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IoT standards

MAC and Routing

Internet of Things, a.a. 2019/2020

Un. of Rome "La Sapienza"

Chiara Petrioli[†]

[†] *Department of Computer Science – University of Rome "Sapienza" – Italy*

Extensions of IEEE 802.15.4
Reading material:

De Guglielmo, Anastasi, Seghetti "From IEEE 802.15.4 to IEEE 802.15.4e: A StepTowards the Internet of Things", advances in intelligence systems and computing, 2014, book chapter available at
https://www.researchgate.net/publication/289220698_From_IEEE_802154_to_IEEE_802154e_A_step_towards_the_Internet_of_Things

IEEE 802.15.4

- Reference PHY/MAC standard for IoT;
- Designed in the early times (2006) when IoT applications were still not deployed. Energy efficiency addressed.
- Good for some applications; but it does not fullfill the needs of some emerging industrial applications, where timeliness, reliability, robustness can be as important and which may demand for:
  - Real time guaranteed exchange of information, (e.g., in factory automation applications which motivated different standards promoted by industries such as WirelessHART, ISA100). Timeliness requirements can go from guaranteed latency below few msec (factory automation) to guaranteed latency within few minutes (asset control) but in any case requires a change of MAC.
  - Resilience to interference (e.g., through frequency hopping)
  - Ability to increase capacity (e.g., through multi-channel solutions).

IEEE 802.15.4

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  - Resilience to interference (e.g., through frequency hopping)
  - Ability to increase capacity (e.g., through multi-channel solutions).
- After a decade of research, after industrial needs identification, emergence of other standards to fullfil such needs, IEEE 802.15.4 working group has released in 2016 an extension of the standard which incorporates some of these ideas.
- Note: IEEE 802.15.4 working group is active. Standards evolve over time.

IEEE 802.15.4

- MAC used in the first version of the standard: CSMA/CA based
- Limits:
  - No delay guarantees;
  - No resilience to interference (lack of frequency hopping support);
  - Not ideal MAC in high traffic scenarios;
  - Some energy optimizations to support tree topologies not explicit/subject to interpretation to what could be a standard compliant IEEE 802.15.4 solution—despite possible and available; needed to be better clarified).
- For applications not properly supported IEEE 802.15.4 (2012, 2016) has provided extensions targeted for specific application domains. General objectives of such extensions:
  - Low energy (LE): It allows a device to operate with a very low duty cycle (e.g., 1%or below),while appearing to be always on to the upper layers.
  - Enhanced Beacons (EB). Extended Beacons are an extension of the 802.15.4 beacon frames. They allow to create application-specific beacons, by including relevant information elements depending on the needs of specific variants of IEEE 802.15.4e.
  - Multipurpose Frame: flexible frame element.
  - MAC Performance metrics, allowing e.g., to provide link quality information to upper layers;
  - Fast association. Changes association procedure which was trading off energy for latency in case of applications which require fast association.

IEEE 802.15.4e variants

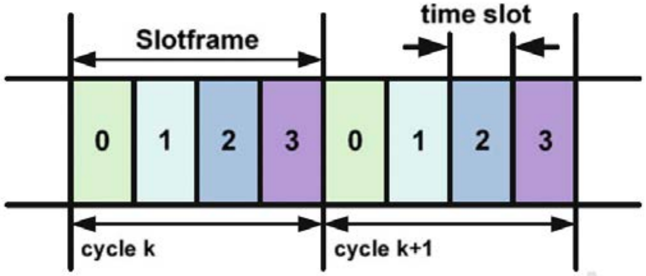
- Radio Frequency Identification Blink (BLINK) mode supports effective ID exchange for sake of item/people identification, location, and tracking
- Asynchronous multi-channel adaptation (AMCA) supports dynamic multi-channel use in distributed beaconless networks
- Deterministic and Synchronous Multi-channel Extension (DSME) supports time-critical applications for large networks in beacon-enabled PANs
  - Guaranteed Time Slot mechanism included in basic IEEE 802.15.4 has limitations, supports only 7 slots per frame, does not allow to use multiple channels
  - DSME enhances GTS by forming a multi-superframe and using multi-channel operation. A multi-superframe is a cycle of superframes, where each superframe includes the beacon frame, the CAP (only for the first superframe in the cycle) and the GTS. A pair of nodes wakes up at a reserved GTS slot to exchange a data frame and an ACK frame.

IEEE 802.15.4e variants

- The Low Latency Deterministic Network (LLDN) supports commercial and industrial applications requiring low and deterministic latency. Large number of actuators and sensors monitoring and controlling an operation. 100 of sensors/actuators need to be supported. Guaranteed latency below tens of msec.→Multi-channel extension (the PAN coordinator has multiple transceivers and can simultaneously tx over multiple channels), slotted beacon-enabled frames, star topologies, shorter slots/packets, short 8-bit addresses.
  - Beacon time slot, management time slot, base timeslot (some dedicated and some shared-in shared CSMA/CA contention), cumulative ACK sent by PAN coordinator at the superframe level)
- Time Slotted Channel Hopping (TSCH) supports industry applications by combining slotted access, multi-channel support and frequency hopping.
  - Topology independent;
  - Supports increased network capacity, high reliability and predictable latency, while enabling low duty cycling.

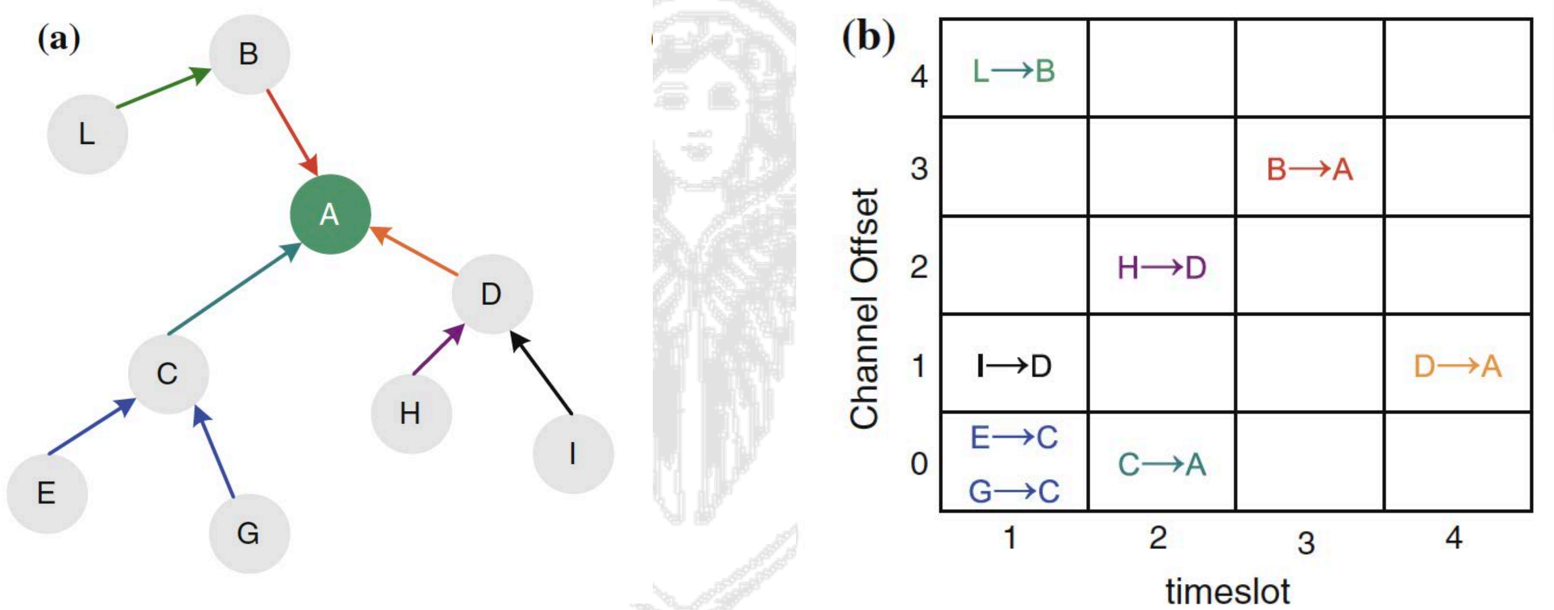
IEEE 802.15.4e TSCH

- Nodes synchronize on a periodic slotframe consisting of x timeslots (case x=4 in the figure).



- Each timeslot allows a node to send max size data and receive ack (if no ack received retransmission in the next time slot)
- A channel is identified by slot associated for bidirectional communication and frequency offset.
- Concurrent transmissions on multiple channels (using different frequencies) is allowed.
- Some frequencies maybe blacklisted if they are experiencing low link quality.

- In the figure the case of application of TSCH with a slotframe made of 4 slots and 5 frequency (out of max 16) used is shown. (it shows also shared channels, in case of shared channels and a collision the backoff is in terms of number of shared links to wait before attempting again)

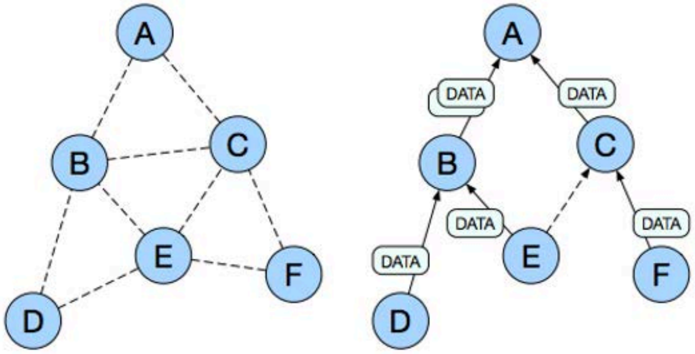


RPL, 2012
Material to read:

http://disi.unitn.it/~picco/papers/commag16.pdf

Routing in IoT

- Desirable features
  - Energy aware, small factor, lightweight solutions, low overhead
  - Should scale to thousands of smart objects
  - Long lasting systems (years or decades)
  - Auto-configuration, self-managing
  - Robust even in presence of varying link quality and unreliable links



(a) A sample wireless network.
(b) Multipoint-to-point communication.

ROLL--Routing Over Low power and Lossy

- "Ripple" routing protocol RPL-- Proactive distance vector routing;
  - specifies how to build a destination oriented acyclic graph (DODAG) – rooted in the edge router
- Multi-hop support
- Flexible metric
  - <Find paths with the best ETX and avoid non encrypted links> or <Find the best path in terms of latency while avoiding battery operated nodes>.
  - Administrator may decide to have multiple routing topologies active at the same time to carry traffic with different requirements
  - dynamic metrics (link quality, CPU overload, battery levels, all fast change over time…)
- Focus on energy constrained, secure solutions
- Routing supported across multiple types of link layers

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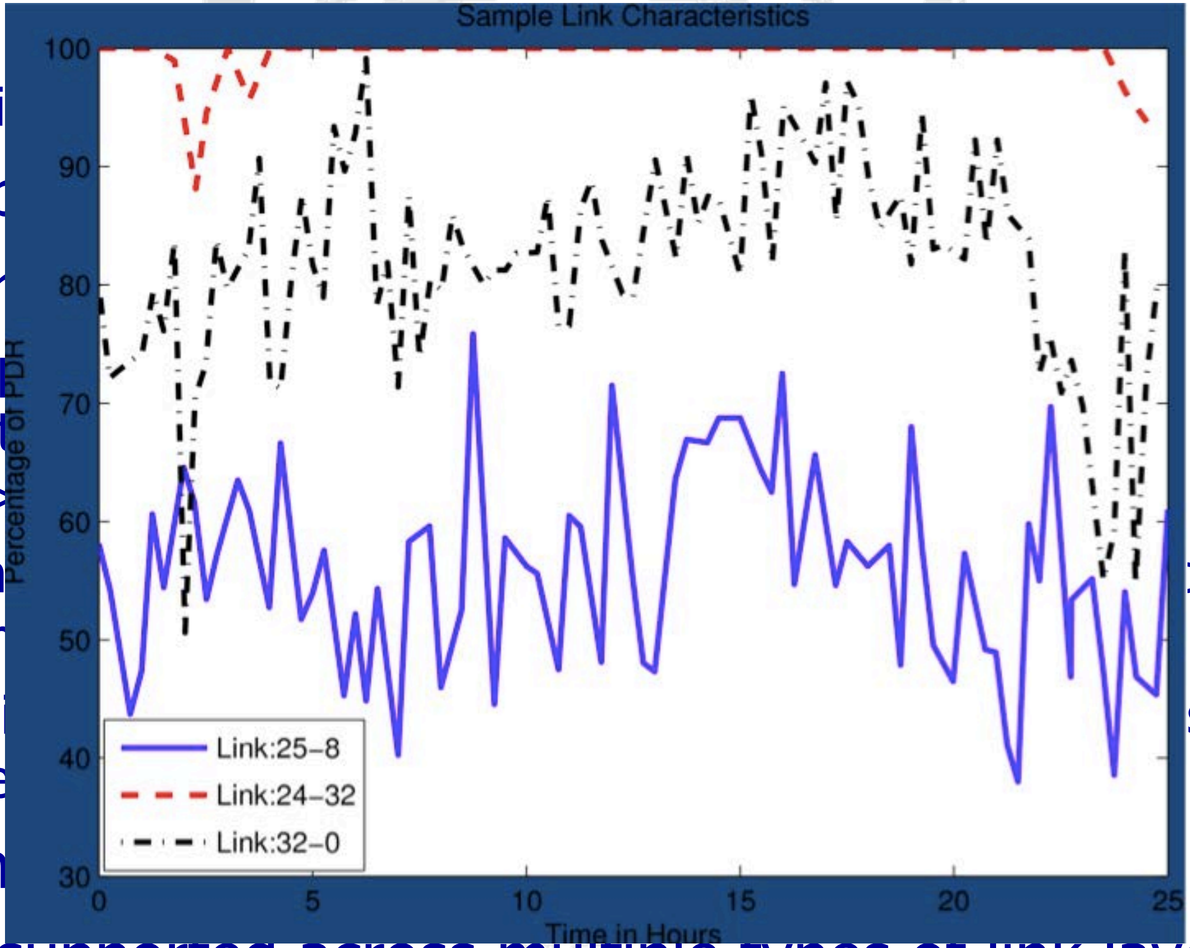

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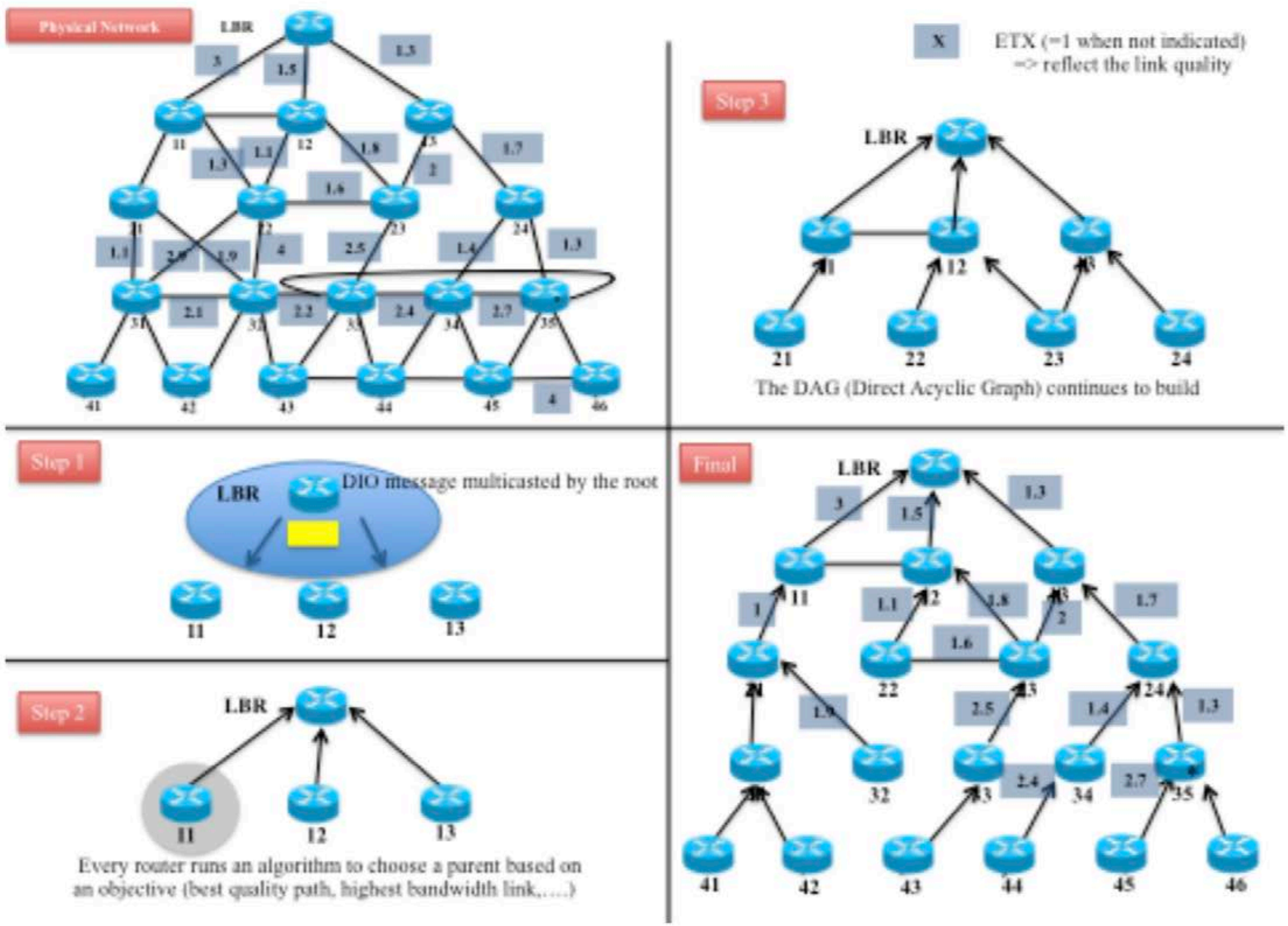
RPL– DODAG formation

- RPL specifies how to build a destination oriented acyclic graph (DODAG)
- Root (ER-LowPAN Border Router) sends a DIO (DODAG Information Object) message
- Neighbors of the root will listen to the DIO and decide whether to join DODAG
  - Each of their neighbors, upon receiving the DIO, selects its parent (according to a suitable metric) and –if it is configured as a router- reforwards the DIO.
  - Lead nodes do not reforward the DIO

This rippling effect builds the graph edges out from the root to the leaf nodes where the process terminates.

RPL– DODAG formation



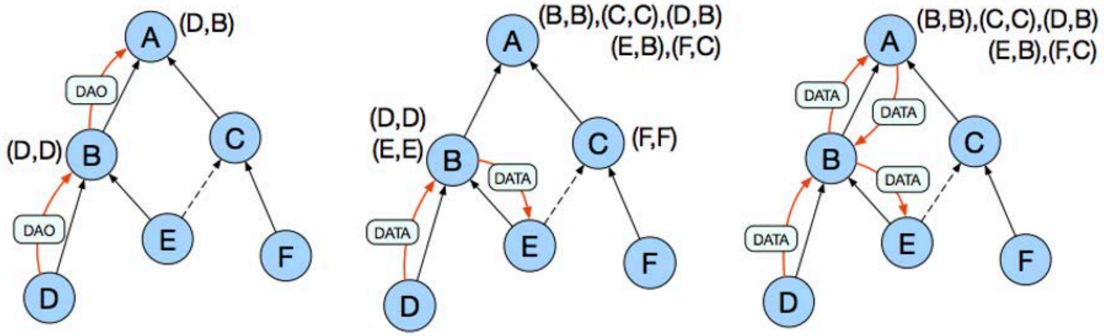
RPL -- How to multicast messages

- Destination Advertisement Object (DAO)
- As a node joins the graph it sends a DAO to its parent (can also be solicited via a DODAG Information Solicitation message- This DIS message is used by the nodes to proactively solicit graph information)
- DAO messages are forwarded till the root
- Prefix reachability info exchange also enables peer to peer communication
  - up along the tree till the common ancestor, then down till the intended destination

DIS, DIO and DAO are new ICMPv6 control messages to exchange graph related information.

RPL -- How to multicast messages

- DAO messages are forwarded till the root
- Prefix reachability info exchange also enables peer to peer communication
  - up along the tree till the common ancestor, then down till the intended destination
  - **In case we operate in non-storing mode the message goes till the root that adds a source route and send it down to the final destination**



(c) Point-to-multipoint route construction: storing mode.

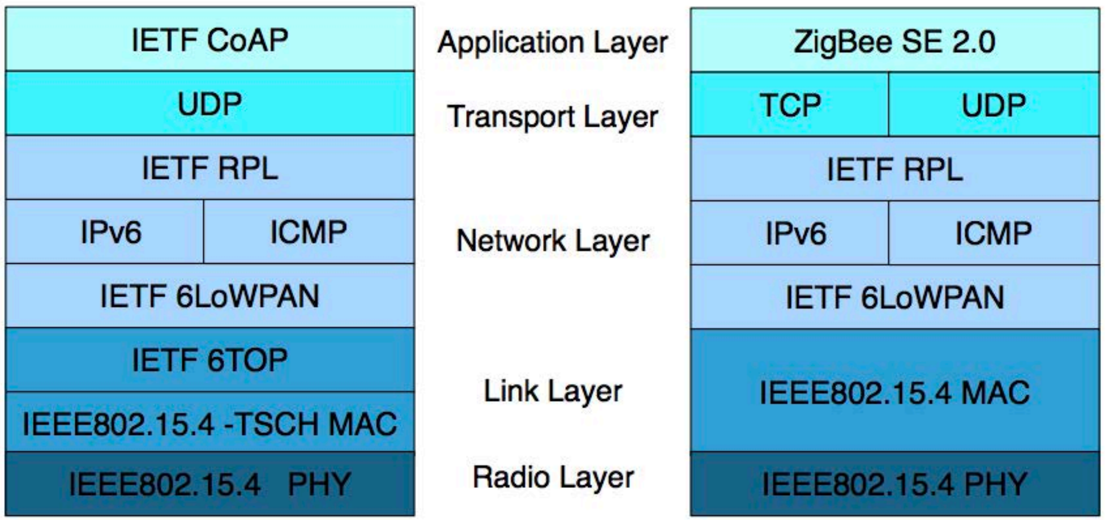
(d) Point-to-point communication: storing mode.

(e) Point-to-point communication: non storing mode.

RPL –trickle timers

- How often are DIO messages sent?
  - Dynamically selected (trickle timer) based on how stable the system is
  - If the system stabilizes it is seldom sent
  - Whenever an inconsistency is detected (such as loop or changes in the DODAG) then the timer is reset to small values

6LowPan and RPL evolution



(a) IETF standardized stack.

(b) ZigbeeIP stack.

Challenges for RPL

-evolving traffic
(from sensing to sensing and actuating; from Multipoint to point to Point to point and Point to multipoint)
-evolving application needs
Possibly mobility support
-novel ideas (e.g. cross layering opportunistic) could be incorporated

Further reading on 6Lo

https://www.recercat.cat/bitstream/handle/2072/355544/COMMAG-16-00534.R3__public.pdf?sequence=1

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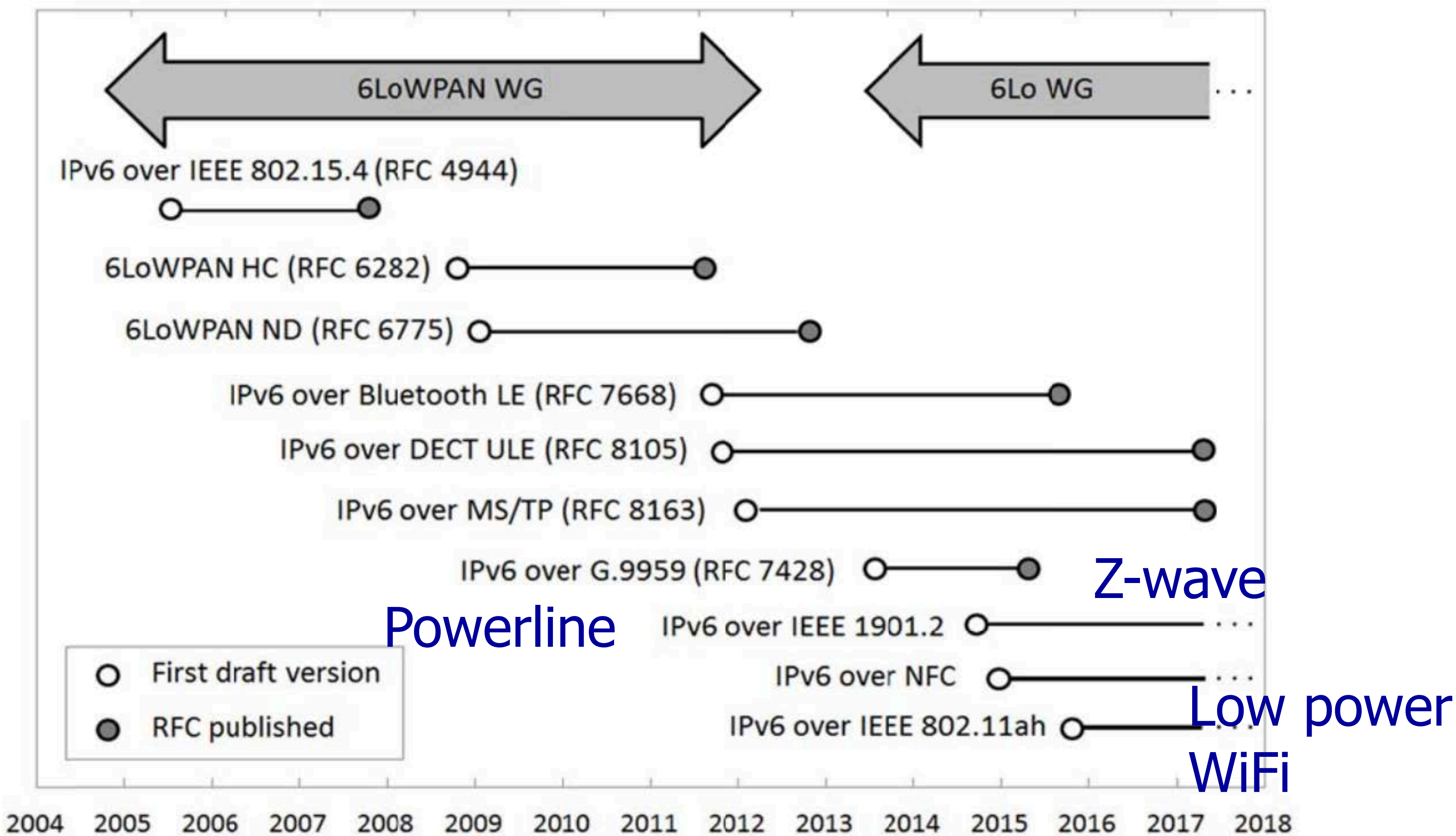
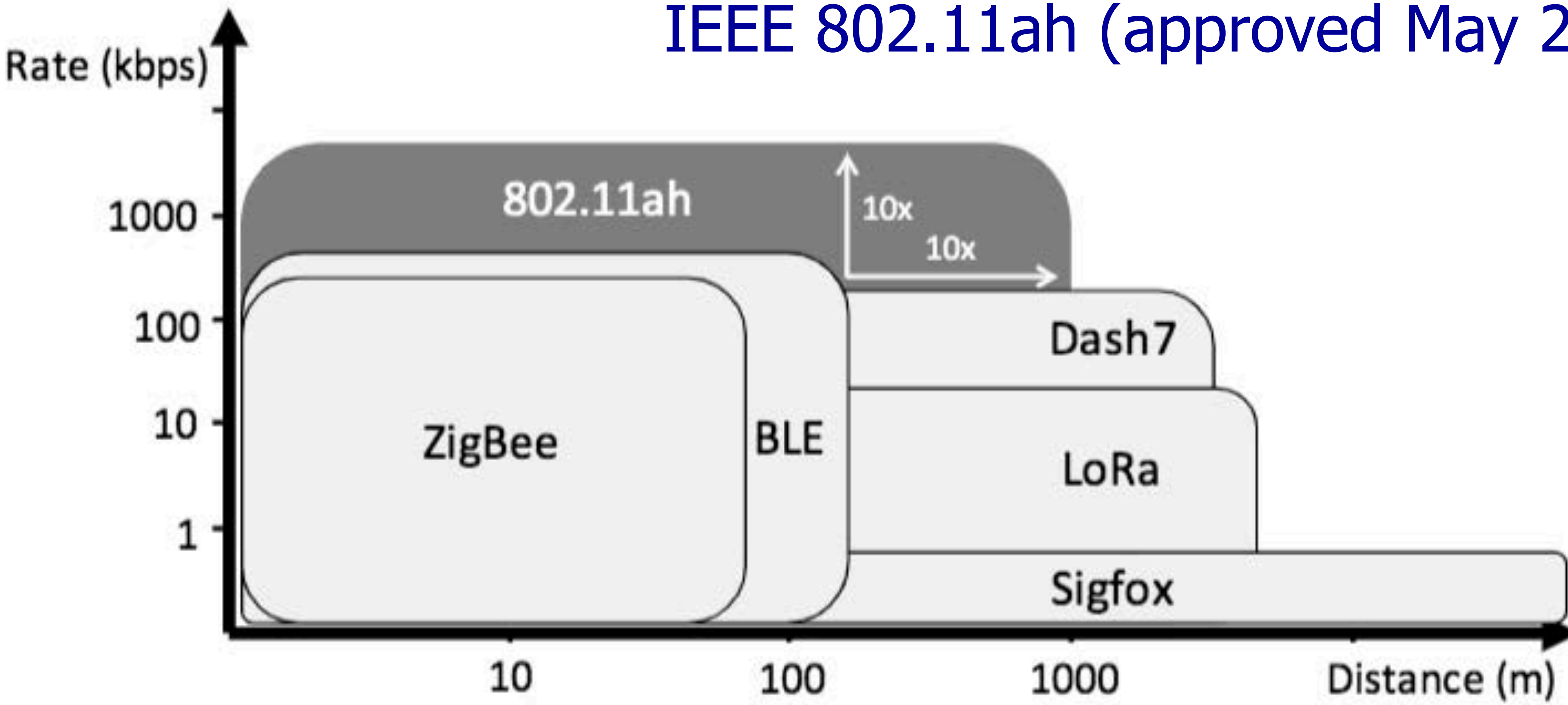
6LowPan evolution



Low Power WiFi

IEEE 802.11ah (approved May 2017)



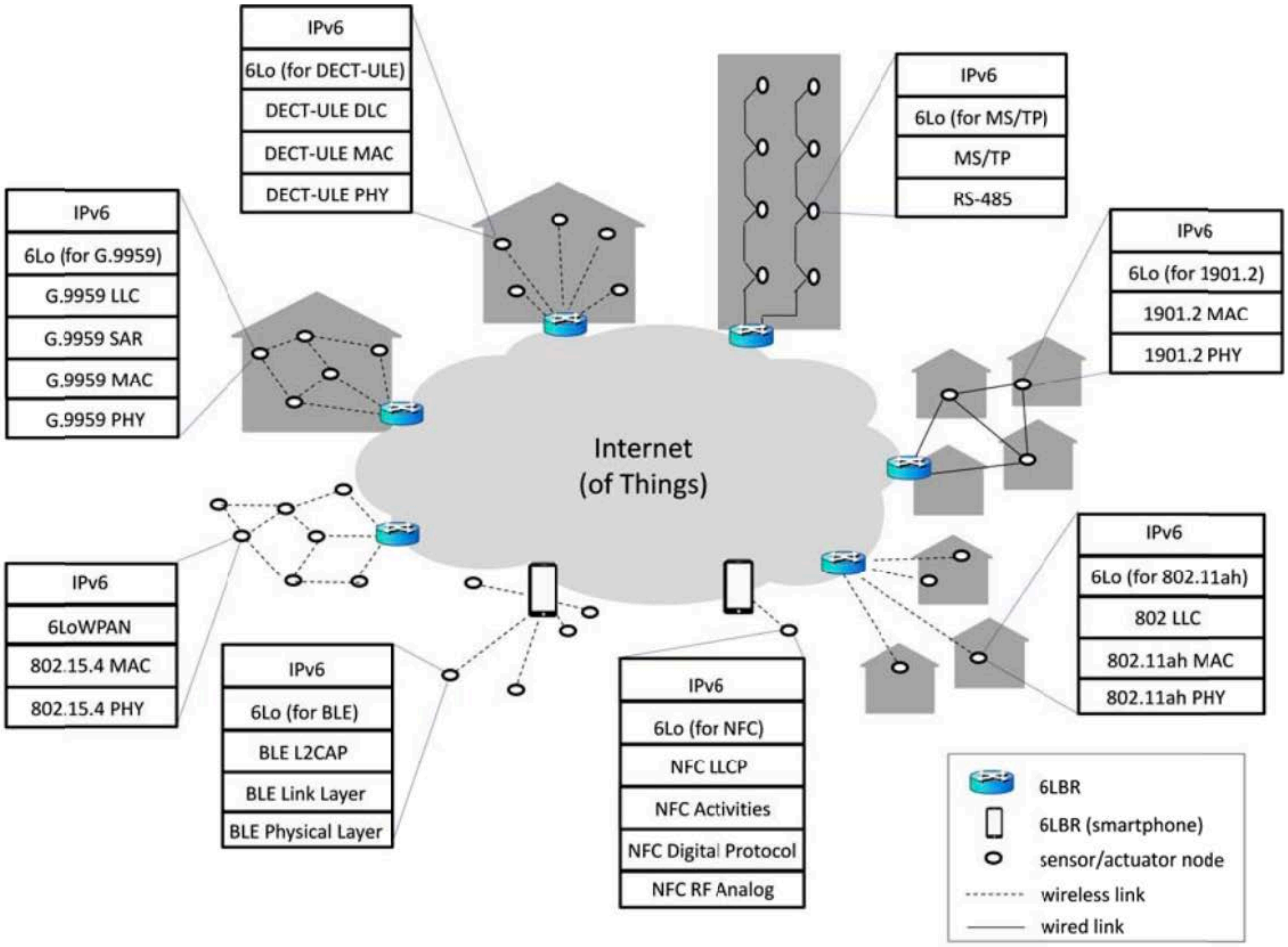
Lower frequency, 1Km range, 150Kbps
More aggressive power saving
At the same time there are very low power new modules
For shorter ranges for traditional WiFi on 2,4GHz

Bluetooth Low ENERGY

Bluetooth 4.0 Low Energy

- Faster device discovery (over a limited number of channels, not overlapping with WiFi)
- Overcomes the limits (existing in Bluetooth Basic) of the 7 slaves per piconet → a master can have associated even thousands of slaves
- Separates channels used for discovery/affiliation and for data transmission. Uses frequency hopping and polling as in the basic Bluetooth.
- Everything from physical design to use models is designed to keep power consumption at a minimum.
- To reduce power consumption, a BLE device is kept in sleep mode most of the time. Maximum/peak power consumption is less than 15 mA and the average power consumption is about 1 μA. The active power consumption is reduced to a tenth of the energy consumption of classic Bluetooth.

6LowPan evolution



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6LowPan evolution

		6LoWPAN	6Lo						
		IEEE 802.15.4	Bluetooth LE	ITU-T G.9959	DECT ULE	MS/TP	NFC	IEEE 1901.2	IEEE 802.11ah
Technology	Medium	Wireless	Wireless	Wireless	Wireless	Wired	Wireless	Wired	Wireless
	Frequency band (MHz)	868/915/2400	2400	868/915	1900	Base-band	13.56	< 0.5	< 1000
	Range (m)	10-100	10-100	100	< 300	1000	< 0.2	> 1000	< 1000
	Bit rate (kbit/s)	20/40/250	1000	9.6/40/100	1152	115.2	106/212/424	≤ 500	150-7800
	Max. single-frame L2 payload (bytes)	105	23	158	38	2032	125	215 (worst case)	7951
	ACKs and retries	Optional	Yes	Optional	Yes	No	ACK/NACK	ACK/NACK (optional)	Yes
	MAC mechanism	CSMA/CA, TDMA	TDMA	CSMA/CA	TDMA	Token passing	TDMA link initialization	CSMA/CA	CSMA/CA
	Address size (bits)	16/64	48	40	20/40/48	8	6	16/64	48
	L2 fragmentation	No	Yes	Yes	Yes	No	Yes	Yes	Yes
	Network topology	Star and mesh	Star	Mesh	Star	Multi-drop bus	Point-to-point	Star and mesh	Star
	Protocol stack	PHY/Link	PHY to App.	PHY/Link	PHY to App.	PHY/Link	PHY to App.	PHY/Link	PHY/Link
	Application	Generic purpose	Smartphone-centric	Home automation	Home automation	Building automation	Contactless exchange	Smart grid, home autom.	Sensors, backhaul
	Standardization organization	IEEE	Bluetooth SIG	ITU-T	ETSI	ANSI/ ASHRAE	NFC Forum	IEEE	IEEE
Adaptation Layer	Routing required	Yes	No	Yes	No	No	No	Yes	No
	Mesh under support	Yes	No	Yes	No	No	No	No	No
	Fragmentation	Yes	No	No	No	No	No	No	No
	6LoWPAN Header Compression	Yes	Yes (star topol.)	Yes (address adaptation)	Yes (star topology)	Yes (address adaptation)	Yes (address adaptation)	Yes	Yes (address adaptation)
	6LoWPAN Neighbor Discovery	Yes	Yes (no multihop)	Yes	Yes (no multihop)	Partially	With DHCPv6	DHCPv6 only	Yes (no multihop)
	Multicast	L2 broadcast	L2 unicast	L2 broadcast	L2 unicast	L2 broadcast	L2 broadcast	No	L2 multicast
	Privacy addresses	Not specified	Random IID	DHCPv6	Random IID	Random IID	Random IID	DCHPv6	Random IID
	L2 security used	Yes	Yes	Yes	Yes	No	No	Yes	Yes