Communications & Controls in IoT

Communication Techniques

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Main Reference

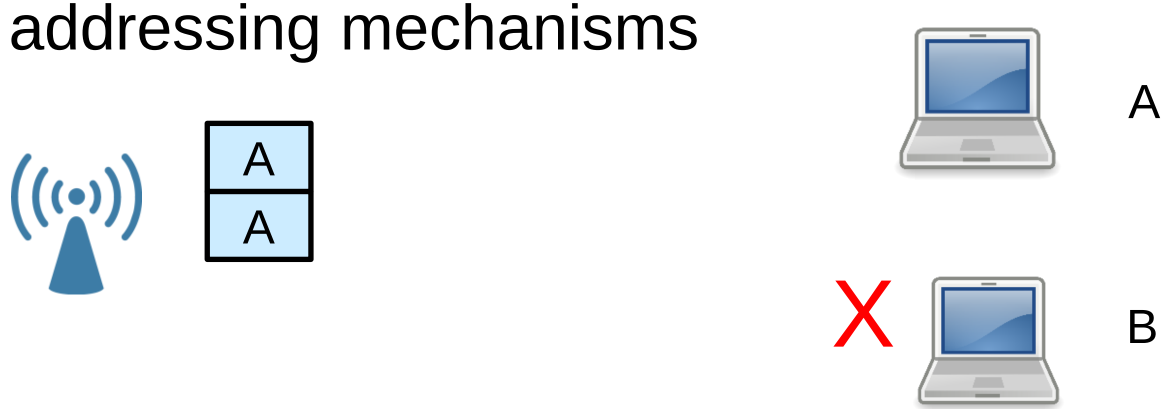
- [Kurose2012] J. Kurose and K. Ross, *Computer Networking*, Pearson, 2012.

Recap: *MAC protocols*

Medium Access Control (MAC)

- One of the two sublayers of data link layer
- Acts as an interface between the logical link control (LLC) and the network's physical layer
- Provides channel access control mechanisms across a shared physical medium

- Provides addressing mechanisms

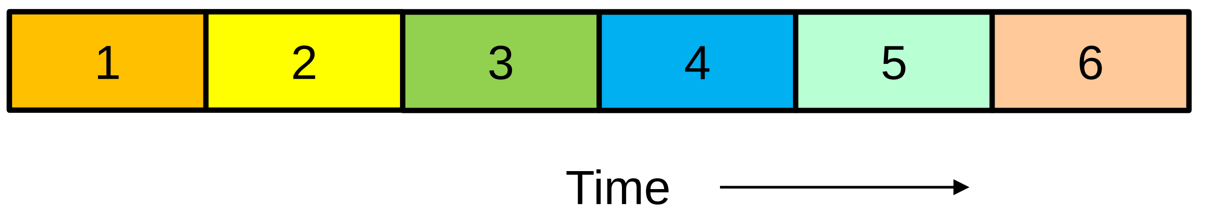


Types of MAC protocols

- Channel Partitioning Protocols (or Fixed Assignment Protocols)
  - TDMA, FDMA, CDMA, SDMA
- Random Access Protocols
  - Aloha, Slotted Aloha, CSMA/CA
- Taking Turn Protocols (or Demand Assignment Protocols)
  - Token Ring
  - Polling

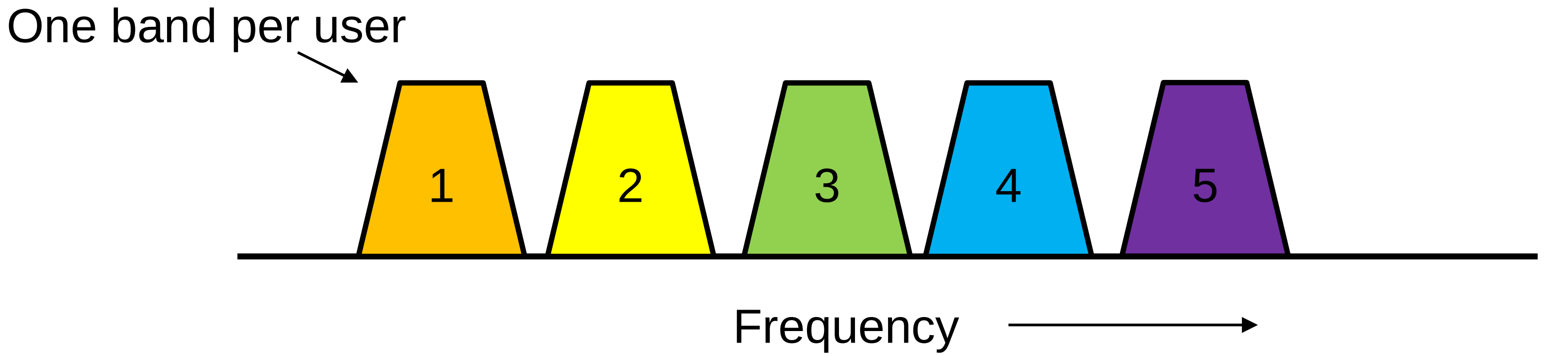
Time Division Multiple Access

- Time Division Multiple Access
  - TDMA is a digital technique that divides a single channel or band into time slots
  - Examples: T1 carrier systems (digital transmission of multiplexed telephone calls), 2G cellular system GSM



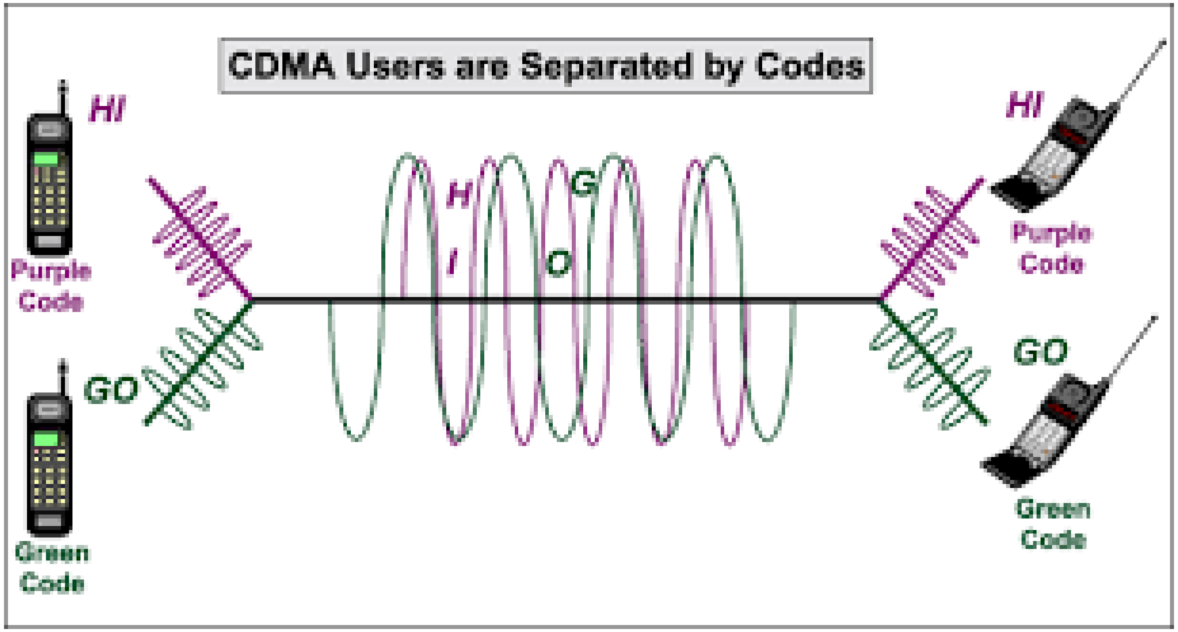
Frequency Division Multiple Access

- Frequency Division Multiple Access
  - FDMA divides the shared medium bandwidth into individual channels
  - Examples: Cable television system, FM stations



Code Division Multiple Access

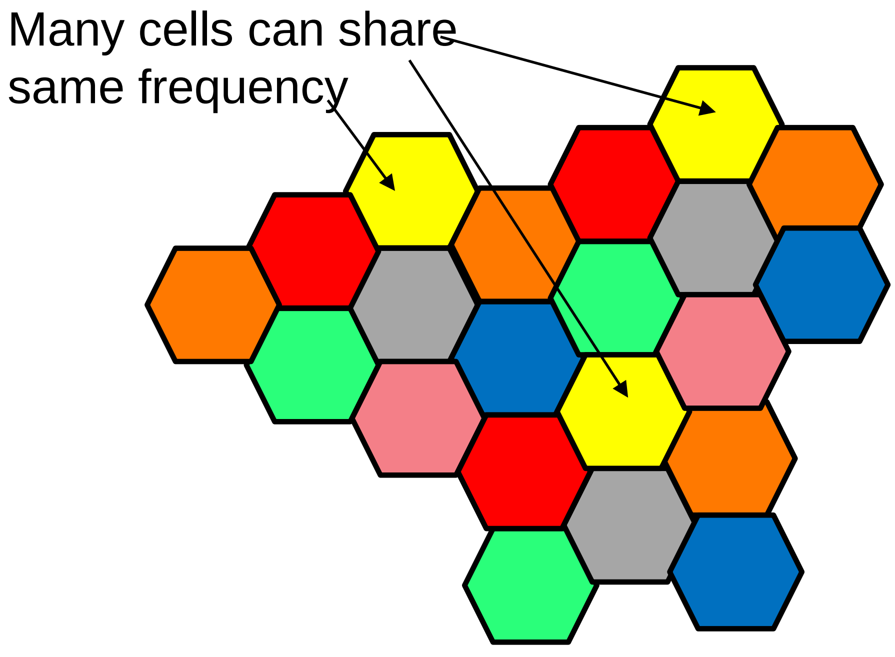
- Code Division Multiple Access
  - It is also known as spread spectrum because it takes the digitized version of an analog signal and spreads it out over a wider bandwidth at a lower power level.
  - Example: 2G IS-95, 3G (WCDMA)



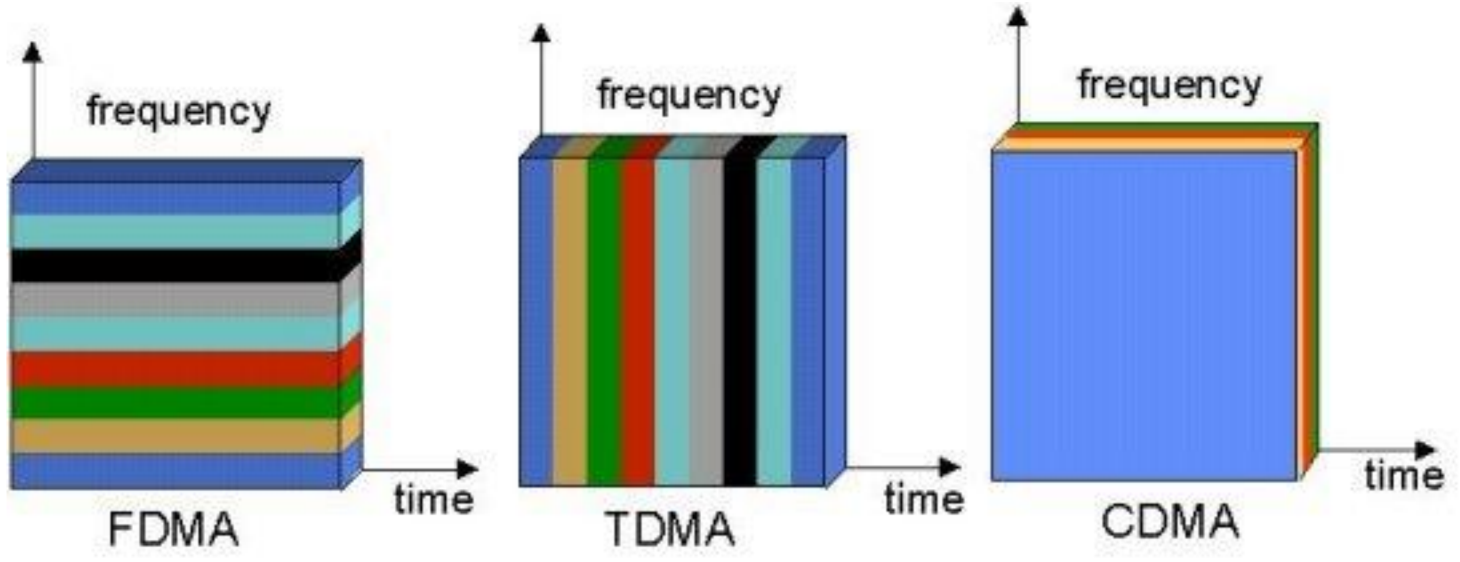
Source: http://www.electronicdesign.com/communications/fundamentals-communications-access-technologies-fdma-tdma-cdma-ofdma-and-sdma

Space Division Multiple Access

- Space Division Multiple Access
  - SDMA uses physical separation methods that permit the sharing of wireless channels. For instance, a single channel may be used simultaneously if the users are spaced far enough from one another to avoid interference. Known as frequency reuse, the method is widely used in cellular radio systems. Cell sites are spaced from one another to minimize interference.

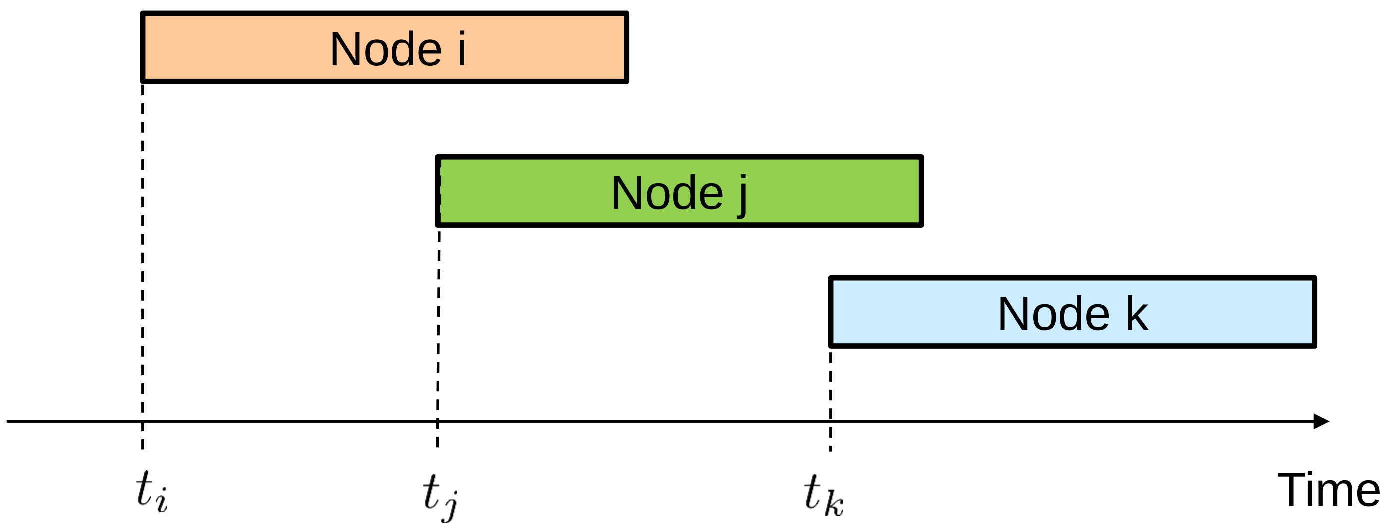


Difference between different TDMA/FDMA/CDMA



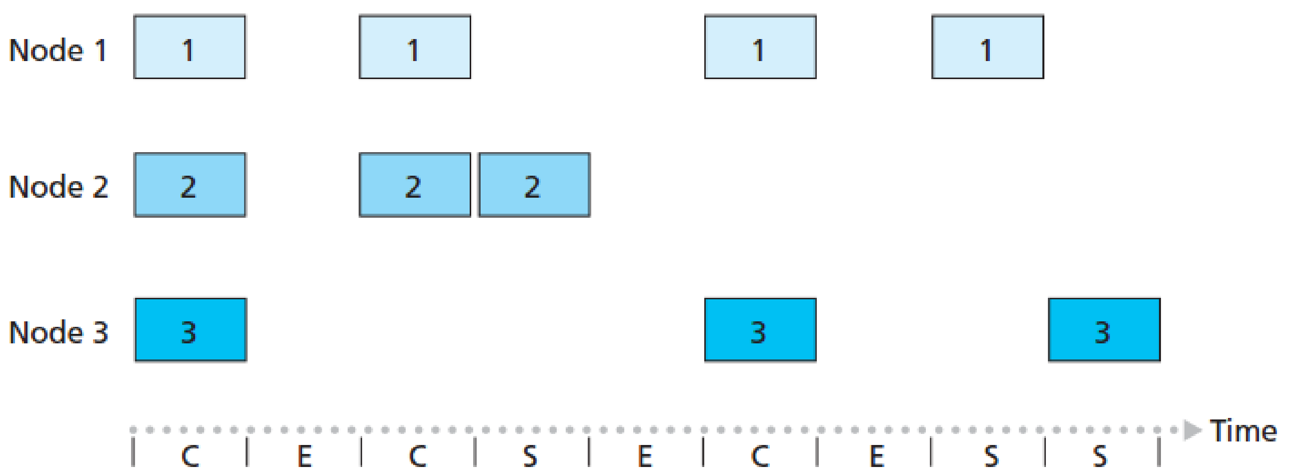
Aloha

- When you have data, send it
- If data doesn't go through, resend it after random delay
- Low efficiency: 18.5% for large *N*
- Suitable only for light loaded network



Slotted Aloha

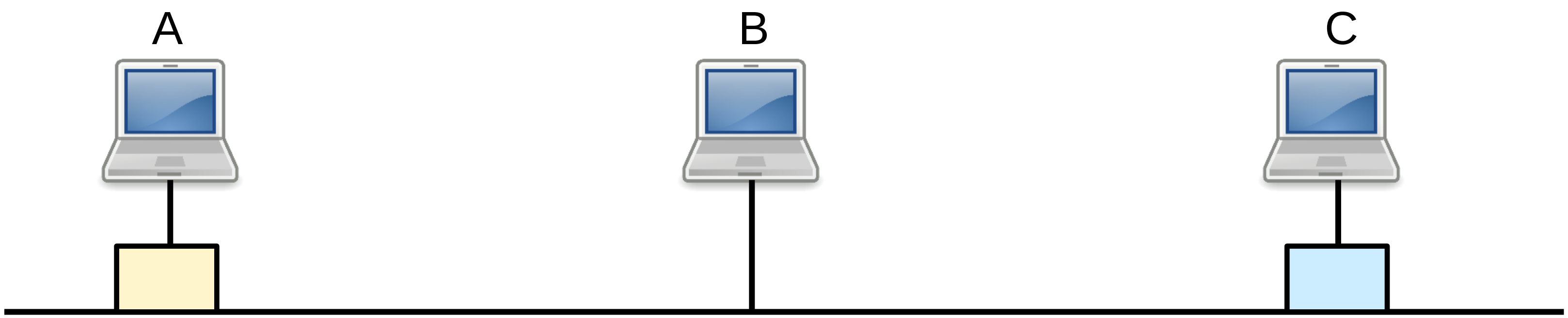
- Time is divided into equal time slots
- Sensor node can send data only at the beginning of a slot
- If have data to send, send at the start of slot. If collision, send in the next slot with probability *p* and do not transmit with probability *1-p*
- Requires time synchronization between nodes
- Efficiency: 37%; Better than Aloha but still low



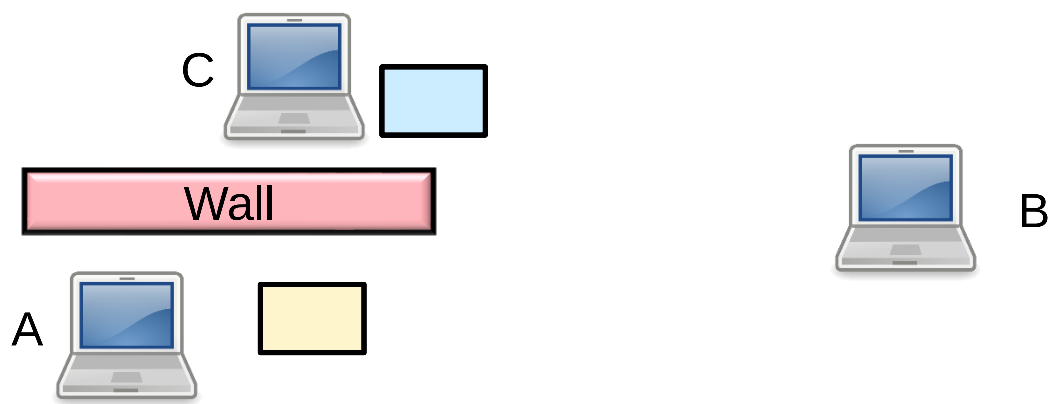
[Kurose2012]

Carrier Sense Multiple Access (CSMA)

- Listen before sending
- Send only if channel is idle
- Collisions can still happen (Hidden Node Problem)
- If collision, back-off for random delay and transmit again

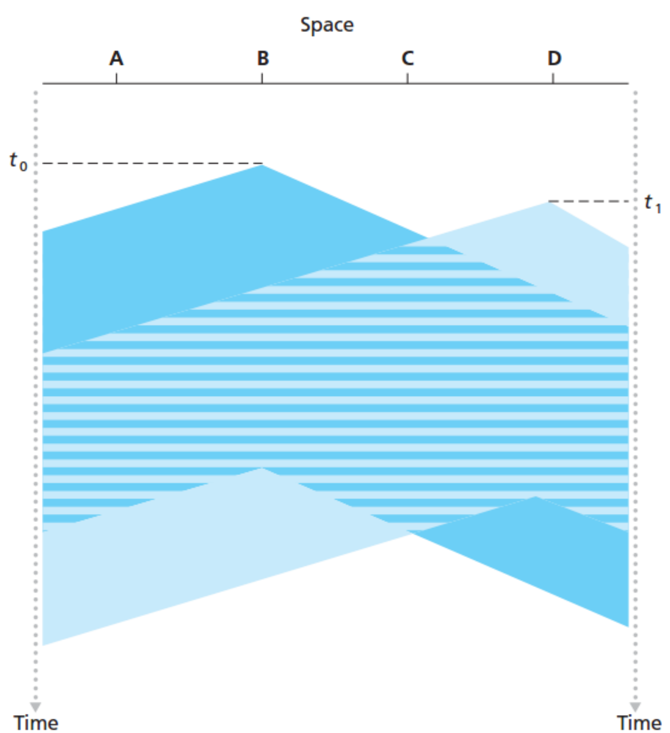


- Hidden Node Problem in Wireless Networks



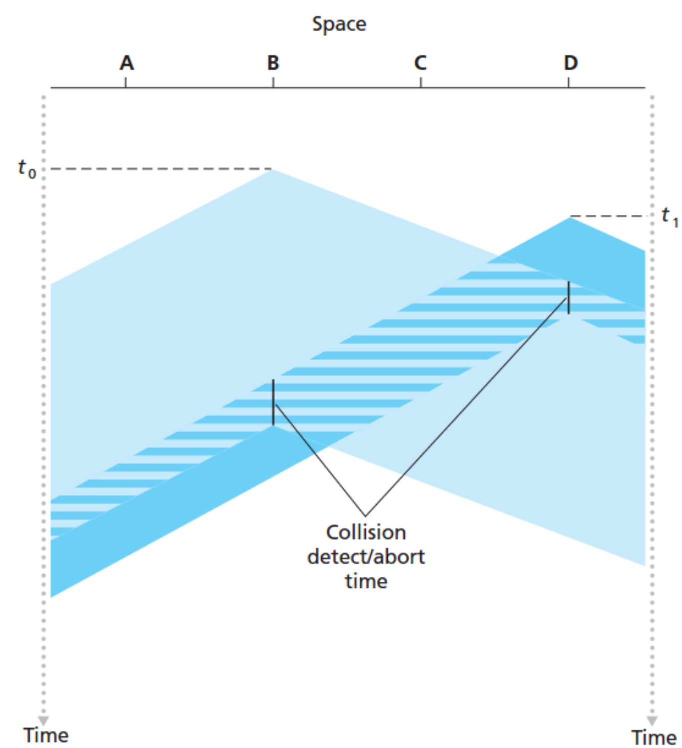
CSMA with collision detection (CD)

- Listen while transmitting!
- Stop transmitting as soon as collision is detected
- Wait for random duration before retry (binary exponential backoff)
- Improves CSMA performance at the cost of complexity
- Used in original Ethernet (wired LAN technology IEEE 802.3)



CSMA

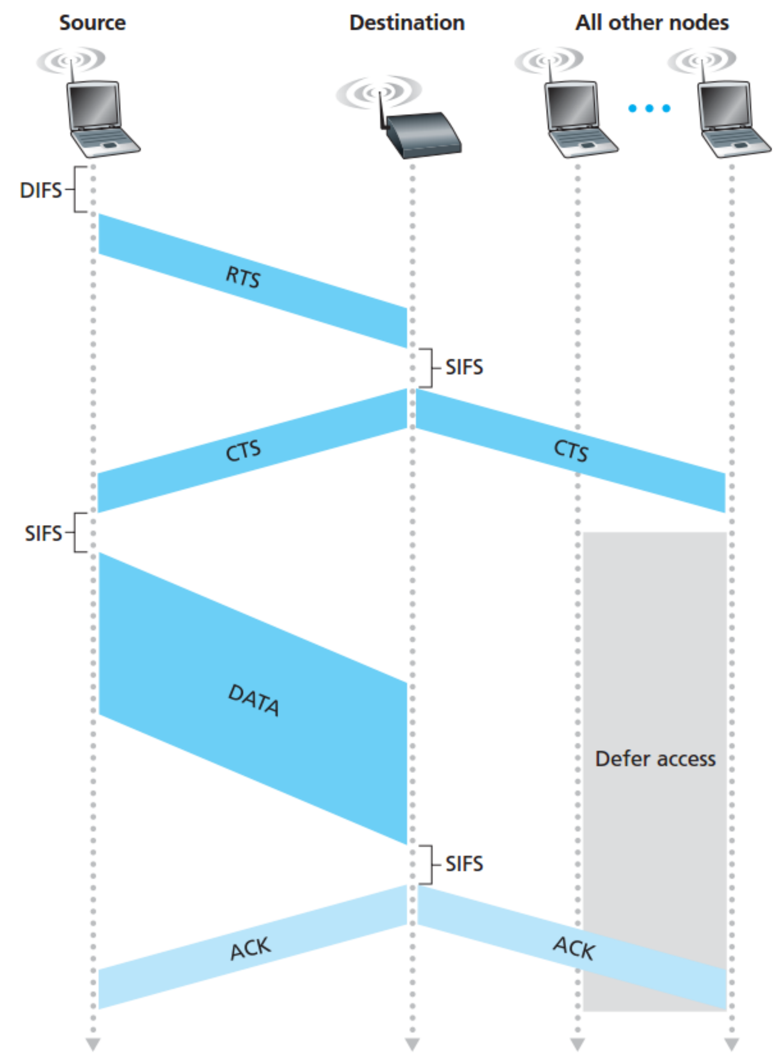
[Kurose2012]



CSMA/CD

CSMA with Collision Avoidance (CA)

- Use of ready to send (RTS) and clear to send (CTS)
  - In RTS/CTS access mode, prior to the data transmission the sending node will send a RTS packet to announce the upcoming transmission
  - When the destination node receives the RTS it will send a CTS packet after a short inter-frame space (SIFS) interval
  - Both the RTS and CTS packets are short control packets
- Used in most of the 802.11 (WLAN) technologies



[Kurose2012]

Today’s Class

Demand Assignment Protocols
(or Taking Turn Protocols)

Motivation

- Problem with channel partitioning
  - Inefficient at low load (idle subchannels)
- Problem with contention-based protocols
  - Inefficient at high loads (collisions)

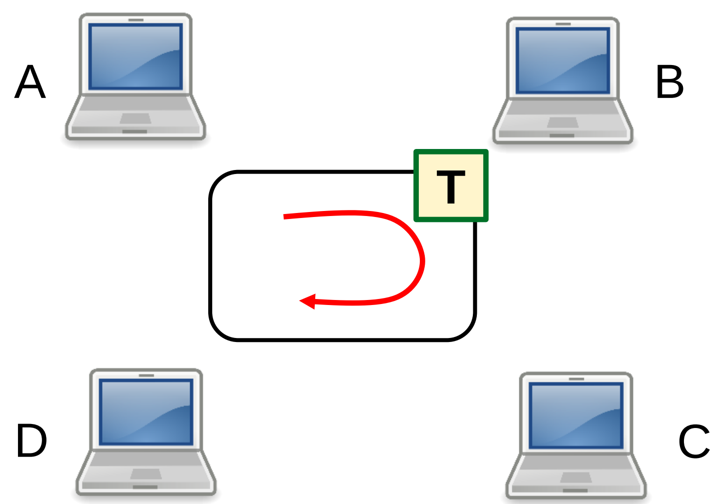
- Taking turn protocols
  - Can improve efficiency of channel partitioning and have no collisions
  - Can potentially also offer guaranteed bandwidth, latency, etc.

Polling Protocol

- One of the nodes becomes master node
- Master node polls each node in round-robin fashion
- Node polled can transmit up to maximum number of frames
- Eliminates the collisions that plague random access protocols and empty slots in channel partitioning protocols
- Issue of single point failure, delay in polling and instructing to send
- Example: used in Bluetooth and 802.15 protocols

Token Passing (or Token Ring)

- A token is circulating in the ring and whichever node grabs that token will have right to transmit the data.
- This protocol provides fairness and eliminates collision
- Advantages: Decentralized and highly efficient
- Disadvantages: Node failure and node not releasing token
- Used in networks prior to Ethernet



Few other things!

Simplex and Duplexing Communications

- Simplex communication system: one device transmits, other listens
  - TV, FM, Surveillance monitors, wireless microphones

- Duplex communication system: both devices can transmit and receive
  - Most of the communication systems including cellphone, laptops, tablets

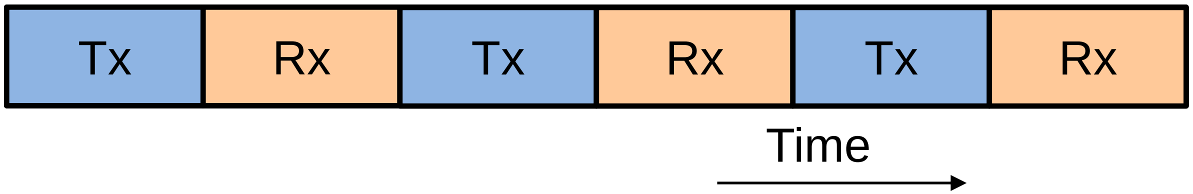
Types of Duplexing

- Half Duplex
  - Both parties cannot communicate simultaneously
  - Walkie-talkie (Push to talk button)

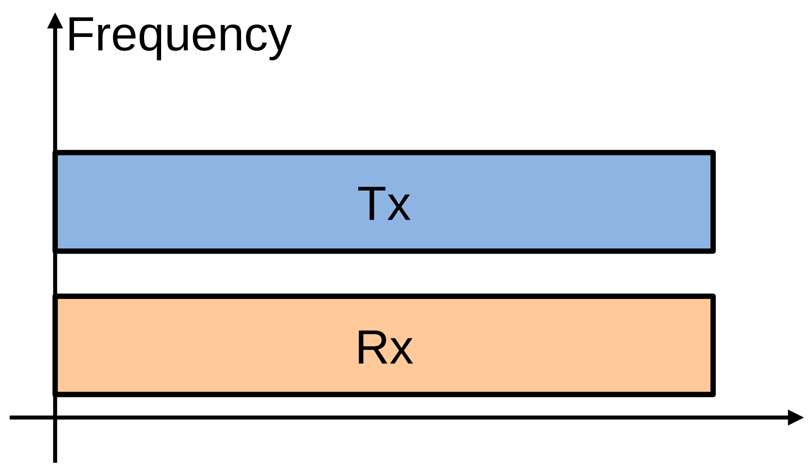
- Full Duplex
  - Both parties can talk simultaneously
  - Most of the communication devices

Duplexing Methods

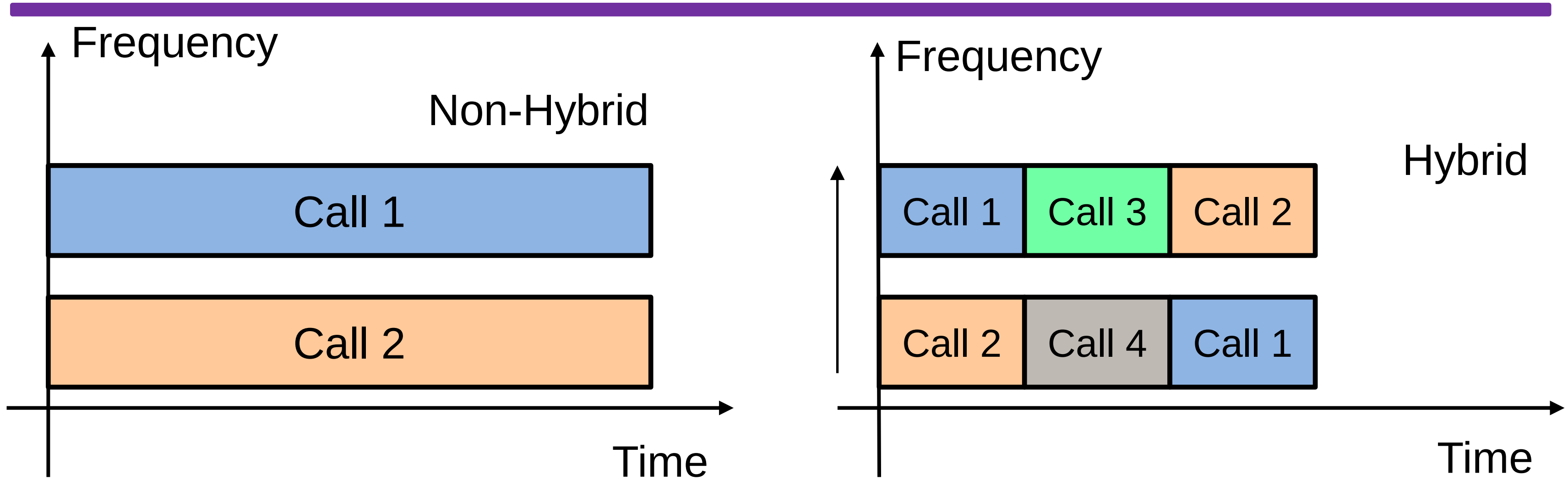
- Methods used for dividing forward and reverse communication channels, they are called as duplexing methods such as
  - Time division duplexing (TDD)
    - Half Duplex



  - Frequency division duplexing (FDD)
    - Full Duplex

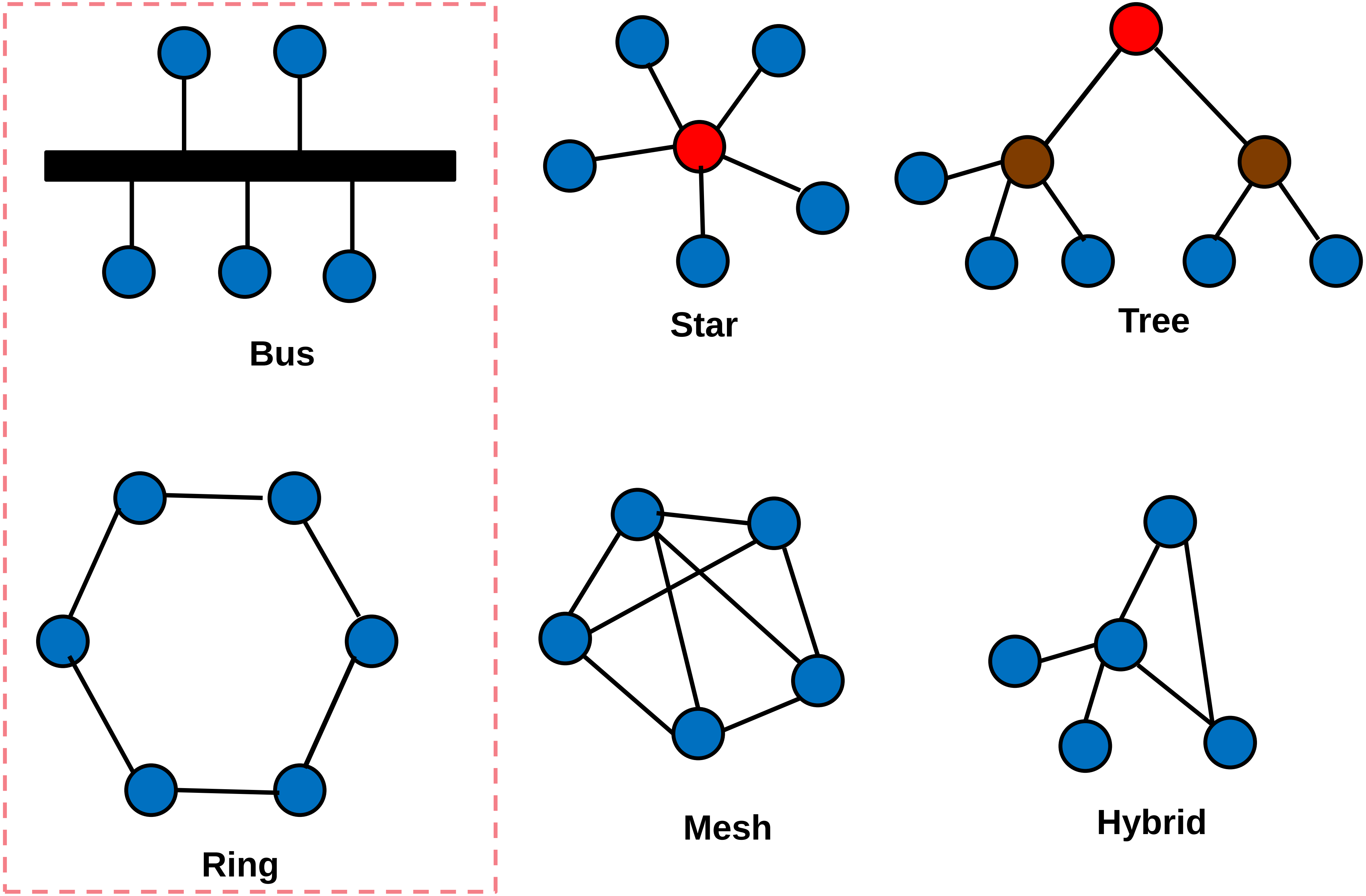


Hybrid Channel Access



- The GSM cellular system combines the use of FDD to prevent interference between outward and return signals with FDMA and TDMA to allow multiple handsets in a single cell.
- Bluetooth packet mode communication combines frequency hopping for shared channel access among several private area networks in the same room with CSMA/CA for shared channel access inside a medium
- IEEE 802.11b WLAN are based on FDMA and DS-CDMA for avoiding interference among adjacent WLAN cells or access points

Network Topologies



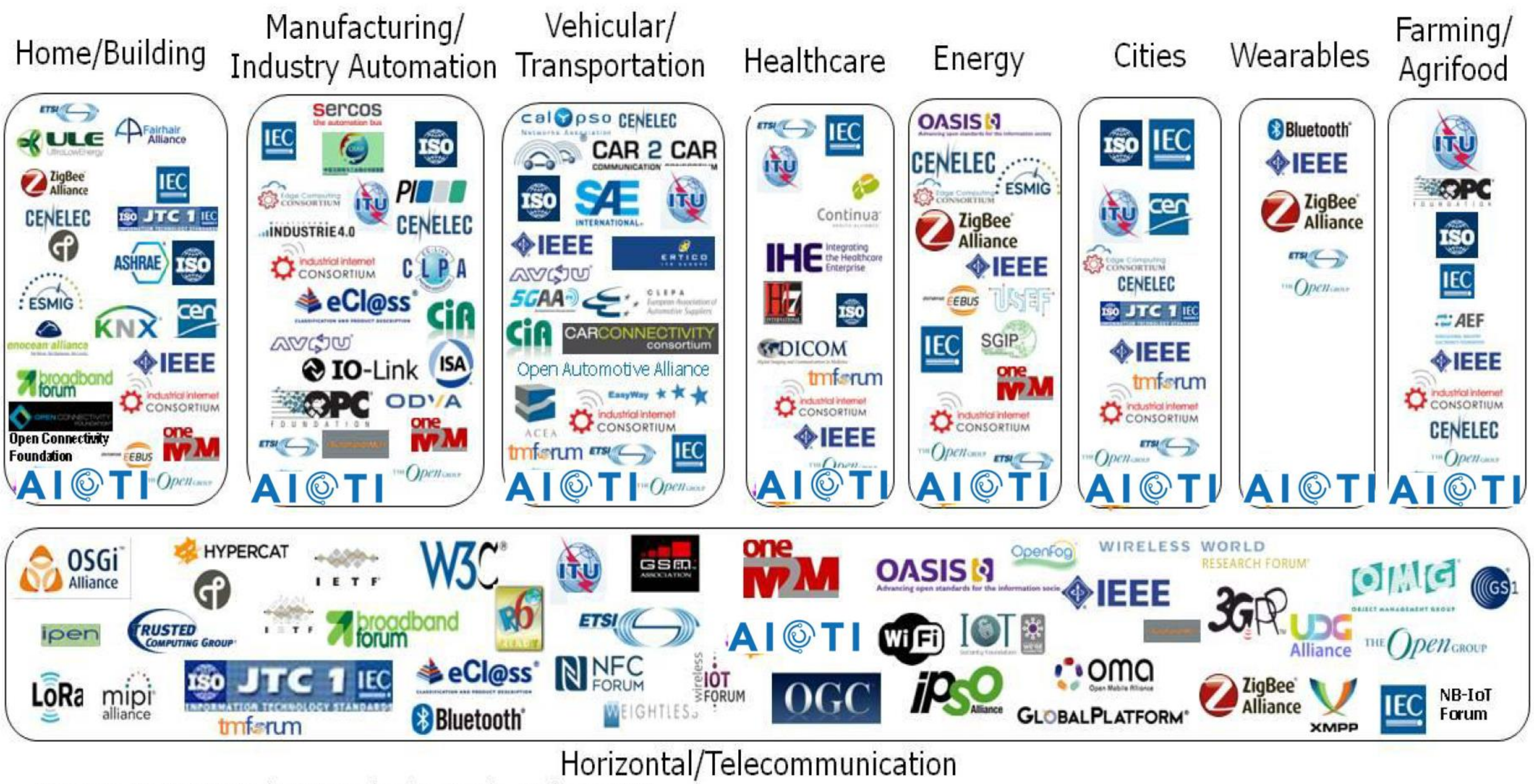
Issues in IoT from Communication Perspective

[Not an exhaustive list!]

- Low power consumption
- Support large number of devices with low data rates
- Coverage
- Quality of service
- Low cost
  - Network/Private (DIY)
  - Licensed/Unlicensed
- Privacy and security
- Standardization for interoperability between different vendors

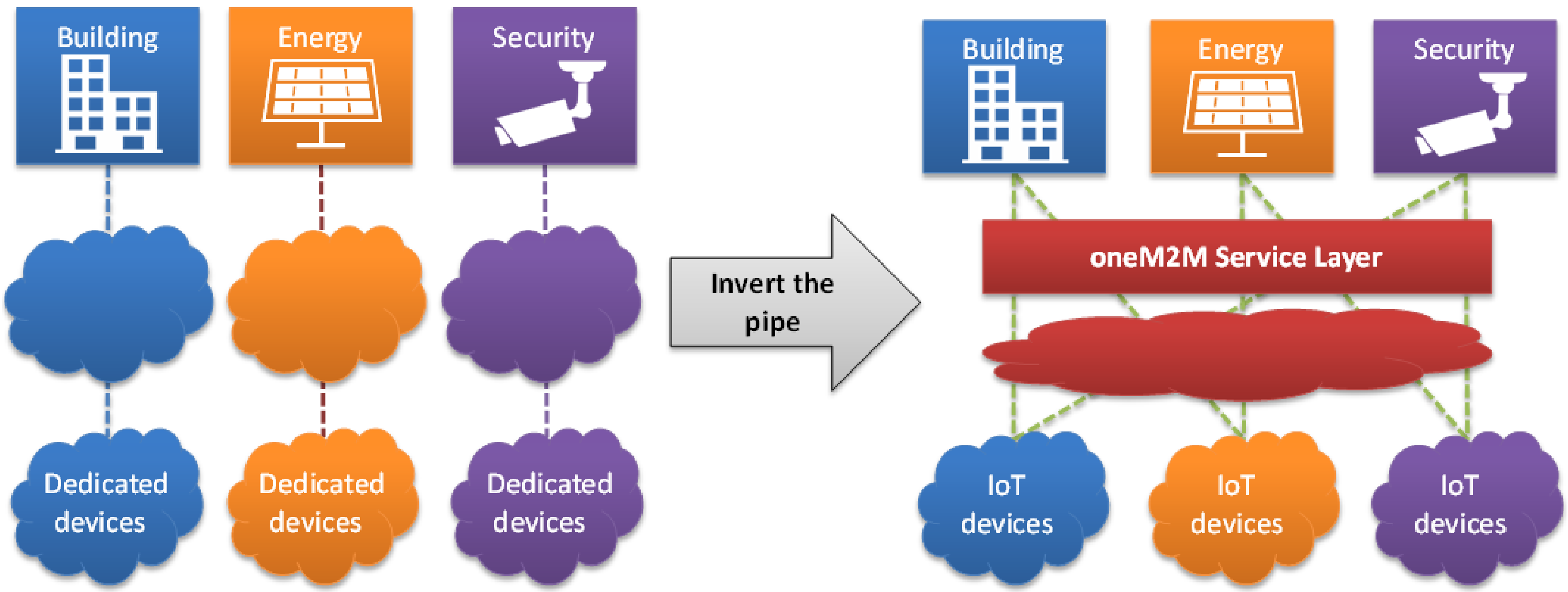
Motivation for Interoperability

- Jungle of IoT standards



Source: AIOTI WG3 (IoT Standardisation) – Release 2.8

oneM2M: interoperability standard



Without oneM2M

- Highly fragmented market with limited vendor-specific applications
- Reinventing the wheel: Same services developed again and again
- Each silo contains its own technologies without interoperability

With oneM2M

- End-to-end platform: common service capabilities layer
- Interoperability at the level of data and control exchanges via uniform APIs
- Seamless interaction between heterogeneous applications and devices

https://www.onem2m.org/getting-started/onem2m-overview/introduction/service-layer

Factors contributing to energy waste/expense

- Energy consumption in transmission
  - Longer distances
  - Higher frequencies
  - More bandwidth

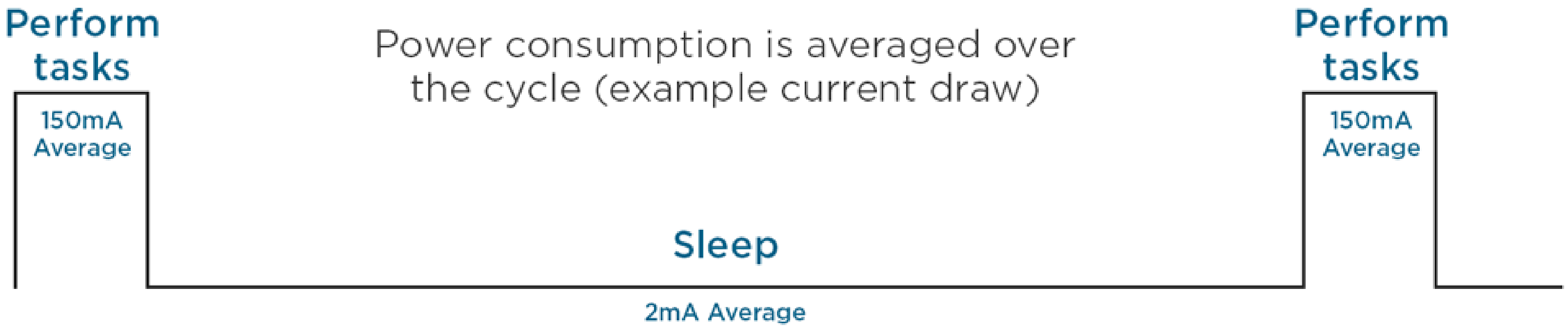
- Energy waste
  - Excessive overhead
  - Idle listening
  - Overhearing
  - Packet collisions and retransmissions

[Not exhaustive!]

Ways to Reduce Energy Waste/Consumption

- Reduced frequency/data rate/ bandwidth/ coverage
- Sleep
  - Low duty cycle
- Energy saving protocols
  - Schedule based (reduction in over-hearing and idle-listening)
    - Licensed spectrum; BLE
  - Contention based (less overhead and no need of synchronization)
    - Zigbee, WiFi
- Multihop and aggregation of data
- Signal processing
  - censoring, predictive filters
- Reduced overhead

Low Duty Cycle



https://core-electronics.com.au/media/wysiwyg/tutorials/sam/example-duty-cycle.png

Duty cycle in our paper 0.66% duty cycle (0.2 of 30ms).
Even with 99% reduction in data-transmissions, the life-time increased only by 3 times

A. Shastri, V. Jain, R. Singh, **S. Chaudhari**, S. Chouhan, S. Werner, "Improving the Accuracy of the Shewhart Test-based Data-Reduction Technique using Piggybacking," *in IEEE WF-IoT*, Ireland, Apr. 2019

Questions?

Ungraded Quiz

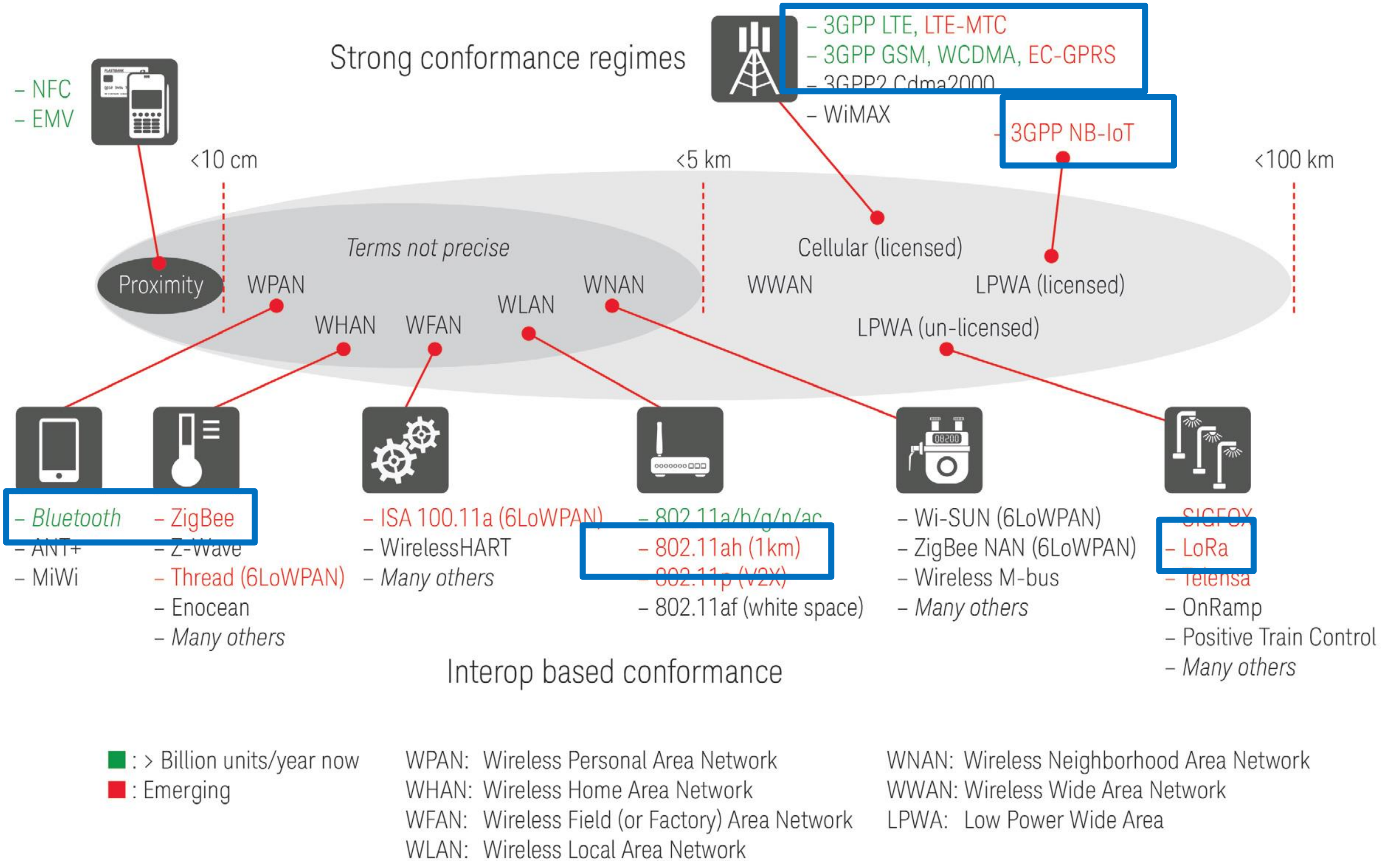
- TV is a duplex system
  - True
  - False

- Lack of interoperability means
  - Vendor Lockin
  - Costly to built different verticals
  - Difficult to exchange data between different verticals
  - All of the above

- In which network topology, loops are allowed
  - Star
  - Cluster Tree
  - Mesh
  - None of the above

Communication Techniques for IoT

Communication Techniques for IoT

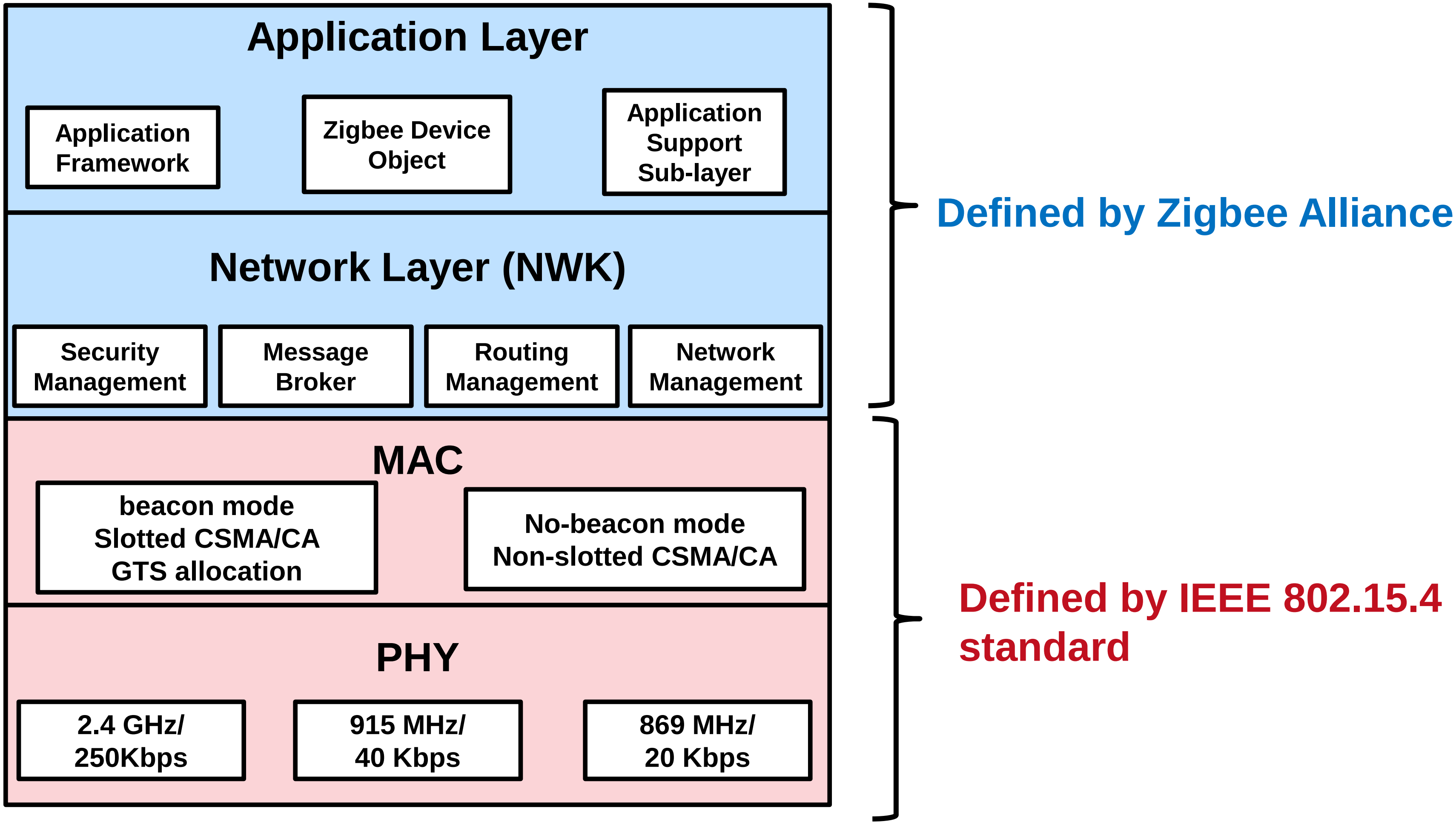


http://2yh5c119vtjz3yoo8229y5bs-wpengine.netdna-ssl.com/wp-content/uploads/2016/04/IoT-technologies-grouped-by-operating-range.jpg

IEEE 802.15.4

Ref: K. Sohraby, D. Minoli, T. Znati, *Wireless Sensor Networks,* Wiley, 2007

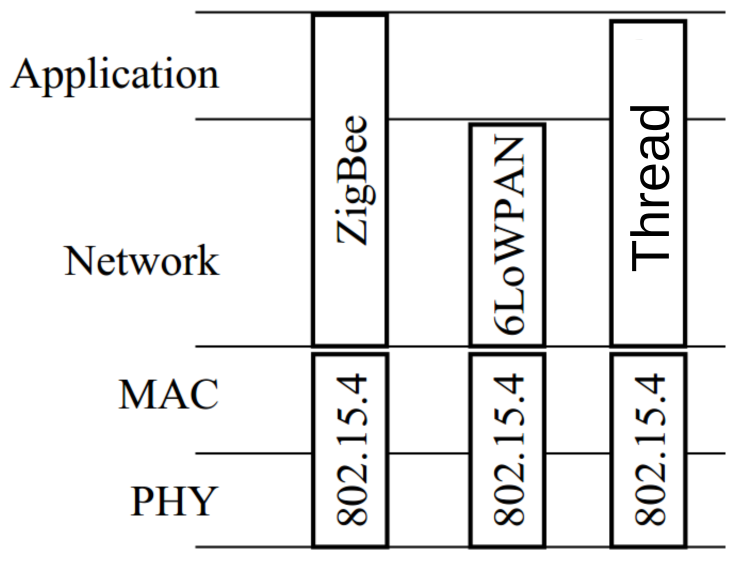
IEEE 802.15.4/Zigbee Protocol Stack



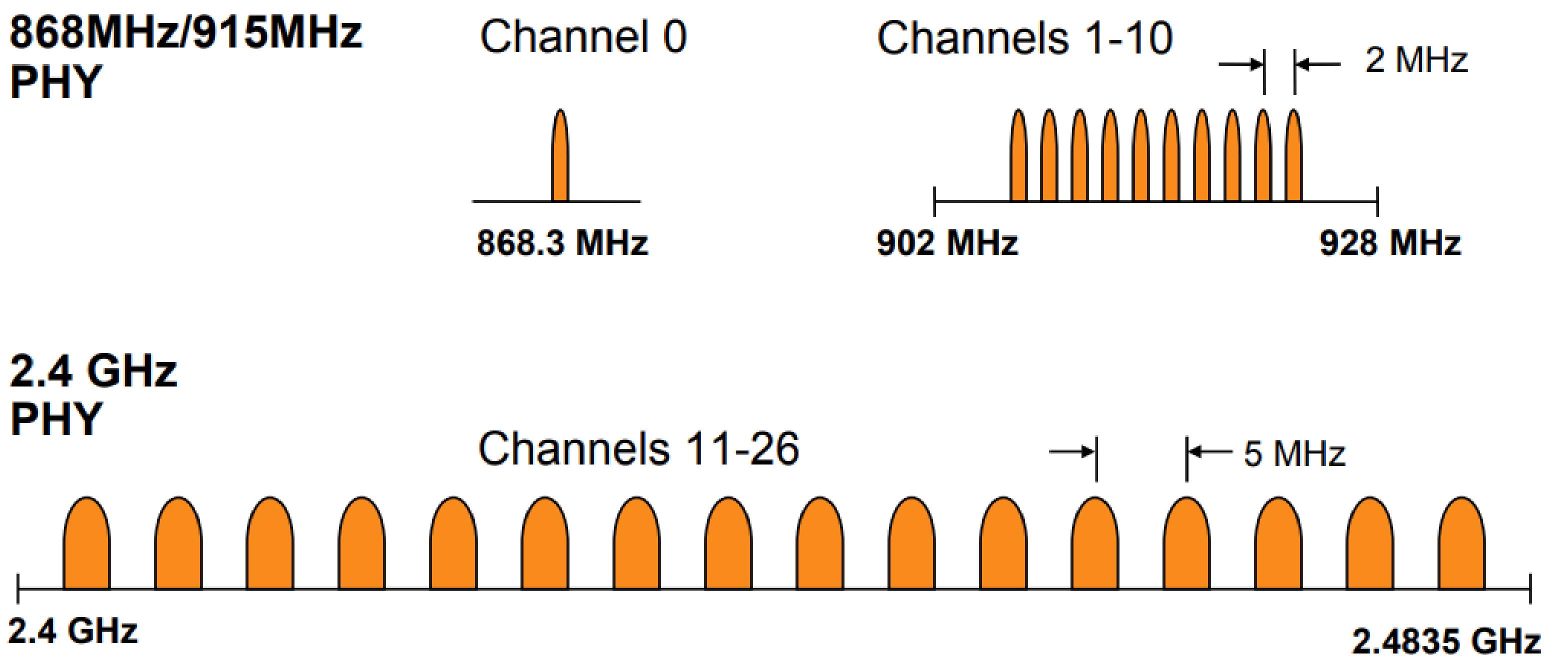
- Full protocol stack for low power, low rate and low cost wireless communications. Also applicable to Low rate WPAN – LR-WPAN.

IEEE 802.15.4

- IEEE 802.15.4 defines the operation of low-rate wireless personal area networks (LR-WPANs)
- Widely used in wireless sensor-network (WSN) applications
  - Vast number of industrial, home and medical applications
- It specifies the physical layer (PHY) and media access control (MAC) for LR-WPANs
- Does not have IP address
- Used by several “Internet of Things” protocols:
  - ZigBee, 6LowPAN, Thread, WiSuN etc.



Physical Layer (PHY): *Operating Frequency Bands*



https://people.eecs.berkeley.edu/~prabal/teaching/cs294-11-f05/slides/day21.pdf

PHY: *Frequency Bands Worldwide*

	Channel	Center Frequency (MHz)	Availability
868 MHz Band	0	868.3	 ***Europe***
915 MHz Band	1	906	 ***Americas***
	2	908	
	3	910	
	4	912	
	5	914	
	6	916	
	7	918	
	8	920	
	9	922	
	10	924	
2.4 GHz Band	11	2405	 ***World Wide***
	12	2410	
	13	2415	
	14	2420	
	15	2425	
	16	2430	
	17	2435	
	18	2440	
	19	2445	
	20	2450	
	21	2455	
	22	2460	
	23	2465	
	24	2470	
	25	2475	
	26	2480	

https://people.eecs.berkeley.edu/~prabal/teaching/cs294-11-f05/slides/day21.pdf

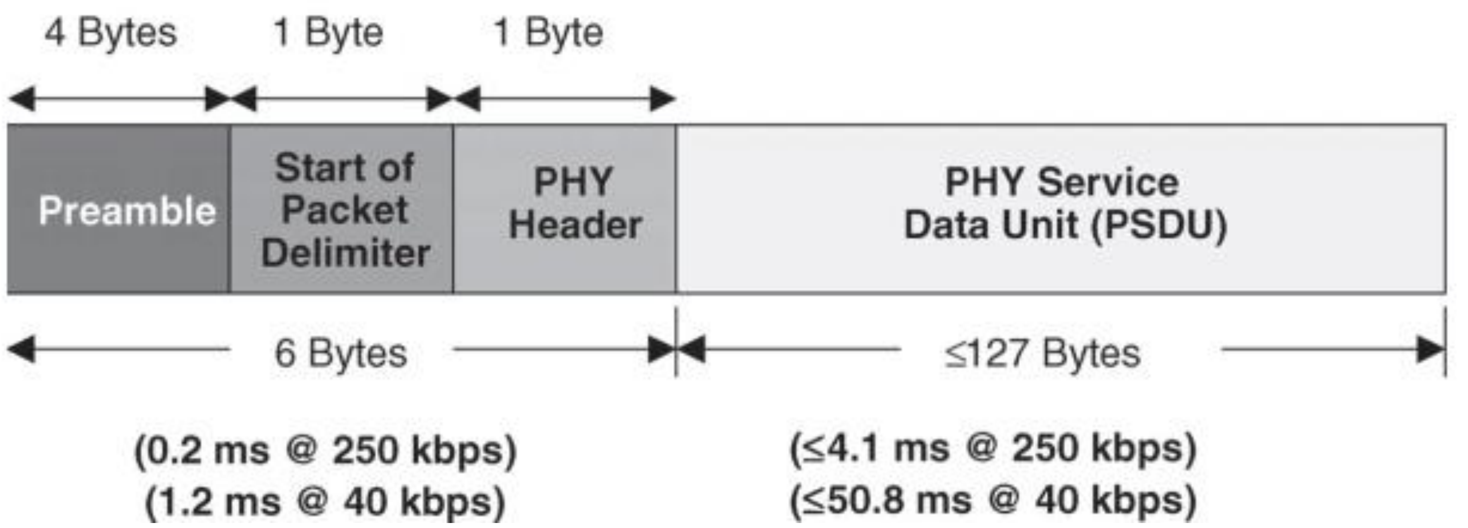
PHY: *Modulation Parameters*

Freq. band (MHz)	Spreading Parameters		Data Parameters		
	Chip rate (kchip/s)	Modulation	Bit rate (kbps)	Symbol rate (ksymbol/s)	Symbols
868	300	BPSK	20	20	Binary
915	600	BPSK	40	40	Binary
2400	2000	O-QPSK	250	62.5	16-ary

[Koubaa2007]

All bands are based on Direct sequence spread spectrum (DSSS), a form of CDMA

PHY-layer packet structure



- Preamble -> Symbol synchronization
- Packet delimiter -> Frame synchronization
- PHY header: length of the PSDU
- PSDU can carry upto 127 bytes

Additional Tasks of PHY of IEEE 802.15.4

- **Activation and deactivation of the radio transreceiver**
  - Three states: Transmitting, receiving and sleeping
- **Receiver energy detection**
  - No decoding or signal identification
  - Required to understand if the channel is busy or idle
- **Link quality indication**
  - Using energy or SNR estimation or both
- **Clear channel assessment**
  - Energy detection or carrier sense or both
- **Channel frequency selection**
  - 27 channels

Questions?