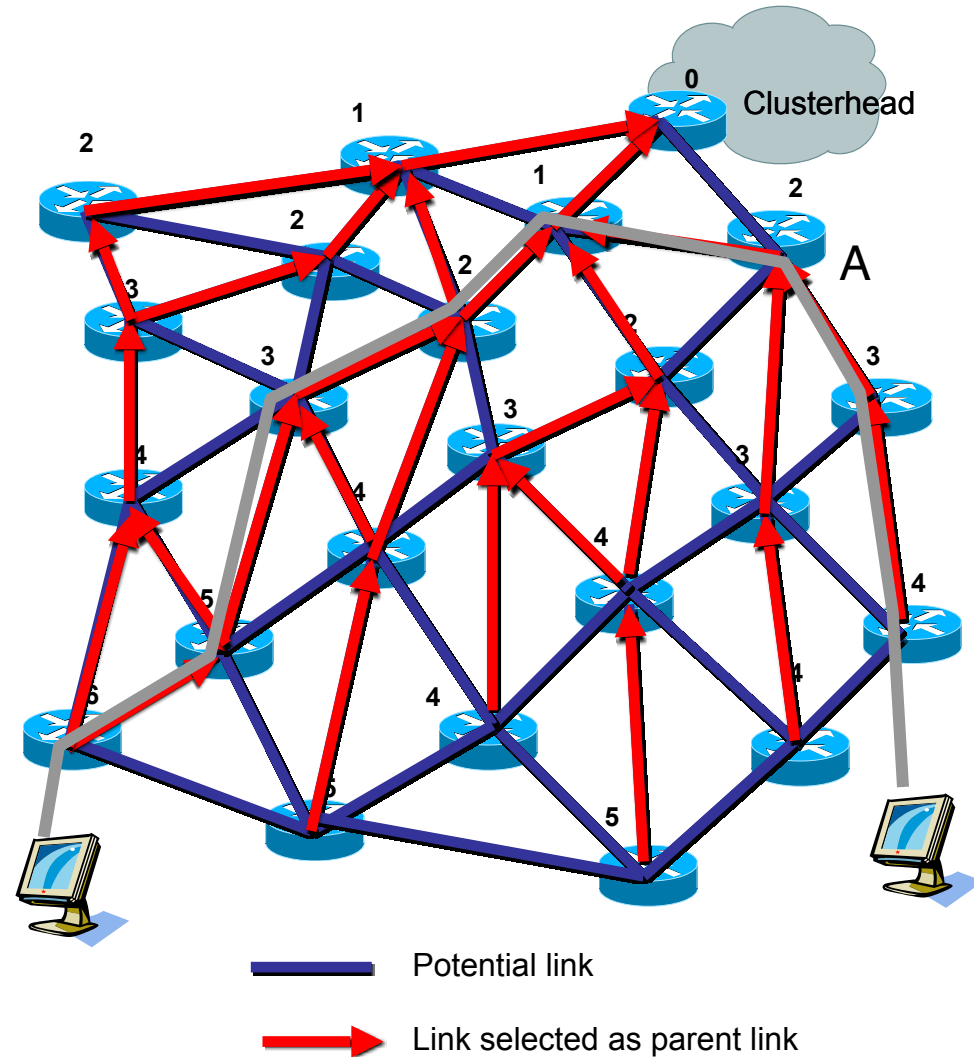
In the floating DAG A is root

The structure is preserved



Local recovery (step 3)

Once poisoned nodes are identified
It is possible for A to re-parent safely
A's descendants inherit from Rank shift
Note: a depth dependent timer can help order things



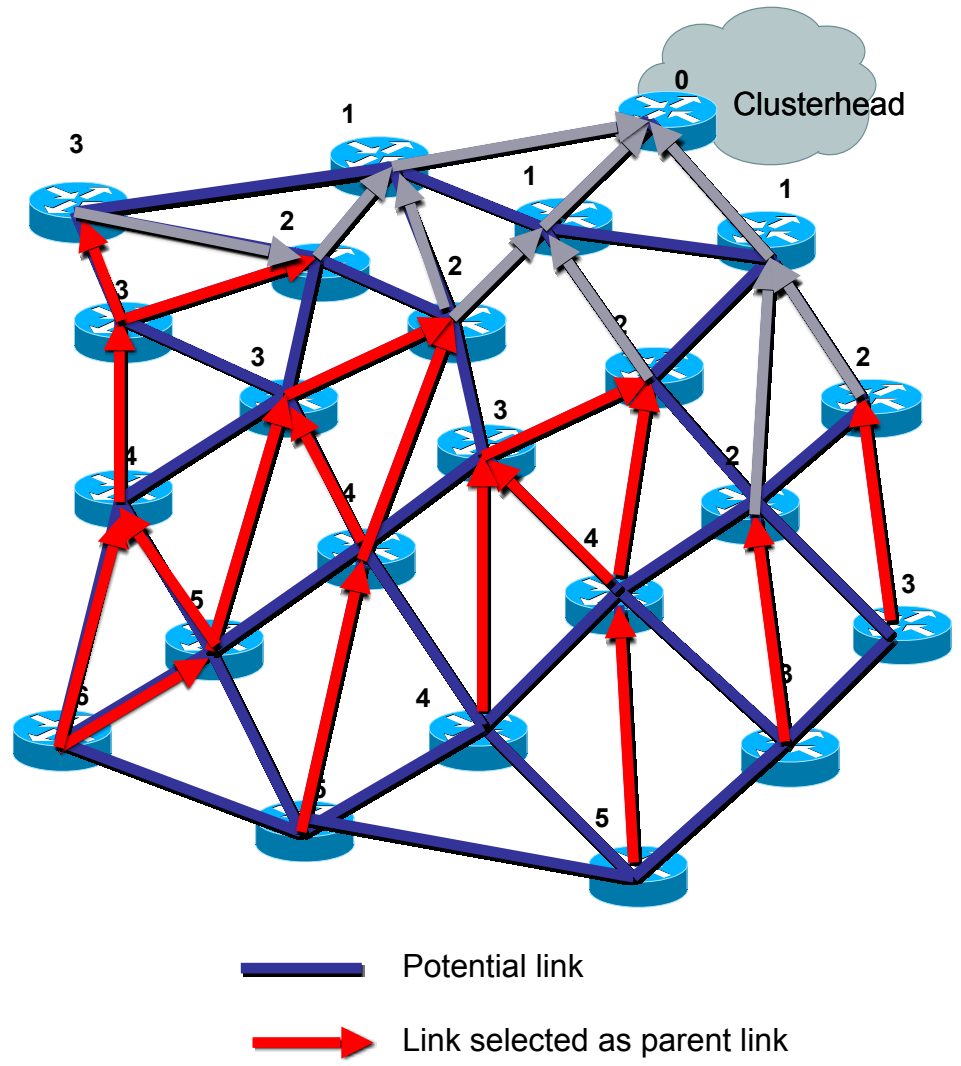
Global recovery

A new DAG iteration

- In Grey, the new DAG progressing

Metrics have changed, the DAG may be different

Forwarding upwards traffic from old to new iteration is allowed but not the other way around



Multiple DODAGs within Instance

A second root is available

- (within the same instance)

The DAG is partitioned

1 root = 1 DODAG

1 Node belongs to 1 DODAG

- (at most, per instance)

Nodes may JUMP

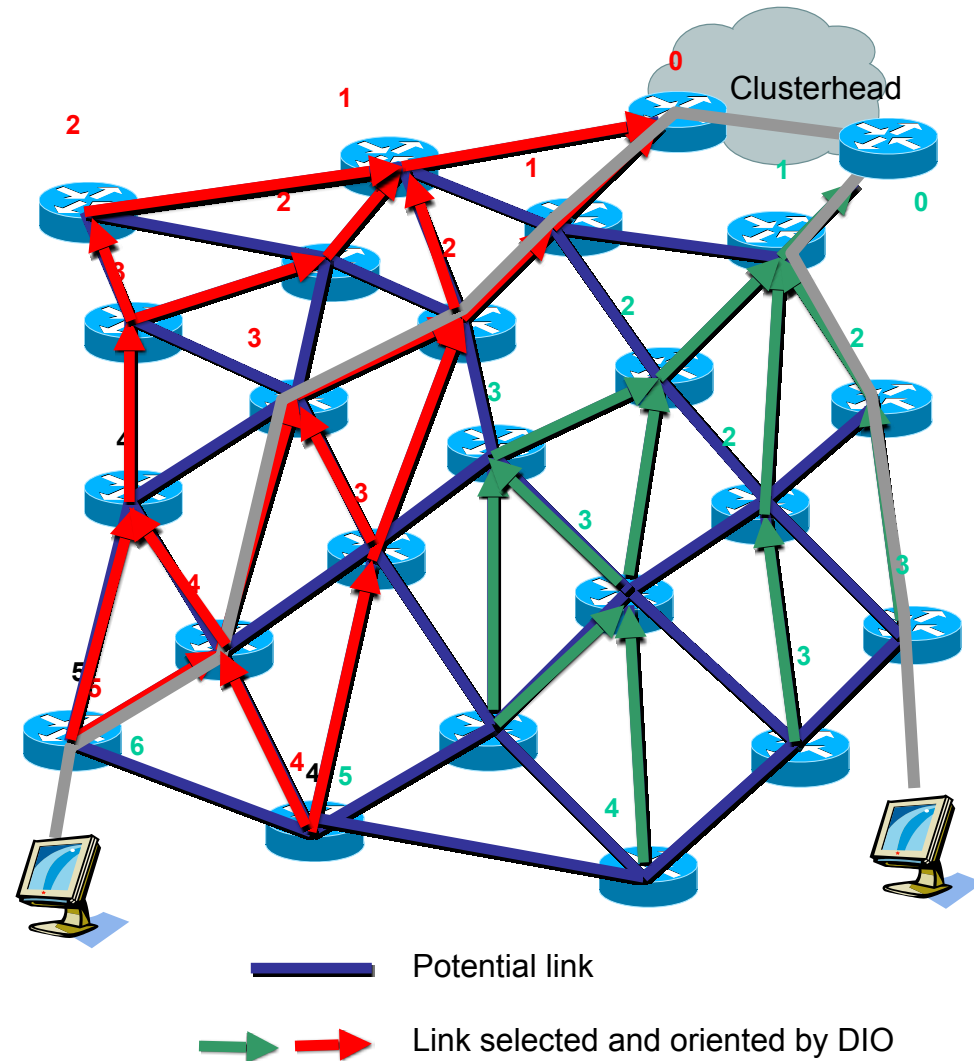
- from one DODAG to the next

Nodes may MOVE

- up the DODAG

Going Down MAY cause loops

- May be done under CTI control



Summary



New Radios issues:

Dynamic Topologies

Peer selection

Constrained Objects

Fuzzy Links

Routing, local Mobility

Global Mobility

Addressed in RPL by:

DV, ORA P2MP/MP2P, LORA P2P

Objective Functions, Metrics

Controlling the control

Directed Acyclic Graphs

Trickle and Datapath validation

Local and Global Recovery

N/A

RPL — Reading Material —

RFC 6206: The Trickle Algorithm

RFC 6550: RPL: IPv6 Routing Protocol for LLNs

RFC 6551: Routing Metrics Used for Path Calculation in LLNs

RFC 6552: Objective Function Zero for the Routing Protocol for LLNs

RFC 6553: RPL Option for Carrying RPL Information in Data-Plane Datagrams

RFC 6554: An IPv6 Routing Header for Source Routes with RPL

RFC 6719: MRHOF Objective Function with hysteresis

draft-ietf-roll-trickle-mcast: Multicast Protocol for LLNs

draft-vilajosana-6tisch-minimal: Minimal 6TiSCH Configuration

“We might be at the eve of pervasive networking, a vision for the Internet where every person and every device is connected to the network in the ultimate realization of Metcalfe's Law.”

Agenda

1. Deep Dive into the layers

1. IEEE802.15.4

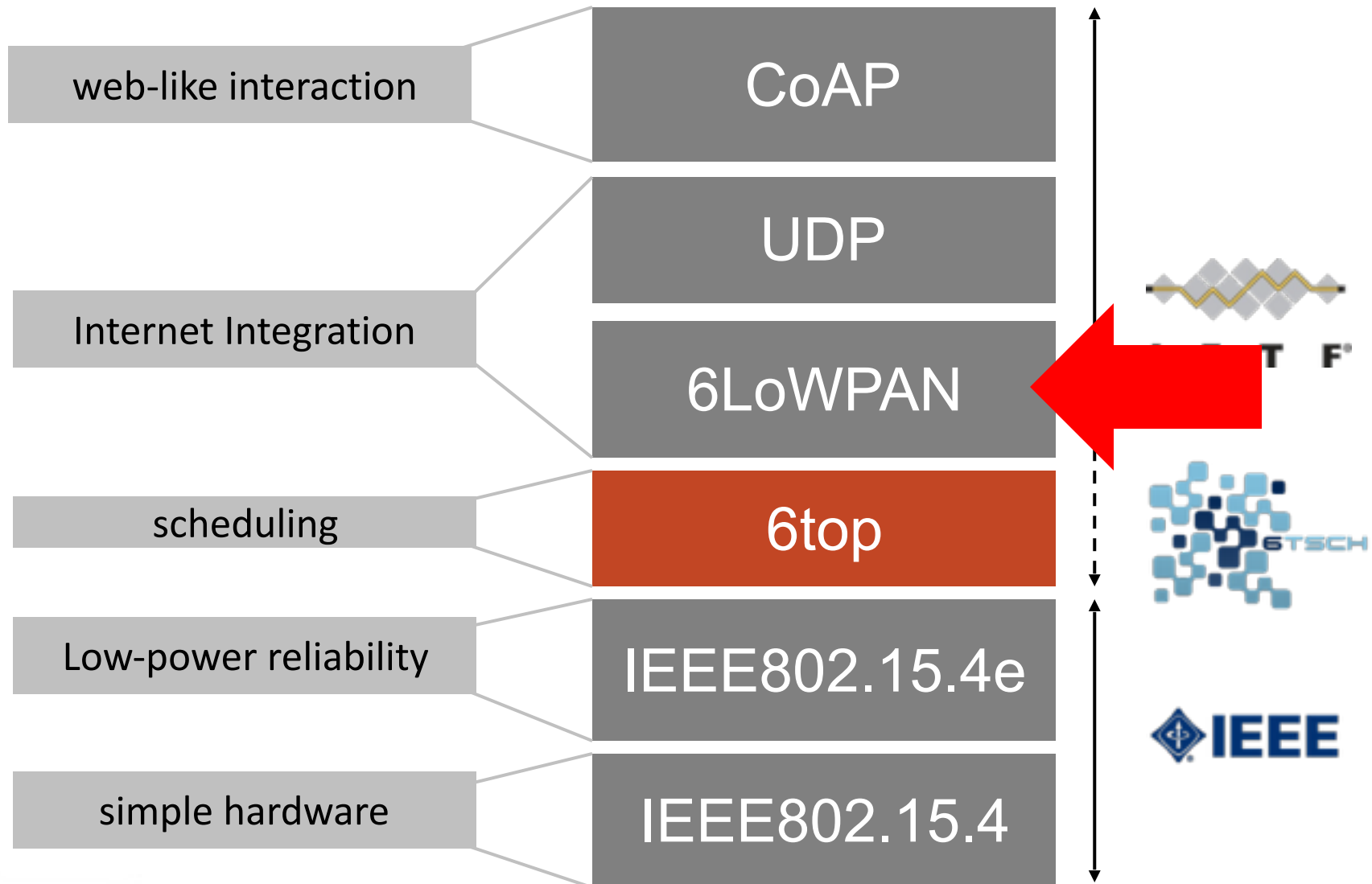
2. IEEE802.15.4.E

3. 6TSCH

4. 6LOWPAN

5. COAP

The Internet of Things Stack



6LowPAN Motivation

- Benefits of IP over 802.15.4 (RFC 4919)
 1. The pervasive nature of IP networks allows use of existing infrastructure.
 2. IP-based technologies already exist, are well-known, and proven to be working.
 3. Open and freely available specifications vs. closed proprietary solutions.
 4. Tools for diagnostics, management, and commissioning of IP networks already exist.
 5. IP-based devices can be connected readily to other IP-based networks, without the need for intermediate entities like translation gateways or proxies.

6LowPAN Challenge

1. Header Size Calculation

1. IPv6 header is 40 octets, UDP header is 8 octets
2. 802.15.4 MAC header can be up to 25 octets (null security) or $25+21=46$ octets (AES-CCM-128)
3. With the 802.15.4 frame size of 127 octets, we have
4. $127-25-40-8 = 54$ octets (null security)
5. $127-46-40-8 = 33$ octets (AES-CCM-128)
6. of space left for application data!

2. IPv6 MTU Requirements

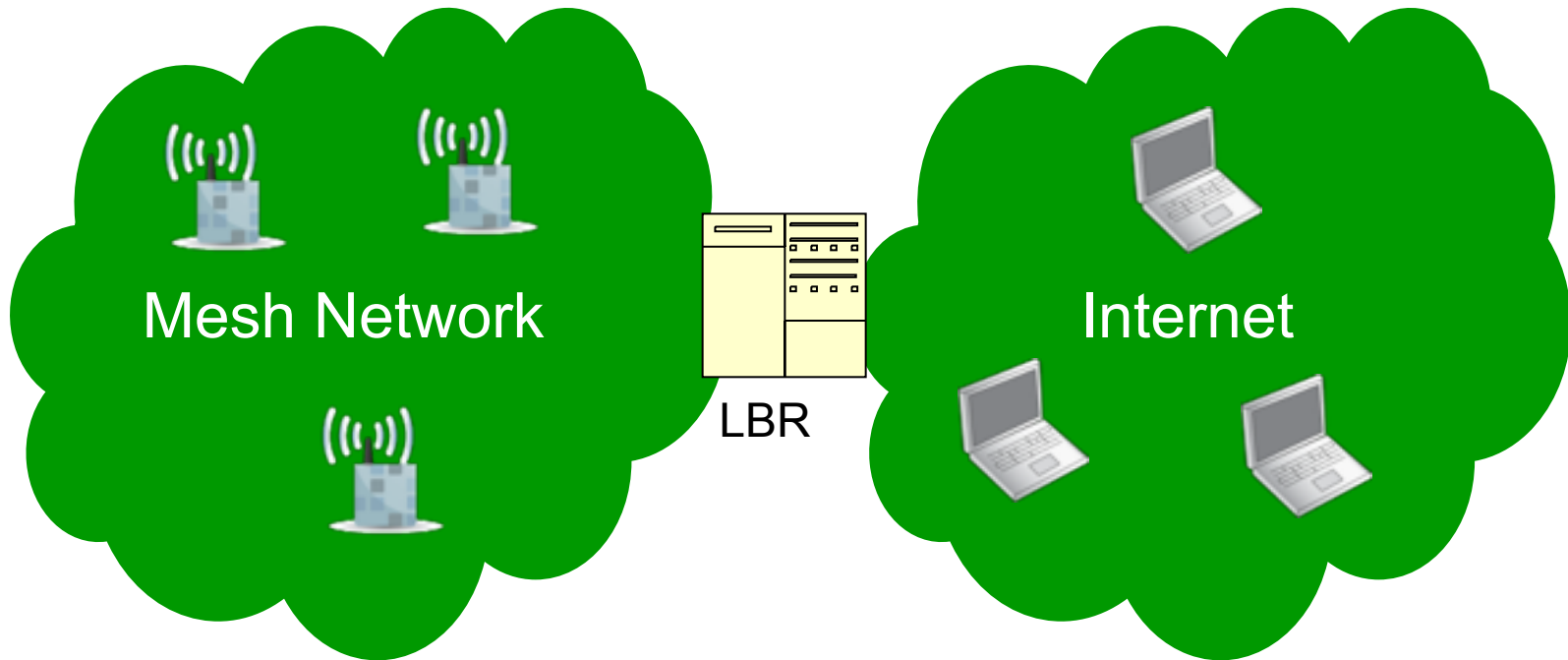
1. IPv6 requires that links support an MTU of 1280 octets
2. Link-layer fragmentation / reassembly is needed

6LowPAN Overview (RFC 4944)

1. The 6LowPAN protocol is an adaptation layer allowing to transport IPv6 packets over 802.15.4 links
2. Uses 802.15.4 in unslotted CSMA/CA mode (strongly suggests beacons for link-layer device discovery)
3. Based on IEEE standard 802.15.4-2003
4. Fragmentation / reassembly of IPv6 packets
5. Compression of IPv6 and UDP/ICMP headers
6. Mesh routing support (mesh under)
7. Low processing / storage costs

6LoWPAN: architecture

compaction



inflation

6LowPAN — Reading Material —

- K.D. Korte, I. Tumar, and J. Schonwalder, Evaluation of 6lowpan Implementations. In 4th IEEE International Workshop on Practical Issues in Building Sensor Network Applications (SenseApp 2009). IEEE, October 2009.
- N. Kushalnagar, G. Montenegro, and C. Schumacher. IPv6 over Low-Power Wireless Personal Area Networks (6LoWPANs): Overview, Assumptions, Problem Statement, and Goals. RFC 4919, Intel Corp, Microsoft Corporation, Danfoss A/S, August 2007.
- G. Montenegro, N. Kushalnagar, J. Hui, and D. Culler. Transmission of IPv6 Packets over IEEE 802.15.4 Networks. RFC 4944, Microsoft Corporation, Intel Corp, Arch Rock Corp, September 2007.

Agenda

1. Deep Dive into the layers

1. IEEE802.15.4

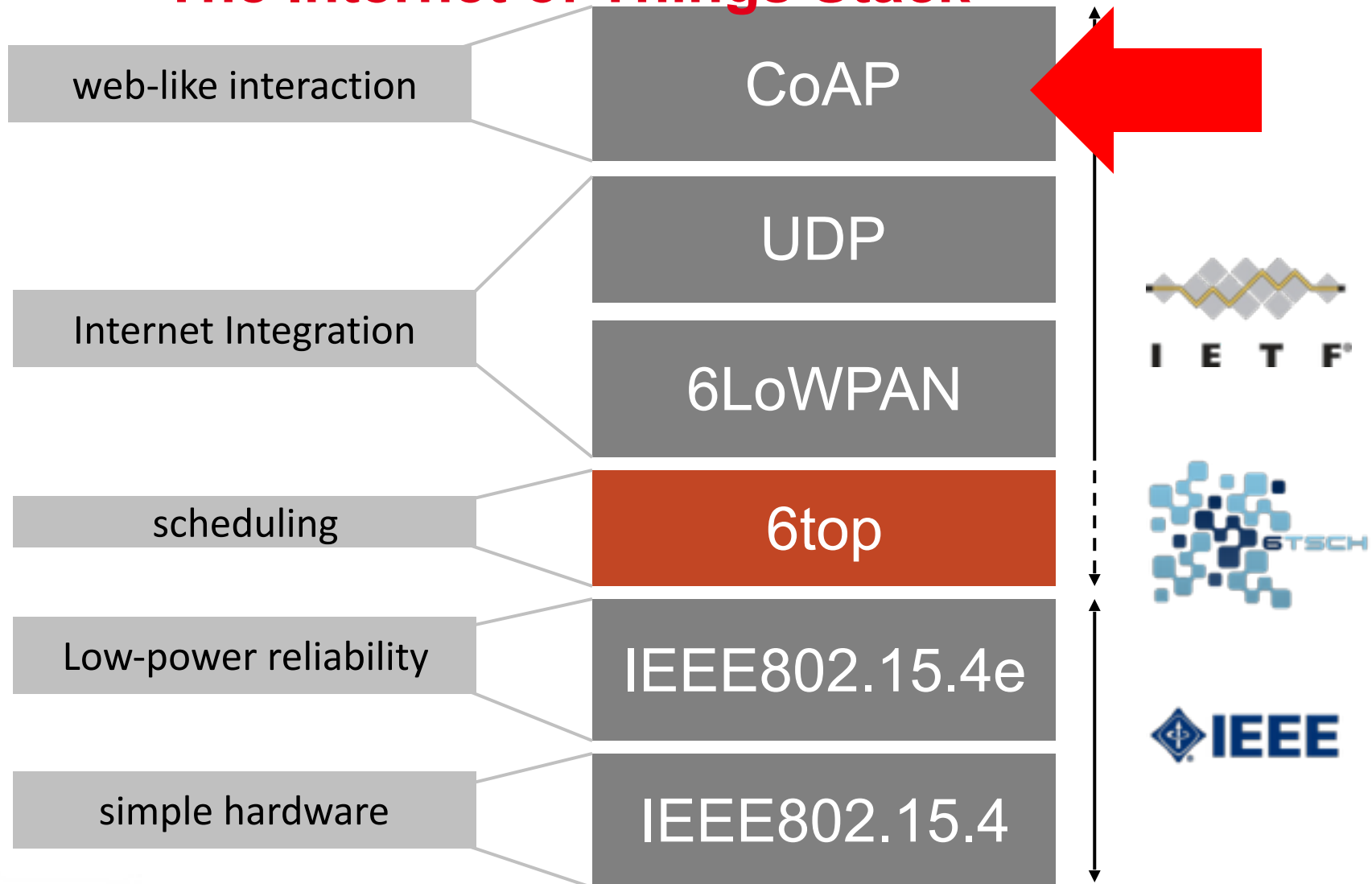
2. IEEE802.15.4.E

3. 6TSCH

4. 6LOWPAN

5. COAP

The Internet of Things Stack



Interoperation - IPSO

- “IP for Smart Objects”
- Alliance of companies
- Promote the use of IP in Smart Objects
- Not a standardization body
- White Papers, interop events...
- www.ipso-alliance.org



BOSCH
Invented for life

dust
networks™

NXP



sensinode



WATTECO



CISCO



Convergence
WIRELESS

freescale™
semiconductor

ember



TEXAS INSTRUMENTS

Atmel



elster

COOPER Power Systems

ORACLE

SILVERSPRING



EMERSON
Climate Technologies

Status of CoAP

In use by

- OMA Lightweight M2M
 - <http://openmobilealliance.org>
- IPSO Alliance
 - www.ipso-alliance.org
- ETSI M2M / OneM2M
 - <http://www.onem2m.org>
- IoT Eclipse
 - <http://iot.eclipse.org>



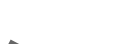
Device management for network operators
Lighting systems for smart cities

Application-layer interoperability and usability for the IoT

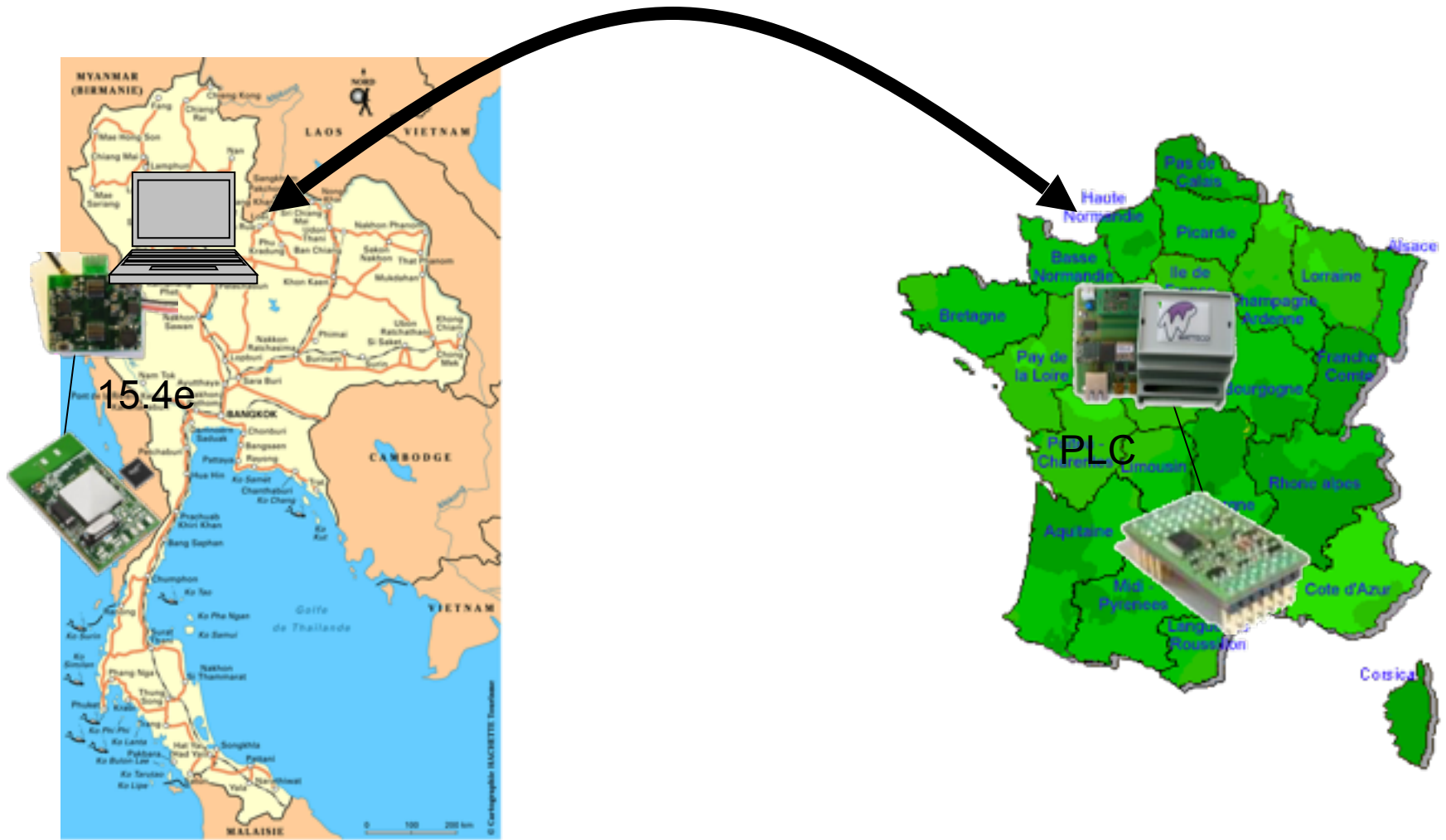
Well-known patterns



Web mashups



Interoperation – Internet Interaction

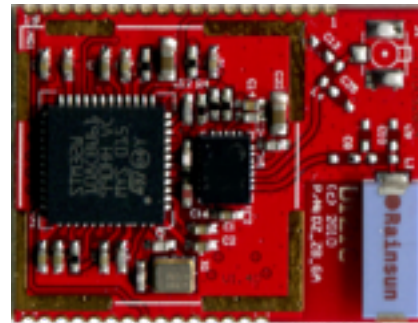


Tiny Resource-constrained devices

Class 1 devices

~100KiB Flash

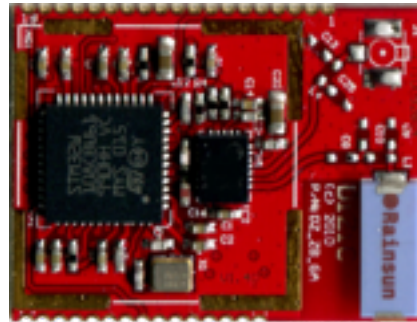
~10KiB RAM



Low-power networks

Tiny Resource-constrained devices

Target
of less than \$1
for IoT SoC



TCP and HTTP
are not a good fit

COAP Motivation

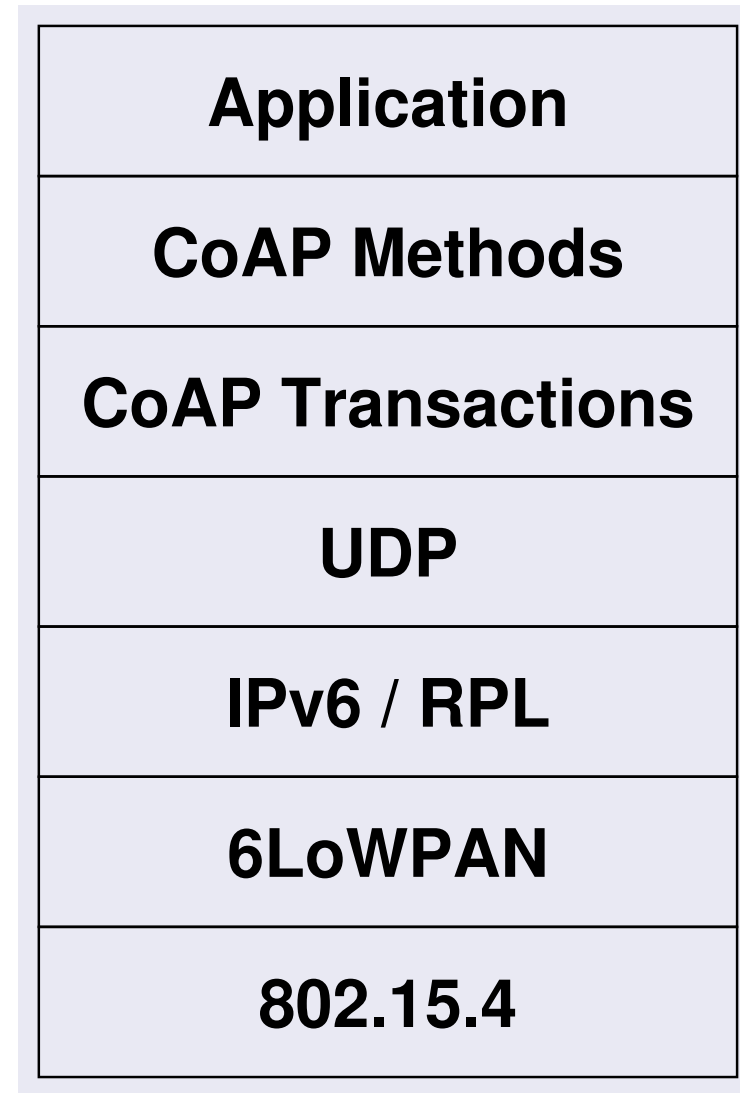
- Constraint Application Protocol
- HTTP is too heavy for LoWPAN
 - TCP is not optimal (1 MSS windows)
 - Demand a lot of parsing to understand HTTP request
- **CoAP is based on UDP and defines:**
 - A simple message format easily processed by devices with limited processing resources,
 - A simple transport protocol to detect and correct packet losses,
 - A way to query or store information on a node using the **REST paradigm**,
 - A way to discover resources inside a LoWPAN network.
- **CoAP includes a simple "transport" protocol**

CoAP Overview

- **Constrained machine-to-machine web protocol**
- **Representational State Transfer (REST) architecture**
- **Simple proxy and caching capabilities**
- **Asynchronous transaction support**
- **Low header overhead and parsing complexity**
- **URI and content-type support**
- **UDP binding (may use IPsec or DTLS)**
- **Reliable unicast and best-effort multicast support**
- **Built-in resource discovery**

CoAP Layers in the Protocol Stack

- **CoAP transactions provide reliable UDP messaging**
- **CoAP methods resemble HTTP method requests and responses**
- **CoAP method calls may involve multiple CoAP transactions**
- **Roles at the transaction layer may change during a method request / response execution**

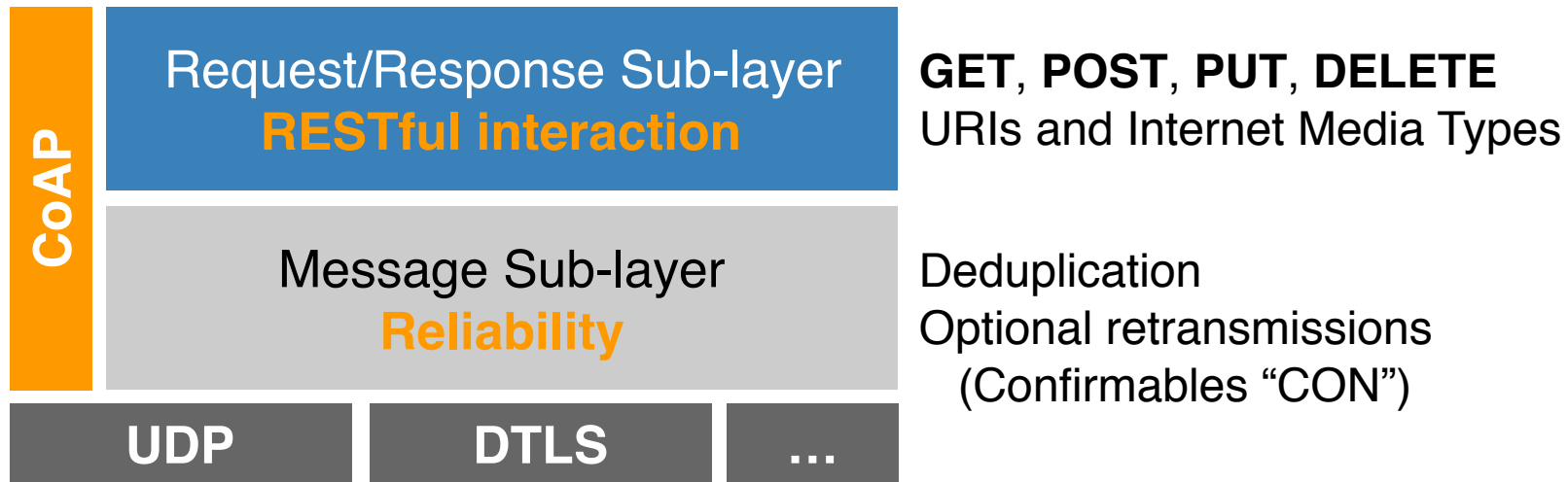


Constrained Application Protocol

RESTful protocol designed from scratch

Transparent mapping to HTTP

Additional features for M2M scenarios



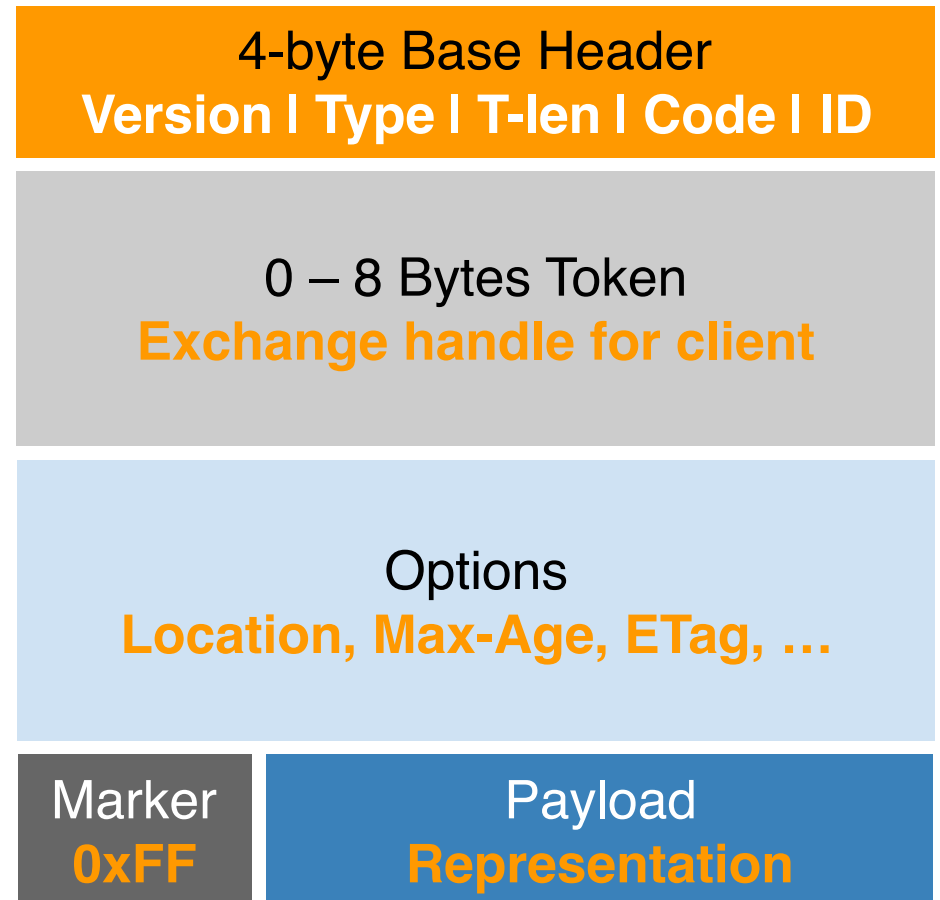
Constrained Application Protocol

Binary protocol

- Low parsing complexity
- Small message size

Options

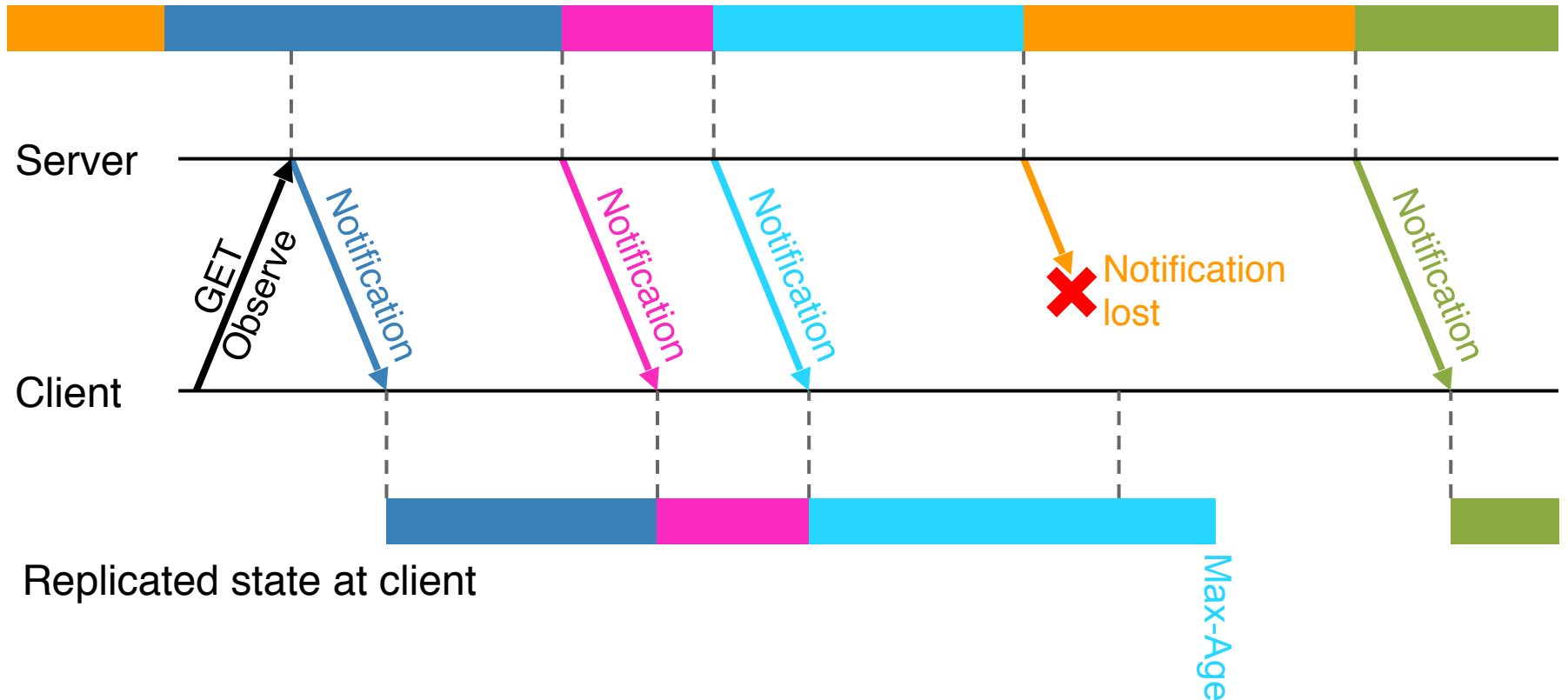
- Numbers in IANA registry
- Type-Length-Value
- Special option header marks payload if present



Observing resources

Resource state at origin server

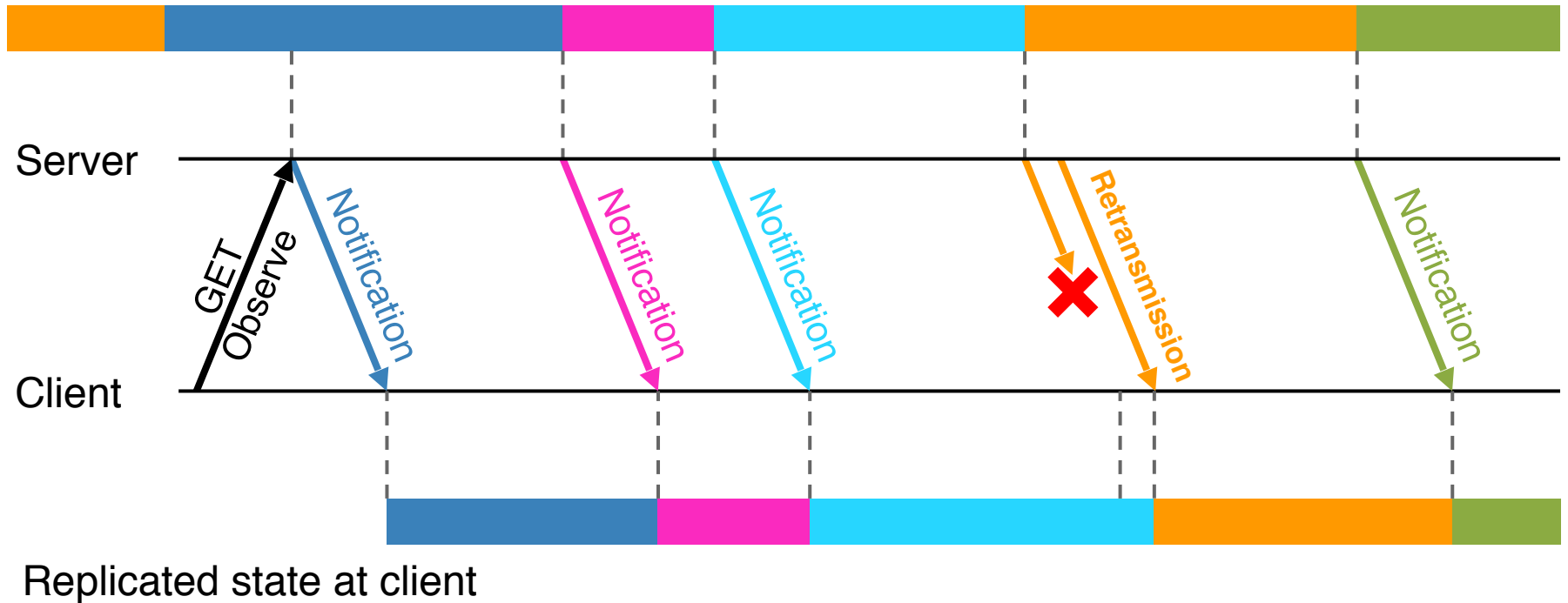
Observe illustration courtesy of Klaus Hartke



Observing resources - CON mode

Resource state at origin server

Observe illustration courtesy of Klaus Hartke



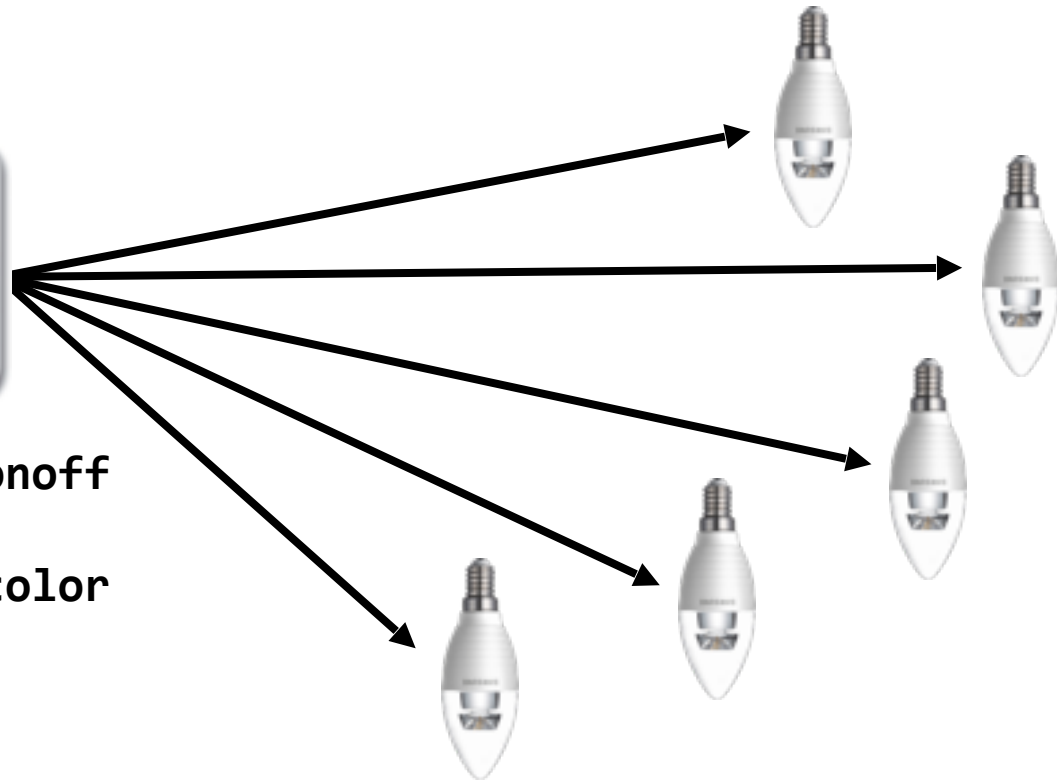
Resource Discovery

- **Discover CoAP server and resources managed by them:**
 - **Use multicast and DNS-SD (Service Discovery)**
 - **Avoid multicast and servers describe their resources using a standard representation.**
 - **Known as Web Linking (RFC 5988)**
 - **Link between resources.**
 - **Do not confuse with IPv6 links**
 - **Well known URI:**
 - **.well-known/core (cf. RFC 5785)**
 - **.well-known: defined by RFC 5988**
 - **core: name of the working group**
 - **Response is structured following RFC 6690**

RESTful group communication

GET /status/power

all-lights.floor-d.example.com



PUT /control/onoff

PUT /control/color
#00FF00



Resource discovery

Based on **Web Linking** (RFC5988)

Extended to **Core Link Format** (RFC6690)

```
GET /.well-known/core
```

```
</config/groups>;rt="core.gp";ct=39,  
</sensors/temp>;rt="ucum.Cel";ct="0 50";obs,  
</large>;rt="block";sz=1280,  
</device>;title="Device management"
```

Decentralized discovery
Infrastructure-based

Multicast Discovery
Resource Directories

Alternative transports

Short Message Service (SMS)

Unstructured Supplementary Service
Data (USSD)

***101# 1**
☎

Addressable through URIs

```
coap+sms://+123456789/bananas/temp*
```

IP connectivity after SMS signal



* illustration only, +123456789 unfortunately not allowed by URI RFC

Security

Based on **DTLS** (TLS/SSL for Datagrams)

Focus on Elliptic Curve Cryptography (**ECC**)

Pre-shared secrets, certificates, or raw public keys

Hardware acceleration in IoT devices

IETF is currently working on

- Authentication/authorization (ACE)

- DTLS profiles (DICE)

e.g.,



Conclusion — Some takeaways

- **The Internet is going through its most considerable change since the first days, adding a nervous system to the bug brain.**
 - Potential is immense and unpredictable.
- **Made possible by IPv6**
 - But not at the core and unbeknownst to the core
- **Stimulated by radio access**
 - Enabling new devices and usages
- **The change happens in the Fringe, which is in fact a collection of virtualized fringes.**
 - The polymorphic Internet is already there.

Deploying real applications

Build new protocols / applications

Specification / Design

Simulation

Deployment / Experimentation



HiKoB



HiKoB

Large scale experimentation is real nightmare

Fastidious for a dozen of nodes

Manual handling / time consuming / boring

Needs for large scale scientific tools

Scientific & Reproducible experiment

4

FIT IoT-LAB in the IoT Context

WHAT / WHERE / WHY / HOW

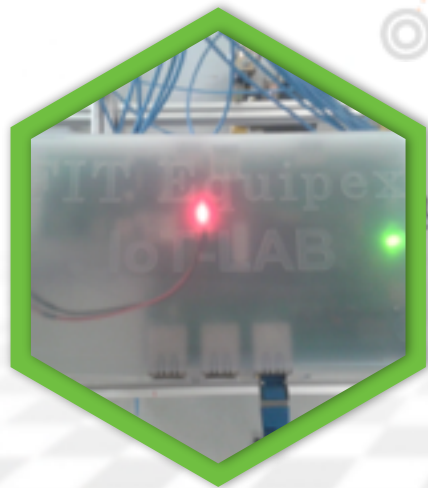
FIT IoT LAB Objectives

- ▶ **Target and challenge:**

- ▶ M2M / scaling

- ▶ IoT (heterogenous)

- ▶ **Designing / Testing / Deploying / Monitoring**



- ▶ **Use Cases:**

- ▶ Home Gateway

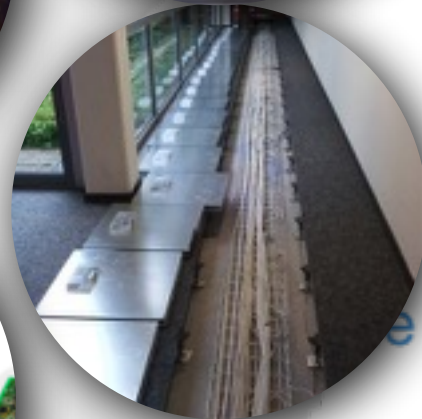
- ▶ Cloud service monitoring

- ▶ IPv6 from sensors to the
Cloud

- ▶ Mobile nodes

What/Where is FIT IoT LAB?

- ▶ More than 2700+ wireless nodes
- ▶ IMS band
- ▶ IEEE 802.15.4
- ▶ Low Power and Lossy Networks
- ▶ Total Remote Access
- ▶ Total Open Access
- ▶ Mobile Nodes/Robots



Ten Commandments

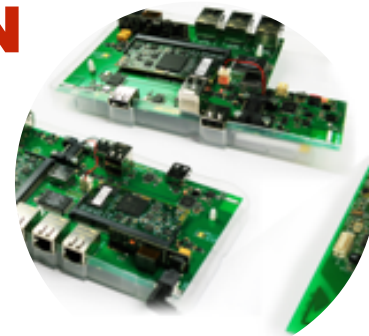
OPEN Nodes == NO CONSTRAINTS AT ALL

- I. Total remote access to open nodes
- II. Direct access to debugger
- III. Access to serial port / aggregator
- IV. On the global Internet (IPv6 end-to-end)



External Monitoring == NO APP MODIFICATION

- v. Packet sniffer
- vi. Precise end-to-end synchronisation (GPS)
- vii. Accurate power consumption



Easy to use / Advance features

- viii. OS supports, tutorials, Open-source (OpenWSN)
- ix. Fleet of robots (40 + 60 + 10)
- x. Free open slots for specific hardware (usb node)

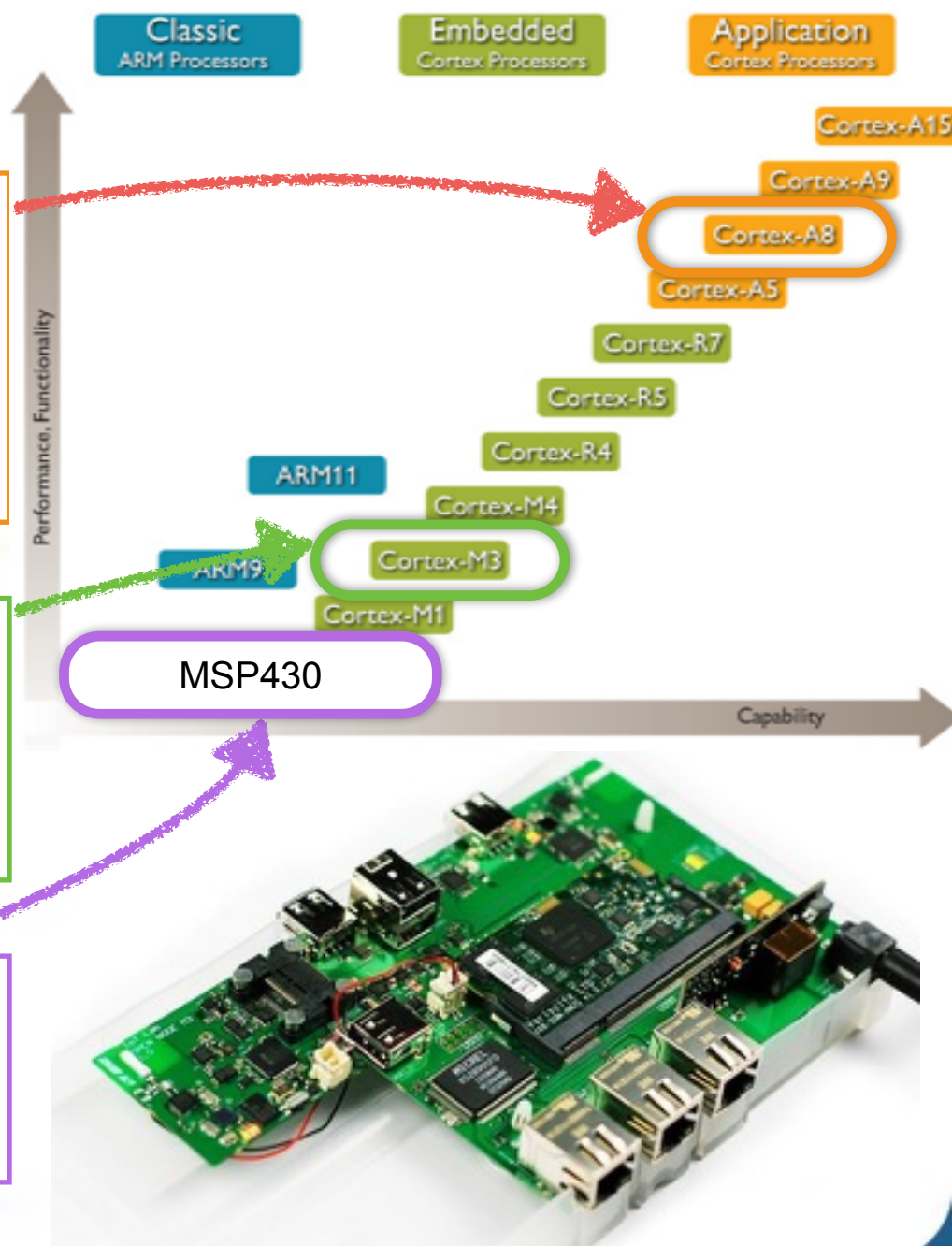


IoT LAB Nodes

- ▶ A8 node : TI-SITARA AM3505
 - ▶ Ethernet, USB
 - ▶ Linux/Android
 - ▶ Indoor GPS for highly accurate synchronisation

- ▶ M3 node : STM32
 - ▶ Radio Atmel AT86RF231
 - ▶ Ambient light, Temp, IMU, Pressure

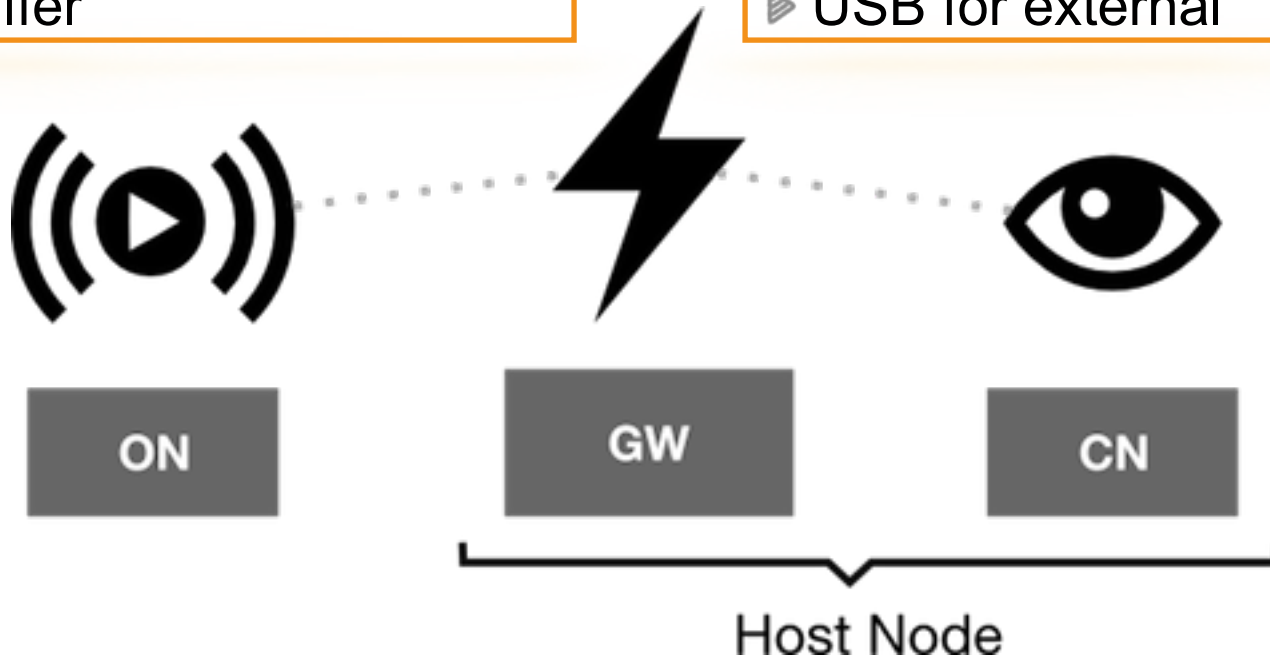
- ▶ WSN430 node : TI MSP430
 - ▶ Radio TI CC1101 / CC2420
 - ▶ Ambient light, Temp



IoT-LAB Node

- ▶ Automatic firmware deployment
- ▶ Consumption Monitoring
- ▶ Sensor polling
- ▶ Radio sniffer

- ▶ Feedback channel
- ▶ Power over ethernet
- ▶ SINK / Internet connexion
- ▶ USB for external

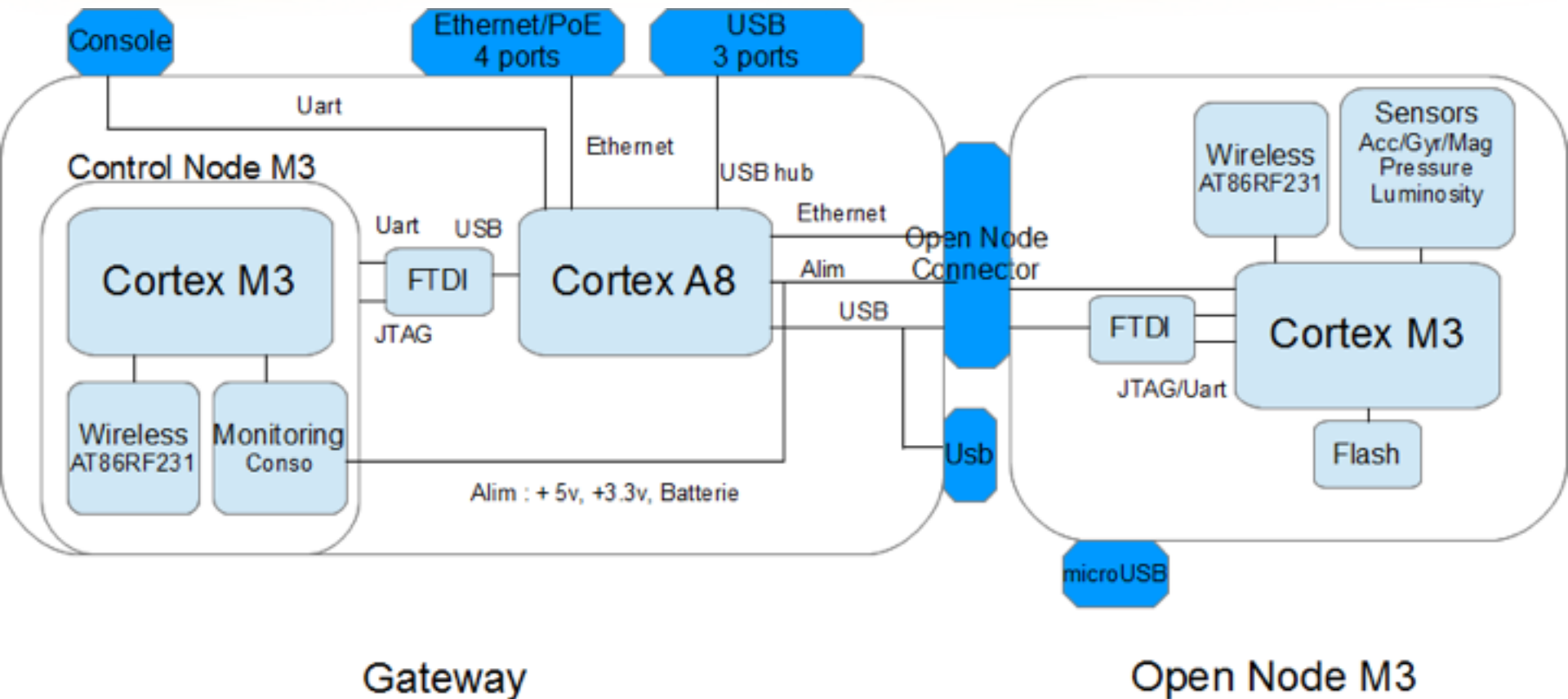


- connection to the global infrastructure
- control and monitor the open node.
- handles the open node serial link if the node is set to be a sink node.

IoT-LAB Node M3 Architecture

- ▶ Automatic firmware deployment
- ▶ Consumption Monitoring
- ▶ Sensor polling
- ▶ Radio sniffer

- ▶ Feedback channel
- ▶ Power over ethernet
- ▶ SINK / Internet connexion
- ▶ USB for external

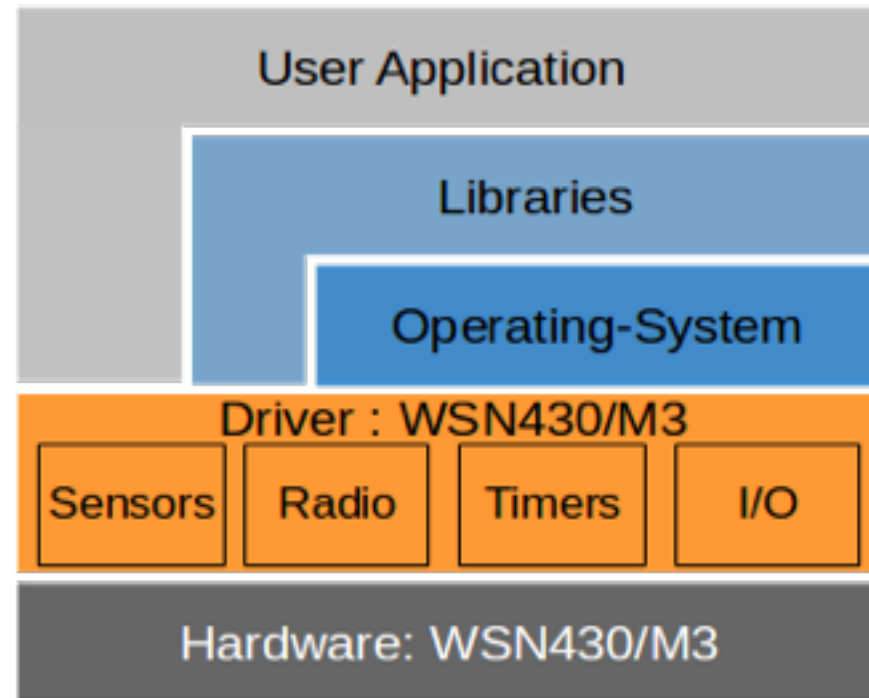


Gateway

Open Node M3







Embedded User Software

- ▶ IoT-LAB offers full support for embedded software development:
 - ▶ direct access to node HW
 - ▶ OS-level features
- ▶ Developers can leverage the different APIs to build applications.



CeCILL

Several Operating Systems

	WSN430	M3 NODE	A8 NODE
	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	
	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	
	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	
	<input checked="" type="checkbox"/>		
	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	
			<input checked="" type="checkbox"/>

What's about iot.eclipse.org ?

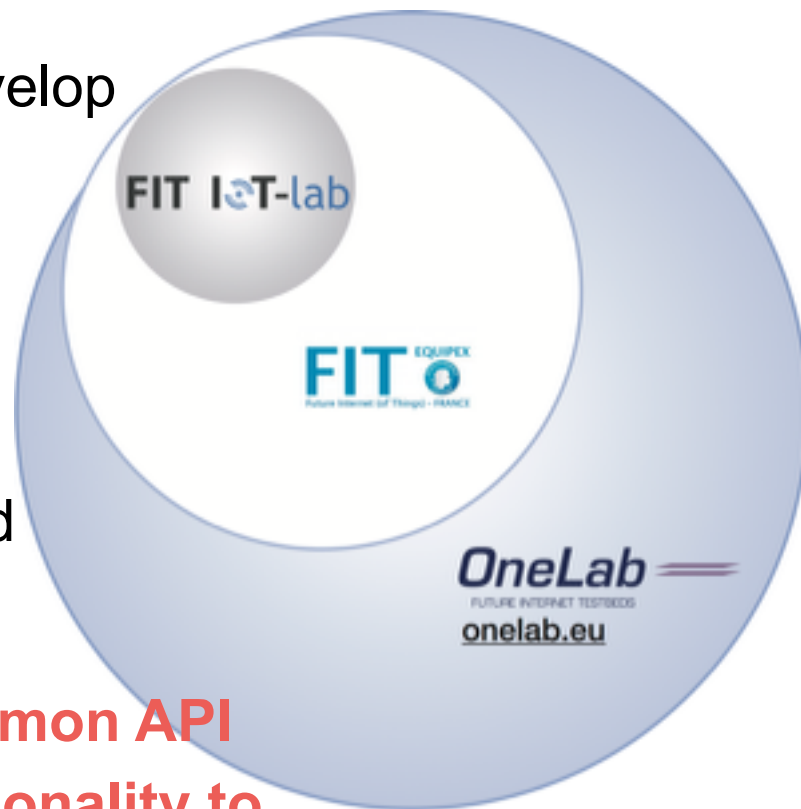
More than just an isolated testbed

▶ An Internet of Testbeds

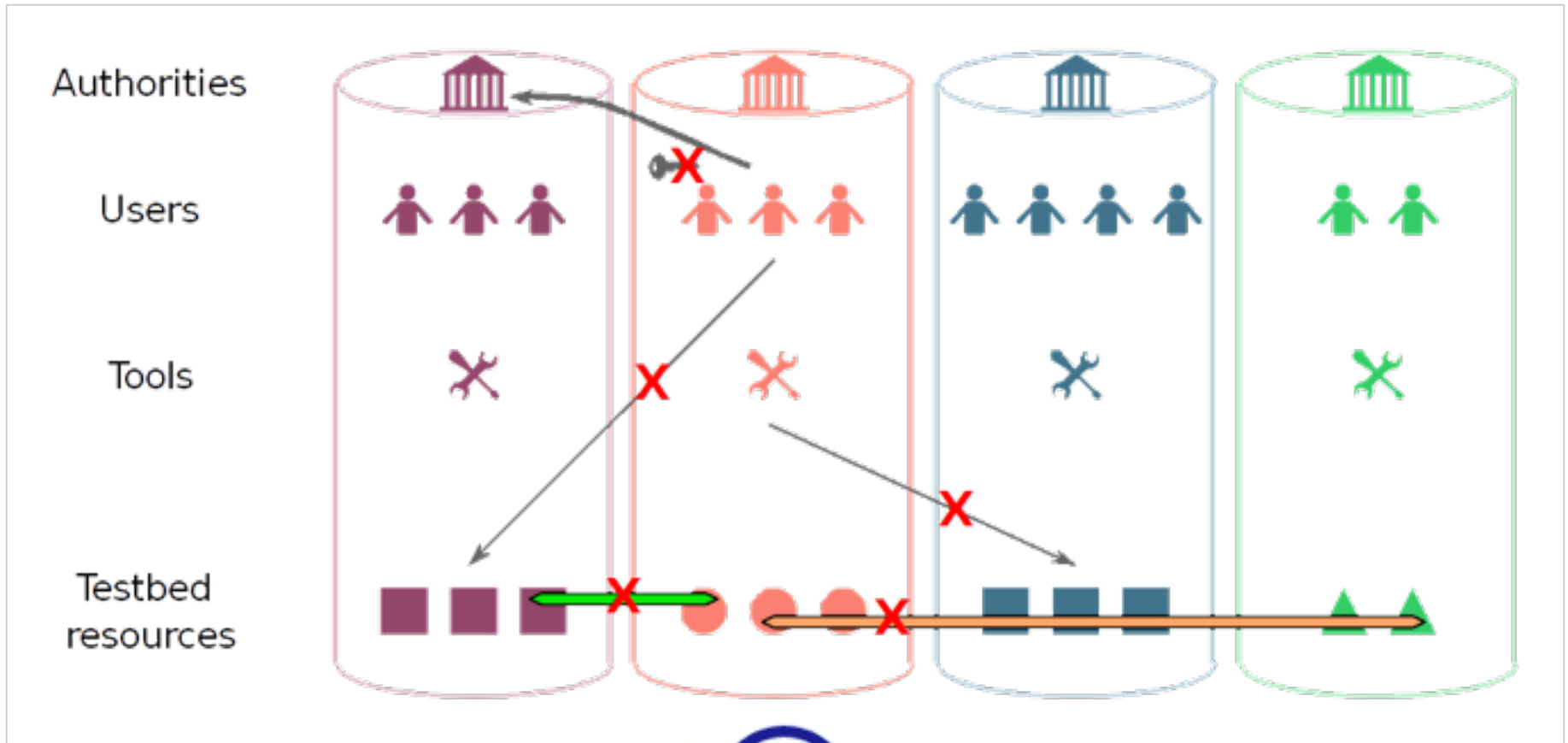
- ▶ A **Facility** – A playground for the future Internet
- ▶ Wide-variety of eco-systems and develop openness

▶ Benefits from FIT / OneLAB.eu

- ▶ An architecture for federation
- ▶ Fundamental components for testbed federation
- ▶ **SFA aims to provide a secure common API with the minimum possible functionality to enable a global testbed federation**



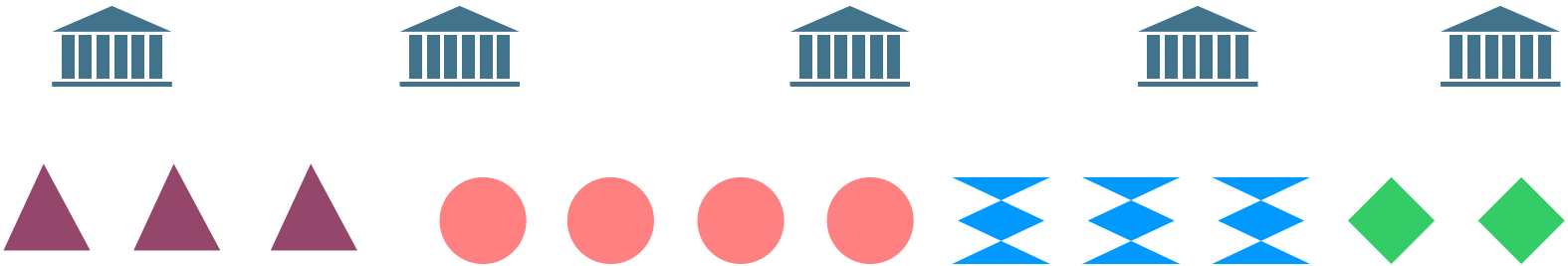
The issue with testbed isolation



Experimenters



compliant to SFA (Slice-Based Facility Architecture)

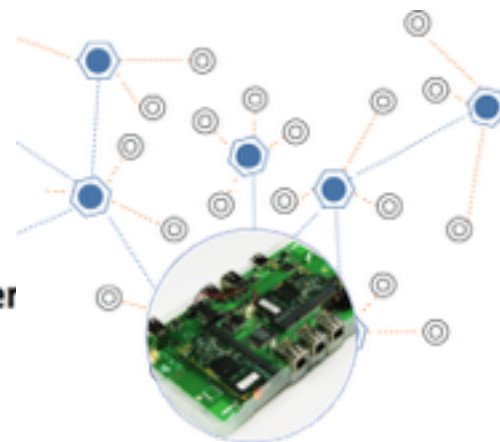


Testbed resources

How to run an experiment



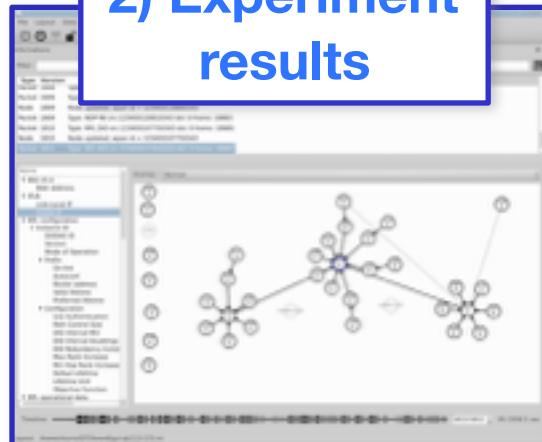
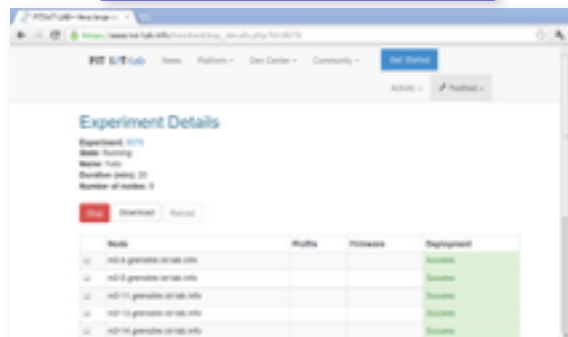
IoT-LAB server



Open systems
with IETF protocols
(RPL/COAP/6TiSCH/...)

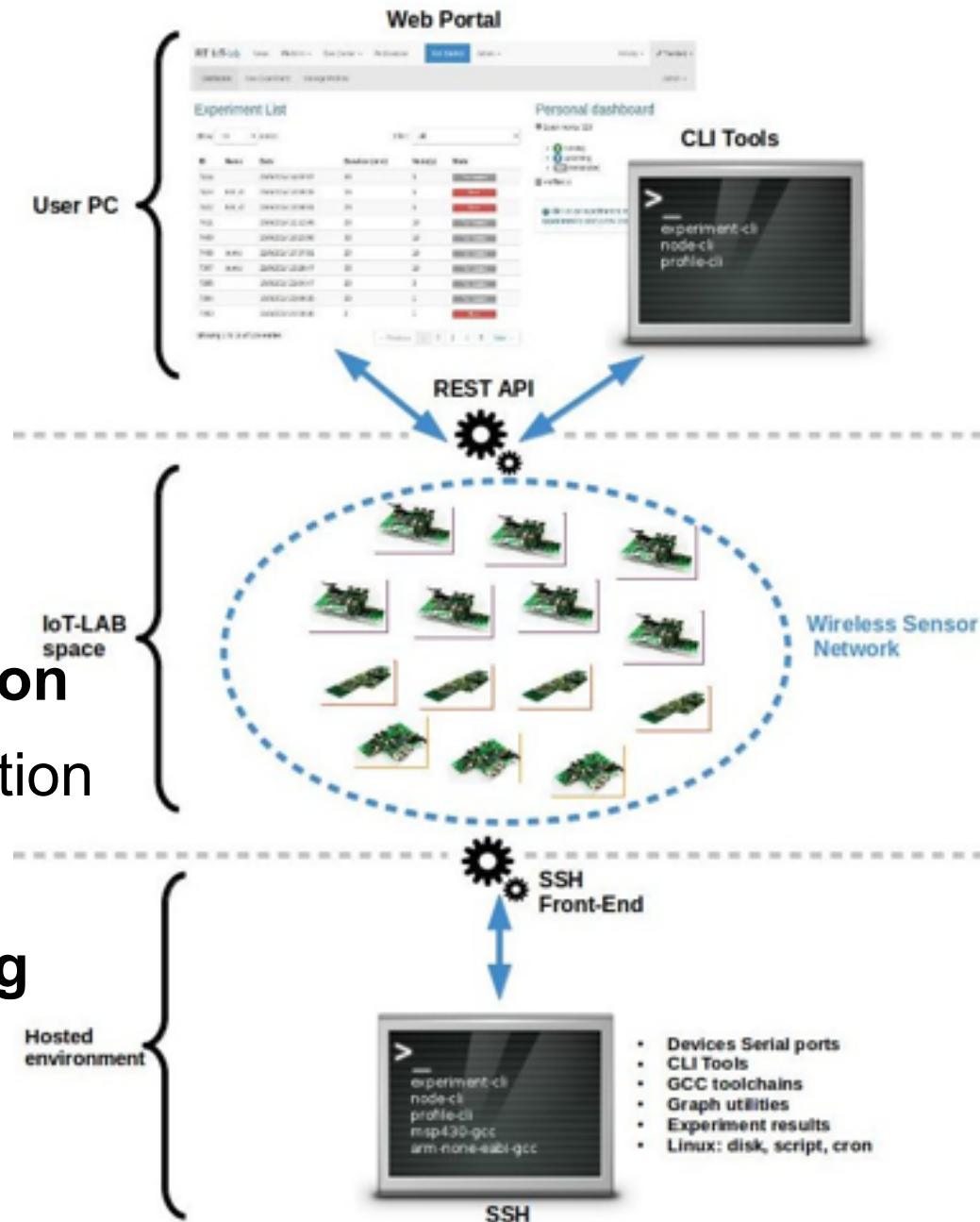
1) Experiment
configuration

2) Experiment
results



How to run an experiment

- ▶ Open a user account
- ▶ Ressources reservation
 - ▶ Geographical sites
 - ▶ WSN430/M3/A8 nodes
- ▶ Experimentation description
 - ▶ Firmware/nodes association
 - ▶ Monitoring tuning
- ▶ Experimentation launching
- ▶ Monitoring data analysis



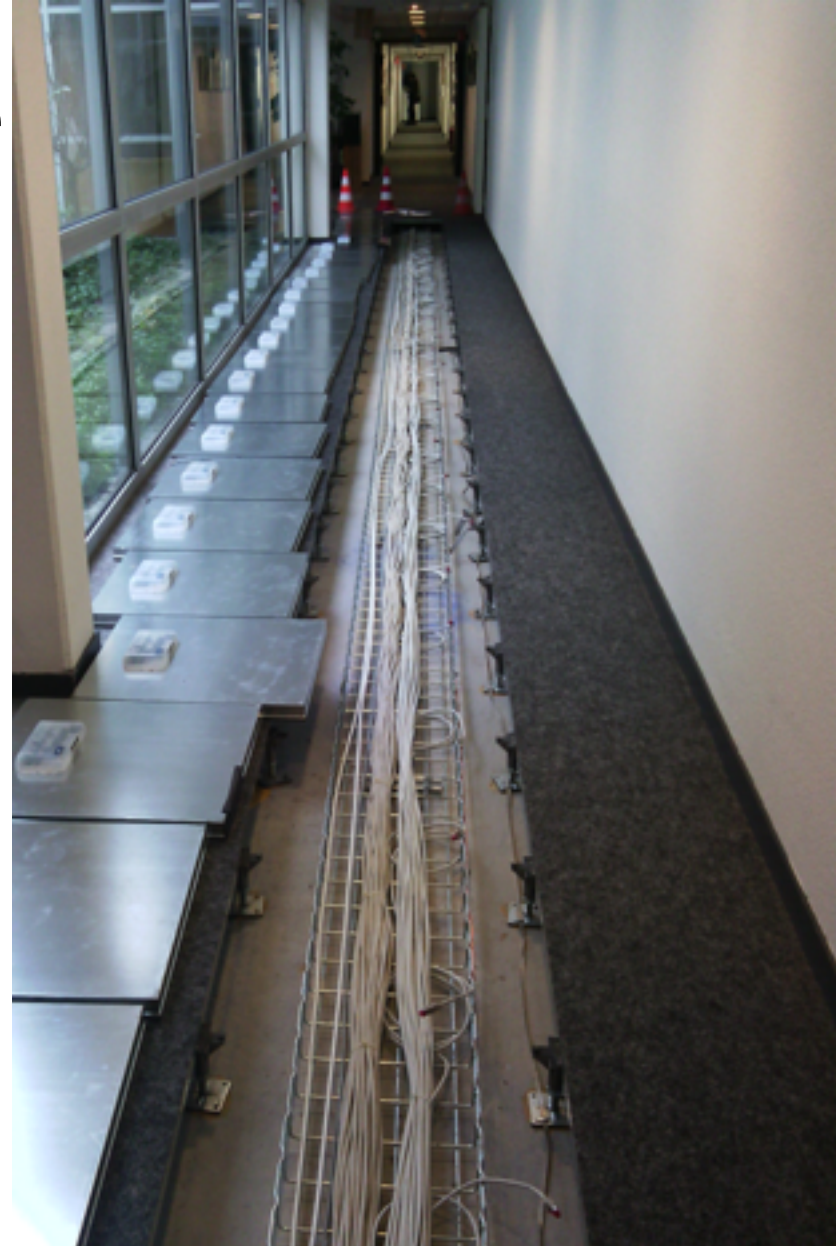
5

IoT-LAB Inria Grenoble Site
IoT-LAB Strasbourg Site

Demo

IoT LAB Inria Grenoble

- ▶ 256 WSN nodes
- ▶ 200/384 M3 nodes
- ▶ 256 A8 nodes
- ▶ 32 Open nodes



Contiki RPL IPv6 Experiment

FIT  **IoT-lab**

Inria
Informatiques mathématiques

FIT EQUIPEX
Future Internet (of Things) - FRANCE

Inria

Eric Fleury ENS de Lyon / Inria



FIT  **IoT-lab**

November 2015

Smart Tiles

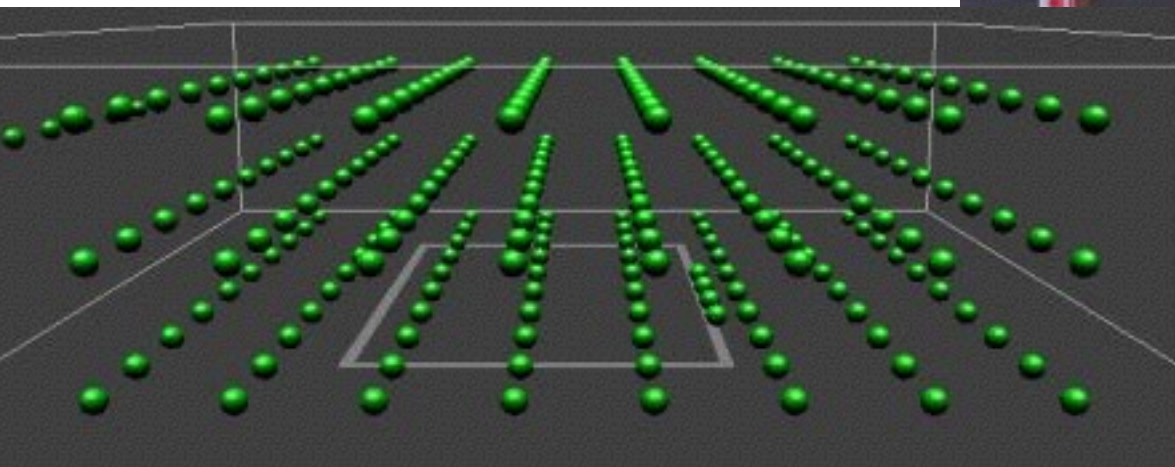
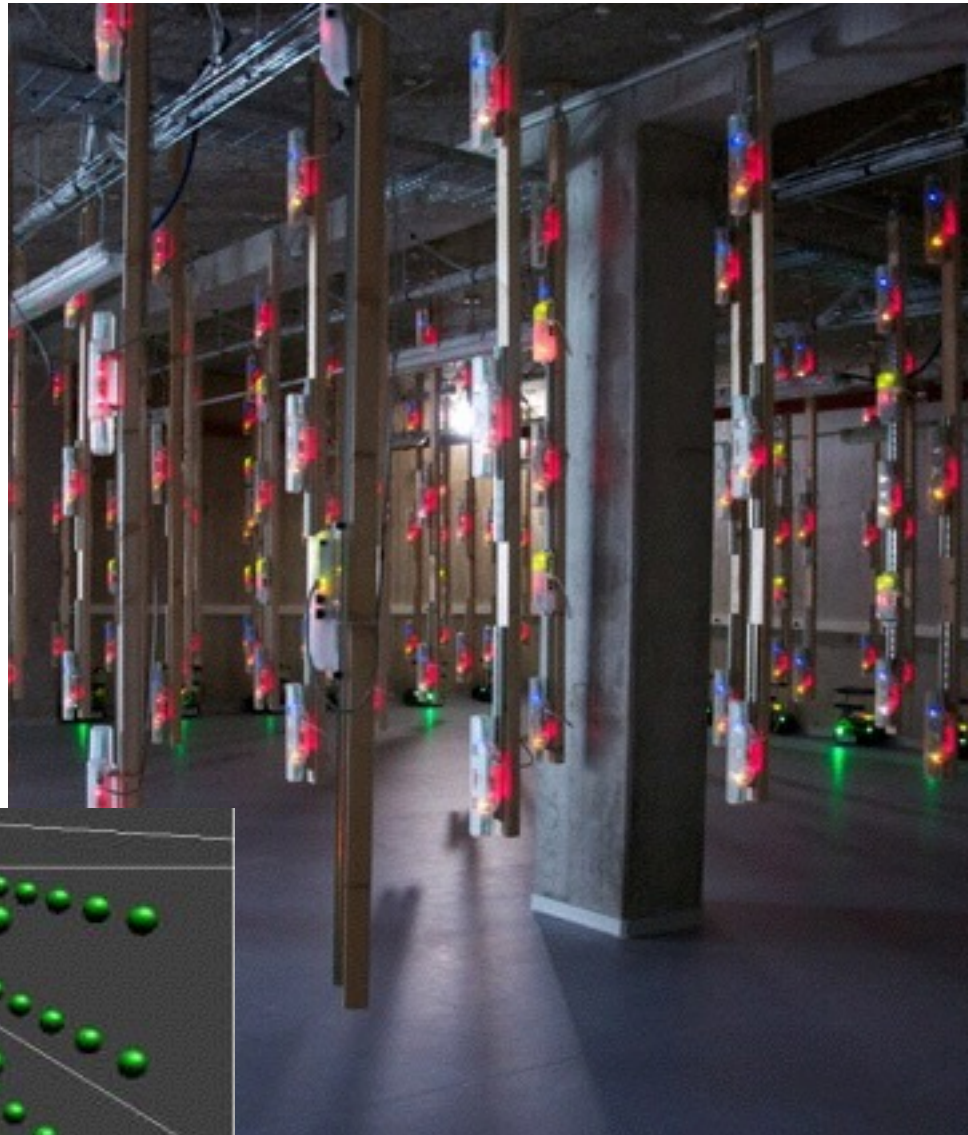
for

Robots and Humans

Detection

IoT LAB Strasbourg

- ▶ 256 WSN nodes
- ▶ 120 M3 nodes
- ▶ 25 A8 nodes
- ▶ 40 mobile nodes





Some video pointers

- **Virtual visit of Grenoble FIT Iot-LAB site**
 - <https://www.youtube.com/watch?v=xxNPQyY-xzw>
- **Smart tiles**
 - <https://www.youtube.com/watch?v=IPxTfgNBjsI>
- **Robot demo**
 - <https://www.youtube.com/watch?v=NWW6KRLOXUU>
- **Contiki RPL Experiment**
 - <https://www.youtube.com/watch?v=oSuWG7ixkjU>

6

Conclusions

Time to use it !

▶ Statistiques

- ▶ more than 350 users registered
- ▶ in more than 45 countries
- ▶ 11K experiments launched



▶ Futur development

- ▶ Full IPv6 support end to end
- ▶ Open robots



▶ H2020 calls on IoT

<https://www.iot-lab.info>

Huge collaborative and collective work

▶ Strasbourg

- ▶ Guillaume Schreiner
- ▶ Erkan Valentin

▶ Rocquencourt

- ▶ Ala-eddin Weslati
- ▶ Ichrak Amdouni
- ▶ Vincent Ladeveze

▶ Lille

- ▶ Julien Vandaele
- ▶ Loic Schmidt
- ▶ Anne-Sophie Tonneau
- ▶ Raymond Borenstein

▶ Grenoble

- ▶ Frédéric Saint-Marcel
 - ▶ Roger Pissard-Gibollet
 - ▶ Nicolas Turro
 - ▶ Gaetan Harter
 - ▶ Olivier Fambon
 - ▶ Sandrine Avakian
 - ▶ Fabien Vauvilliers
 - ▶ Jean-Francois Cuniberto
- ▶ C. Chaudet, N. Mitton, T. Noel, C. Adjih, E. baccelli

<https://www.iot-lab.info>

For more information

▶ IOT-lab

▶ <https://www.iot-lab.info>

▶ **Wiki:** <https://github.com/iot-lab/iot-lab/wiki>

▶ **Sources:** <https://github.com/iot-lab/>

▶ **Issues:** <https://github.com/iot-lab/iot-lab/issues>

▶ **Mailing-list:** users@iot-lab.info

▶ OneLab

FUTURE INTERNET TESTBEDS

▶ <https://onelab.eu>

▶ HIKOB

LEARN FROM REALITY.

▶ <http://www.hikob.com>

