The Devil is in the Detail:
How a Real-World IoT Technology is Made – IETF 6TiSCH

Mališa Vučinić, PhD

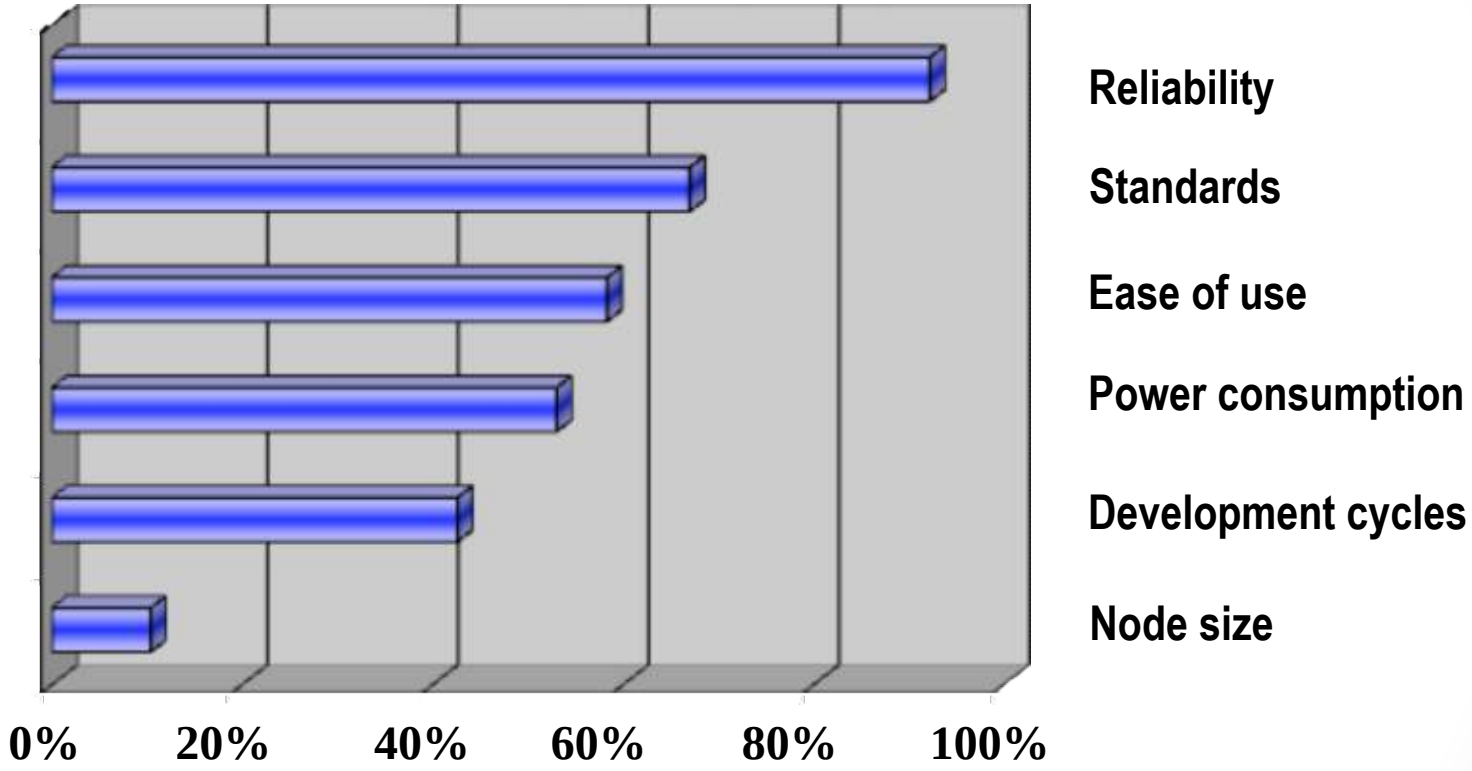
University of Montenegro

Thanks

Most of these slides, or figures were created by the following people.

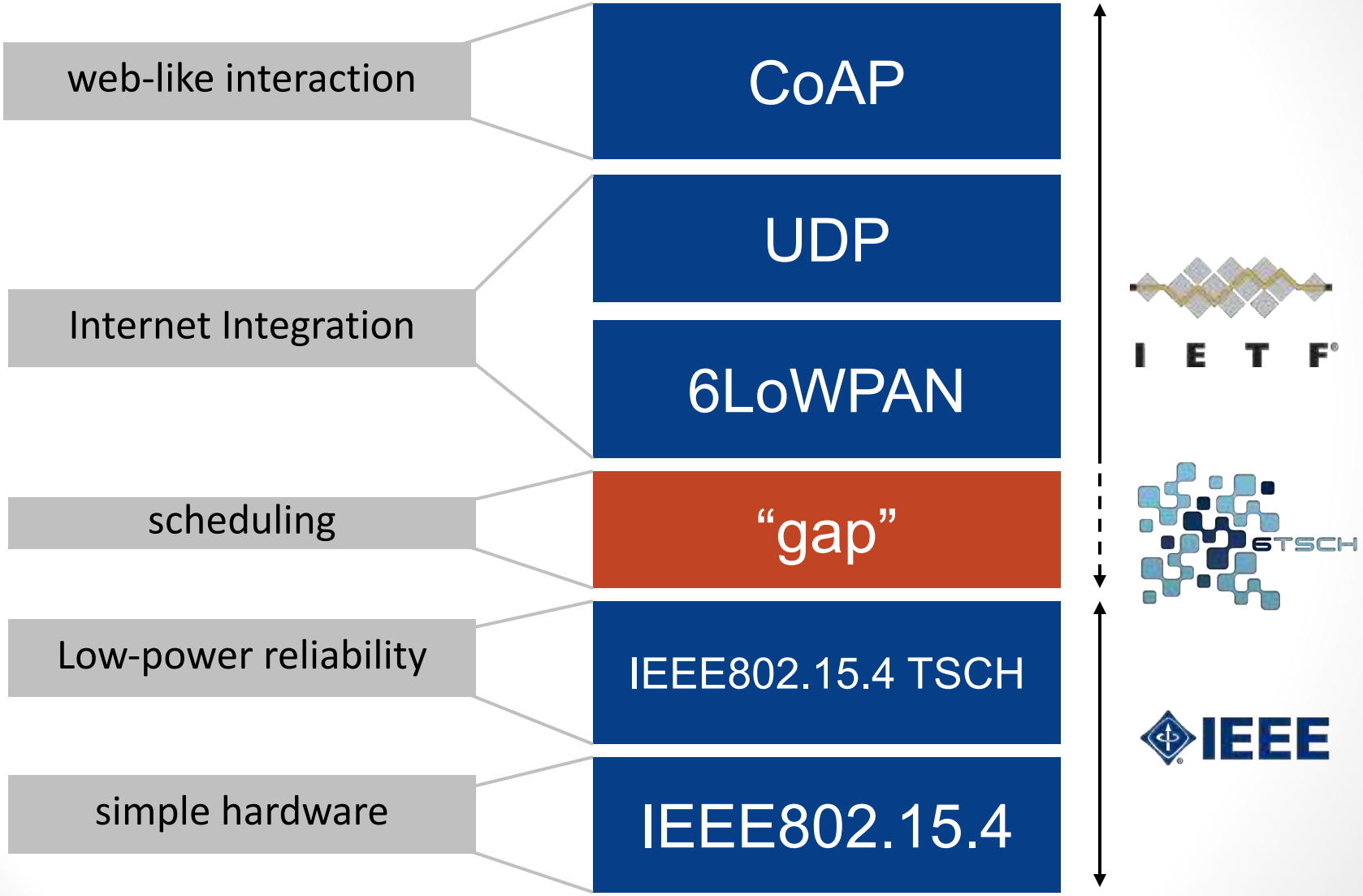
- Thomas Watteyne
- Mischa Dohler
- Zach Shelby
- Xavier Vilajosana

Internet of Things: Barriers to Adoption

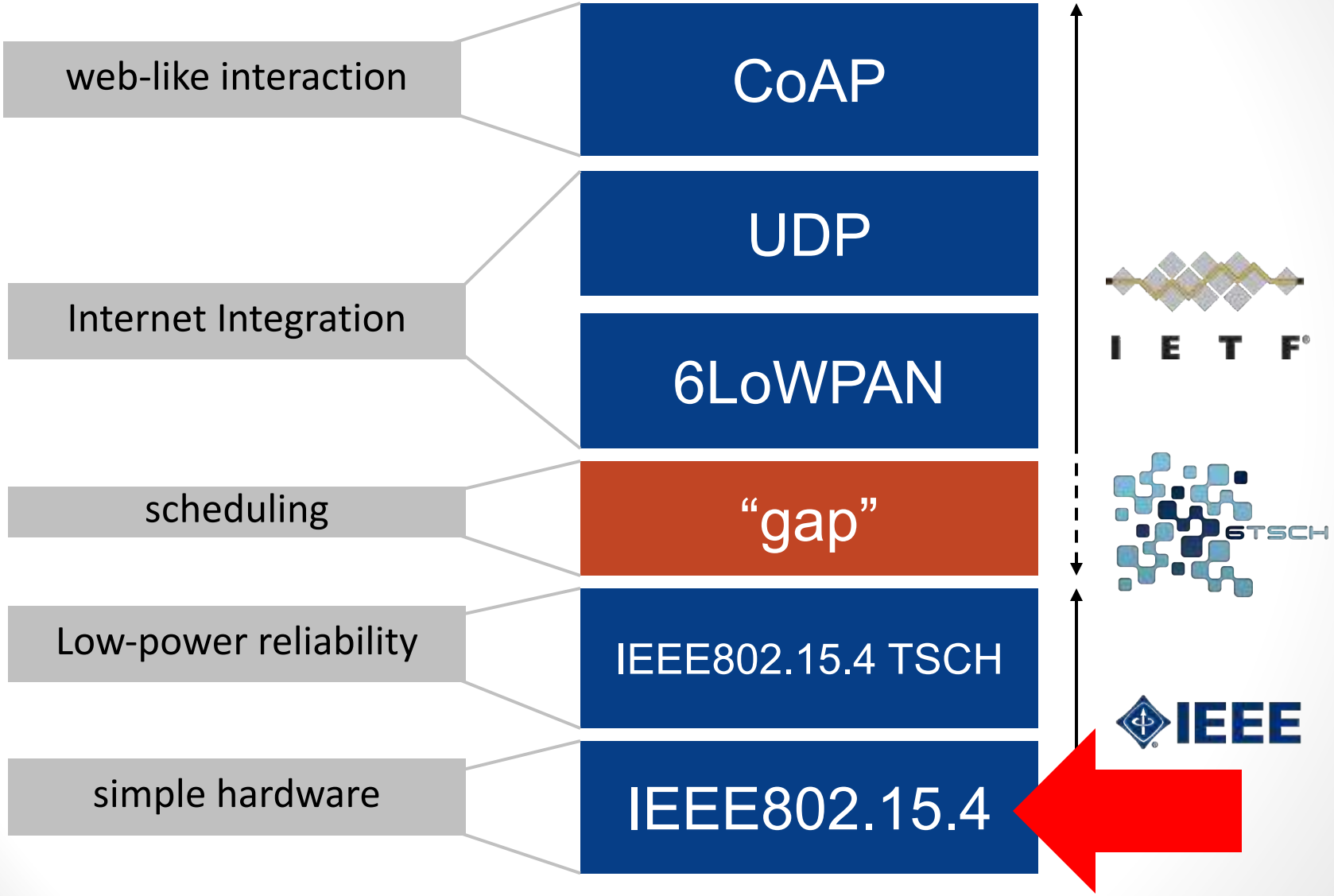


source: OnWorld

The Internet of Things Stack: 6TiSCH



The Internet of Things Stack: 6TiSCH



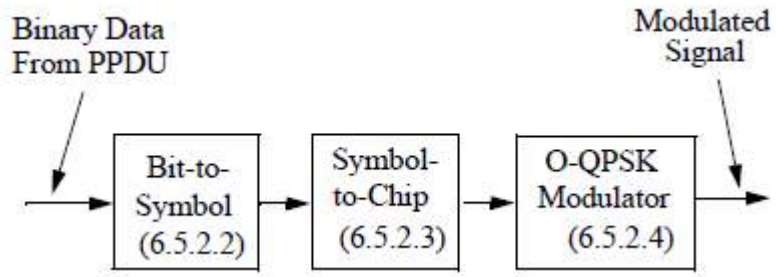
IEEE802.15.4

- Standard by the IEEE:
  - Physical and MAC layer
  - Revisions: 2003, 2006, 2011, 2015
- 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

IEEE802.15.4: 2.4GHz PHY

- O-QPSK, 2Mcps, 250 kbps
- **Direct Sequence Spread Spectrum**
- **Max PSDU = 127B**

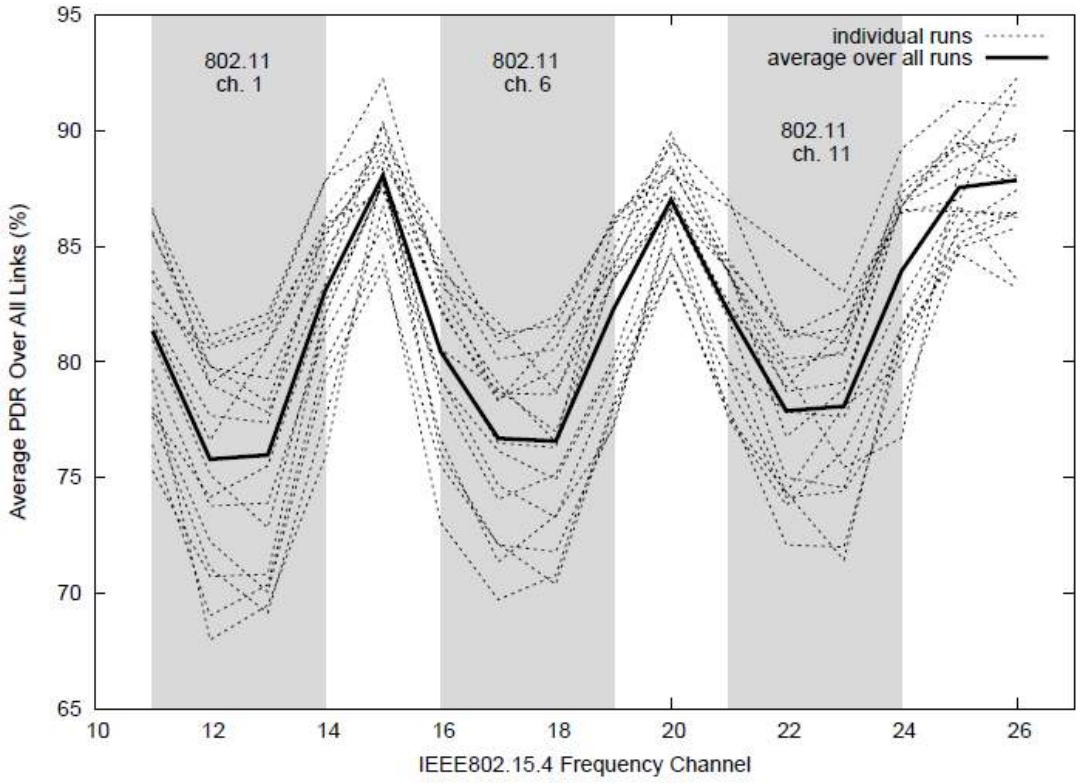


Data symbol (decimal)	Data symbol (binary) ($b_0\ b_1\ b_2\ b_3$)	Chip values ($c_0\ c_1 \cdots c_{28}\ c_{31}$)
0	0000	11011001110000110101001000101110
1	1000	11101101100111000011010100100010
2	0100	00101110110110011100001101010010
3	1100	00100010111011011001110000110101
4	0010	01010010000101110110110011100001
5	1010	00110101001000101110110110011100
6	0110	11000011010100100010111011011001
7	1110	10011100001101010010001011101101
8	0001	10001100100101100000011101111011
9	1001	10111000110010101100000011101111
10	0101	01111011100011001001011000000111
11	1101	01110111101110001100100101100000
12	0011	00000111011110111000110010010110
13	1011	01100000011101111011100011001001
14	0111	10010110000001110111011100011100
15	1111	11001001011000000111011110111000

DSSS: 4 bits of information = 32 chips

IEEE802.15.4: 2.4GHz PHY

First Challenge: External Interference

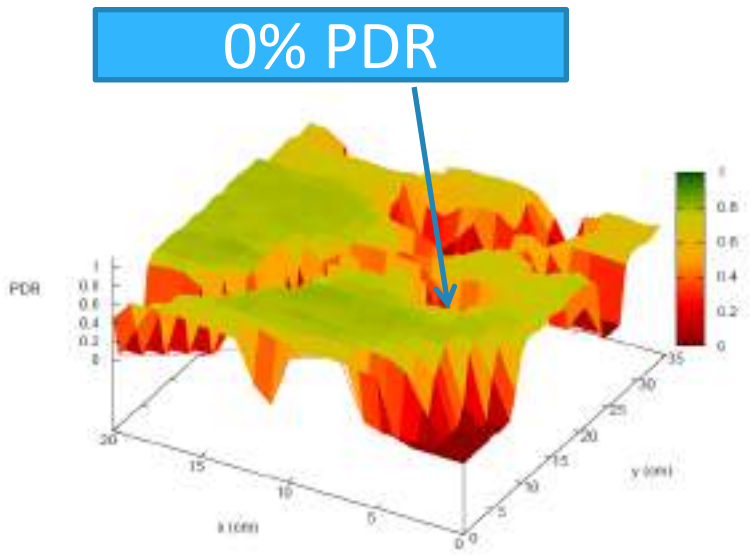


- 45 motes*
- 50x50m office environment
- 12 million packets exchanged, equally over all 16 channels

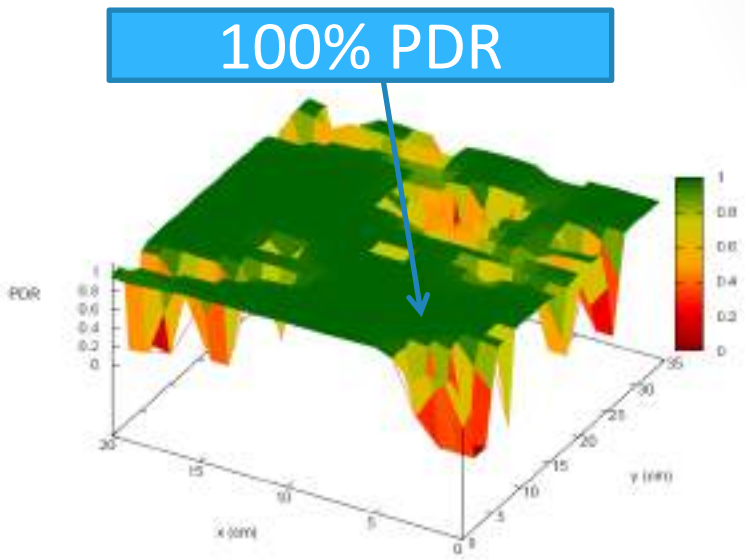
*data collected by Jorge Ortiz and David Culler, UC Berkeley

IEEE802.15.4: 2.4GHz PHY

Second Challenge: Multipath Fading



ch.11



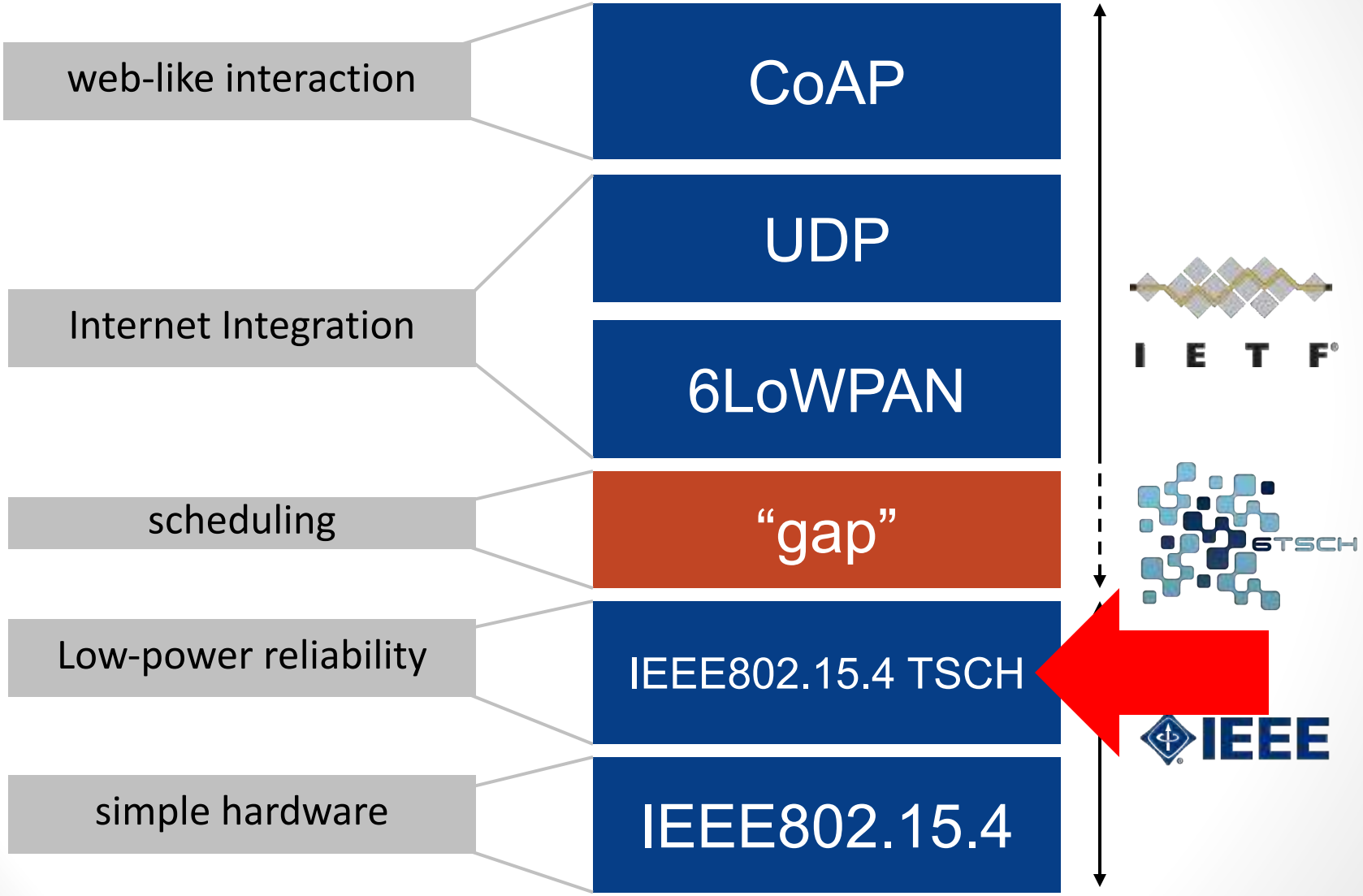
ch.12

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

changing channel improves performance

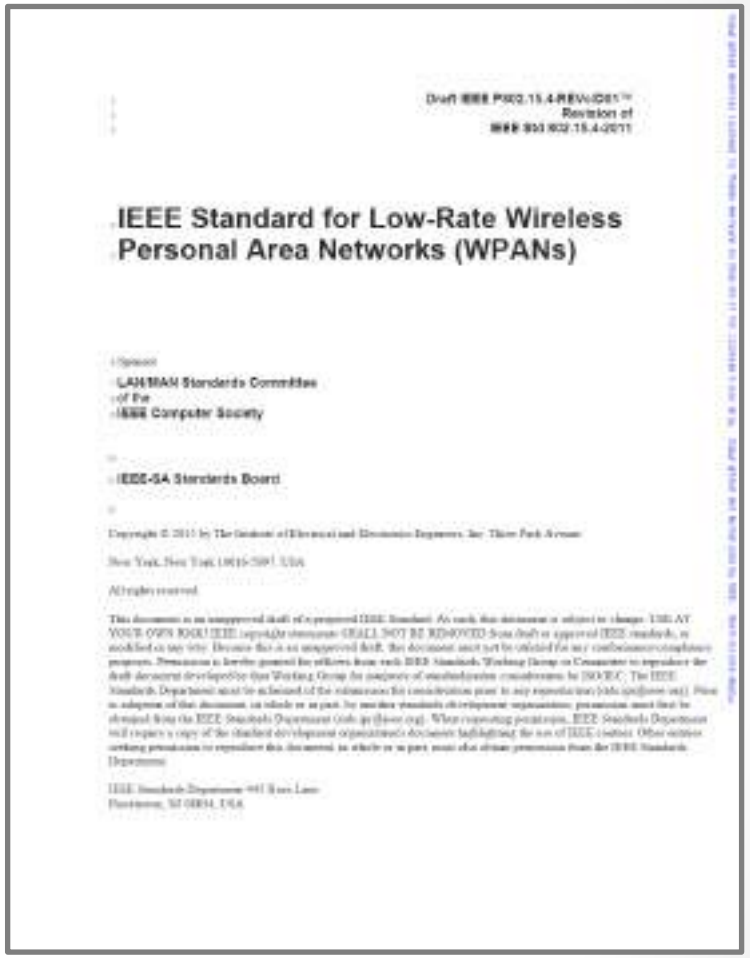
*data collected by Thomas Watteyne, Inria

The Internet of Things Stack



IEEE802.15.4 TSCH

- Published in 2012 as IEEE802.15.4e
- Only amends MAC layer of IEEE 802.15.4-2011:
  - Does not modify PHY layer
- "Time-slotted Channel Hopping" (TSCH) mode:
  - Ultra low-power operation by synchronizing nodes
  - Ultra high reliability through channel hopping



IEEE Standard for Low-Rate Wireless Personal Area Networks (WPANs)

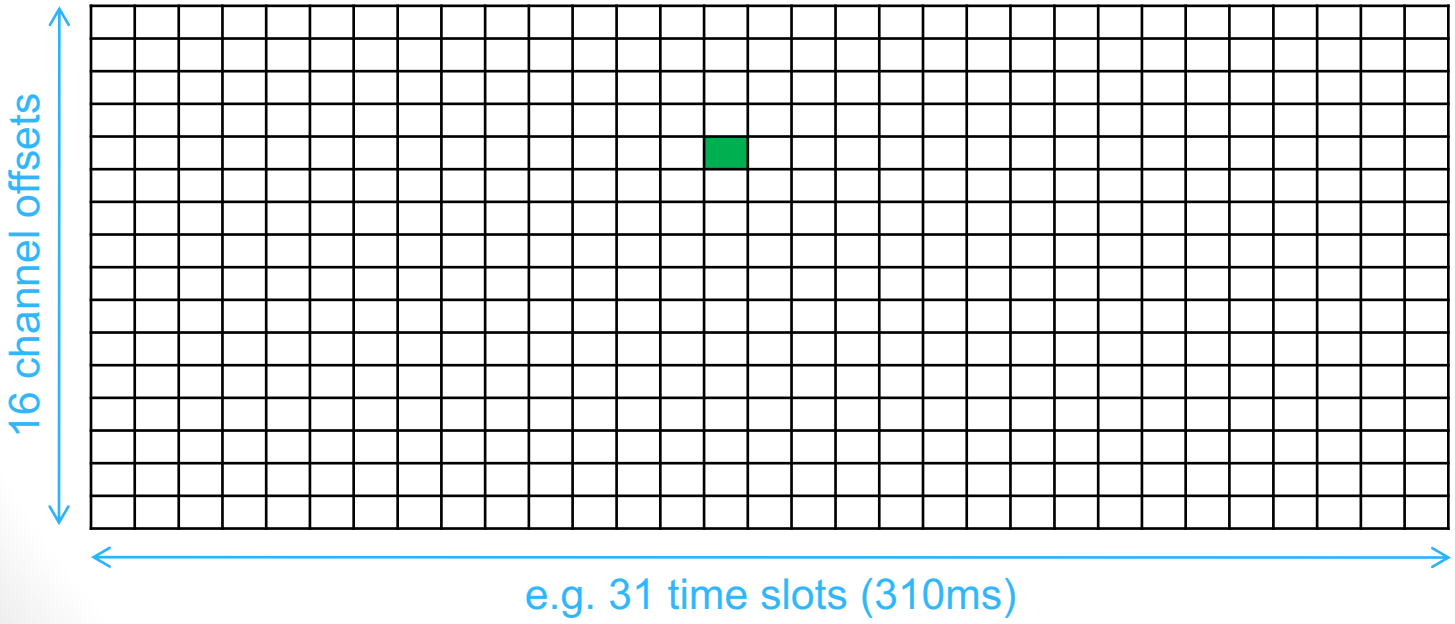
LAN/MAN Standards Committee of the IEEE Computer Society

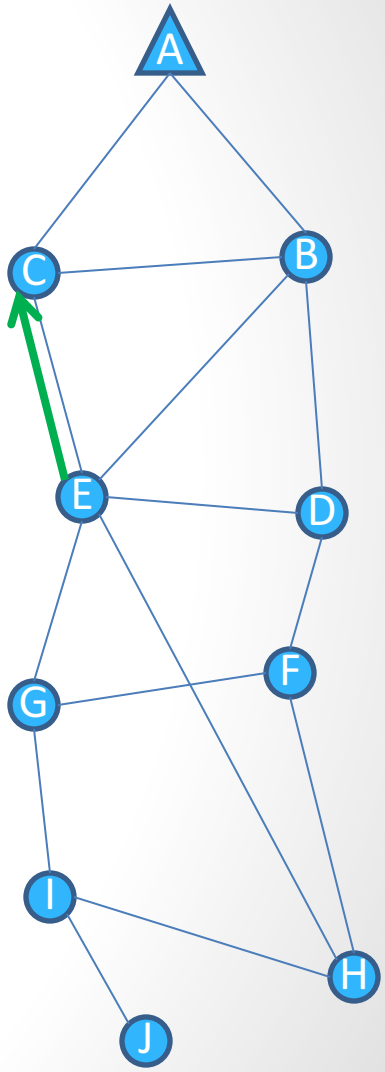
IEEE-SA Standards Board

IEEE802.15.4 TSCH: Communication Schedule

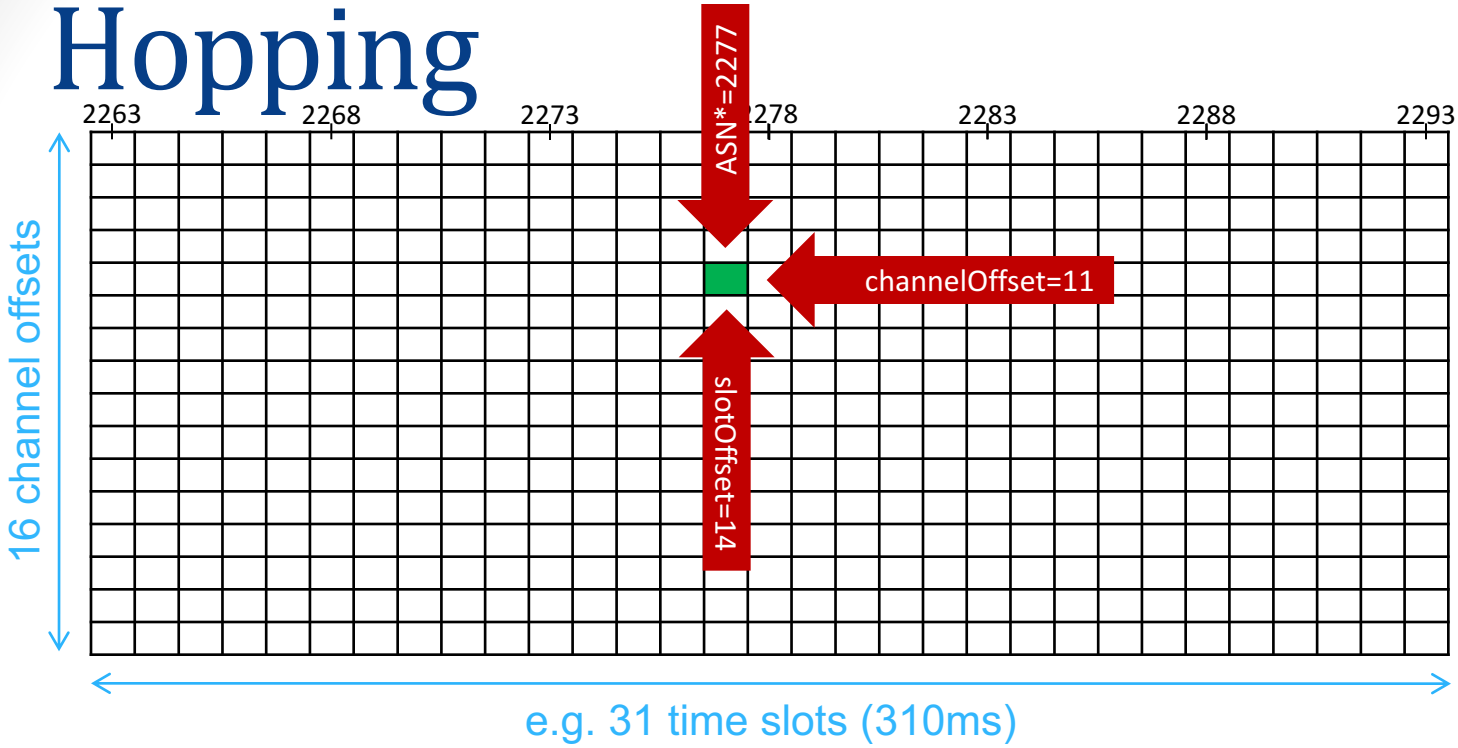
A slotframe repeats over time

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





IEEE802.15.4 TSCH: Channel Hopping



frequency = (channelOffset+ASN)%16+11

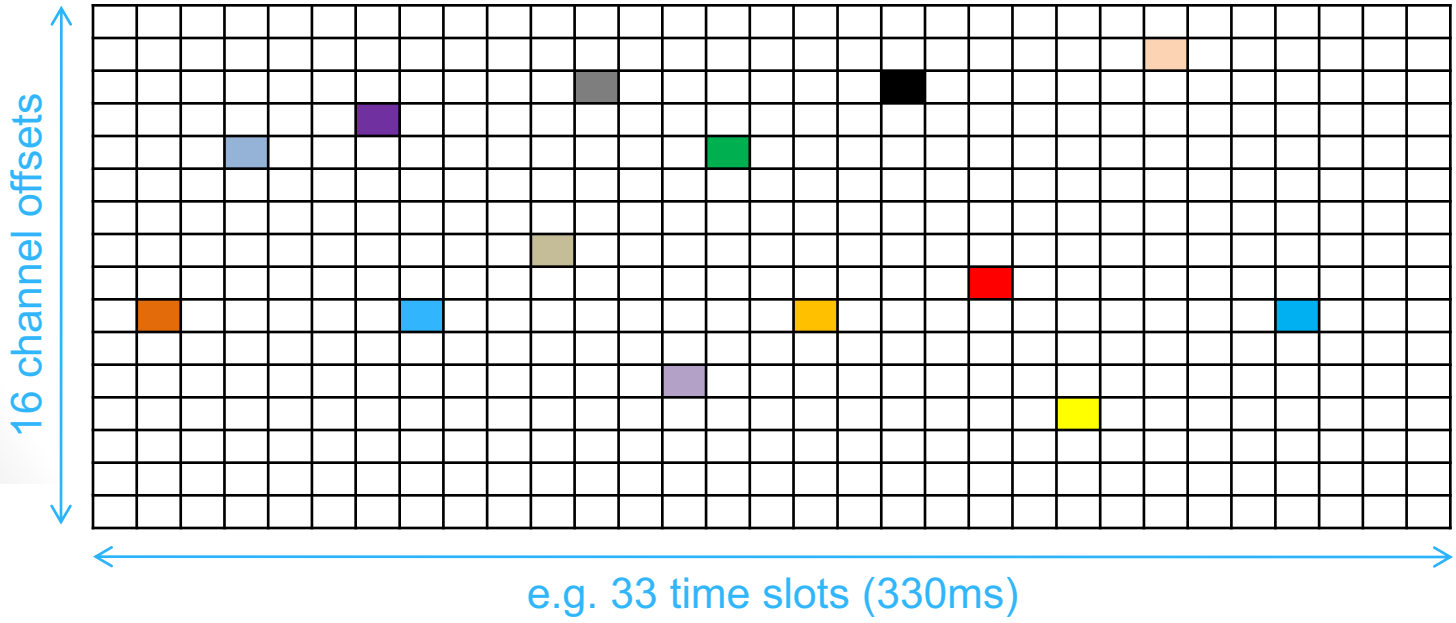
Now:
Ch. 11 (**2.405GHz**)

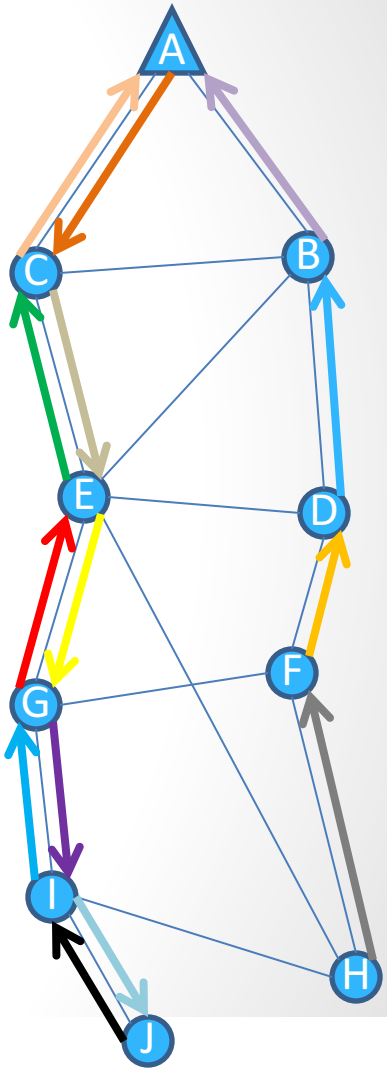
Next slotframe:
Ch. 26 (**2.480GHz**)

*Absolute Slot Number

IEEE802.15.4 TSCH: Slotted Structure

- Cells are assigned according to application requirements

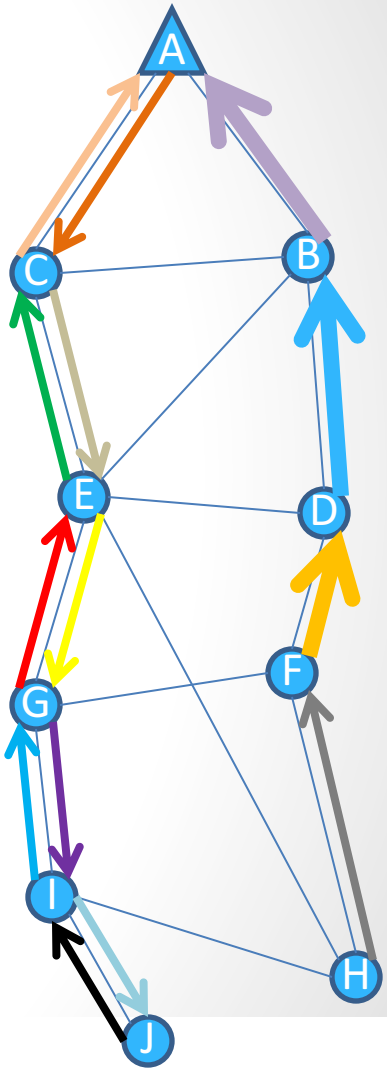


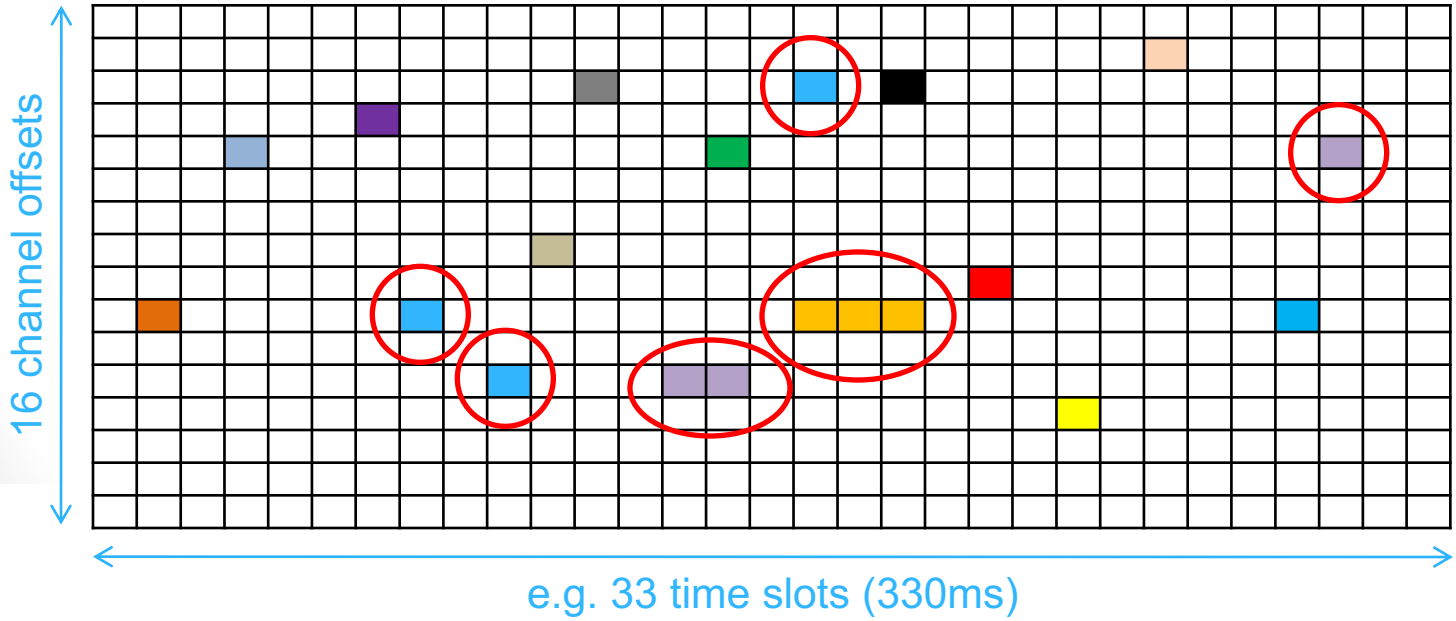


IEEE802.15.4 TSCH: Slotted Structure

- Cells are assigned according to application requirements
- Tunable trade-off between
  - capacity (i.e. packets/second)

…and energy consumption

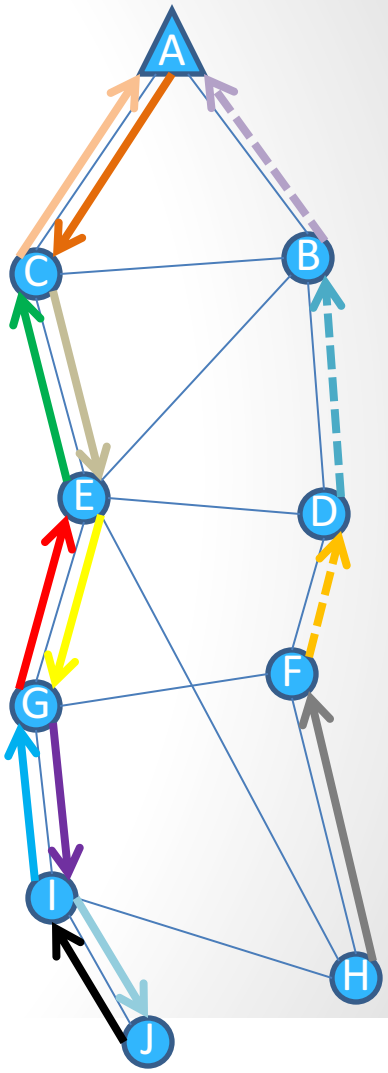


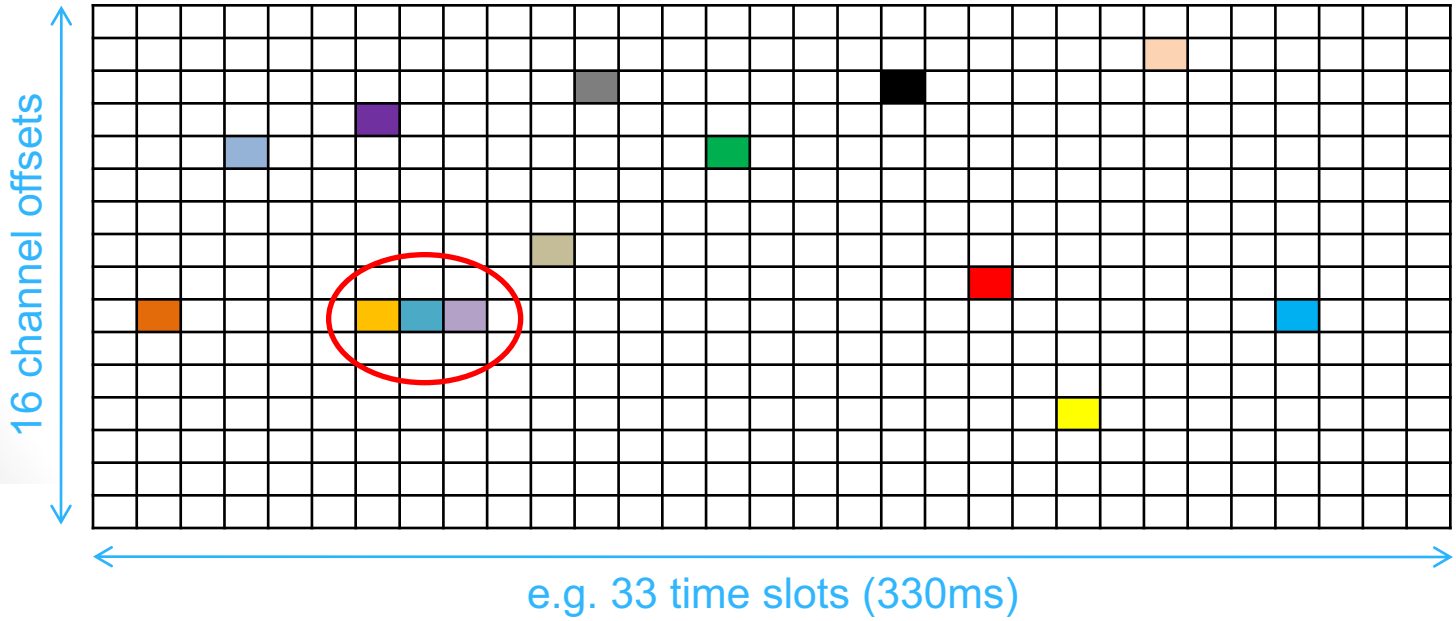


IEEE802.15.4 TSCH: Slotted Structure

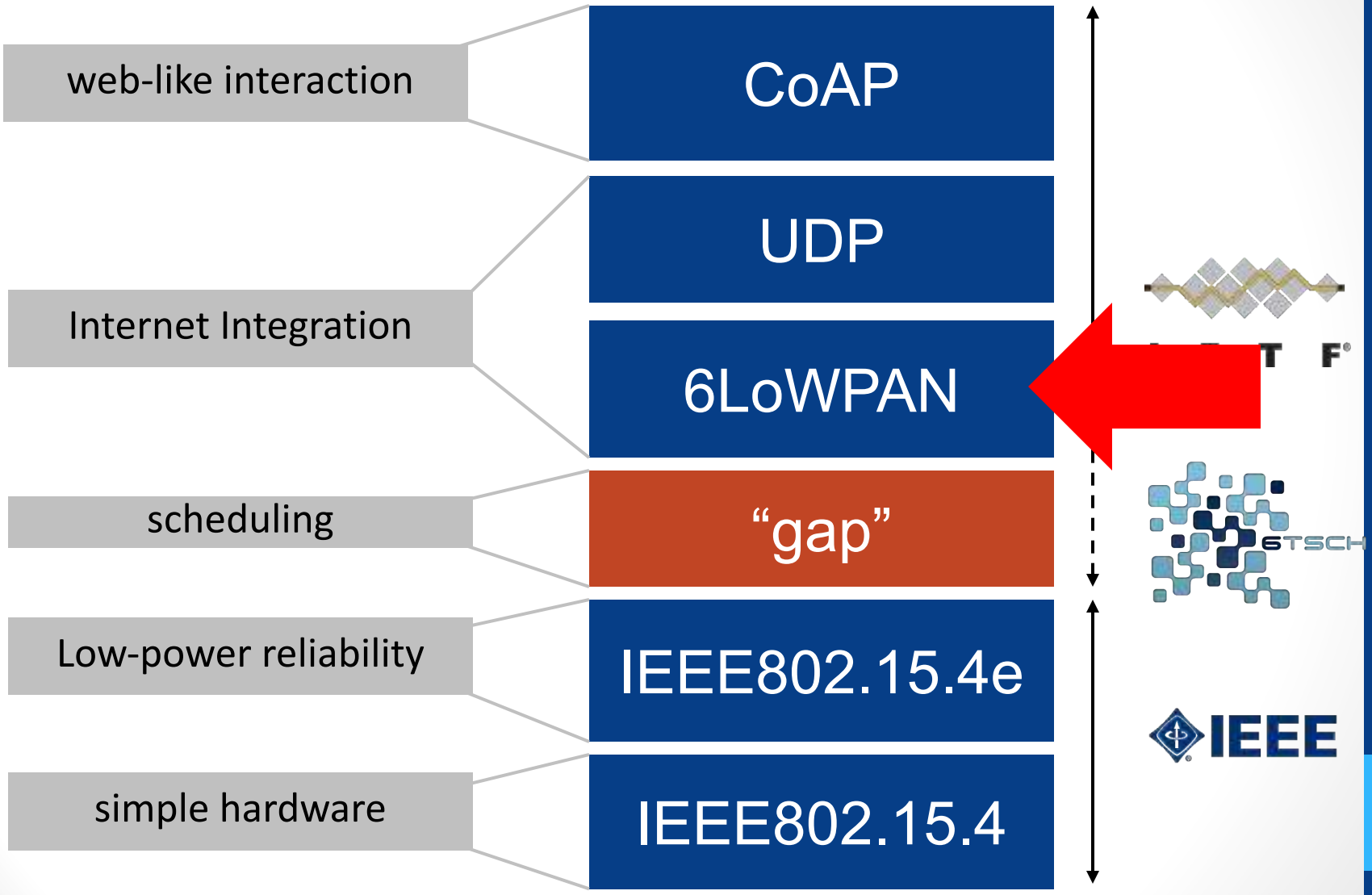
- Cells are assigned according to application requirements
- Tunable trade-off between
  - capacity (i.e. packets/second)
  - latency

…and energy consumption

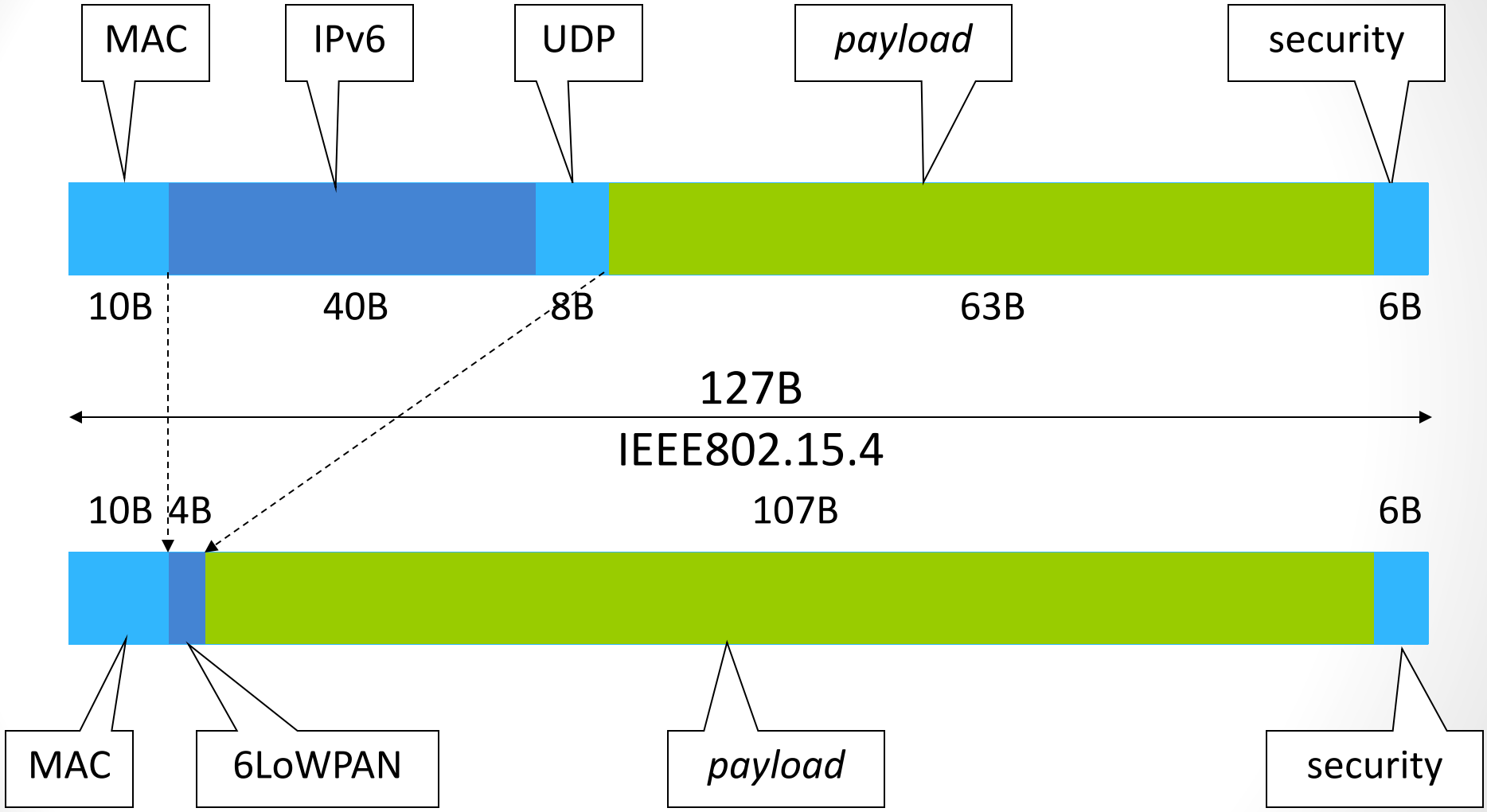




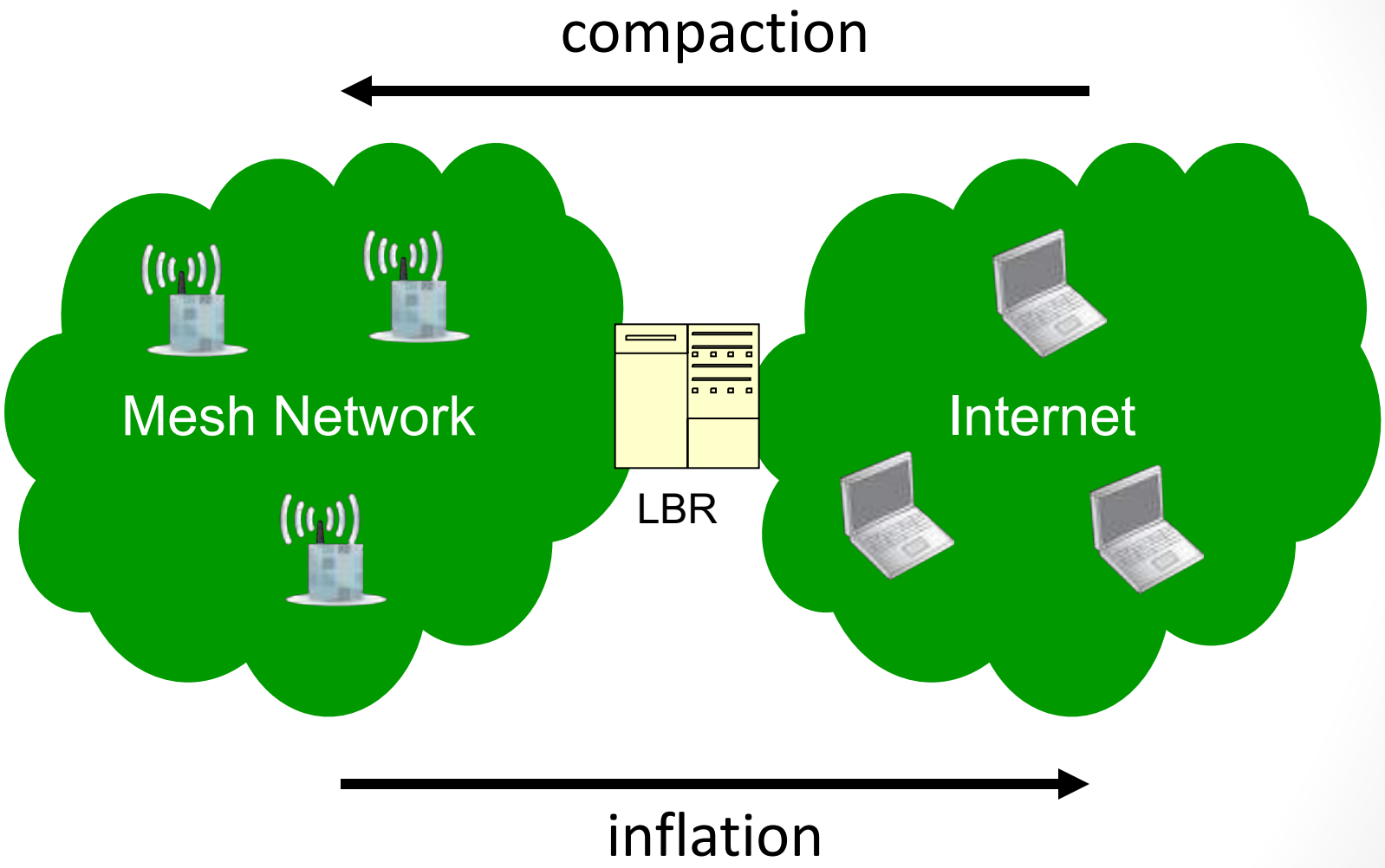
The Internet of Things Stack



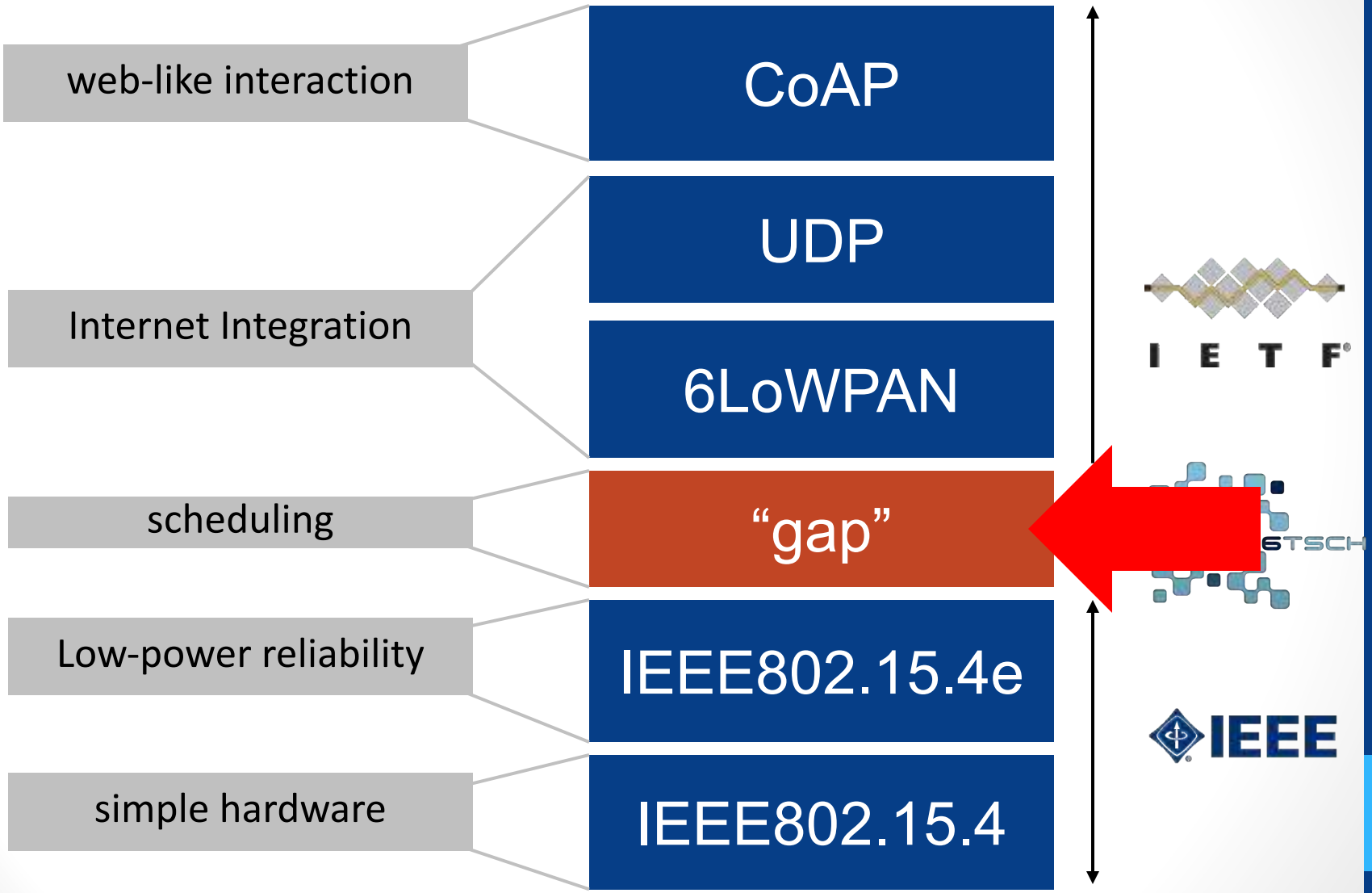
IETF 6LoWPAN



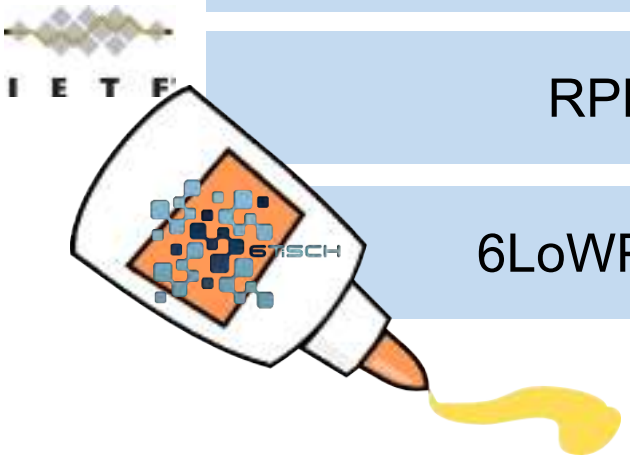
6LoWPAN: architecture



The Internet of Things Stack



We want the best of both worlds!



CoAP — 2014

RPL — 2012

6LoWPAN — 2011

Ease-of-use of IPv6
- global addressing
- web-like interactions

- how to build the TSCH schedule
- secure network access

IEEE

IEEE802.15.4
Time
Slotted
Channel
Hopping

2012

Industrial Performance
- wire-like reliability
- “deploy and forget” lifetimes

IETF 6TiSCH

- Created October 2013
- *IPv6 over the TSCH mode of IEEE 802.15.4e*
- **>400 members** (mix between academic and non-academics)
- Face-to-face meetings at IETF86, IETF87, IETF88, IETF89, IETF90, IETF91, IETF92, IETF93, IETF94, IETF95, IETF96, IETF97, IETF98, IETF99, IETF100, IETF101, IETF102
- plugfests/**interop events**:
  - London, 2014
  - Toronto, 2014
  - Prague, 2015
  - Paris, 2016
  - Berlin, 2016
  - Prague, 2017
  - Paris, 2018


ETSI
Meeting
1st F-Interop 6TiSCH Interoperability
Event
6TiSCH

Research & Development Projects

H2020: Remote interoperability testing platform

f-interop.eu

spots.ac.me

H2020: IoT security solutions

armour-project.eu

Reference performance datasets of 6TiSCH

ucg.ac.me/etf/soda

ETSI reference implementation of 6TiSCH

openwsn.org

6TiSCH Simulator

bitbucket.org/6tisch/simulator

The OS for Next Generation IoT Devices

contiki-ng.org

A bit more about SODA and IoT performance evaluation in general…

- Vast majority of academic papers evaluate incremental optimizations
- The evaluation methodology varies significantly
- Testbeds are there, everybody uses them differently!
- Industry lacks an unbiased performance benchmark of different IoT technologies

Standardizing how IoT networking technologies are evaluated:

iotbench.ethz.ch

18 institutions involved

UC Berkeley, ETH Zurich, RISE SICS, Inria, …

ucg.ac.me/etf/soda

The Devil is in the Detail

- Publishing *one* RFC
  - Takes 2-3 years
  - 15-20 document revisions on average
  - Reviews from lead authors of Internet standards
- Real-world means ”real code”
  - 6TiSCH firmware counts over **770,000** lines of C code*
  - That’s an equivalent of a book **30,800**-pages long
- Real-world means real hardware
  - Testbeds
  - *My PDR is a bit lower than expected.*

*Up-to-date OpenWSN firmware repository.

Hvala*!

*Thanks!