



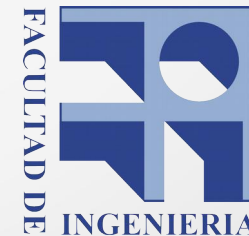
Cyber Physical Systems Workshop

WSCF 2019

Introduction to Wireless Sensor Networks

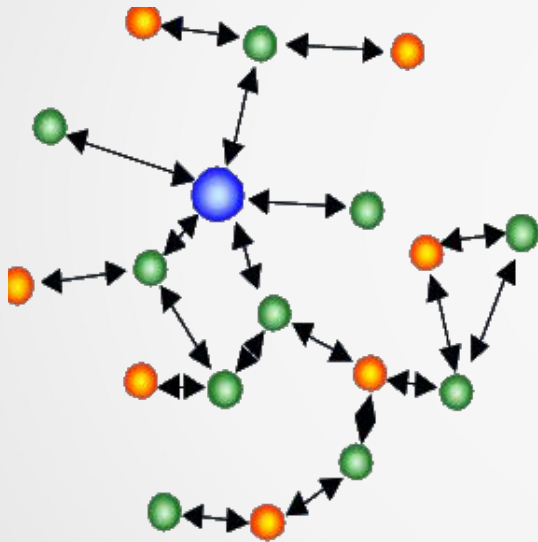
Leonardo Steinfeld

Inst. de Ingeniería Eléctrica, Fac. de Ingeniería
Universidad de la República (Uruguay)

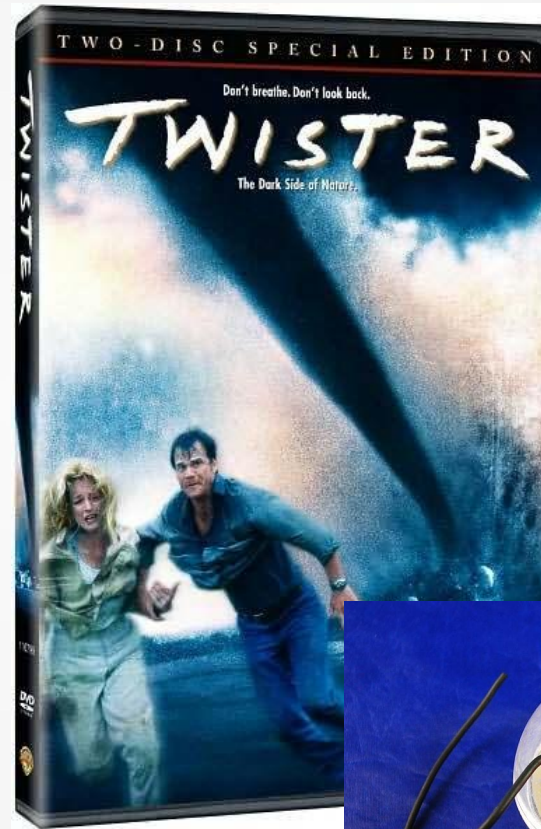
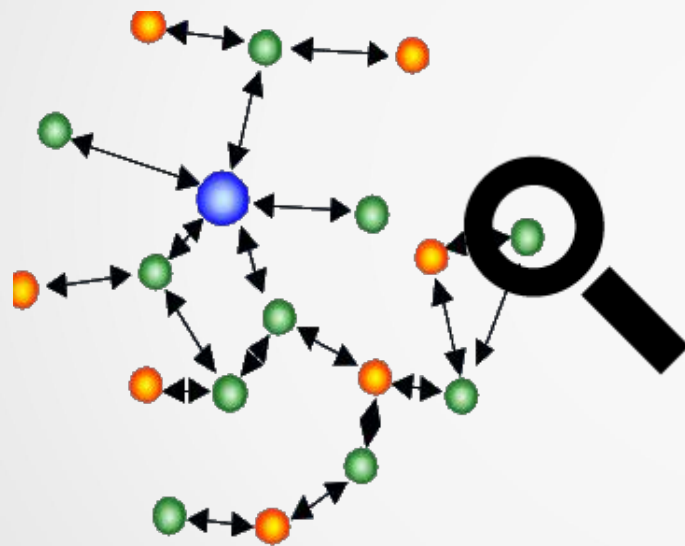


what are the wireless sensor networks?

- WSN
 - Wireless
 - Sensor (& actuators)
 - Network



WSN: from fiction to reality

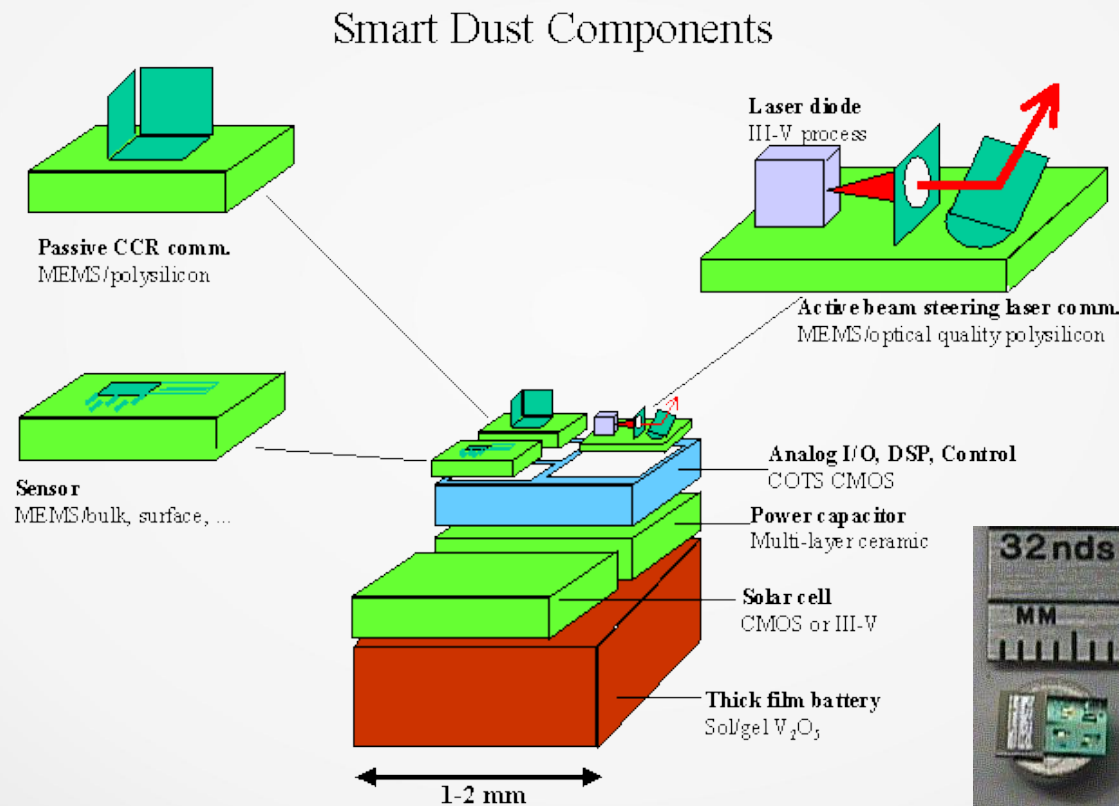


Twister (1996)



Wireless Sensor Networks (WSN): begin

“smart dust” (~2000)



Fuente: <http://robotics.eecs.berkeley.edu/~pister/SmartDust/>

WSN: reality today

- **TelosB /sky (2005)**
 - MSP430F1611 (8 MHz)
 - 10 KB RAM
 - 48 KB Flash
 - 4mA active / 10 uA sleep
 - CC2420 (transceiver 2.4 GHz)

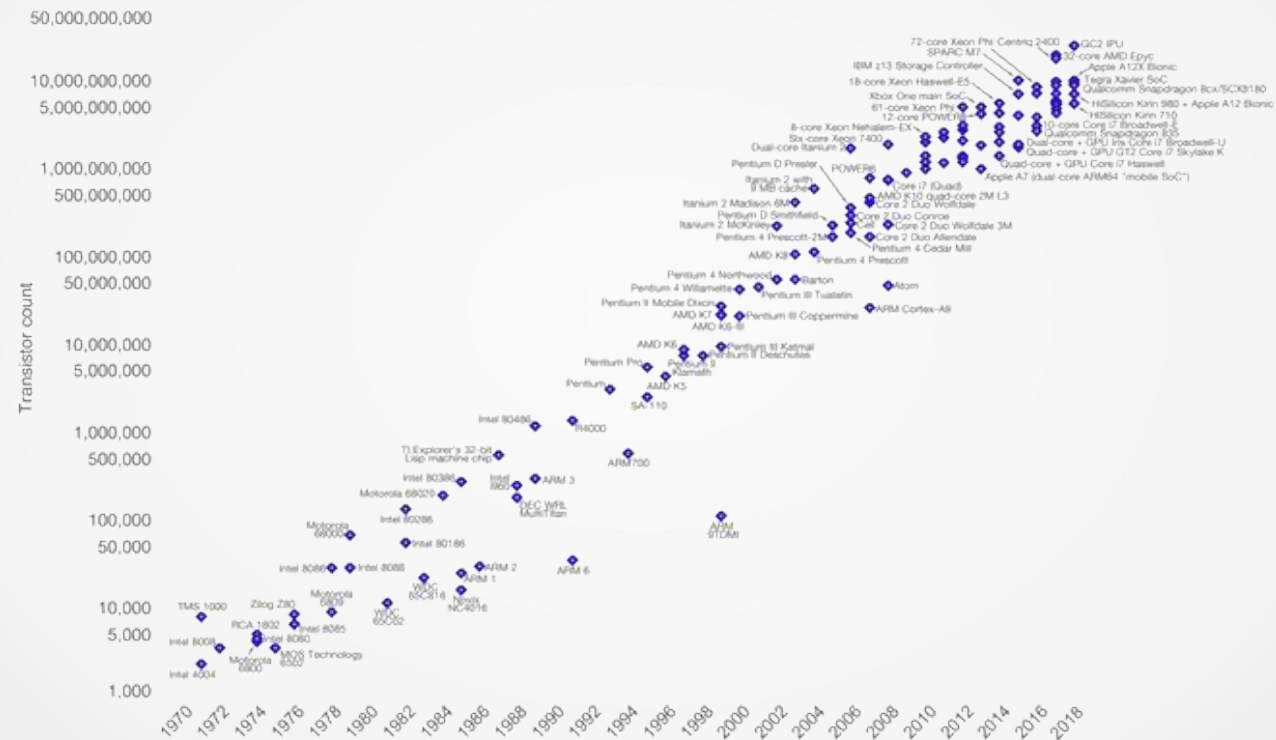


- **Benefits of moore's law?**

Moore's Law

Moore's Law – The number of transistors on integrated circuit chips (1971-2018)

Moore's law describes the empirical regularity that the number of transistors on integrated circuits doubles approximately every two years. This advancement is important as other aspects of technological progress – such as processing speed or the price of electronic products – are linked to Moore's law.



Data source: Wikipedia (https://en.wikipedia.org/wiki/Transistor_count)
The data visualization is available at OurWorldinData.org. There you find more visualizations and research on this topic.

Licensed under CC-BY-SA by the author Max Roser.

WSN: reality today

- **TelosB /sky (2005)**
 - MSP430F1611 (8 MHz)
 - 10 KB RAM
 - 48 KB Flash
 - 4mA active / 10 uA sleep
 - CC2420 (transc. 2.4 GHz)
- **CCC2538 SoC (2013)**
 - Cortex M (32 MHz)
 - 32 KB RAM
 - 256 KB Flash
 - ~10 mA active / ~1uA sleep
 - “CC2520” integrated

- Benefits of moore's law?



EMB-Z2538PA

IoT device / mote / sensor node

- Requirements
 - low



cost

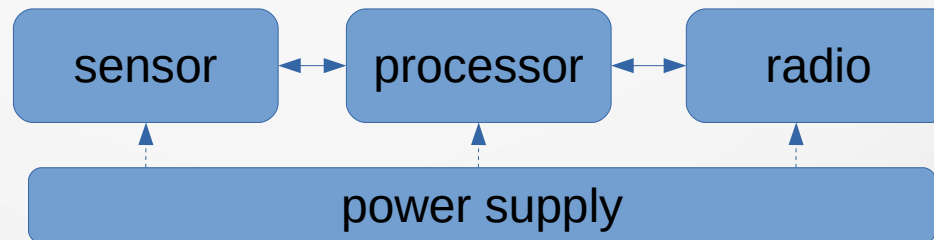


size



consumption


- Components



Communication technologies



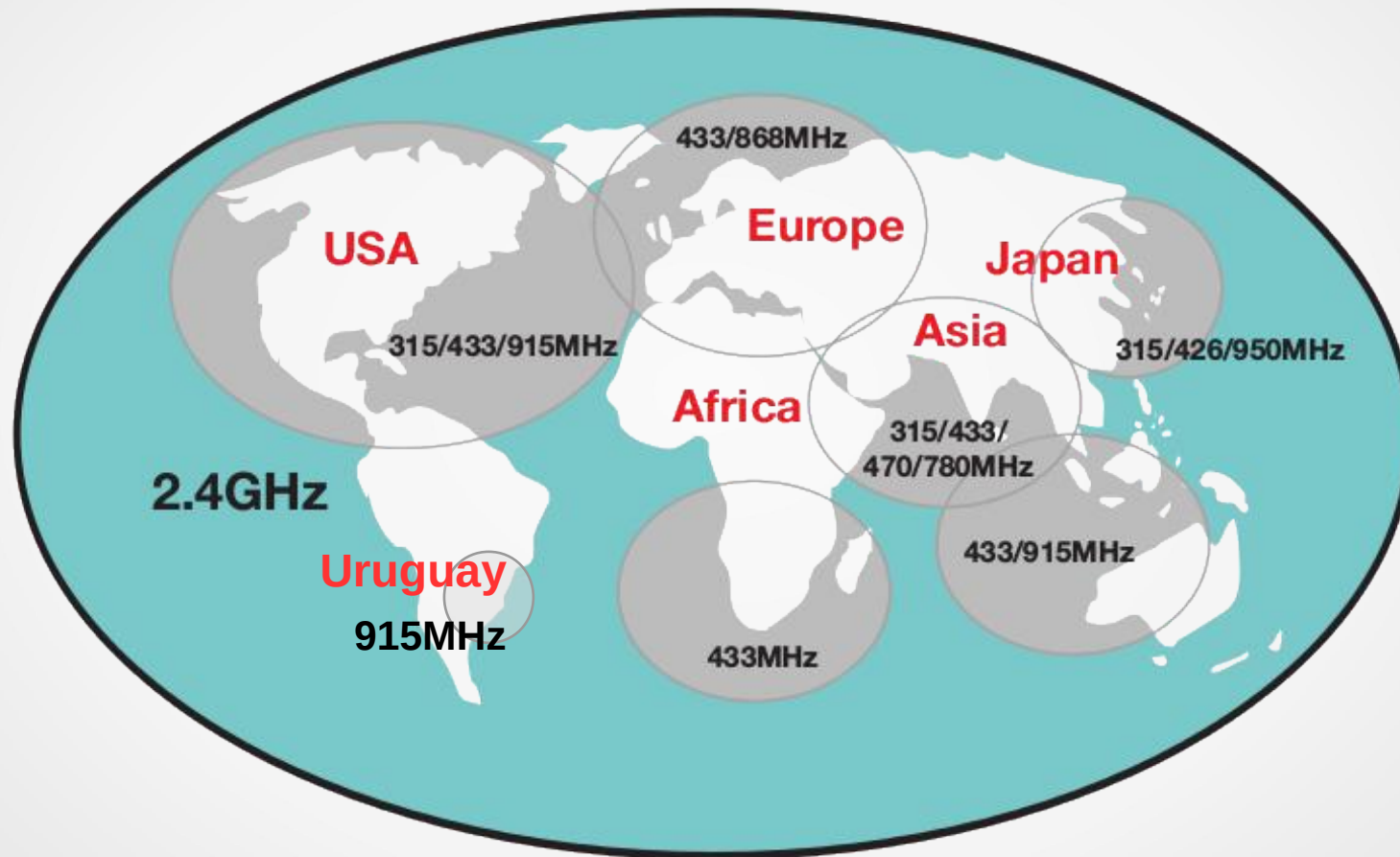
Communication technologies

- LAN (Local)
 - WLAN (Wireless Local)
 - CAN (Campus)
 - MAN (Metropolitan)
 - WAN (Wide Area)
 - **PAN** (Personal Area)
 - **WPAN** (Wireless PAN)
 - **LPWAN** (Low Power WAN)
- 
- The diagram shows the text 'WSN' on the right side of the slide. Two blue arrows originate from the left side of 'WSN' and point towards the text 'WPAN' and 'LPWAN' in the list above, indicating that WSN encompasses these two categories.

Technology menu

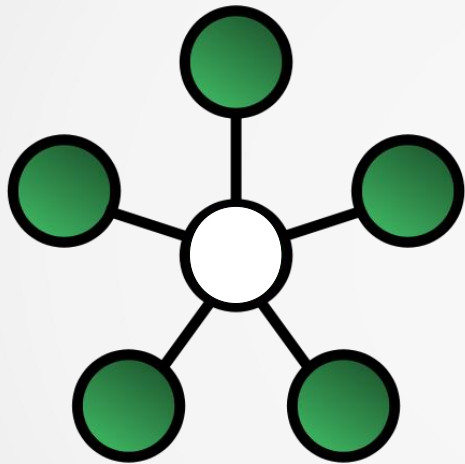
- LPWAN
 - SigFox
 - LoRa
 - Weightless/Telensa
 - RPMA/Ingenu
- Cell
 - NB-IoT
 - LTE-M
- WPAN
 - IEEE 802.15.4
 - 6lowpan
 - Zigbee
 - many others

Radio communication: ISM bands

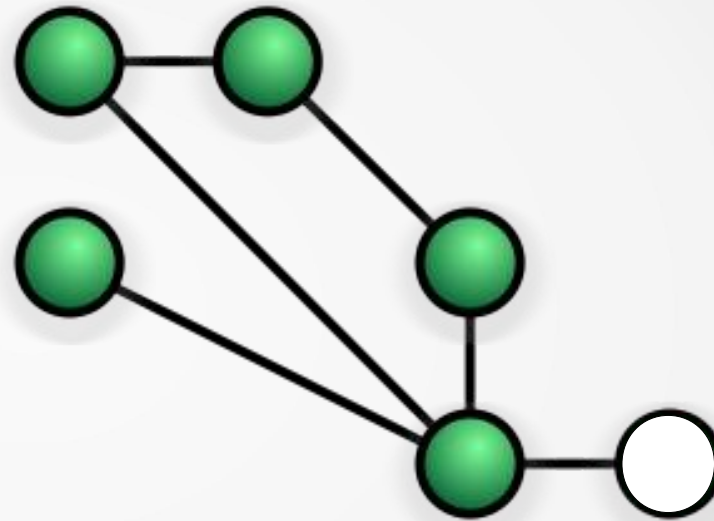


ISM: Industrial, Scientific and Medical

Differences: topology

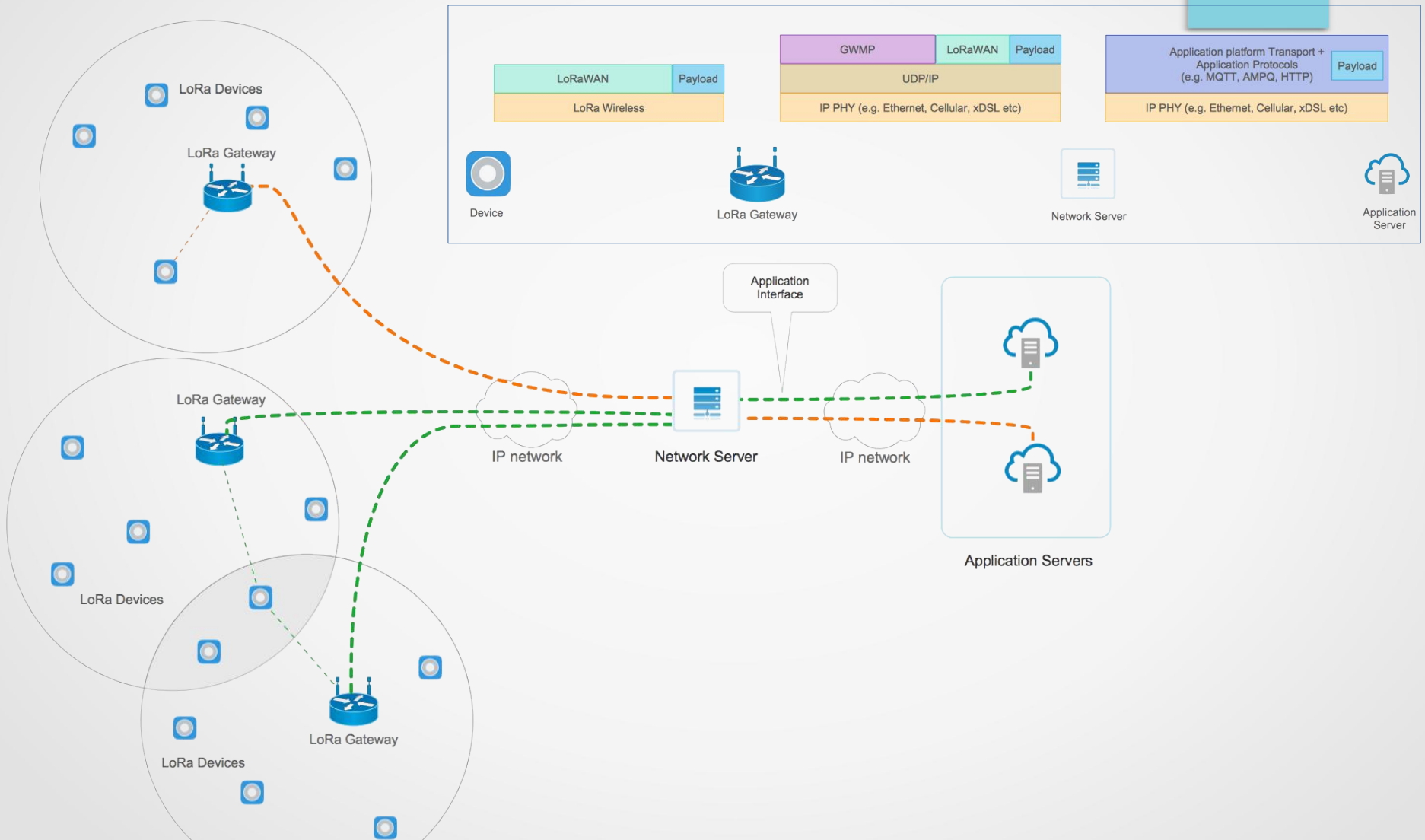


star

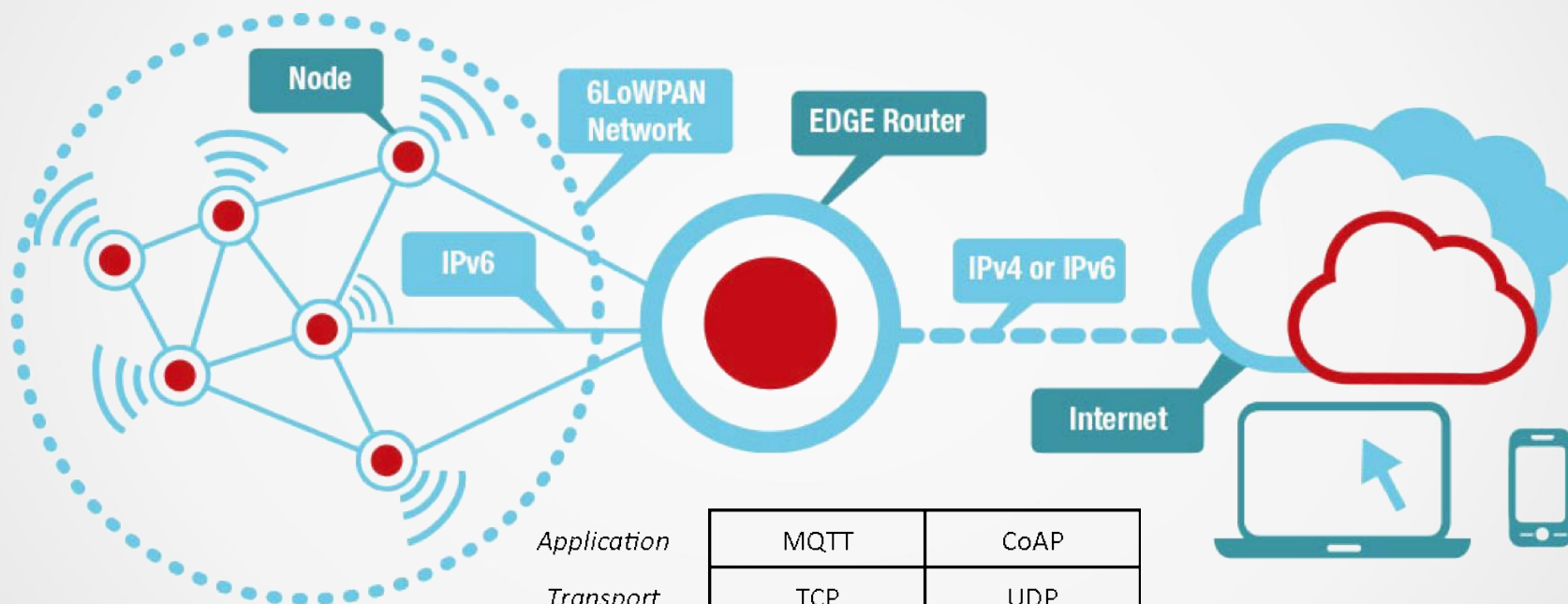


mesh

Star: LoRaWAN

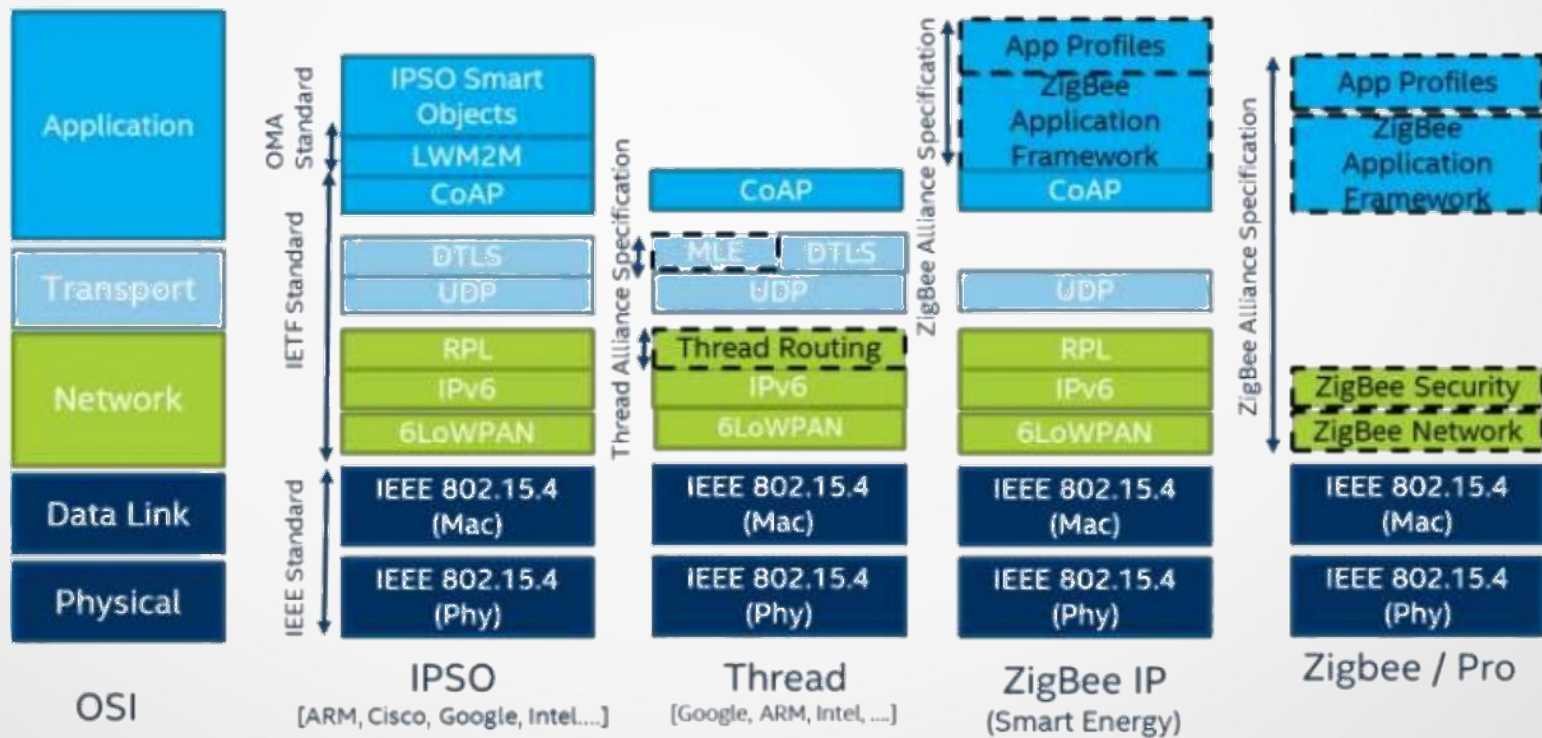
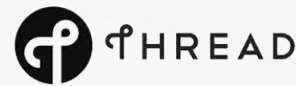


Mesh: IEEE 802.15.4 / 6lowpan



<i>Application</i>	MQTT	CoAP
<i>Transport</i>	TCP	UDP
<i>Network</i>	IPv6	
<i>Adaptation</i>	6LoWPAN	
<i>Link Physical</i>	IEEE 802.15.4	Bluetooth Low Energy

IEEE 802.15.4: stack options



Outline

- More introduction
- “6LoWPAN stack”
 - IEEE 802.15.4 MAC
 - 6LoWPAN
 - RPL
 - CoAP
- Final thoughts

WSN: reference architecture

- TCP/IP versus 6LoWPAN

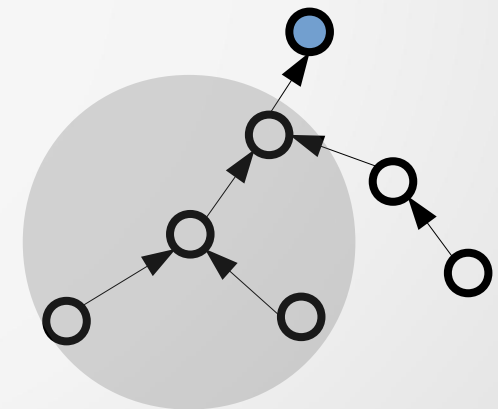


TCP/IP Protocol Stack

HTTP		RTP	
TCP	UDP	ICMP	
IP			
Ethernet MAC			
Ethernet PHY			

6LoWPAN Protocol Stack

Application	Application	
Transport	UDP	ICMP
Network	IPv6 with LoWPAN	
Data Link	IEEE 802.15.4 MAC	
Physical	IEEE 802.15.4 PHY	



Fuente: <http://orbigo.net/2011/06/6lowpan-second-part-more-concepts-about-6lowpan/>

Standardization

- Technical standards:
 - agreements among the involved parties
- Aims and Benefits:
 - interoperability:
 - market competition and reduces vendor blockage
 - replication:
 - reuse technology (software & hardware)
 - best practices in different solutions

IEEE & IETF: as standardization bodies

- IEEE (Institute of Electrical and Electronics Engineers)
 - IEEE 802: family of IEEE standards
 - IEEE 802.**15** Working group **Wireless PAN**
 - IEEE 802.**15.4** Task Groups **Low Rate WPAN**
- IETF (Internet Engineering Task Force): WG (working groups)
 - **6LoWPAN**: IPv6 over Low power WPAN (concluded)
 - **6lo**: IPv6 over Networks of Resource-constrained Nodes
 - **6TiSCH**: IPv6 over the TSCH mode of IEEE 802.15.4e
 - **RoLL**: Routing over Low-power and Lossy networks
 - **CoRE**: Constrained RESTful Environments

IEEE 802.15.4 / 6LoWPAN stack



IEEE 802.15.4 PHY & MAC: funciones

- PHY

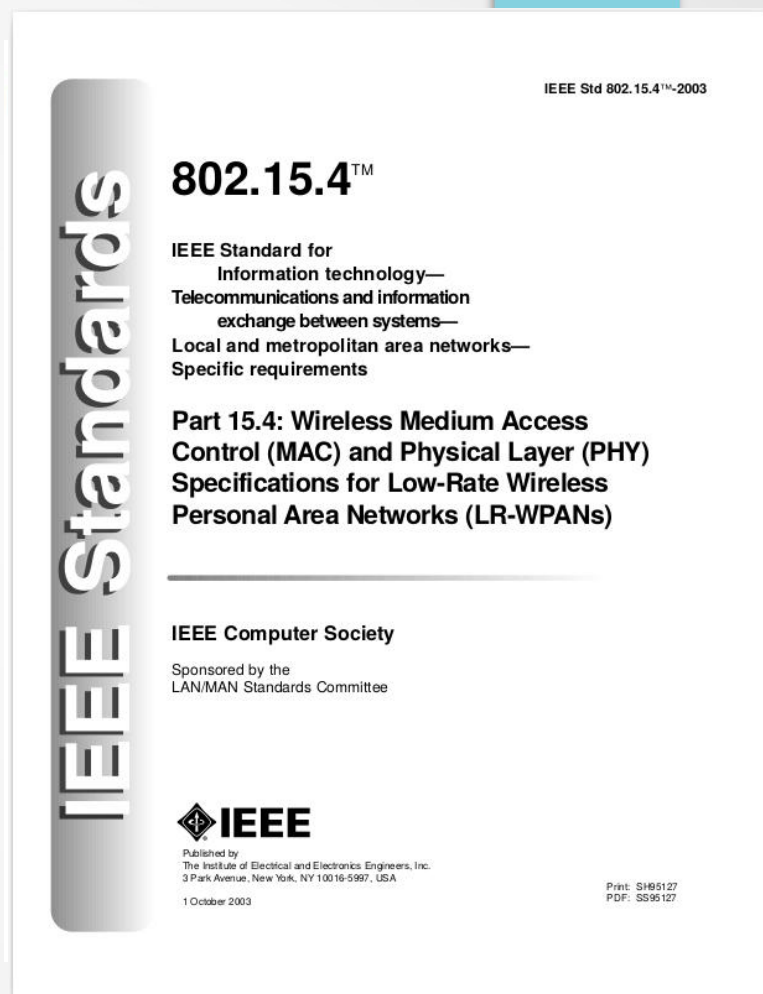
- Tx & Rx data
- ED: energy detection
- RSSI: receive signal strength indicator
- LQI: link quality indication
- channel selection
- CCA: clear channel assesment

- MAC

- channel access
- frame validation
- acknowledged frame delivery
- beacon management
- GTS management
- etc.

IEEE Std 802.15.4™-2015

- LR-WAN (Low Rate WPAN), spec.:
 - PHY: physical layer
 - MAC: medium access control
- versions: 2003, 2006, 2011, 2015
- amendment:
 - added to version 2015, e.g:
 - 802.15.4e-2012
 - 802.15.4g-2012
 - existing (to be added):
 - 802.15.4q-2016 (ULP PHY)



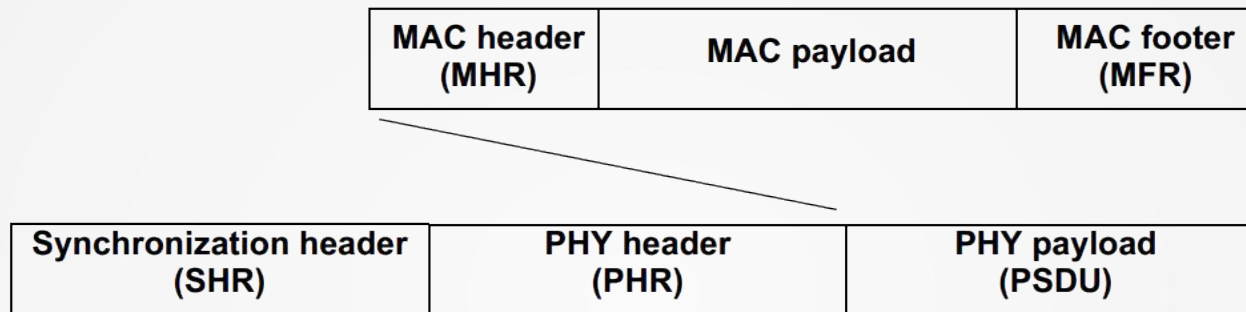
IEEE GET Program

IEEE 802.15.4 PHY

- Band and channels
- Initially (2003)
 - channel freq. identified by number
 - limited to 27 channel
 - three fixed options
- Since IEEE 802.15.4-2006
 - channel pages: scale
- Channel pages:
 - 0: defined in 2003 ⁽¹⁾
 - 1: optional in 2006 ⁽²⁾

Page	Num.	Description
0 ⁽¹⁾	0	868 MHz band (BPSK)
	1–10	915 MHz band (BPSK)
	11–26	2.4 GHz band (O-QPSK)
1 ⁽²⁾	0	868 MHz band (ASK)
	1–10	915 MHz band (ASK)
	11–26	Reserved
2	0	868 MHz band (O-QPSK)
	1–10	915 MHz band (O-QPSK)
	11–26	Reserved
3	0-13	2450 MHz (CSS)
4	0	sub-GHz band for UWB
	1-4	low band for UWB PHY
	5-15	high band for UWB PHY
5	0-3	780 MHz band (O-QPSK)
	4-7	780 MHz band (MPSK)
6	0-9	950 MHz band (BPSK)
	10-21	950 MHz band (GFSK)
7-31	Reser.	Reserved

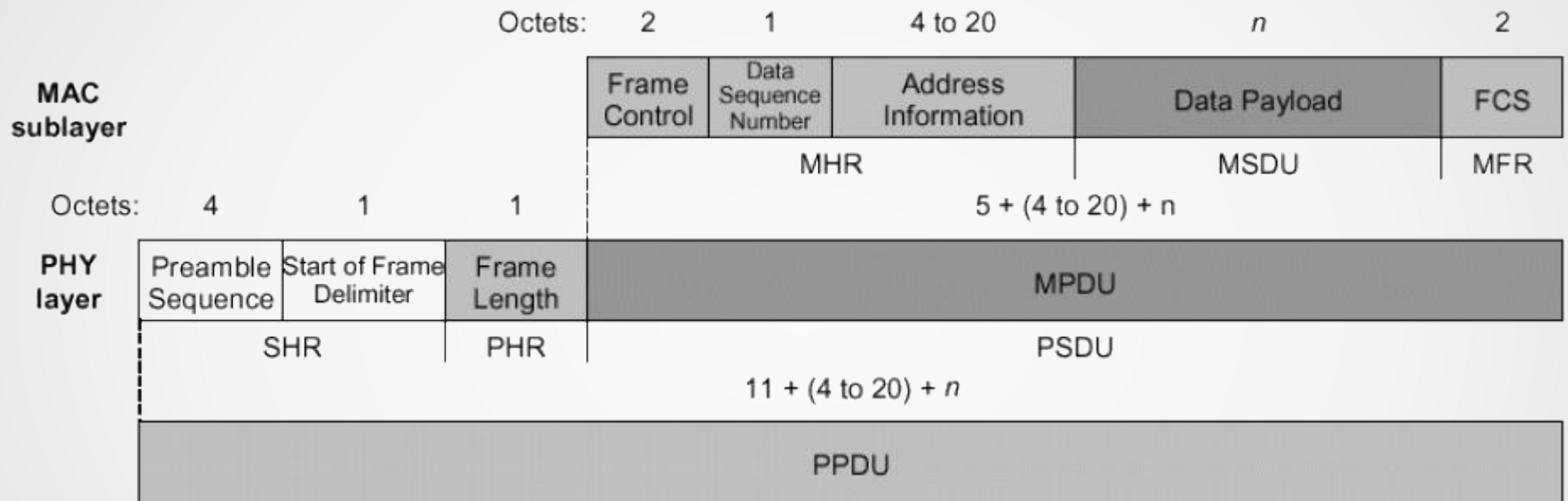
IEEE 802.15.4 PHY & MAC: frames



"IEEE standard for Low-Rate wireless networks," IEEE Std 802.15.4-2015, pp. 53, Apr. 2016.

- PHY service data unit (PSDU) \Leftrightarrow MAC frame

IEEE 802.15.4: frame format



M: MAC × PDU: **protocol** data unit = MSDU: MAC service data unit
 P: PHY SDU: **service** data unit MPDU: MAC protocol data unit
 PSDU: PHY service data unit
 PPDU: PHY protocol data units

Frame format (version 1, 2006)

Octets: 2	1	0/2	0/2/8	0/2	0/2/8	0/5/6/10/14	variable	2
Frame Control	Sequence Number	Destination PAN Identifier	Destination Address	Source PAN Identifier	Source Address	Auxiliary Security Header	Frame Payload	FCS
		Addressing fields						
MHR							MAC Payload	MFR

Bits: 0-2	3	4	5	6	7-9	10-11	12-13	14-15
Frame Type	Security Enabled	Frame Pending	AR	PAN ID Compression	Reserved	Dest. Addressing Mode	Frame Version	Source Addressing Mode

"IEEE standard for Low-Rate wireless networks," IEEE Std 802.15.4-2006, Sept. 2006.

Frame format (version 1, 2006)

Octets: 2	1	0/2	0/2/8	0/2	0/2/8	0/5/6/10/14	variable	2
Frame Control	Sequence Number	Destination PAN Identifier	Destination Address	Source PAN Identifier	Source Address	Auxiliary Security Header	Frame Payload	FCS
Addressing fields								
MHR							MAC Payload	MFR

Bits: 0-2	3	4	5	6	7-9	10-11	12-13	14-15
Frame Type	Security Enabled	Frame Pending	AR	PAN ID Compression	Reserved	Dest. Addressing Mode	Frame Version	Source Addressing Mode



Frame type value b ₂ b ₁ b ₀	Description
000	Beacon
001	Data
010	Acknowledgment
011	MAC command
100-111	Reserved

"IEEE standard for Low-Rate wireless networks," IEEE Std 802.15.4-2006, Sept. 2006.

Addressing

Octets: 1/2	0/1	0/2	0/2/8	0/2	0/2/8	variable	variable		variable	2/4
Frame Control	Sequence Number	Destination PAN ID	Destination Address	Source PAN ID	Source Address	Auxiliary Security Header	IE		Frame Payload	FCS
		Addressing fields					Header IEs	Payload IEs		
MHR							MAC Payload		MFR	

Bits: 0–2	3	4	5	6	7	8	9	10–11	12–13	14–15
Frame Type	Security Enabled	Frame Pending	AR	PAN ID Compression	Reserved	Sequence Number Suppression	IE Present	Destination Addressing Mode	Frame Version	Source Addressing Mode

Addressing mode value b1 b0	Description
00	PAN ID and address fields are not present.
01	Reserved
10	Address field contains a short address (16 bit).
11	Address field contains an extended address (64 bit).

Frame types: Data & ACK

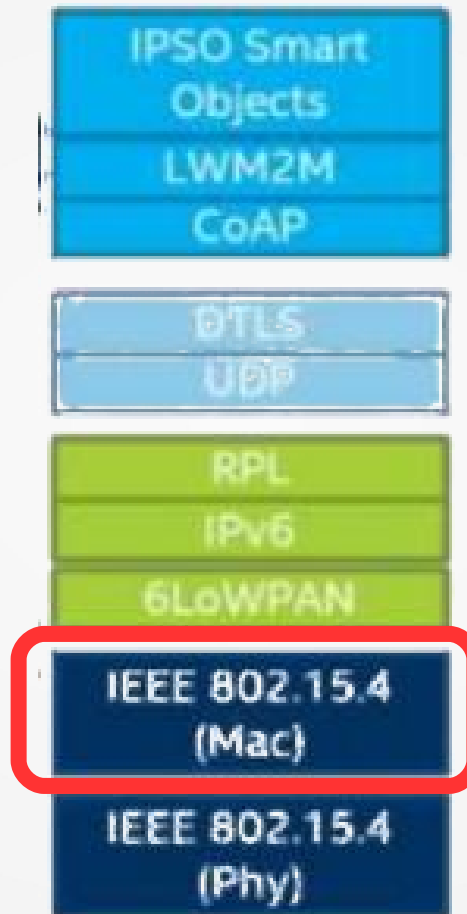
Data Frame Format

Octets:2	1	4 to 20	variable	2
Frame control	Data sequence number	Address information	Data payload	Frame check sequence
MAC header			MAC Payload	MAC footer

Acknowledgement Frame Format

Octets:2	1	2
Frame control	Data sequence number	Frame check sequence
MAC header		MAC footer

IEEE 802.15.4: MAC



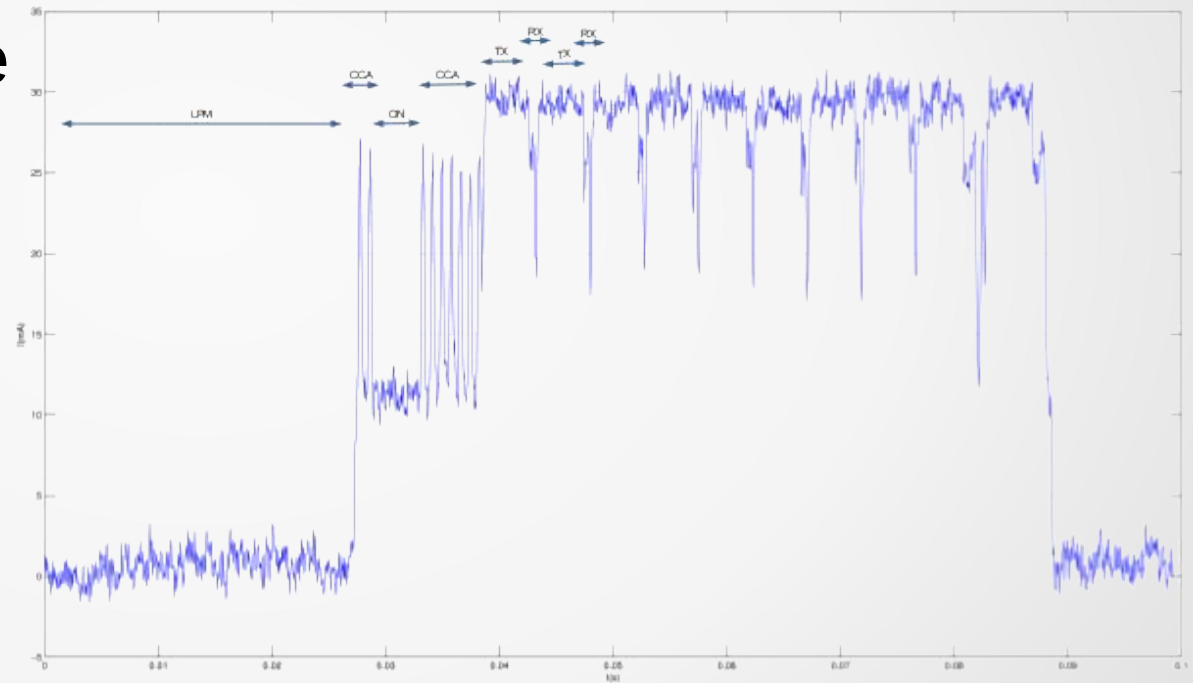
MAC: medium access control

- Challenges
 - shared medium
 - interference
 - packet losses
- Requirements
 - as usual:
 - high throughput, low overhead, low error rates, ...
 - added:
 - energy-efficient → radio duty-cycle

MAC: power consumption

- Power / Energy electrical consumption
 - Tx: expensive
 - Rx: also expensive
 - CCA (listening): also but less

State	$I_{avg}(mA)$
ON	11.23
TX	29.64
RX	24.17
CCA	21.64



MAC: energy efficiency

- Source of energy waste:
 - Collisions
 - Overhearing
 - Idle listening
 - Protocol overhead
- Generally:
 - The **simplest solution** is the **best**

“Super” frames structures

- Beacon superframe

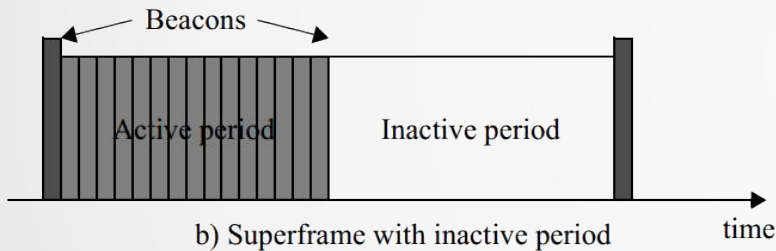
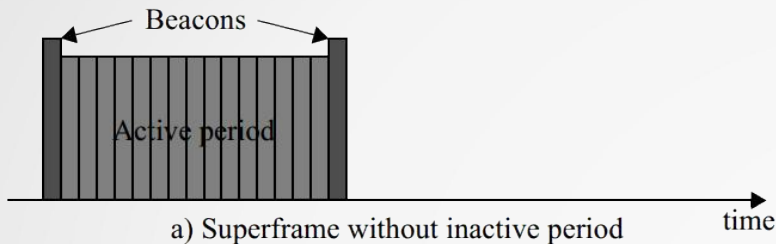


Figure 5-5—Superframe structure

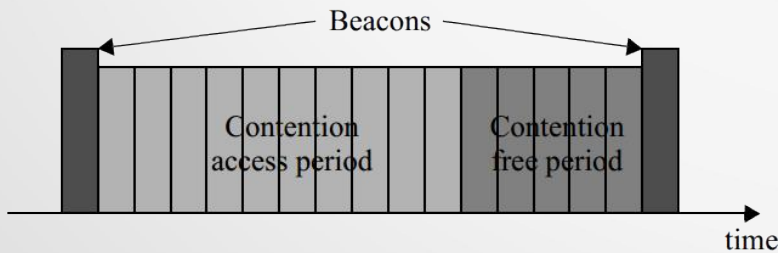


Figure 5-6—Structure of the active periods with GTSS

- DSME multi-superframe

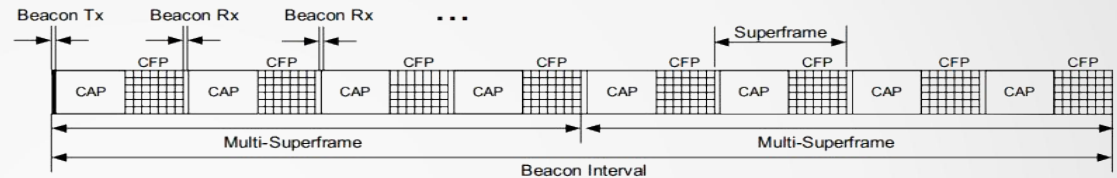


Figure 5-7—General DSME Multi-superframe Structure

- Slotframes

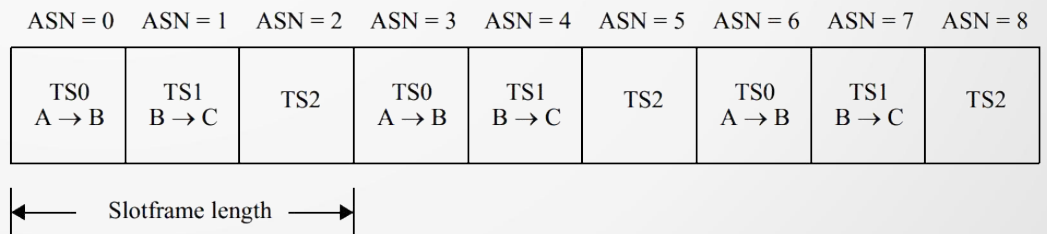


Figure 6-9—Example of a three time-slot slotframe

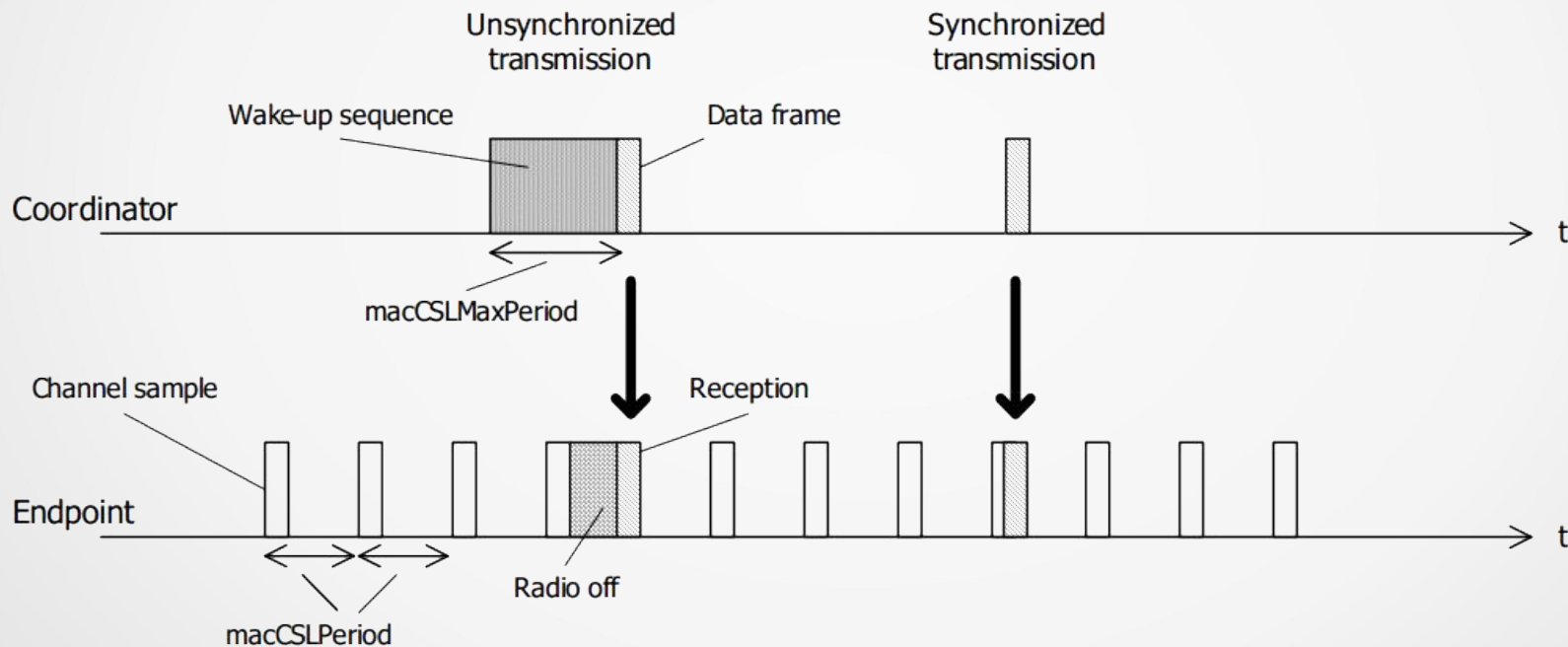
- Libre (sin beacon/superframe)

MAC: multiple access protocol

- Nonbeacon-enabled (libre): unslotted CSMA-CA
- Beacon-enabled: slotted CSMA-CA
- TSCH (slotframe)
 - TSCH CCA: non-shared slots
 - TSCH CSMA-CA: shared slots
 - otros

IEEE 802.15.4: CSL

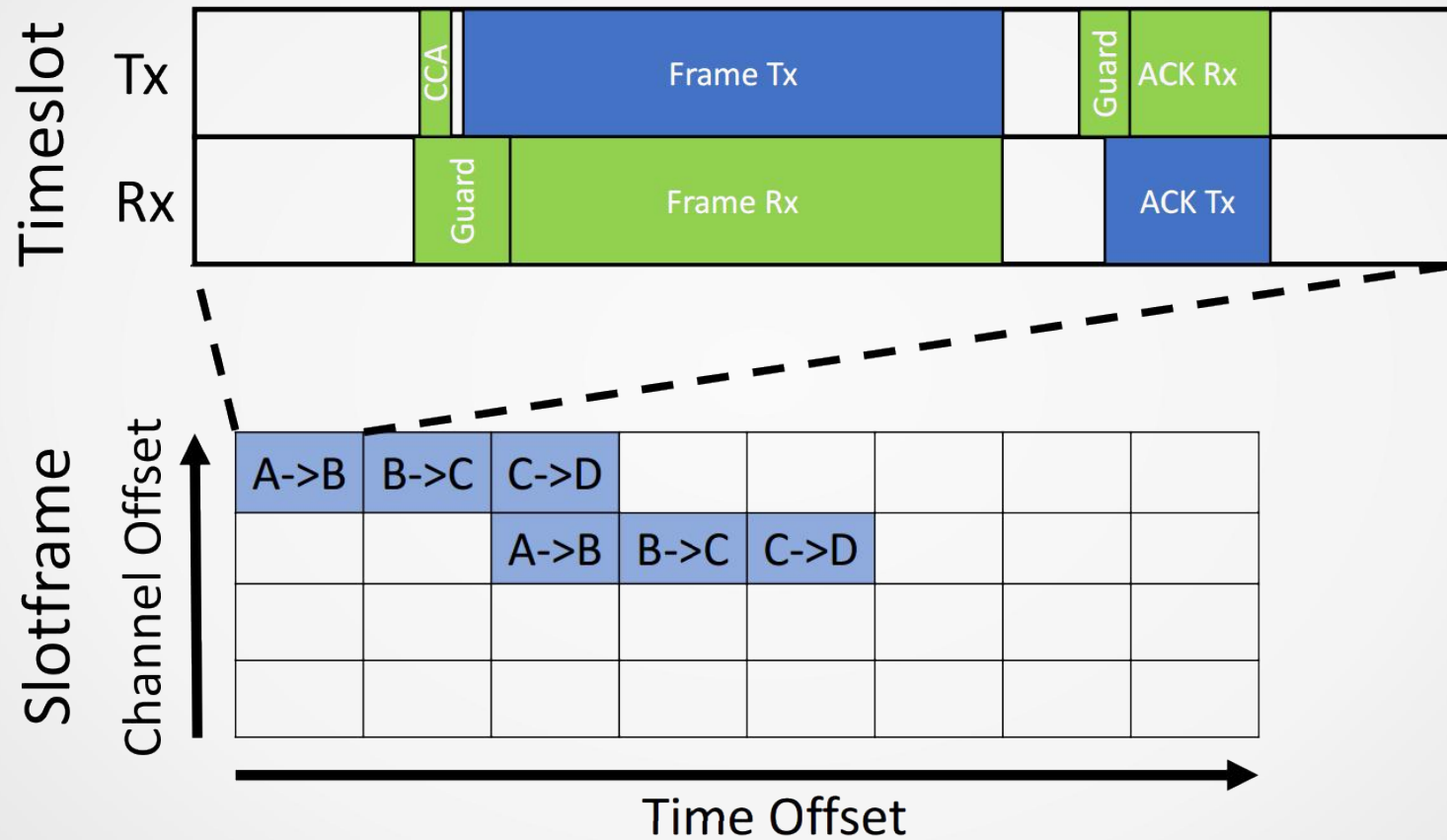
- CSL: Coordinated Sampled Listing



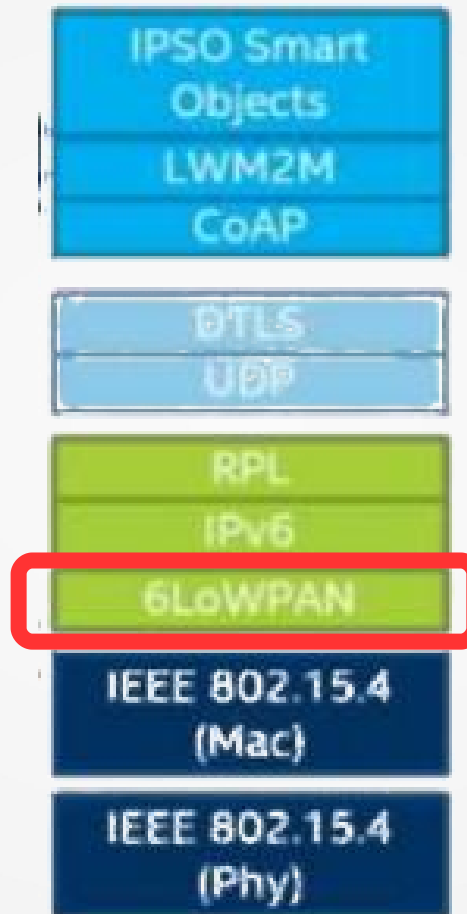
IEEE 802.15.4: TSCH

- TSCH: Time-Slotted Channel Hopping
 - **TS** (Time-Slotted): synchronization
 - **CH** (Channel Hopping):
- Objectives and benefits
 - low power consumption (keep the radio off)
 - Increasing reliability (channel diversity)
- Come from industrial protocols:
 - WirelesHART / ISA100.11

IEEE 802.15.4: TSCH



6lowpan: adaptation layer



IPv6 over Low power WPAN

- **6lowpan: IETF Working Group (concluded)**

- IPv6 Packets over IEEE 802.15.4
 - RFC 4944: basis
 - RFC 6282: NHC
 - RFC 6775: ND

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WGs:
[concluded...](#)
[6lo](#)
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6lowpan Status Pages

Int Area: Eric Vyncke, Suresh Krishnan | 2005-Mar-08 — 2014-Jan-16

IPv6 over Low power WPAN (Concluded WG)

Chairs: Carsten Bormann, Geoffrey Mulligan

[Drafts](#) | [Agendas](#) | [Minutes](#) | [Wiki](#) | [Training](#) | [Source](#) | [Charters](#) | [Jabber](#) [Room](#) [Logs](#) | [List Archive](#) |

Working Group Documents: Document collections: [epub](#) [mobi](#)

<u>Draft name</u>	Rev.	<u>Dated</u>	<u>Status</u>	Comments, Issues
Published:				
Draft name	Rev.	Dated	Status	Obsoleted by/(Updated by)
draft-ietf-6lowpan-format	-13	2007-04-04	RFC 4944	(RFC 6282 RFC 6775 RFC 8025 RFC 8066)
draft-ietf-6lowpan-hc	-15	2011-02-24	RFC 6282	(RFC 8066)
draft-ietf-6lowpan-nd	-21	2012-08-24	RFC 6775	(RFC 8505)
draft-ietf-6lowpan-problem	-08	2007-03-02	RFC 4919	
draft-ietf-6lowpan-routing-requirements	-10	2011-11-20	RFC 6606	
draft-ietf-6lowpan-usecases	-10	2011-07-26	RFC 6568	
Replaced, Dead or Unknown:				
draft-ietf-6lowpan-btle	-12	2013-02-12	Replaced by draft-ietf-6lo-btle	

Related Active Documents (not working group documents):

(To see all 6lowpan-related documents, go to [6lowpan-related drafts in the ID-archive](#))

[Draft dependency graphs](#)

IPv6 over Netw. of Resource-constrained Nodes

- **6lo**: IETF Working Group (active)
 - extends **6lowpan**
- IPv6-over-foo adaptation layer specifications
 - RFC 8163: MS/TP Networks (RS-485)
 - RFC 7668: Bluetooth Low Energy
 - RFC 8105: DECT – ULE
 - RFC 7428: ITU-T G.9959 Networks

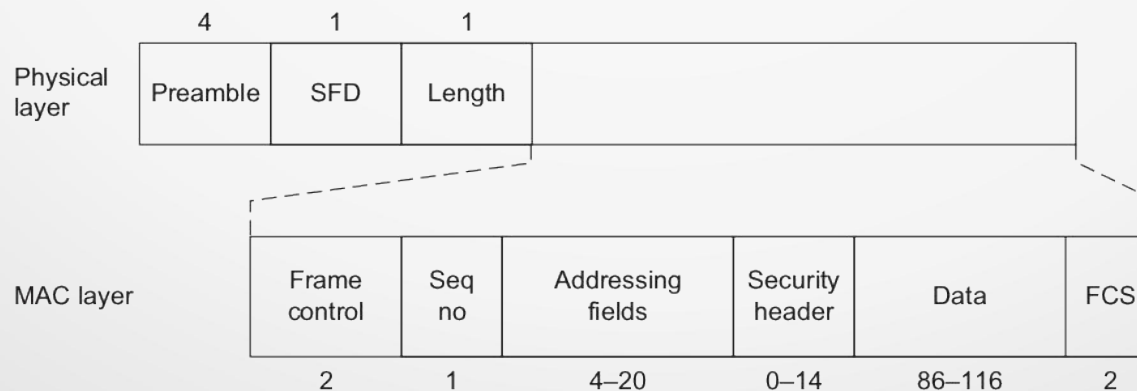
The screenshot shows the IETF 6lo Status Pages website. The page title is "6lo Status Pages" and the subtitle is "IPv6 over Networks of Resource-constrained Nodes (Active WG)". The page contains a navigation menu on the left with links to IETF Home, About Tools, Tools, News, Get Passwd, IETF-105, Rooms, Agenda, Calendar, Documents, RFCs, and Doc fetch. The main content area is divided into sections: "Working Group Documents" and "Published".

Working Group Documents:

Draft name	Rev.	Dated	Status	Comments, Issues
Active:				
draft-ietf-6lo-backbone-router	-12	ipr	2019-09-02	Active
draft-ietf-6lo-fragment-recovery	-05		2019-07-22	Active
draft-ietf-6lo-minimal-fragment	-04		2019-09-02	Active
draft-ietf-6lo-use-cases	-07	new	2019-09-11	Active
Recently Expired:				
draft-ietf-6lo-biamesh	-05		2019-03-09	Expired
draft-ietf-6lo-plc	-00		2019-02-02	Expired
IESG Processing:				
draft-ietf-6lo-ap-nd	-12		2019-04-11	AD Evaluation
draft-ietf-6lo-deadline-time	-05		2019-07-08	IESG Evaluation:AD Followup
draft-ietf-6lo-nfc	-15	ipr	2019-07-08	IESG Evaluation:AD Followup
Published:				
Draft name	Rev.	Dated	Status	Obsoleted by/(Updated by)
draft-ietf-6lo-globac	-08		2017-03-13	RFC 8163
draft-ietf-6lo-btle	-17		2015-08-05	RFC 7668
draft-ietf-6lo-dect-ule	-09		2016-12-15	RFC 8105
draft-ietf-6lo-dispatch-lana-registry	-07		2016-12-08	RFC 8066
draft-ietf-6lo-ethertype-request	-01		2016-06-06	RFC 7973
draft-ietf-6lo-ghc	-05		2014-09-19	RFC 7400
draft-ietf-6lo-lowpan-mib	-04		2014-09-05	RFC 7388
draft-ietf-6lo-lowpanz	-08		2014-10-30	RFC 7428
draft-ietf-6lo-paging-dispatch	-05		2016-10-12	RFC 8025
draft-ietf-6lo-privacy-considerations	-04		2016-10-31	RFC 8065
draft-ietf-6lo-fc6775-update	-21		2018-06-19	RFC 8505
Expired:				
draft-ietf-6lo-mesh-link-establishment	-00		2015-12-01	Expired
draft-ietf-6lo-mle-hip-dex	-01		2016-04-19	Expired
draft-lho-6lo-expiration-time			2017-10-25	Expired

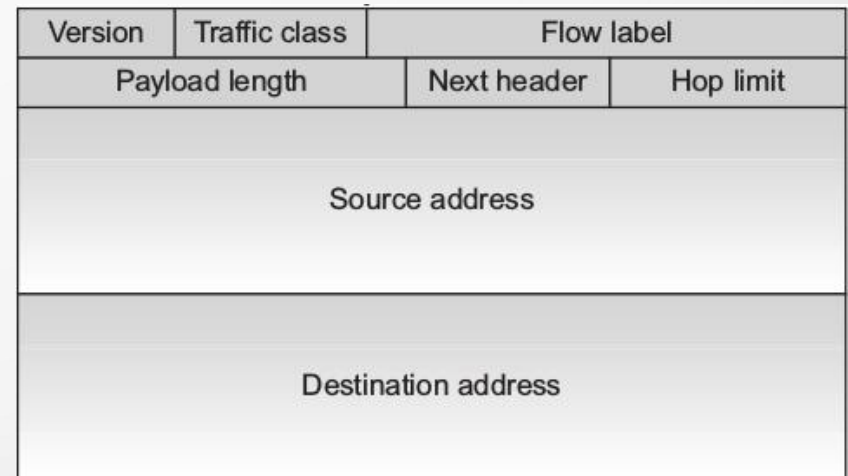
IEEE 802.15.4: some features

- Small frame: 127 bytes
 - PER reasonably low for non-negligible BER
- Addressing
 - 16-bit short / IEEE 64-bit extended MAC.
- Low data rates
 - From 50 kbps (915 MHz) to 250 kbps (2.45 GHz).



IPv6: some features

- Relatively large package: 1280 bytes.
- Addressing: 128 bits.
- Stateless address autoconfiguration (SAA)
 - Simplify configuration and management
- IPv6 includes multicast as an integral part of its architecture,
 - Neighbor Discovery (ND) uses link-local multicast for
 - address resolution
 - duplicate address detection
 - router discovery.



IPv6 over LoWPAN: challenges

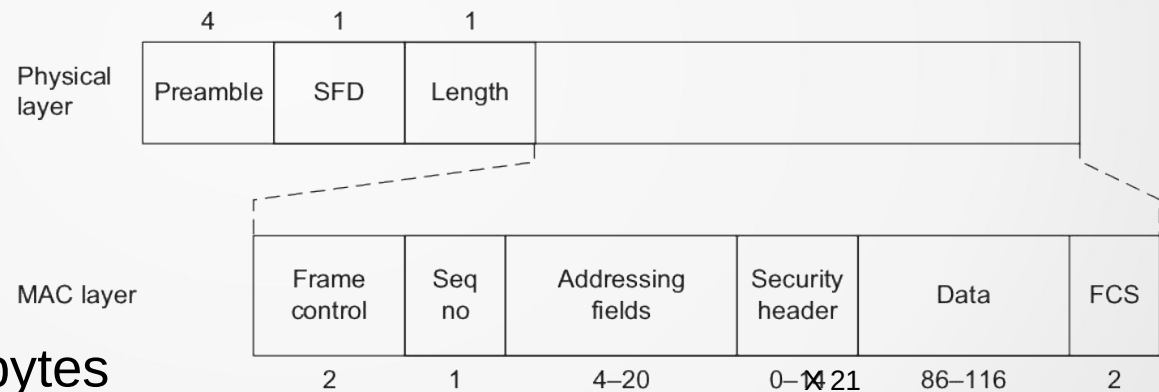
- Packets IPv6 over LoWPANs.
 - Low throughput
 - Limited buffers
 - **Frames ~10 times smaller than MTU minimum MTU required by IPv6**

- Need

- Fragmentation
- Compression

- Example:

- Payload effective 81 bytes
- IPv6 header: 40 bytes
- UDP/TCP header: 8 / 20 bytes,
- Remains:



$$127 - (2 + 1 + 20 + 2) = 102 \text{ bytes}$$

AES-CCM-128: 21 extra bytes

6LoWPAN: services & design

- Services:
 - Fragmented and reassembled packages
 - Header Compression
 - Layer 2 routing “mesh-under”
- IEEE 802.15.4 encapsulates IPv6 packet
 - “encapsulation header stack” before each IPv6 packet
 - dispatch byte (primer byte): identify the next header
 - Three headers:
 - mesh addressing header
 - fragment header
 - IPv6 header compression header

6lowpan: wireshark

File Edit View Go Capture Analyze Statistics Telephony Wireless Tools Help

Apply a display filter ... <Ctrl-/> Expression... +

No.	Time	Source	Destination	Length	Info	Protocol
1102	16:22:01.515068			5	Ack	IEEE 802.15.4
1103	16:22:01.518940	::212:7408:8:4	::212:7408:8:2	47	Payload Unk: 6, Bad FCS	SKYPE
1104	16:22:01.520857			5	Ack, Bad FCS	IEEE 802.15.4
1105	16:22:01.539668	00:12:74:08:00:08:00:03	00:12:74:08:00:08:00:02	120	Data, Dst: NitLab_08:00:08:00:02, Src: NitLab_08:00:08:00:03, Bad FCS	6LoWPAN
1106	16:22:01.544497	00:12:74:08:00:08:00:03	00:12:74:08:00:08:00:02	120	Data, Dst: NitLab_08:00:08:00:02, Src: NitLab_08:00:08:00:03, Bad FCS	6LoWPAN
1107	16:22:01.549318	00:12:74:08:00:08:00:03	00:12:74:08:00:08:00:02	120	Data, Dst: NitLab_08:00:08:00:02, Src: NitLab_08:00:08:00:03, Bad FCS	6LoWPAN

Frame 1105: 120 bytes on wire (960 bits), 120 bytes captured (960 bits)

IEEE 802.15.4 Data, Dst: NitLab_08:00:08:00:02, Src: NitLab_08:00:08:00:03, Bad FCS

- 6LoWPAN
 - Fragmentation Header
 - 1100 0... = Pattern: First fragment (0x18)
 - Datagram size: 147
 - Datagram tag: 0x0000
 - IPHC Header
 - 011. = Pattern: IP header compression (0x03)
 - ...1 1... .. = Traffic class and flow label: Version, traffic class, and flow label compressed (0x3)
 -0... .. = Next header: Inline
 -00 ... = Hop limit: Inline (0x0)
 -1... .. = Context identifier extension: True
 -1... .. = Source address compression: Stateful
 -01 ... = Source address mode: 64-bits inline (0x0001)
 -0... .. = Multicast address compression: False
 -1... .. = Destination address compression: Stateful
 -11 ... = Destination address mode: Compressed (0x0003)
 - 0000 = Source context identifier: 0x0
 - 0000 = Destination context identifier: 0x0
 - Next header: IPv6 Hop-by-Hop Option (0x00)
 - Hop limit: 63
 - Source: ::212:7408:8:4
 - Destination: ::212:7408:8:2
 - Reassembled in: 1119
 - Data (120 bytes)
 - Data: 60000000006b003f0000000000000000212740800080004...
 - [Length: 120]

```
0000 71 dc b6 cd ab 02 00 08 00 08 74 12 00 03 00 08 q.....t....
0010 00 08 74 12 00 00 93 00 00 78 d7 00 00 3f 02 12 ..t...x...?..
0020 74 08 00 08 00 04 11 00 63 04 00 1e 02 59 04 57 t.....c...Y-W
0030 04 57 00 63 2f ce 4c 61 62 20 52 53 49 20 32 30 -W-c/La b RSI 20
0040 31 36 2e 2e 2e 2e 2e 2e 2e 33 30 31 32 33 34 35 16.....3012345
0050 36 37 38 39 34 31 32 33 34 35 36 37 38 39 35 31 67894123 45678951
0060 32 33 34 35 36 37 38 39 36 31 32 33 34 35 36 37 23456789 61234567
0070 38 39 37 31 32 33 bc 07 897123..
```


6lowpan: wireshark

The image shows a Wireshark network traffic analysis interface. The main display area shows a list of captured packets. Packet 1119 is selected, and its details pane is expanded to show the 6LoWPAN structure. The details pane includes:

- Fragmentation Header
 - 1110 0... = Pattern: Fragment (0x1c)
 - Datagram size: 147
 - Datagram tag: 0x0000
 - Datagram offset: 120
- [14 Message fragments (147 bytes): #1105(120), #1106(120), #1107(120), #1108(120), #1109(120), #1110(120), #1111(120), #1112(120), #1113(120), #1114(120), #1115(120), #1116(120), #1117(120), #1119(27)]
 - [Frame: 1105, payload: 0-119 (120 bytes)]
 - [Frame: 1106, payload: 0-119 (120 bytes)]
 - [Frame: 1107, payload: 0-119 (120 bytes)]
 - [Frame: 1108, payload: 0-119 (120 bytes)]
 - [Frame: 1109, payload: 0-119 (120 bytes)]
 - [Frame: 1110, payload: 0-119 (120 bytes)]
 - [Frame: 1111, payload: 0-119 (120 bytes)]
 - [Frame: 1112, payload: 0-119 (120 bytes)]
 - [Frame: 1113, payload: 0-119 (120 bytes)]
 - [Frame: 1114, payload: 0-119 (120 bytes)]
 - [Frame: 1115, payload: 0-119 (120 bytes)]
 - [Frame: 1116, payload: 0-119 (120 bytes)]
 - [Frame: 1117, payload: 0-119 (120 bytes)]
 - [Frame: 1119, payload: 120-146 (27 bytes)]
- [Message fragment count: 14]
- [Reassembled 6LoWPAN length: 147]

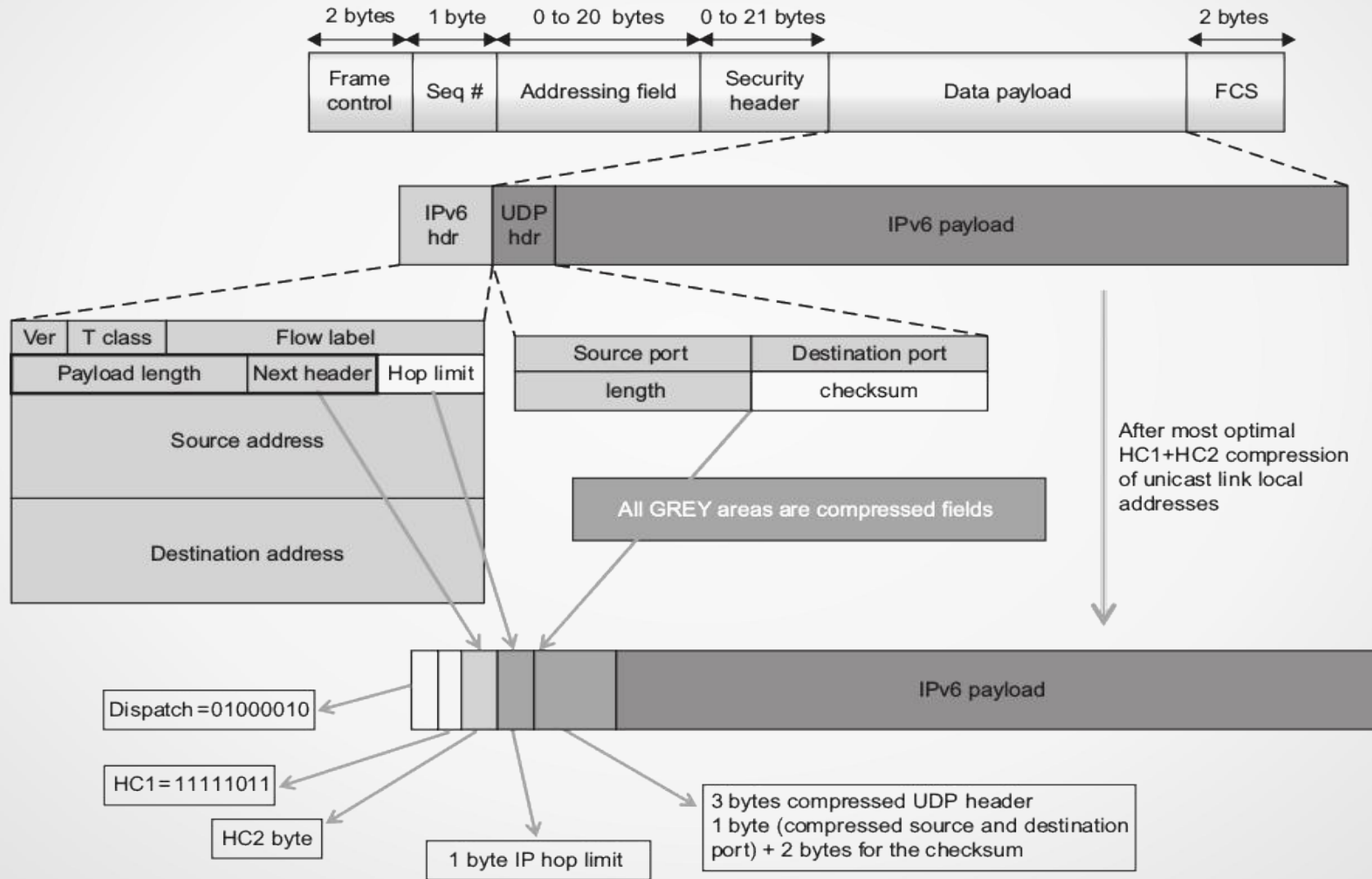
The packet list shows the following details for packet 1119:

No.	Time	Source	Destination	Length	Info	Protocol
1117	16:22:01.597530	00:12:74:08:00:08:00:03	00:12:74:08:00:08:00:02	120	Data, Dst: NitLab_08:00:08:00:02, Src: NitLab_08:00:08:00:03, Bad FCS	6LoWPAN
1118	16:22:01.601776			5	Ack, Bad FCS	IEEE 802.15.4
1119	16:22:01.605607	::212:7408:8:4	::212:7408:8:2	55	1111 → 1111 Len=91, Bad FCS	UDP
1120	16:22:01.607780			5	Ack, Bad FCS	IEEE 802.15.4
1121	16:22:02.207148	fe80::212:7408:8:3	fe80::212:7408:8:2	102	RPL Control (DODAG Information Object), Bad FCS	ICMPv6
1122	16:22:02.211393	fe80::212:7408:8:3	fe80::212:7408:8:2	102	RPL Control (DODAG Information Object), Bad FCS	ICMPv6

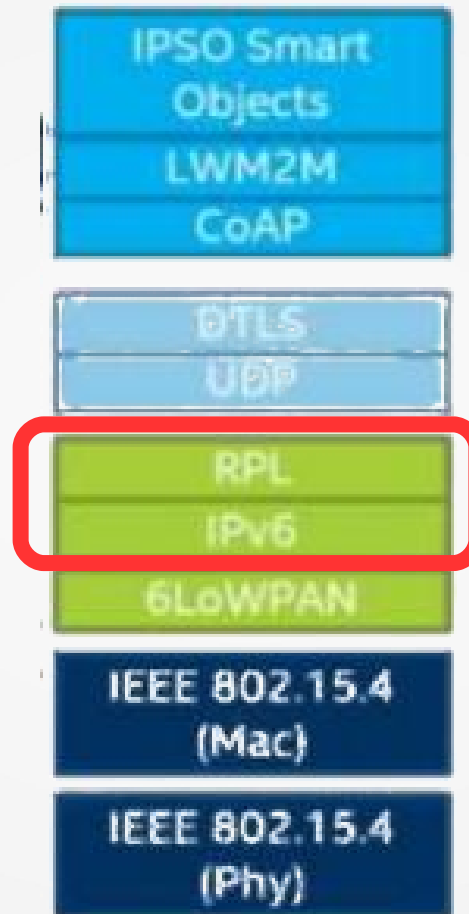
The packet bytes pane shows the raw data for the selected packet:

```
0030 04 57 00 63 2f ce 4c 61 62 20 52 53 49 20 2016... 30123
0040 32 30 31 36 2e 2e 2e 2e 2e 2e 2e 33 30 31 32 33 45678941 23456789
0050 34 35 36 37 38 39 34 31 32 33 34 35 36 37 38 39 45678941 23456789
0060 35 31 32 33 34 35 36 37 38 39 36 31 32 33 34 35 51234567 89612345
0070 36 37 38 39 37 31 32 33 34 35 36 37 38 39 38 31 67897123 45678981
```


6lowpan: example



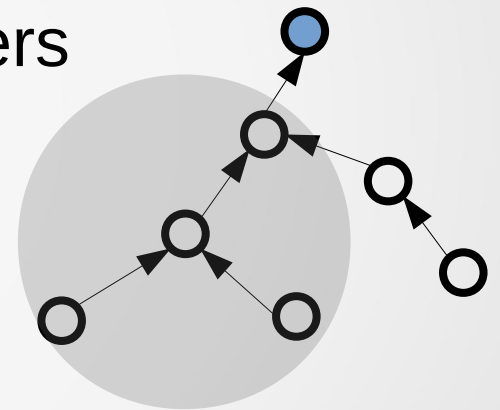
RPL: routing layer



RPL

- IPv6 **R**outing **P**rotocol for **L**ow-Power and **L**ossy Networks (RPL, pronounced ripple)
- Features
 - Physical medium: IEEE 802.15.4 or others
 - Proactive: distance vector based
 - Topology: tree (build graph distributed)
 - Traffic: "up" and "down" directions
 - Parent selection: based on objective function
 - Operation mode: non-storing and storing

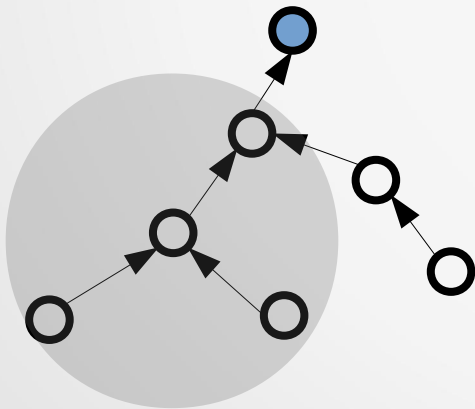
MESH



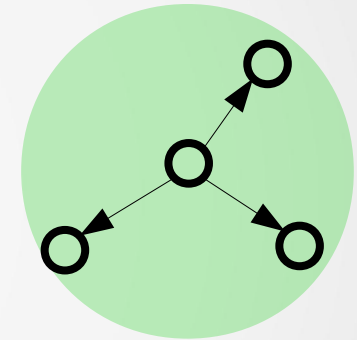
RPL

- Requires:
 - broadcast and unicast messages to build tree

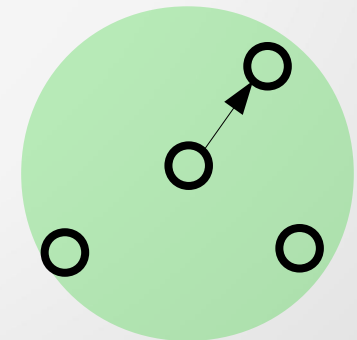
MESH



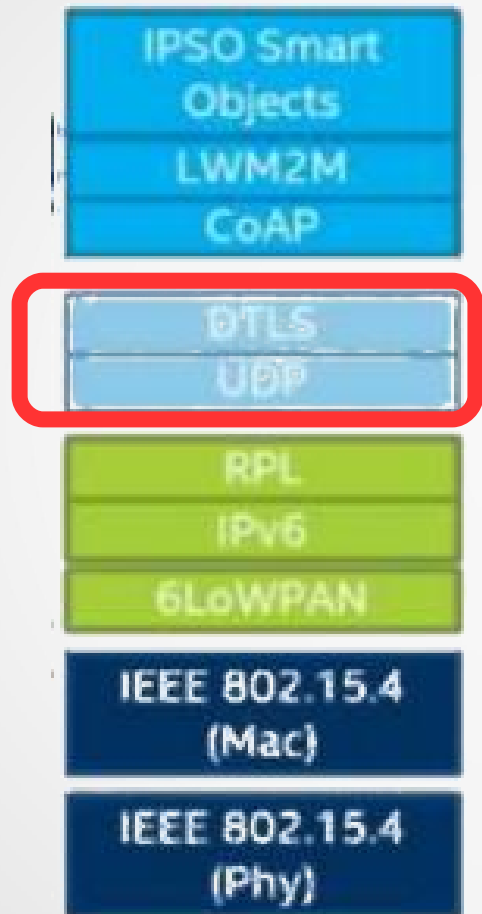
broadcast



unicast

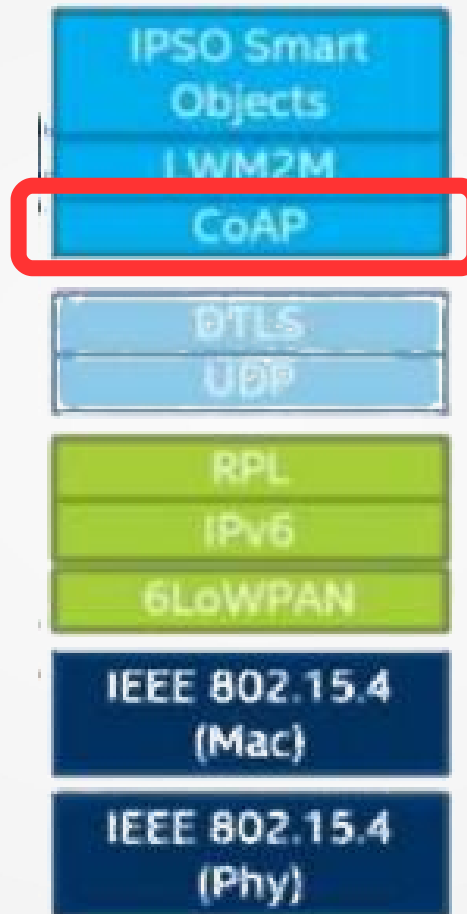


TCP / UDP: transport layer



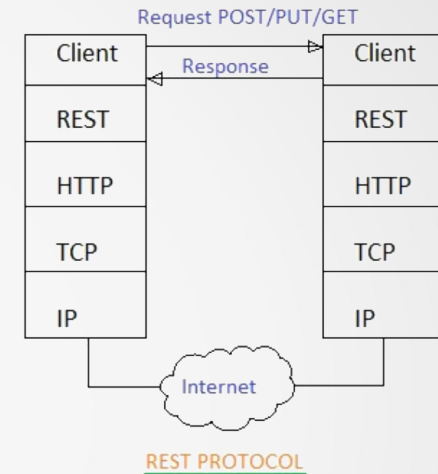
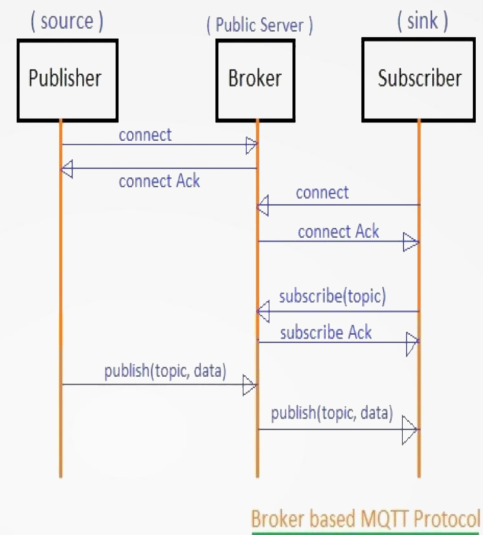
- TCP versus UDP

CoAP: application layer



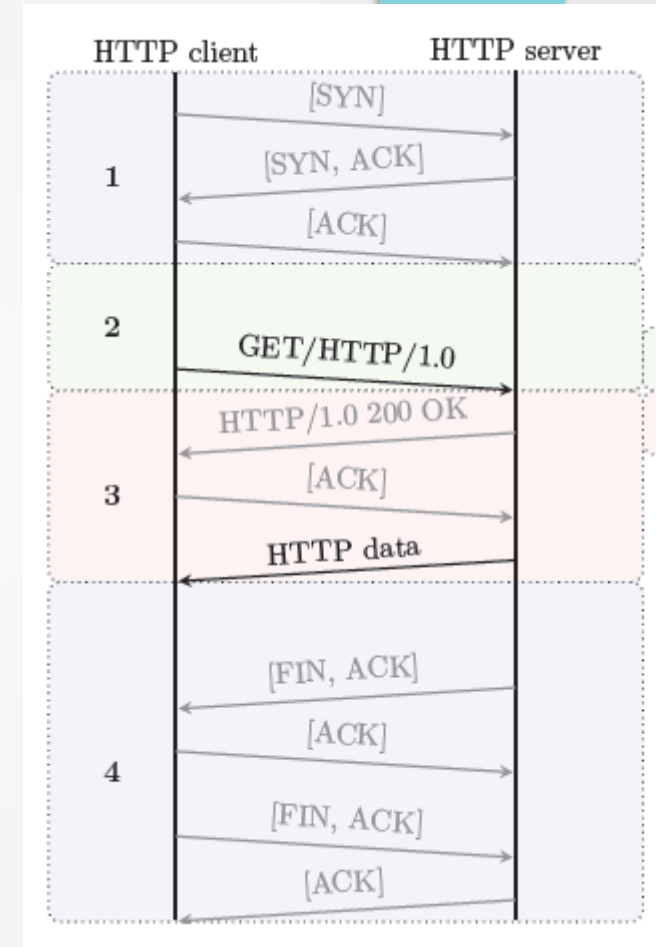
Application protocols: options

- Proprietary solutions
 - disadvantages
- Existing solutions
 - Client - Server
 - Publish - Subscribe
- Example: Extend the use of web services (client server)
 - Hypertext Transfer Protocol (HTTP)
 - New protocols



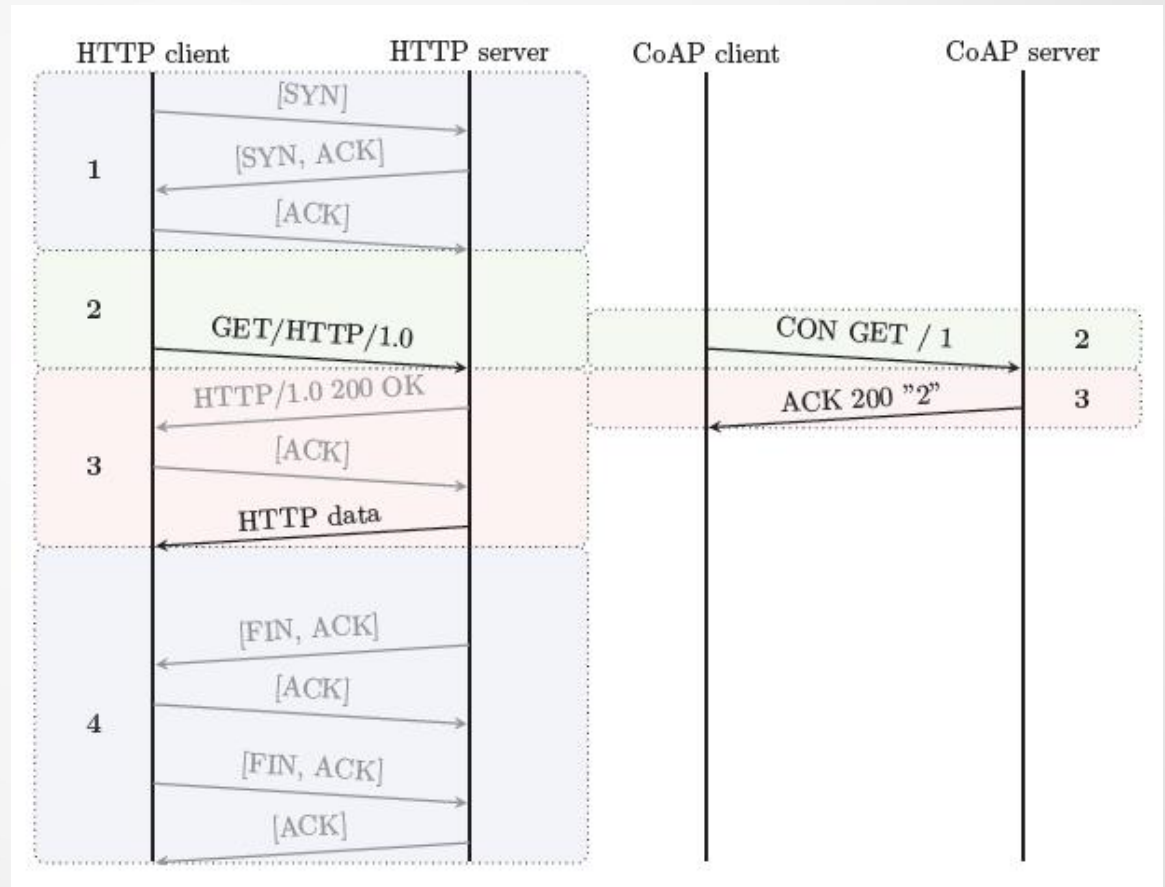
Example: HTTP

- Features
 - Restful
 - TCP
- Is it a good idea for WSN?
 - No



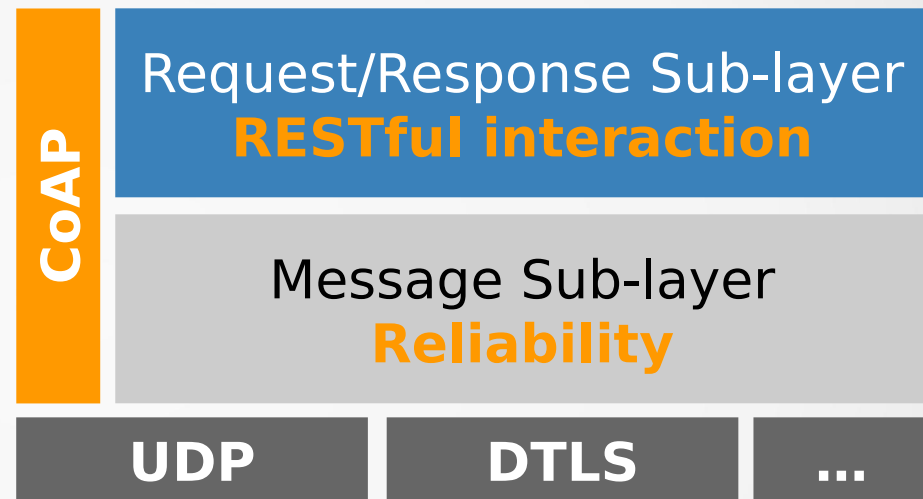
CoAP: new proposal

- RFC 7252: The Constrained Application Protocol (CoAP)
- RESTful
 - fresh start
- Transport: UDP (optionally DTLS)

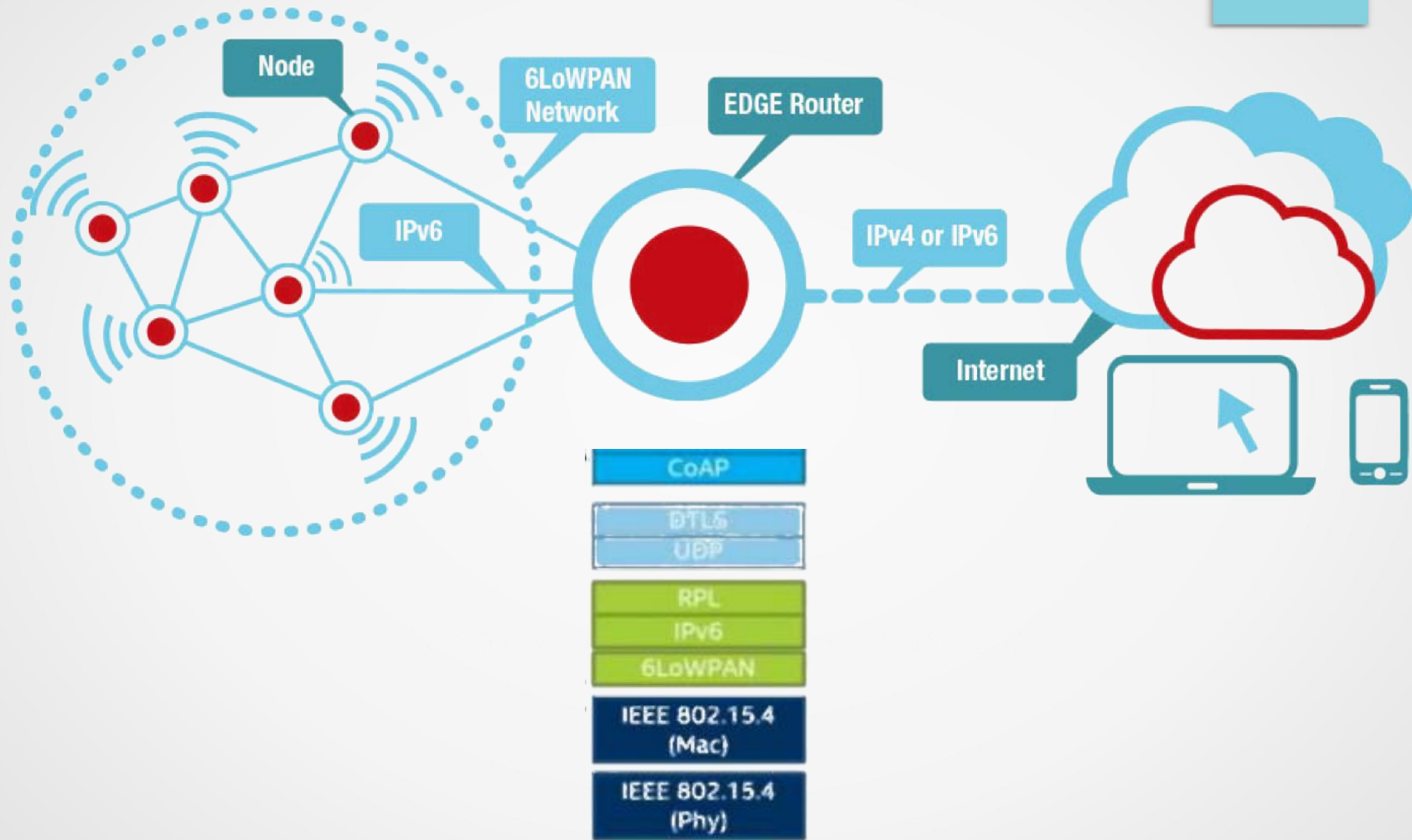


CoAP: two layers

- Methods
 - GET
 - PUT
 - POST
 - DELETE
- Messages
 - Confirmable
 - Non-confirmable
 - Acknowledgment
 - Reset



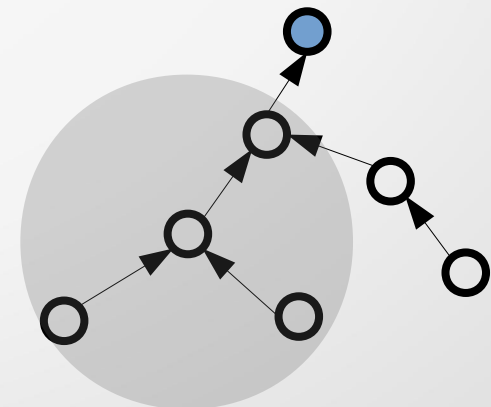
Recap

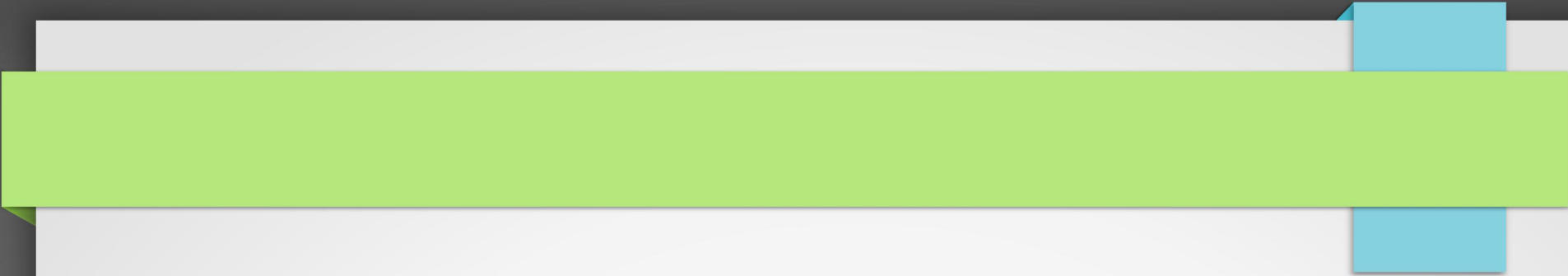


WSN (mesh) and Cyber Physical Systems

- Some potential benefits
 - 2.4 GHz and sub-GHz bands available
 - homogeneous devices and communications (allows)
 - relative high throughput (compared to other LPWAN)
 - traffic upwards and downwards (do not prioritize upwards)
 - enable peer to peer communications

MESH





thanks
¿questions?