Communication Technologies for IoT

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Outline

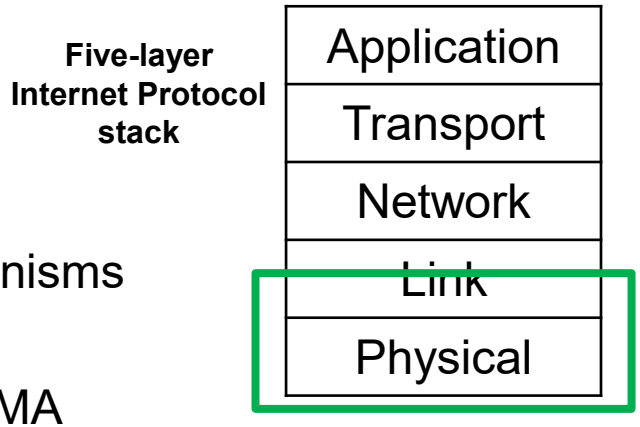
- Introduction
  - Basic issues
  - Scope of presentation
  - Basics of Communications (MAC)
- Different wireless technologies for IoT
  - LoRaWAN
  - Cellular Technologies: LTE-M and NB-IoT
  - IEEE 802.11ah (WiFi)
  - IEEE 802.15.4
  - BLE
- Summary

Scope of the Presentation

IoT PROTOCOLS

- The various protocols that are emerging:
  - **Infrastructure** (ex: 6LowPAN, IPv4/IPv6, RPL)
  - **Identification** (ex: EPC, uCode, IPv6, URIs)
  - **Comms / Transport** (ex: Wifi, Bluetooth, LPWAN)
  - **Discovery** (ex: Physical Web, mDNS, DNS-SD)
  - **Data Protocols** (ex: MQTT, CoAP, AMQP, Websocket, Node)
  - **Device Management** (ex: TR-069, OMA-DM)
  - **Semantic** (ex: JSON-LD, Web Thing Model)
  - **Multi-layer Frameworks** (ex: Alljoyn, IoTivity, Weave, Homekit)

Scope of the Presentation



- Medium access control (MAC)
  - Provides channel access control mechanisms across a shared physical medium
  - Example: Aloha, CSMA/CA, TDMA, CDMA
  - Provides addressing mechanisms

- Physical Layer (PHY)
  - Defines the means of transmitting raw bits rather than logical data packets over a physical link/medium connecting two nodes on the same network
  - Signal processing of bits and physical signals: Modulation, Coding, Bit Interleaving, Synchronization, Carrier sensing and collision detection, etc.
  - Example: WLAN 802.11, LR-WPANs 802.15.4, Ethernet 802.3, Bluetooth 802.15.1

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

Link Layer: *Various multiple access channels*

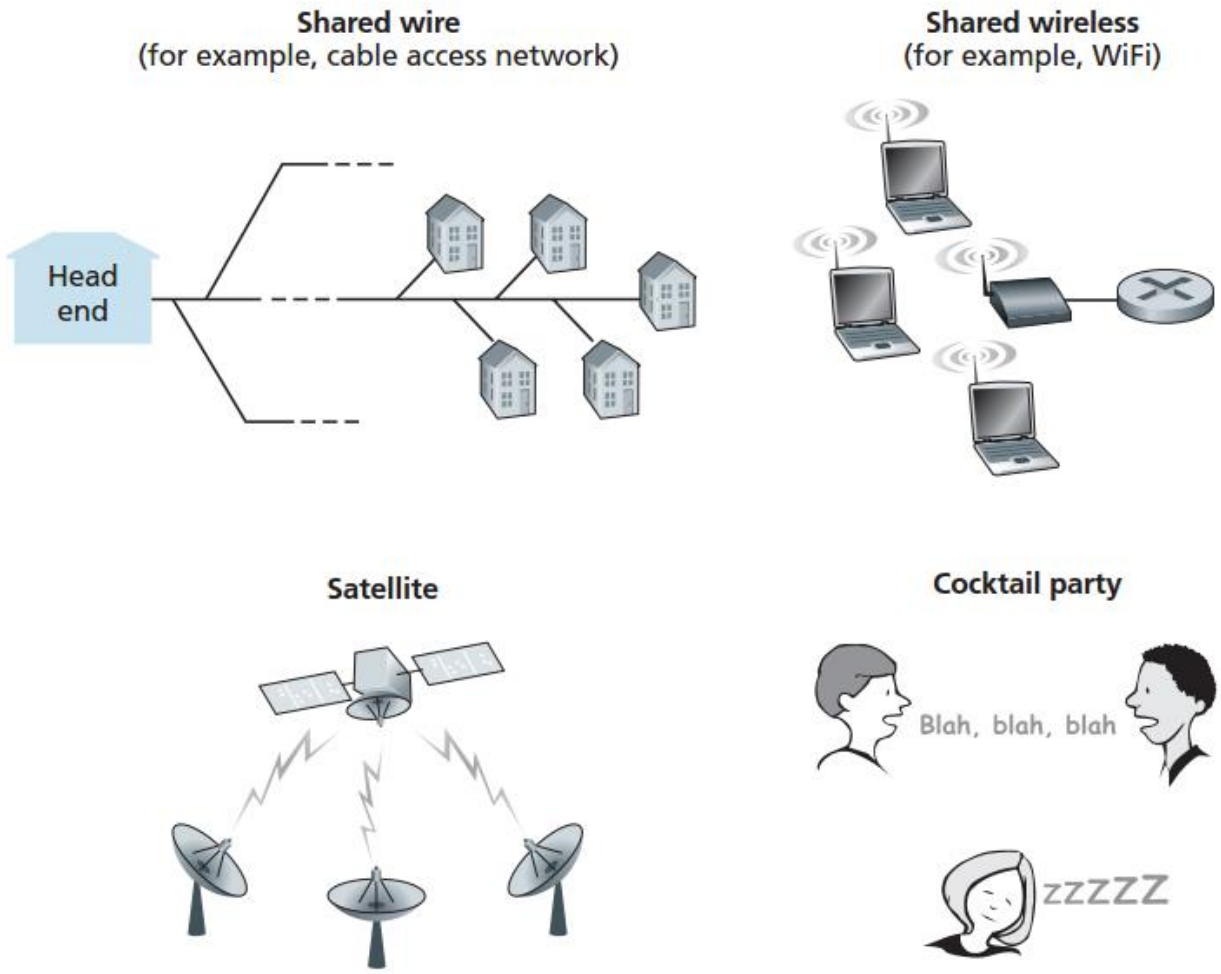


Figure 5.8 ♦ Various multiple access channels

Another Analogy: Roads

https://www.freepik.com/vectors/travel

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

Conversation Etiquettes

- Give everyone a chance to speak
- Don’t monopolize the conversation
- Don’t speak until you are spoken to
- Don’t interrupt when someone is speaking
- Don’t fall asleep when someone is speaking
  - What happens if you sleep while speaking?

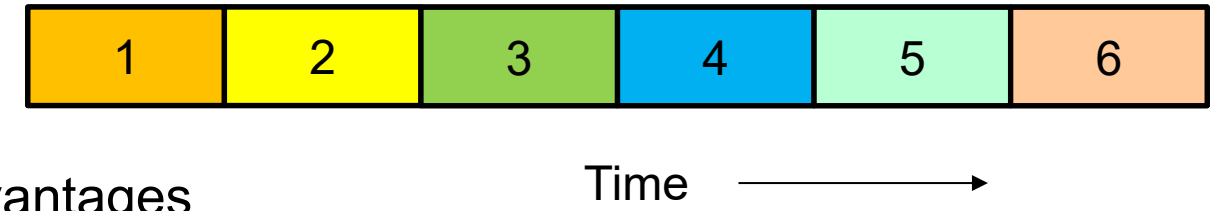
Desirable Properties of MAC protocols

- A MAC protocol for a broadcast channel of rate *R* bps should have the following desirable properties
  - When only one node has to send data, that node has a throughput of *R* bps
  - When *N* nodes have to send data, each of the nodes should have an average rate of *R/N* bps
  - The protocol is decentralized so that there is no master node with a single point of failure
  - The protocol is simple so that it is inexpensive to implement

Channel Partitioning Protocols

Time Division Multiple Access

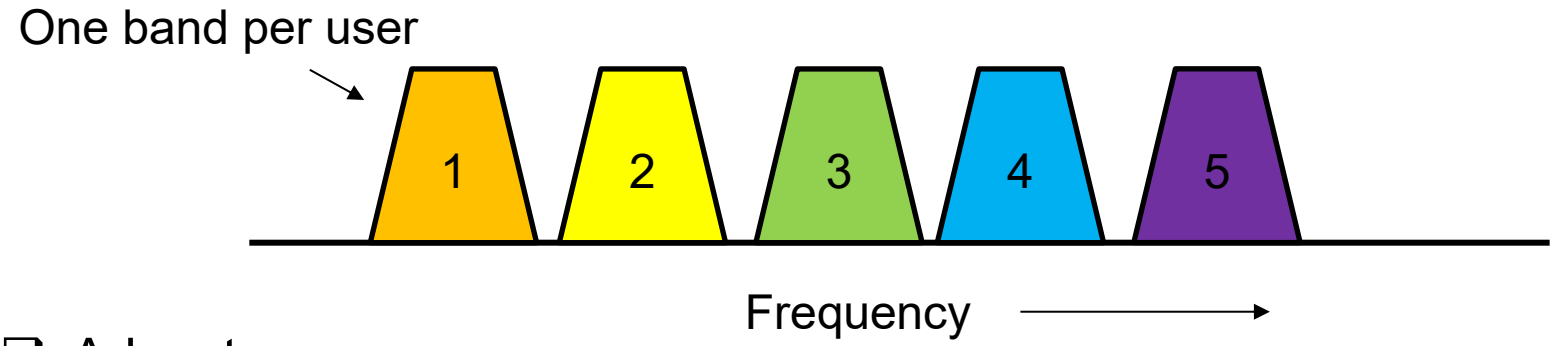
- Time Division Multiple Access
  - TDMA is a digital technique that divides a single channel or band into time slots
  - Examples: T1 carrier systems (digital transmission of multiplexed telephone calls), 2G cellular system GSM



- Advantages
  - No Collision
  - Fair usage
- Disadvantages
  - Wastage of resources
  - Delay
  - Need Synchronization

Frequency Division Multiple Access (FDMA)

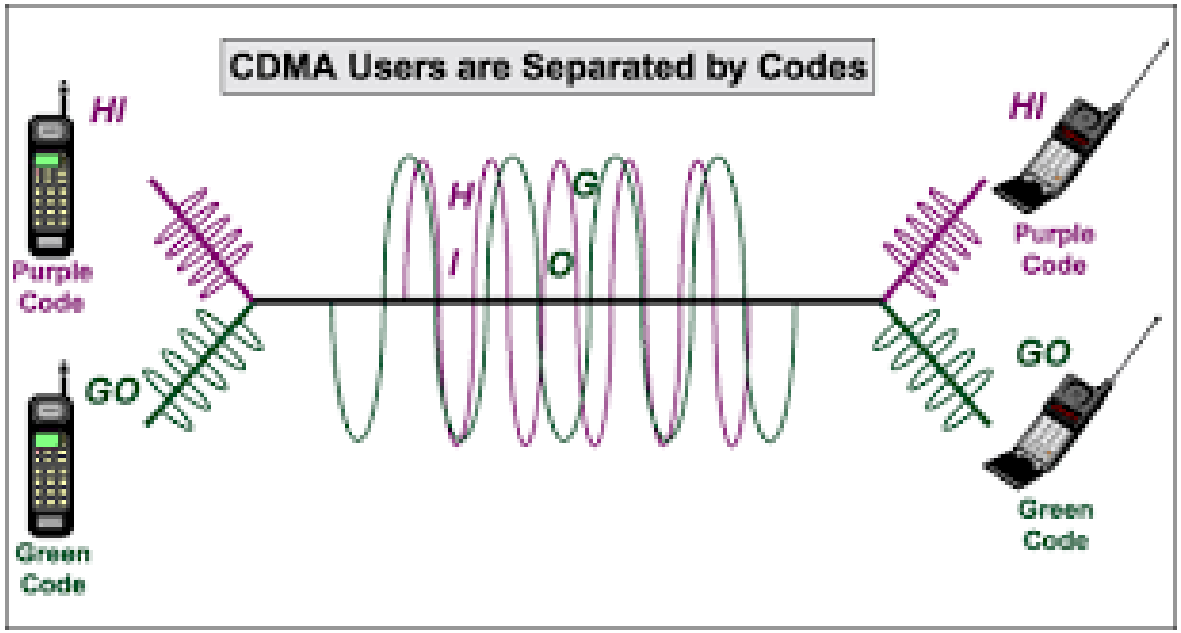
- FDMA divides the shared medium bandwidth into individual channels
- Examples: Cable television system, FM stations



- Advantages
  - No Collision
  - Fair usage
- Disadvantages
  - Wastage of resources
  - Need synchronization

Code Division Multiple Access (CDMA)

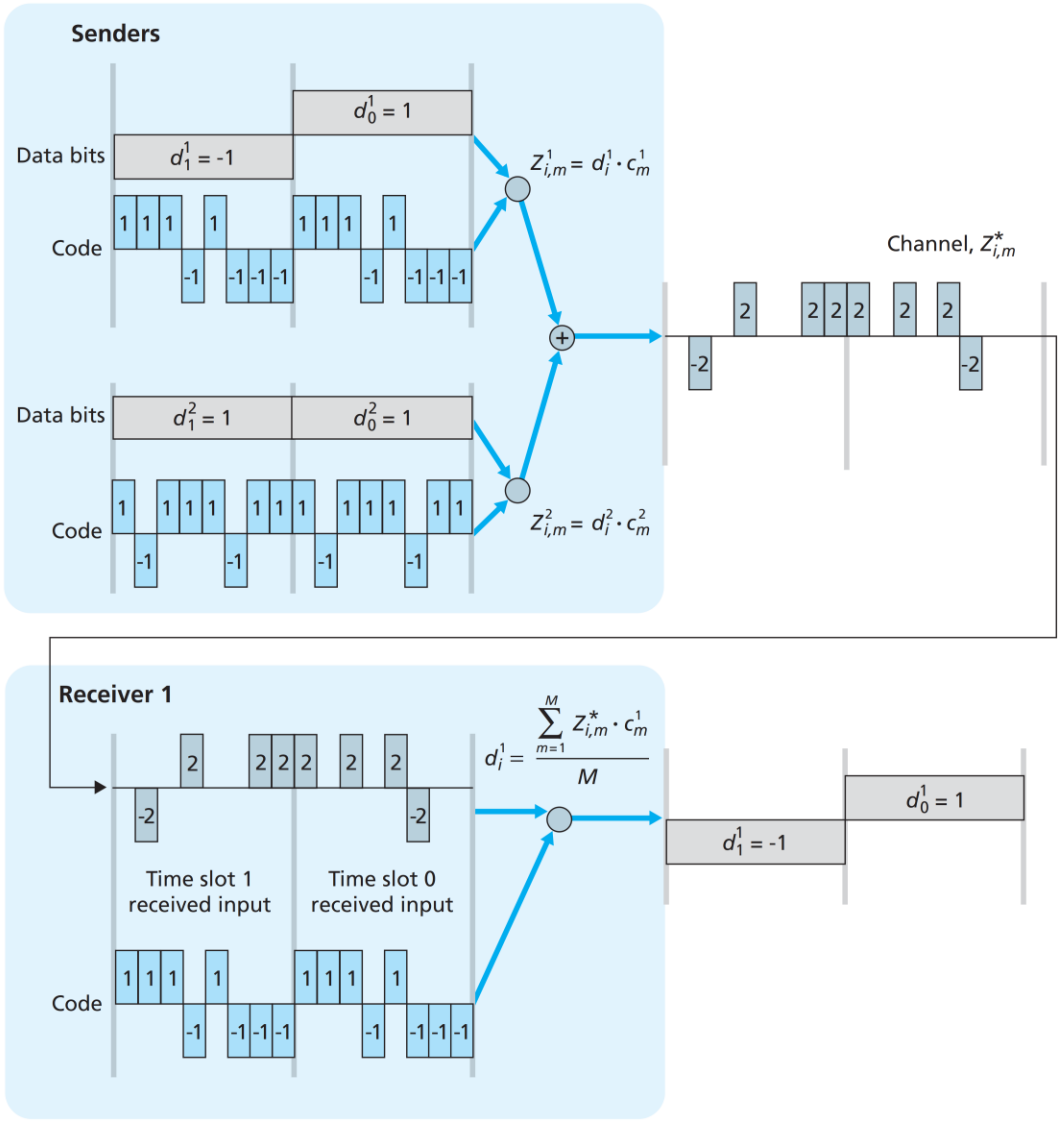
- It is also known as spread spectrum because it takes the digitized version of an analog signal and spreads it out over a wider bandwidth at a lower power level.
- Example: 2G IS-95, 3G (WCDMA)



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

CDMA

- Use of higher rate PN sequences
- Low auto and cross correlation

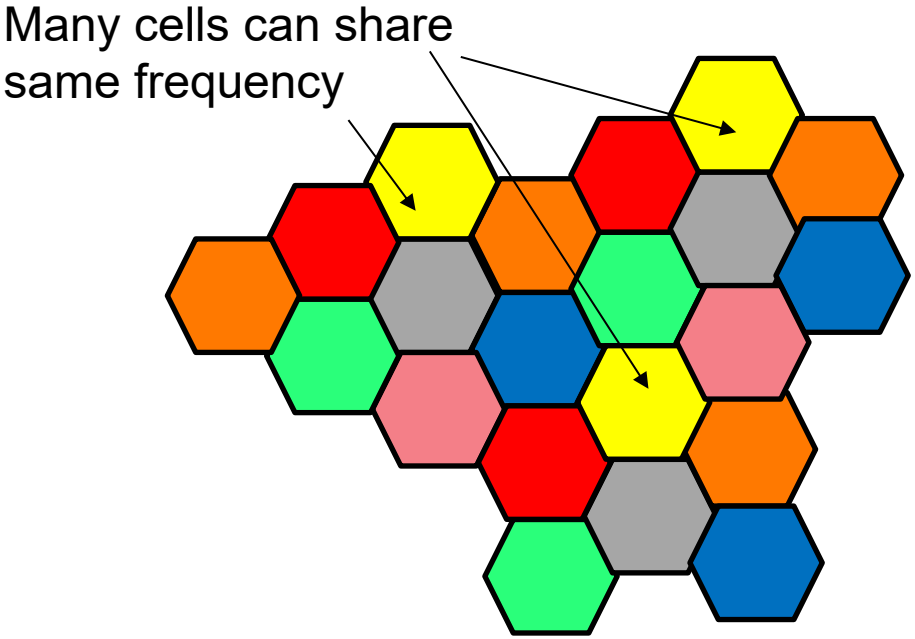


CDMA

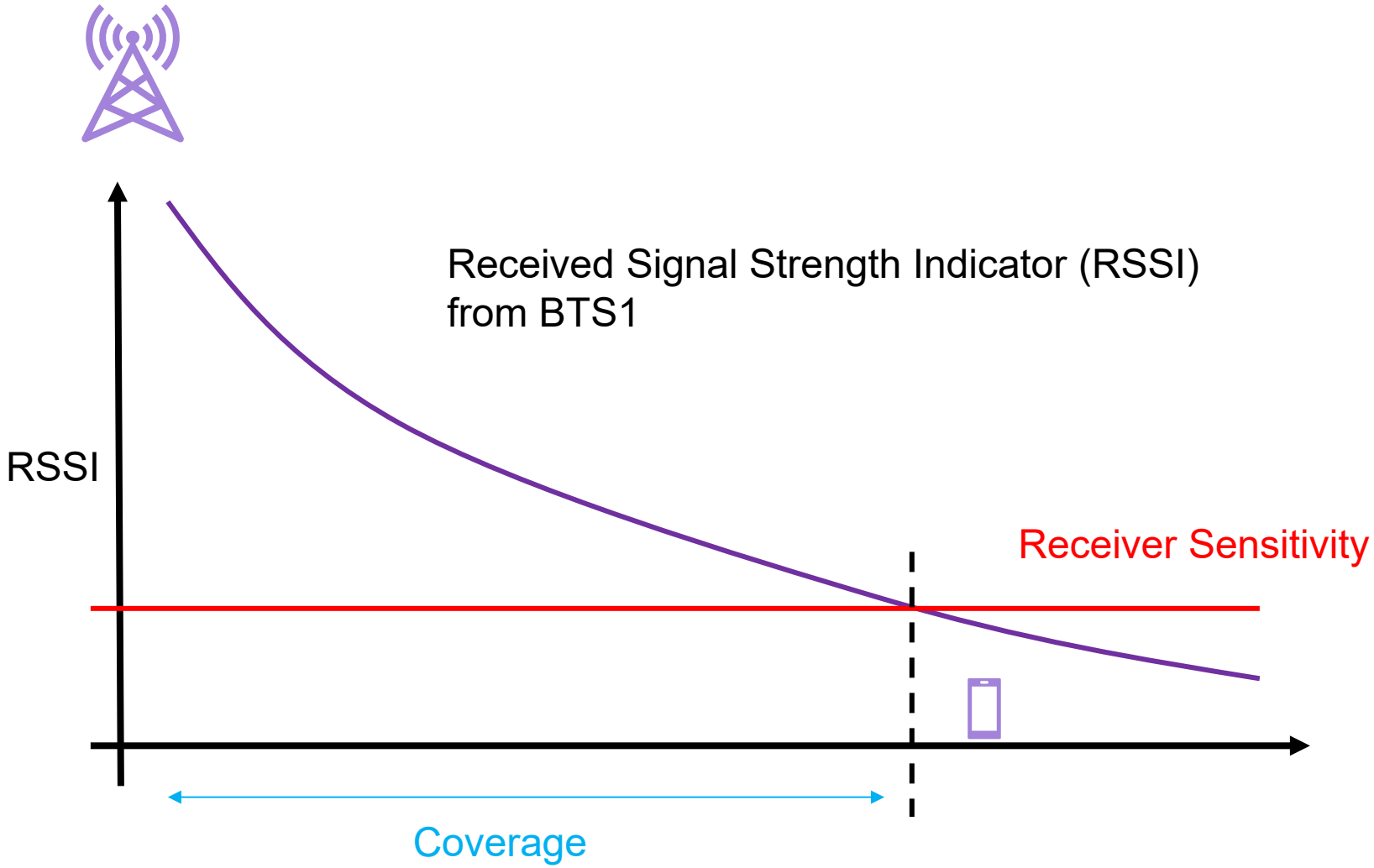
- Advantages
  - No collisions
  - Asynchronous CDMA possible
  - Better efficiency than TDMA and FDMA
- Disadvantages
    - Need extra processing
    - Power control is needed

Space Division Multiple Access (SDMA)

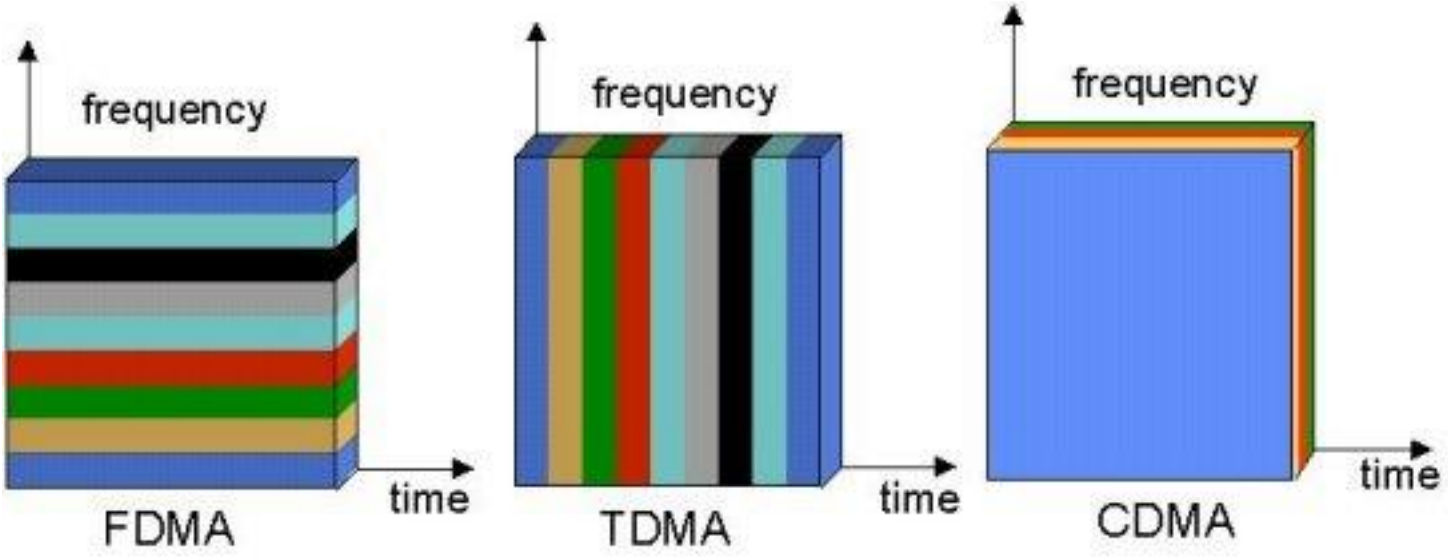
- SDMA uses physical separation methods that permit the sharing of wireless channels. For instance, a single channel may be used simultaneously if the users are spaced far enough from one another to avoid interference. Known as frequency reuse, the method is widely used in cellular radio systems. Cell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



Coverage in Free-Space



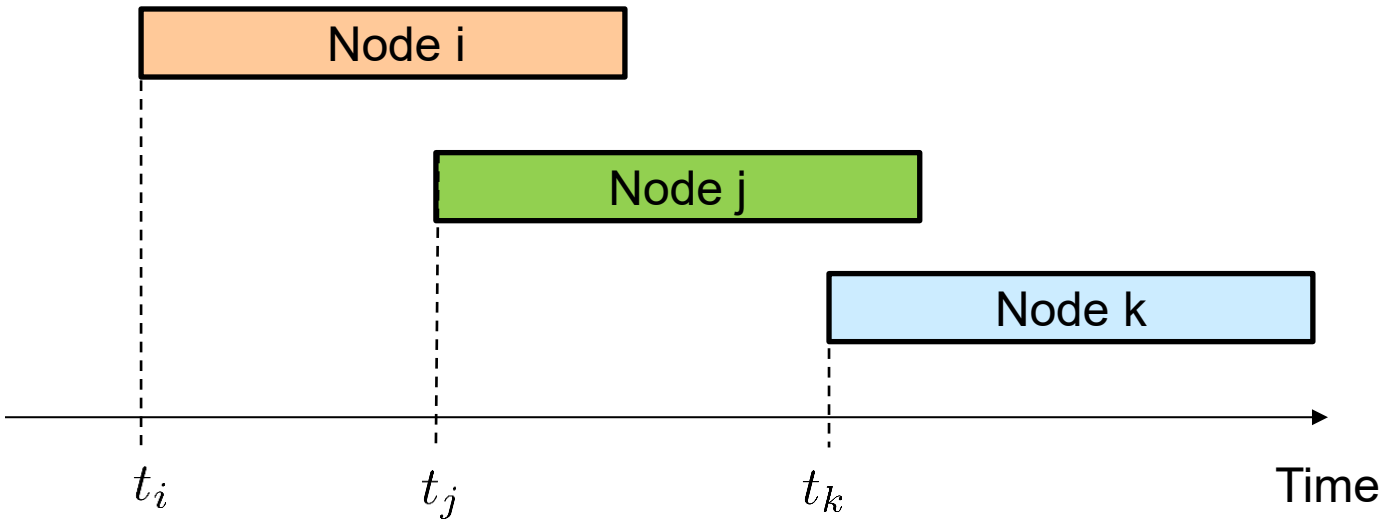
Difference between different TDMA/FDMA/CDMA



Random Access Protocols

Aloha

- When you have data, send it
- If data doesn't go through, resend it after random delay
  - Send with probability *p* or wait for one transmission frame with probability *1-p*

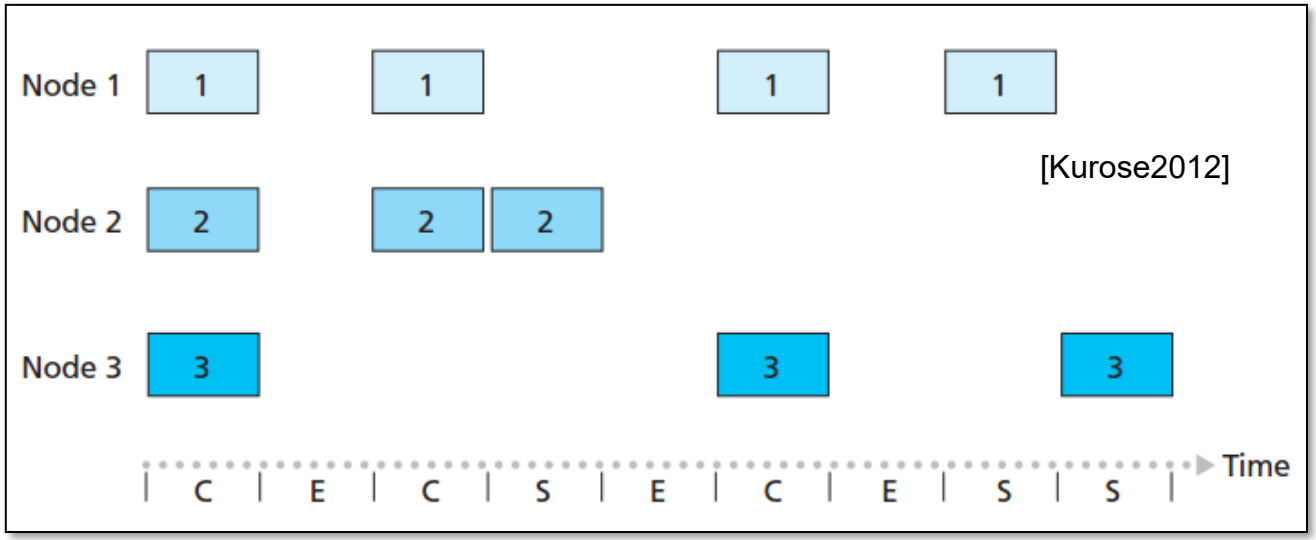


Aloha

- Advantages
  - Full instantaneous rate
  - Fully decentralized
- Disadvantages
  - Low efficiency:
    - Probability of success is $p(1-p)^{2(N-1)}$
    - 18.5% for large *N*
  - Suitable only for light loaded network
  - Unstable for certain channel conditions
    - Avalanche of retransmission attempts
    - Nice animation
      - http://www.wirelesscommunication.nl/reference/chaptr06/aloha/alohplay.htm

Slotted Aloha

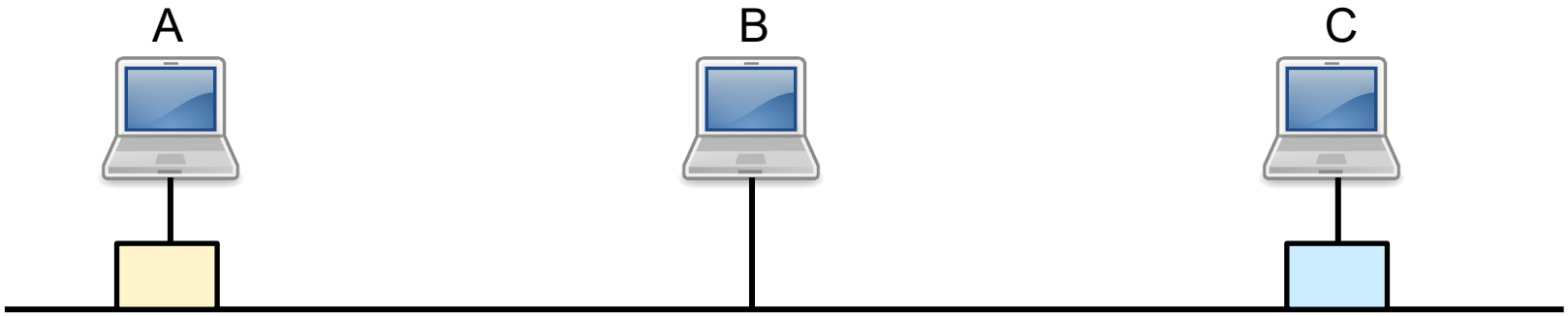
- Time is divided into equal time slots
- Sensor node can send data only at the beginning of a slot
- If have data to send, send at the start of slot. If collision, send in the next slot with probability *p* and do not transmit with probability *1-p*
- Requires time synchronization between nodes
- Better than Aloha but still low
  - Probability of success is $Np(1-p)^{N-1}$
  - Asymptotic numbers: Efficiency: 37%; Wastage: 37%; Collisions: 26%



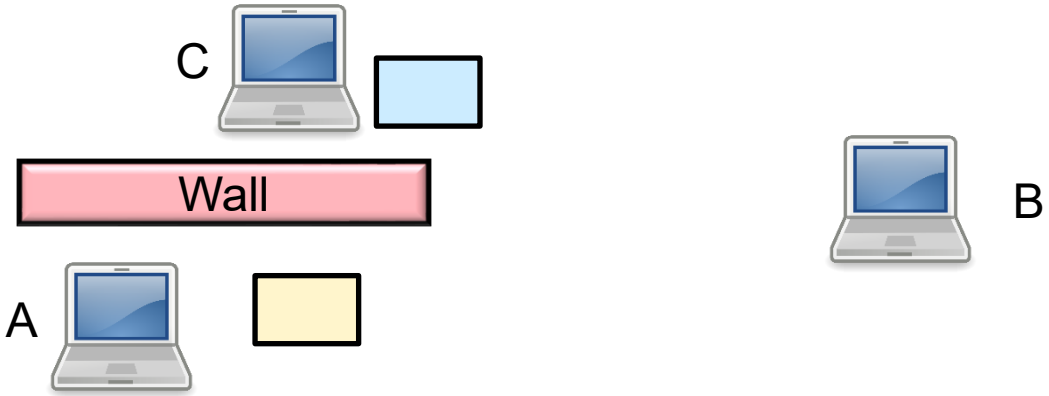
[Kurose2012]

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

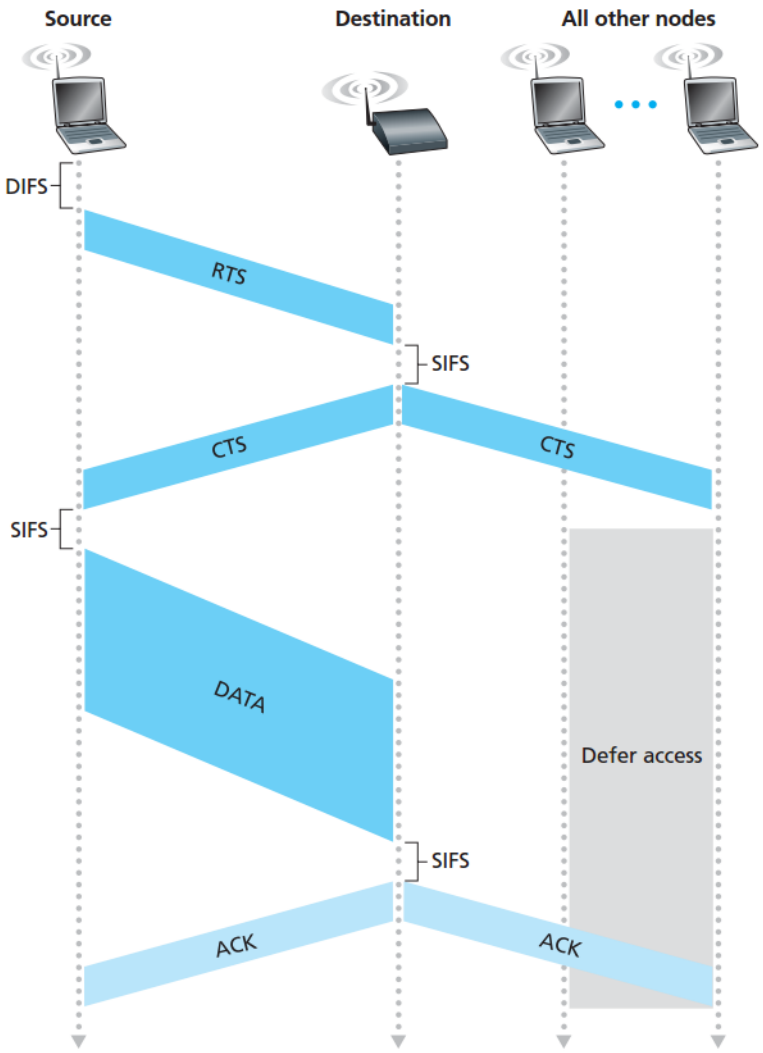


- Hidden Node Problem in Wireless Networks



CSMA with Collision 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]

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)

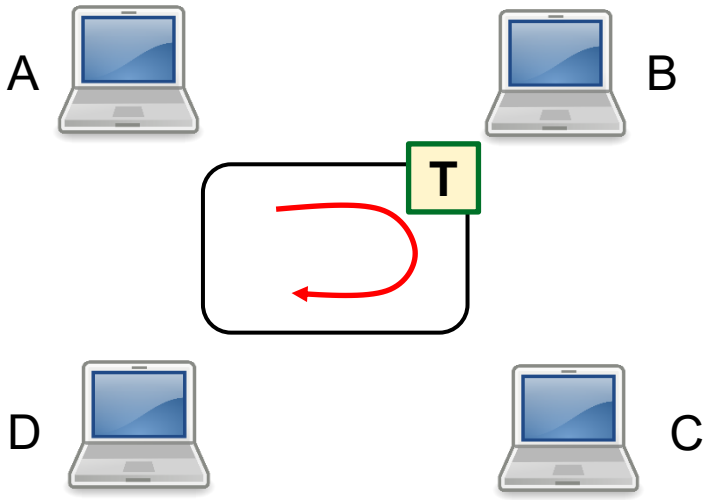
- Taking turn protocols
  - Can improve efficiency of channel partitioning and have no collisions
  - Can potentially also offer guaranteed bandwidth, latency, etc.

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

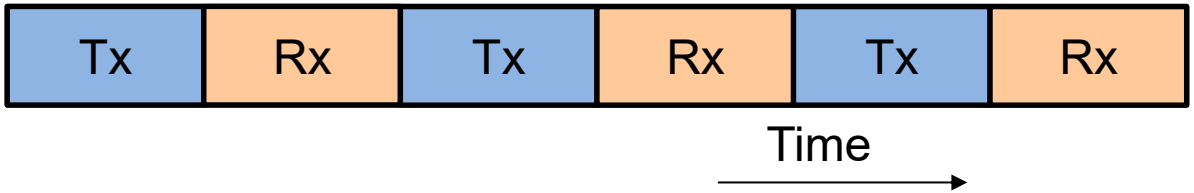
Types of Duplexing

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

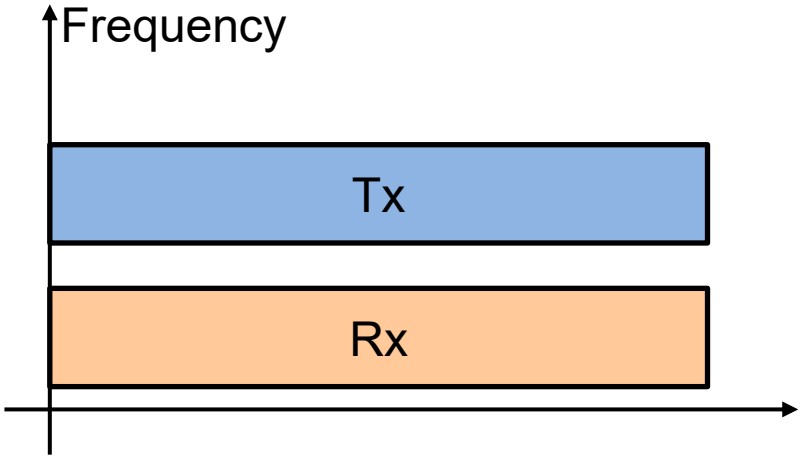
- Full Duplex
  - Both parties can talk simultaneously
  - Most of the communication devices

Duplexing Methods

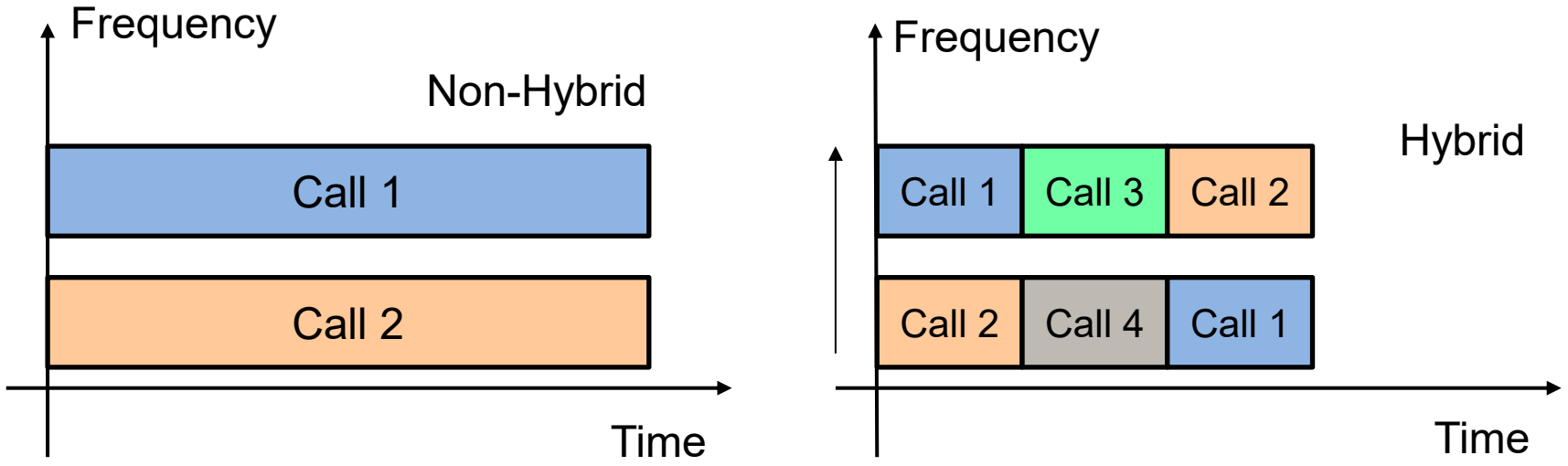
- Methods used for dividing forward and reverse communication channels, they are called as duplexing methods such as
  - Time division duplexing (TDD)



  - Frequency division duplexing (FDD)

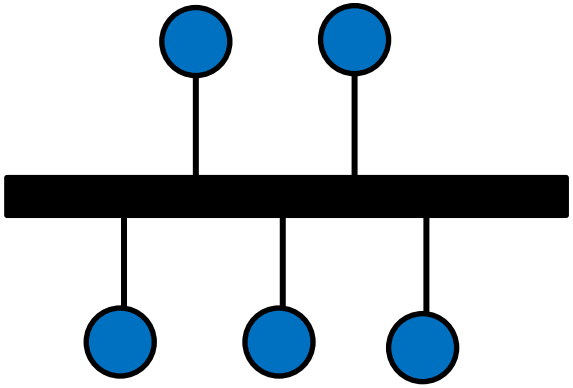


Hybrid Channel Access

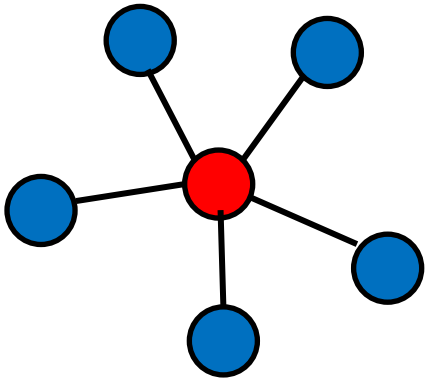


- The GSM cellular system combines the use of FDD to prevent interference between outward and return signals with FDMA and TDMA to allow multiple handsets in a single cell.
- Bluetooth packet mode communication combines frequency hopping for shared channel access among several private area networks in 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

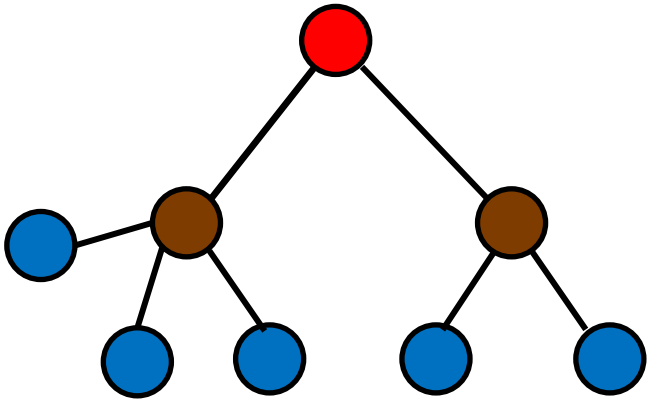
Network Topologies



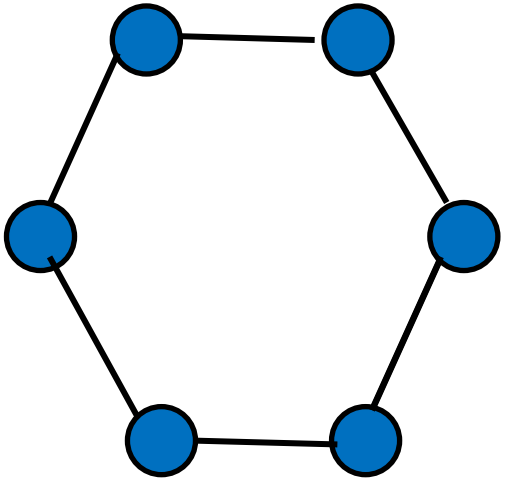
Bus



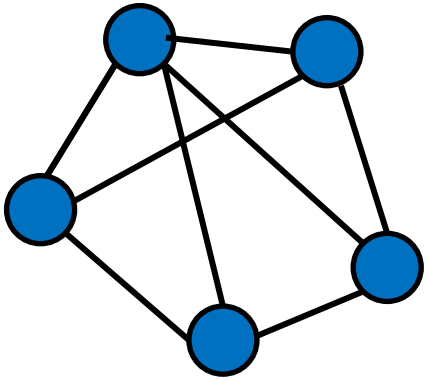
Star



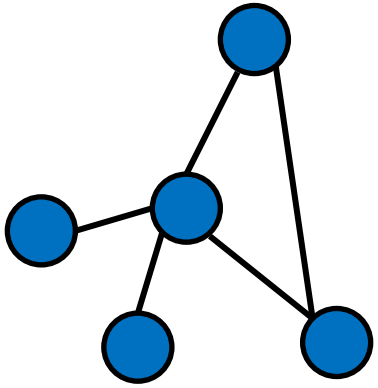
Tree



Ring



Mesh



Hybrid

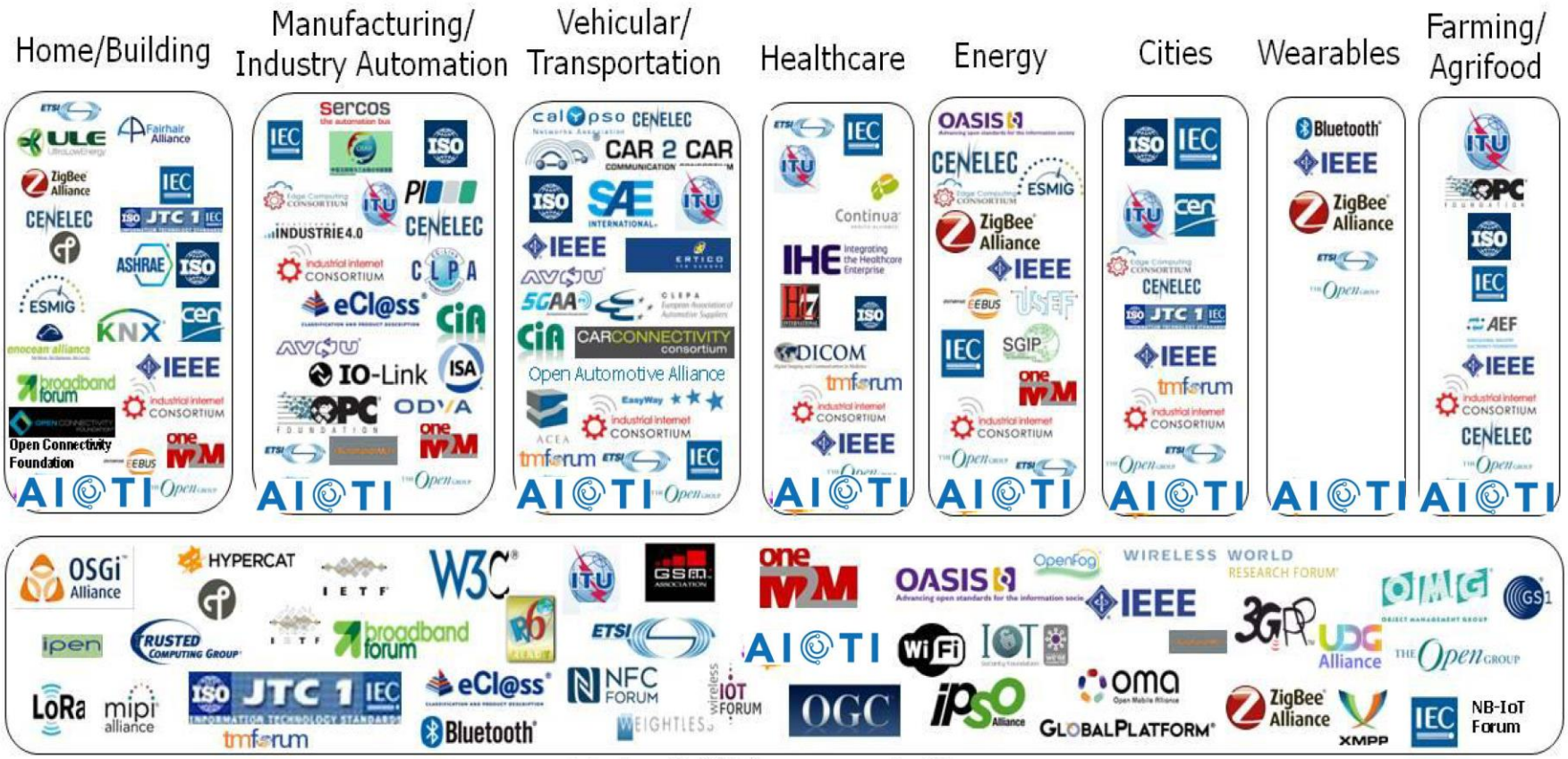
Issues in IoT from Communication Perspective

[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

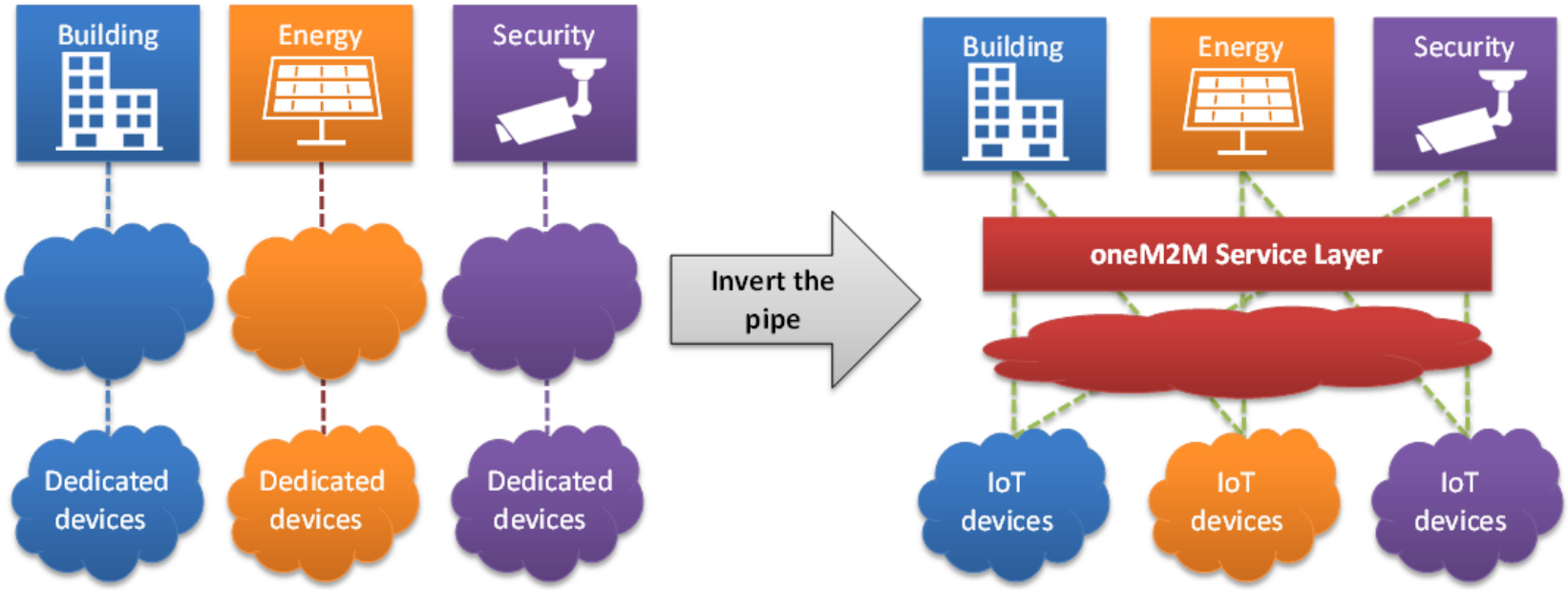
Motivation for Interoperability

- 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

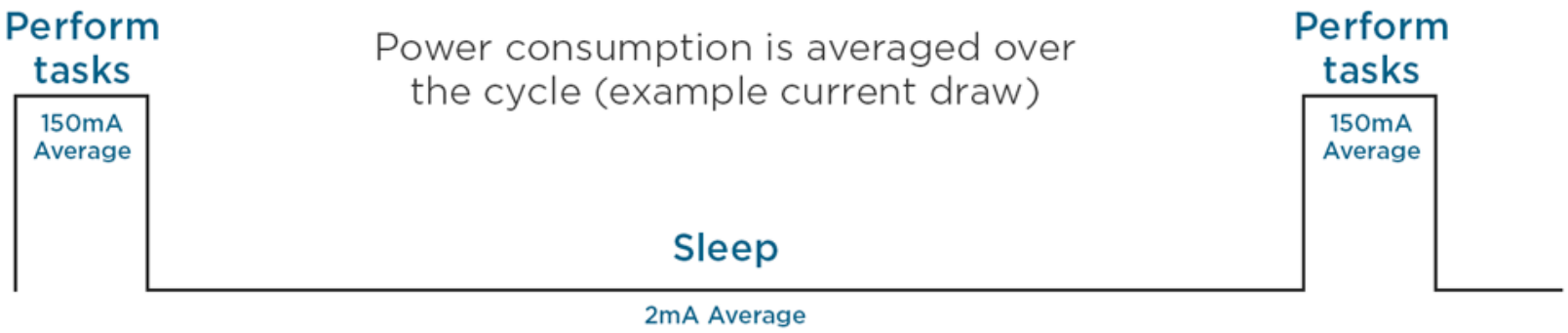
- Energy waste
  - Excessive overhead
  - Idle listening
  - Overhearing
  - Packet collisions and retransmissions

  [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