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Mobile and Wireless Computing CITS4419 Week 3 MAC Protocols

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Why study MAC?

(should CS students study WSN MAC protocols)

- Controlling when to send a packet and when to listen for a packet are perhaps the two most important operations in a wireless network
  - Especially, idle waiting wastes huge amounts of energy
- Communication in a sensor network is challenging because
  - Power is limited
  - The channel is shared
- MAC protocols for sensor networks aim to share the channel in an energy efficient manner

What

- Last week we saw how data could be transmitted on wireless channel
- This is the Physical Layer of a sensor network
- This week we will consider the next layer: the MAC layer
- The MAC layer is responsible for managing the exchange of messages between pairs of nodes in a sensor network

Overview

- WSN MAC challenges
- Contention MACs – Aloha
- Scheduled MACs – SMAC, FlexiMAC
- Hybrid MACs - IEEE 802.15.4 MAC
- LoRaWAN

Shared Channel Challenges

- Energy
  - To save energy need to minimise collisions, overhearing, re-transmissions, hidden terminal
- Latency
  - Application dependent – deliver data as soon as possible

Recommended Reading

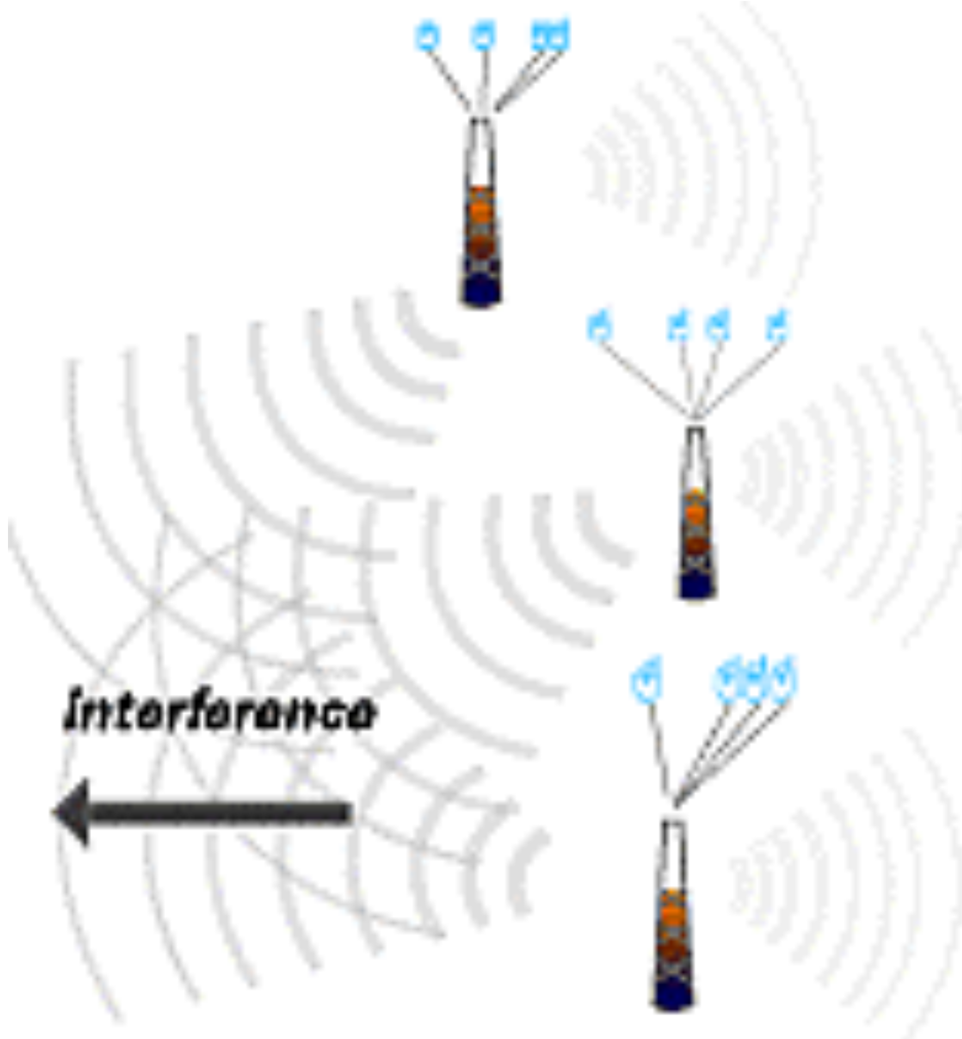
A. Bachir, M. Dohler, T. Watteyne, and K. Leung, *MAC Essentials for Wireless Sensor Networks*, Communications Surveys and Tutorials 12(2) 2010

What is a MAC protocol ?

- The term *protocol* refers to the rules that govern what each node in a network is allowed to do and how it should operate
- MAC protocols define how multiple nodes control their access to a shared medium
- They are termed *media access (MAC) protocols* or *multiple access protocols*.

Challenge 1: Shared Channel

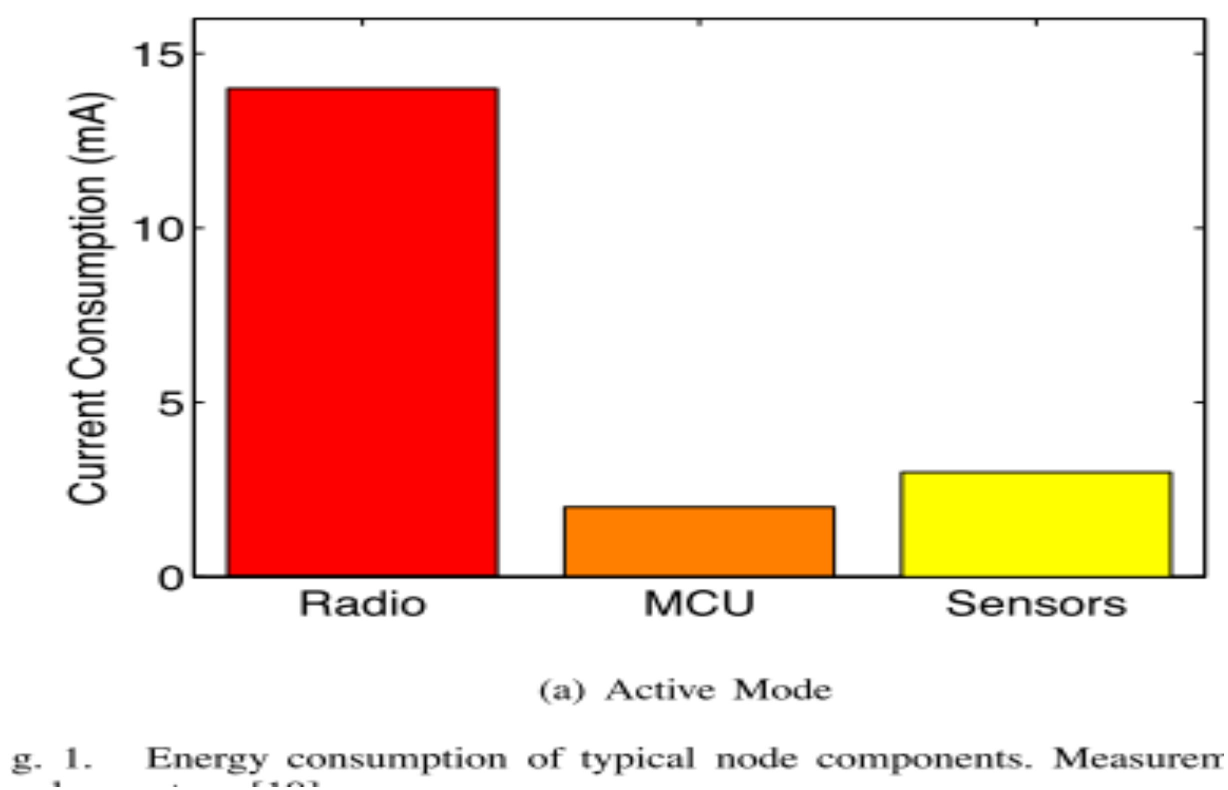
Packet Collisions



Challenge 2: Power

Power consumption in WSNs

Energy consumption



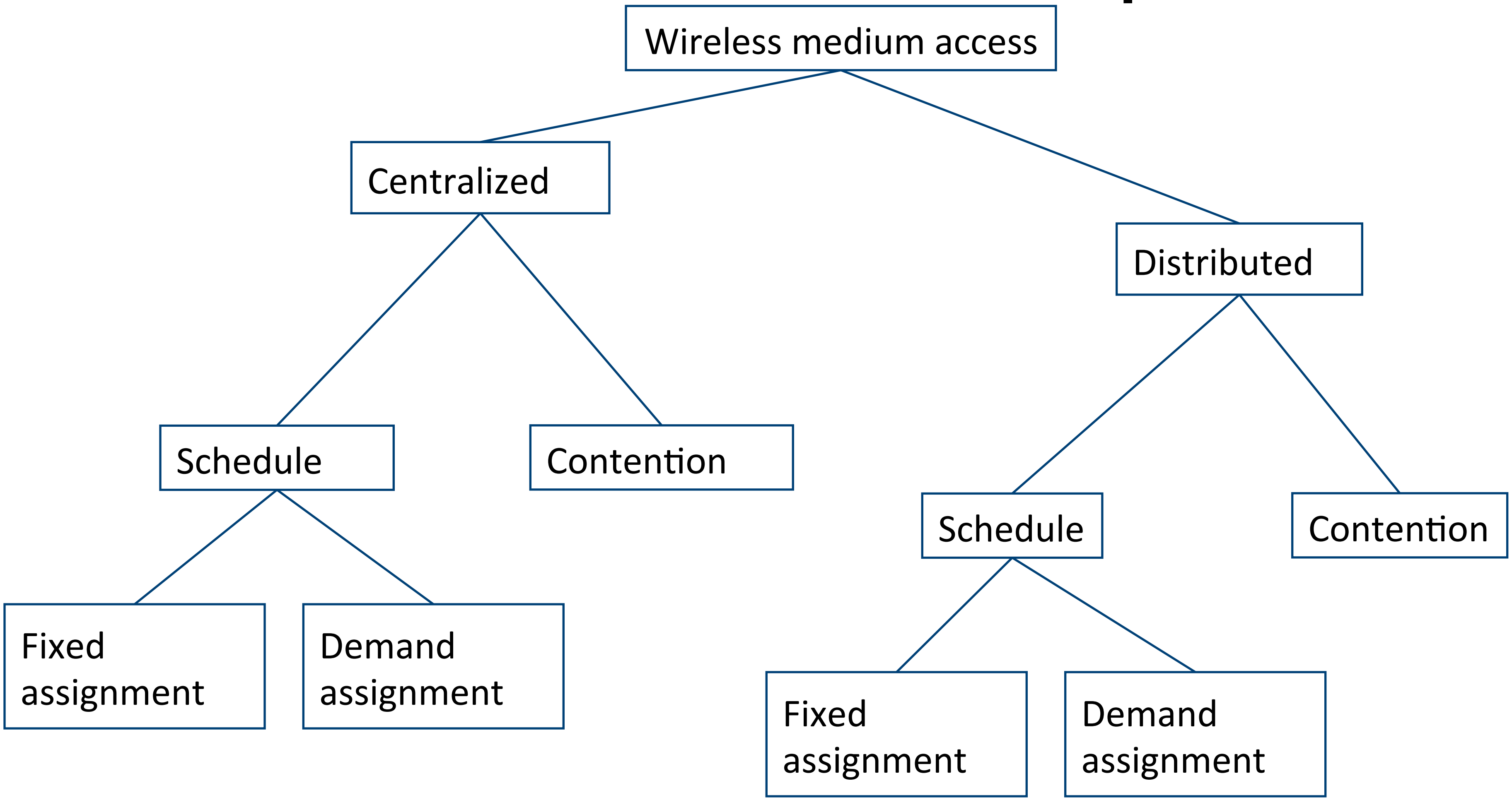
Source: MAC Essentials for Wireless Sensor Networks, Bachir 2010

Overview of MAC protocols

WSN MAC Requirements

- Design Constraints
  - Transmissions are costly
  - Receiving about as expensive as transmitting
  - Idling can be cheaper but is still expensive
- Energy problems
  - ***Collisions*** – wasted effort when two packets collide
  - ***Overhearing*** – waste effort in receiving a packet destined for another node
  - ***Idle listening*** – sitting idly and trying to receive when nobody is sending
  - ***Protocol overhead***
- Always nice: Low complexity solution

Main wireless MAC options



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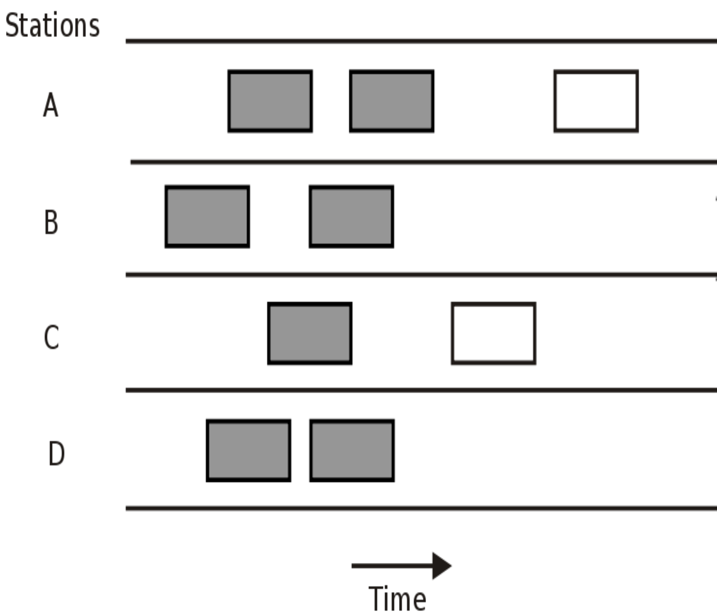
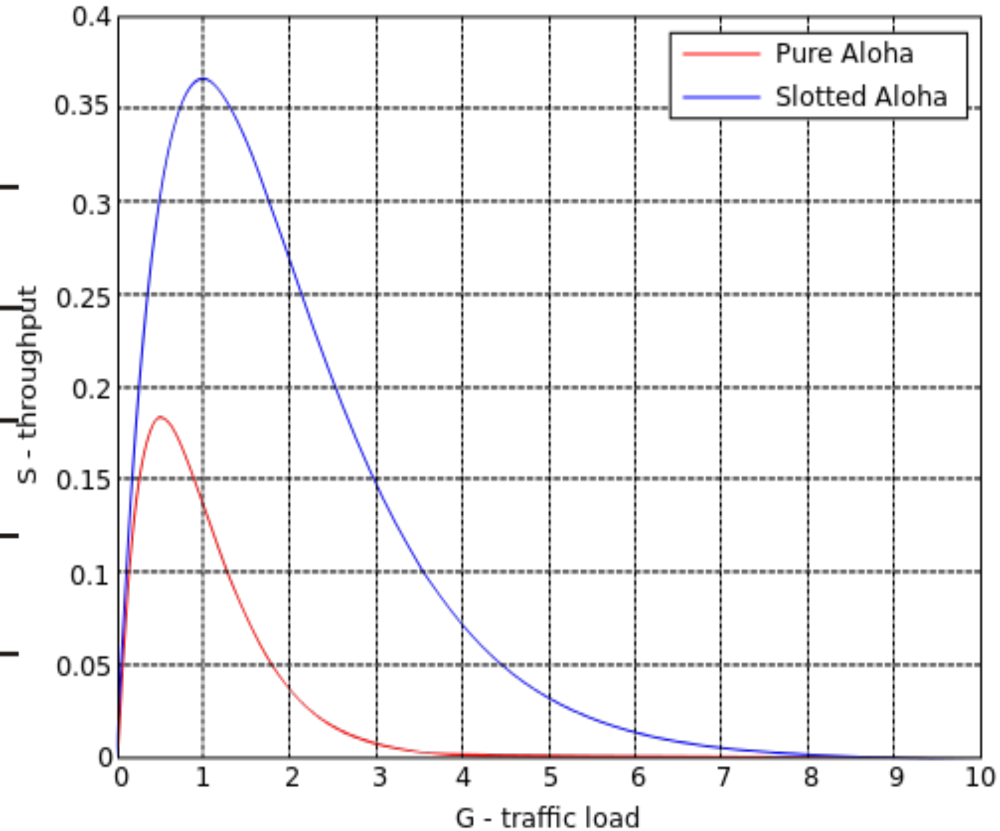
Contention MACs

Aloha (1968 Hawaii)

Protocol = When ready then send message

(Distributed, Contention)





Aloha improvements

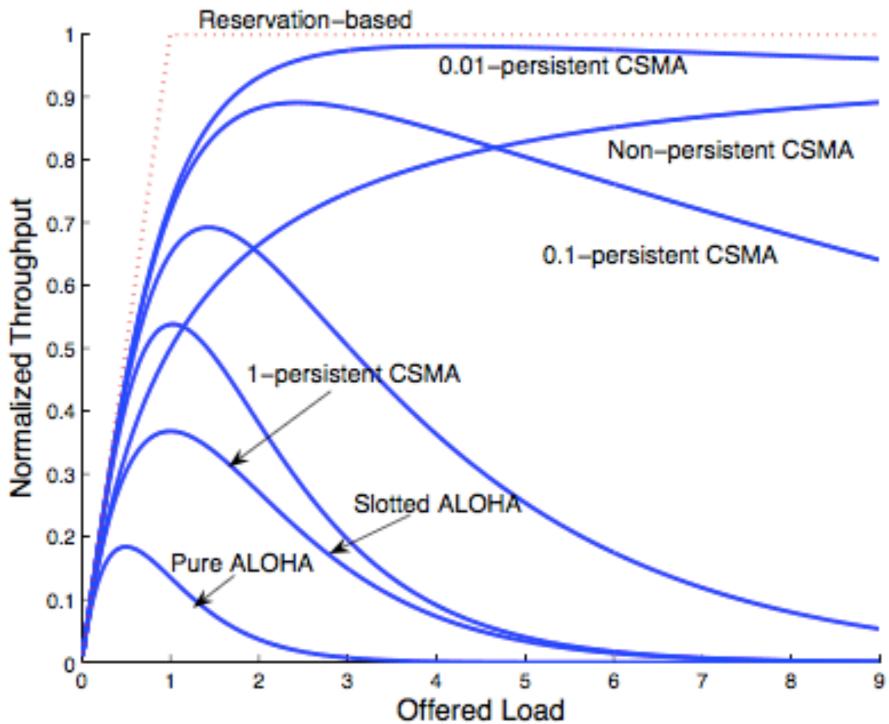


Fig. 2. Qualitative throughput comparison between reservation (dotted line) and contention based (solid lines, [17]) MAC protocols.

Source: MAC Essentials for Wireless Sensor Networks, Bachir 2010

Scheduled MACs

Scheduled MAC protocols

Idea:

Coordinate node schedules

Advantages:

Turn off radio when not needed (allocated time slot)

Limits collision, idle listening, overhearing

Disadvantages:

Rigidity – fixed sleep times

Not flexible to changes in sensor density or movements

Sleep delays increase packet delivery time (latency)

S-MAC

Strategy :

Each node broadcasts and follows its listen/sleep schedule

To talk to your neighbour, wake up when she is listening
Use RTS/CTS to resolve conflict

Periodically listen for all nodes' schedules

SYNC pkts synchronise nodes' clocks

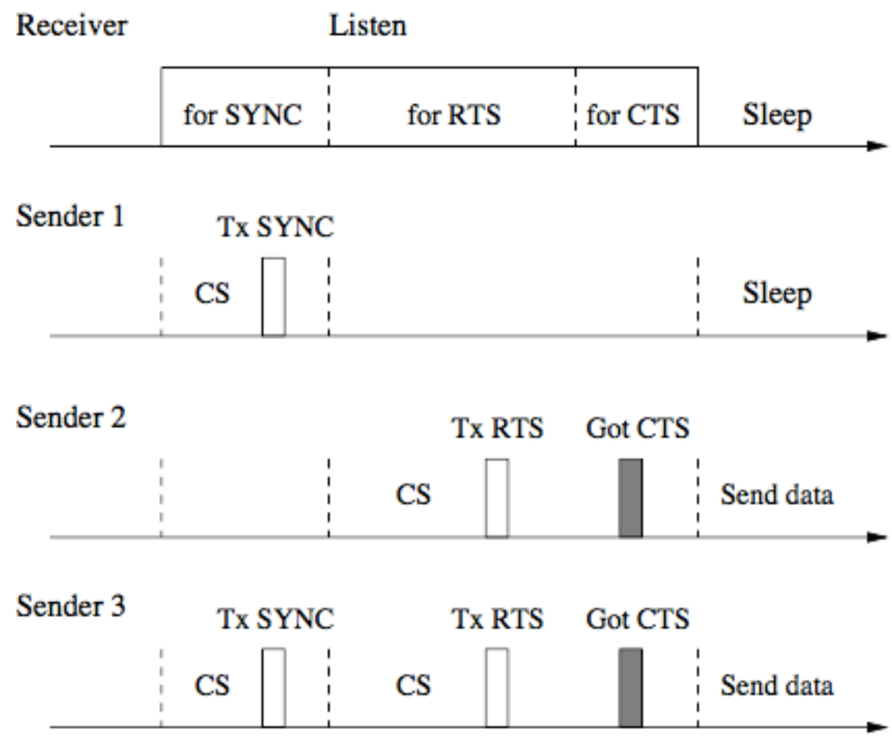


Fig. 3. Timing relationship between a receiver and different senders. CS stands for carrier sense.

Ye et al, *Medium Access Control with Coordinated Adaptive Sleeping for WSNs*, IEEE Transactions on Networking 2004

S-MAC coordination

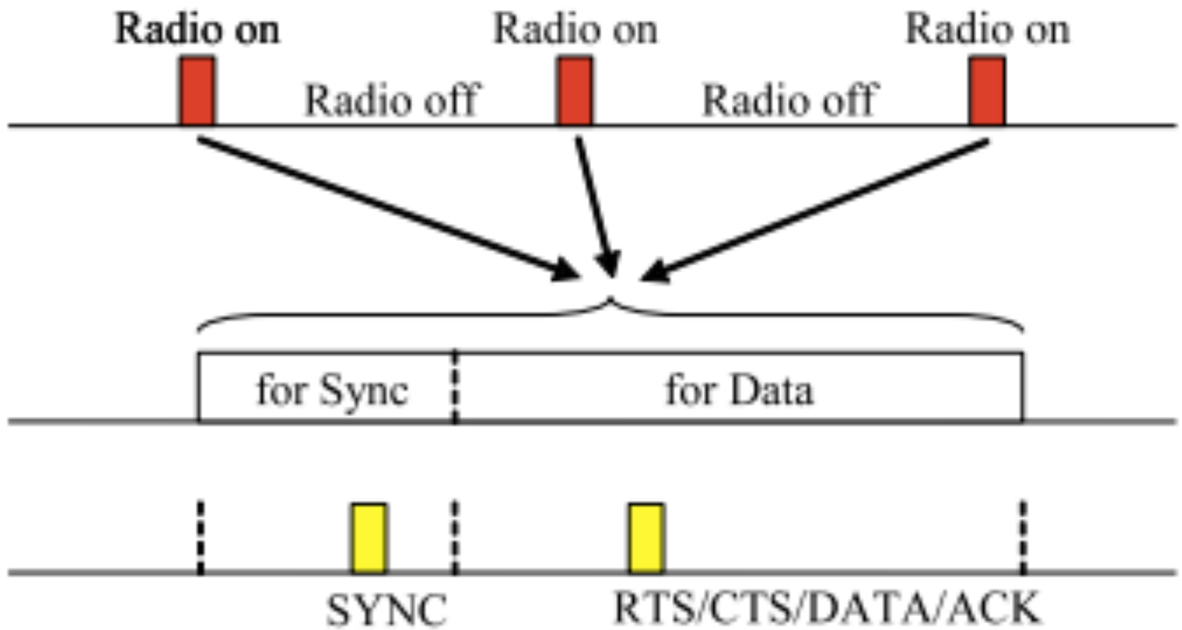
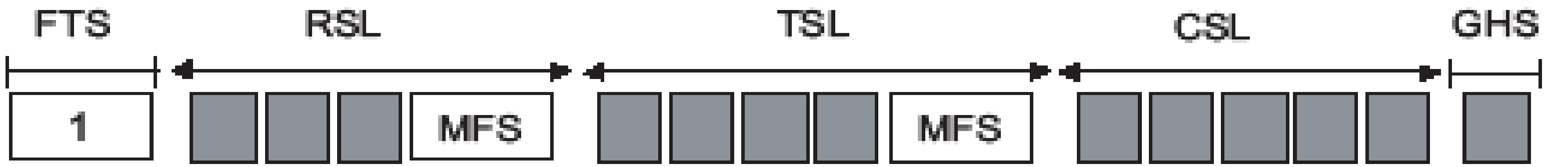
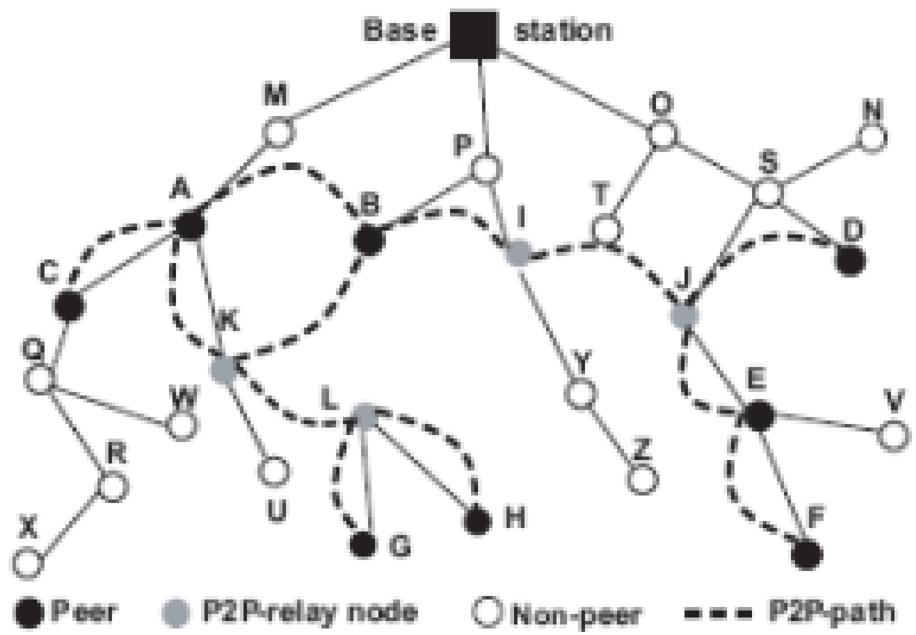


Fig. 6. SMAC alternates turning on and off the radio. SMAC splits the active period into two sub-periods: one for exchanging sync packets and the other for exchanging data packets. Data packet exchange may require RTS, CTS and ACK [57].

Source: MAC Essentials for Wireless Sensor Networks, Bachir 2010

FlexiTP

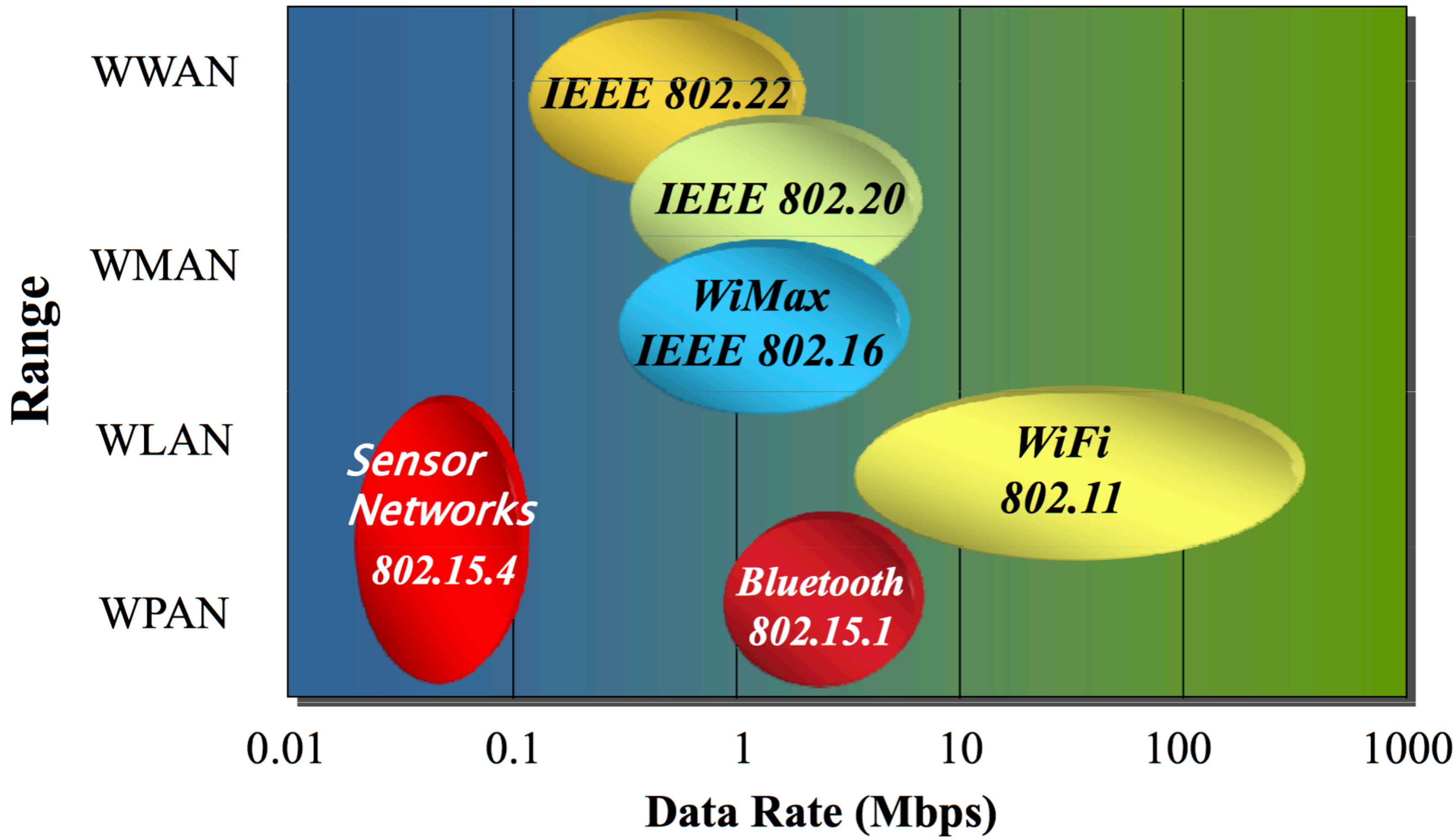




FlexiTP: A Flexible-Schedule-Based TDMA Protocol for Fault-Tolerant and Energy-Efficient Wireless Sensor Networks, Lee, Winnie Louis; Datta, Amitava; Cardell-Oliver, Rachel, In **IEEE Transactions on Parallel and Distributed Systems**, vol.19, no.6, pp.851-864, June 2008

Hybrid MACs

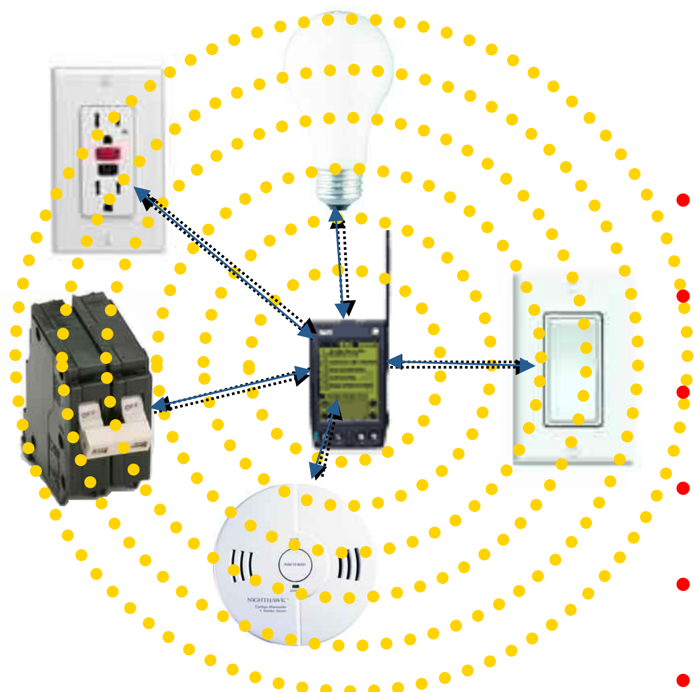
IEEE 802.15.4


Range
WWAN
WMAN
WLAN
WPAN
IEEE 802.22
IEEE 802.20
WiMax
IEEE 802.16
Sensor
Networks
802.15.4
Bluetooth
802.15.1
WiFi
802.11
0.01
0.1
1
10
100
1000
Data Rate (Mbps)

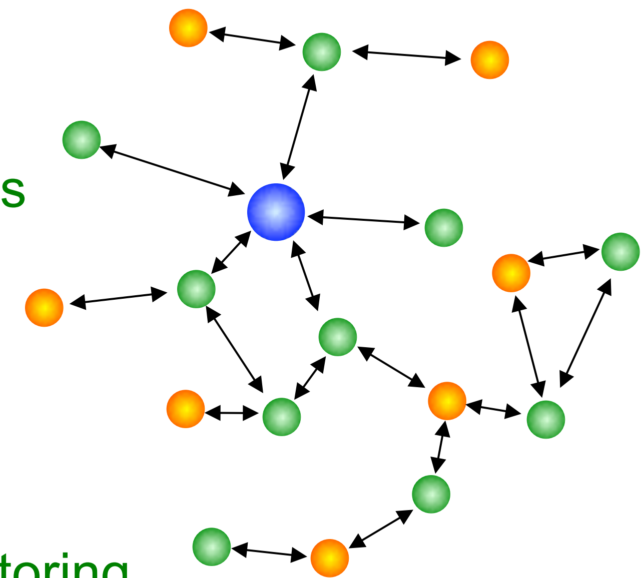
IEEE 802.15.4 Standard

- For low-rate wireless personal area networks
- 10m comms range, data rate 250 kbit/s
- Defines physical layer and MAC protocols
- Used as base protocols for
  - Zigbee IoT mesh procotol
  - ISA100.11a Process and factory automation
  - WirelessHART real-time automation and industry apps
  - MiWi, SNAP
  - 6LoWPAN for IPv6 over personal area nets

IEEE 802.15.4 Applications Space



- Home Networking
- Automotive Networks
- Industrial Networks
- Interactive Toys
- Remote Metering
- Environmental Monitoring sensor networks
- Infrastructure monitoring sensor networks



Features

- Network beacons for comms management
- Guarded time slots (for eg. alarms)
- Security support
- Frequency bands: 868/915/2450 MHz

Topologies

- MAC supports **peer to peer** or **star** networks
- Peer to peer for self managing, ad hoc networks (mesh networks)
- Star pattern has coordinators, full function devices (cluster heads) and reduced function devices (leaf nodes)

IEEE 802.15.4 MAC Overview

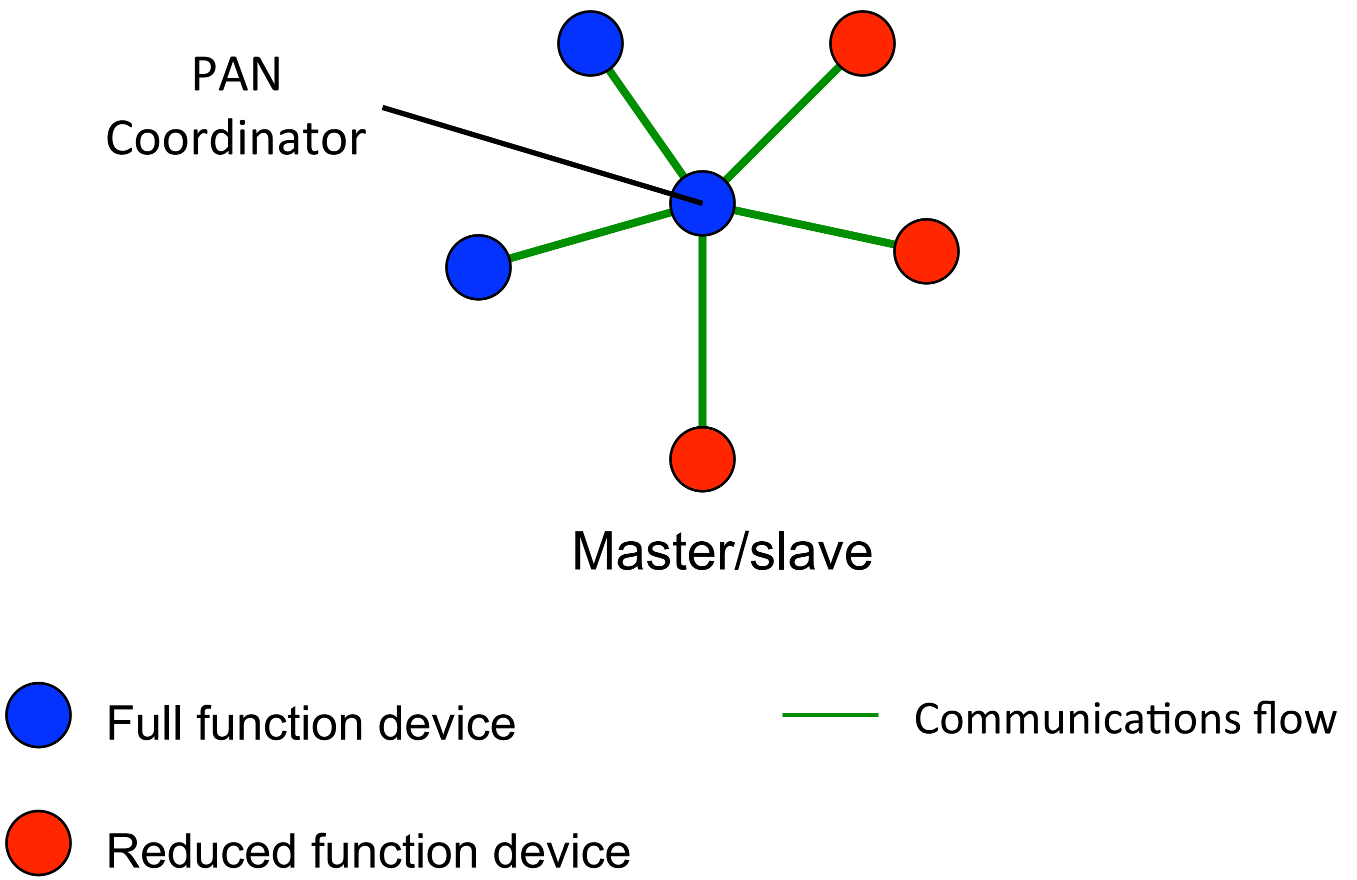
Device Classes

- Full function device (FFD) — **Base node or cluster head**
  - Any topology
  - Network coordinator capable
  - Talks to any other device

- Reduced function device (RFD) — **Sensor node**
  - Limited to star topology
  - Cannot become a network coordinator
  - Talks only to a network coordinator
  - Very simple implementation

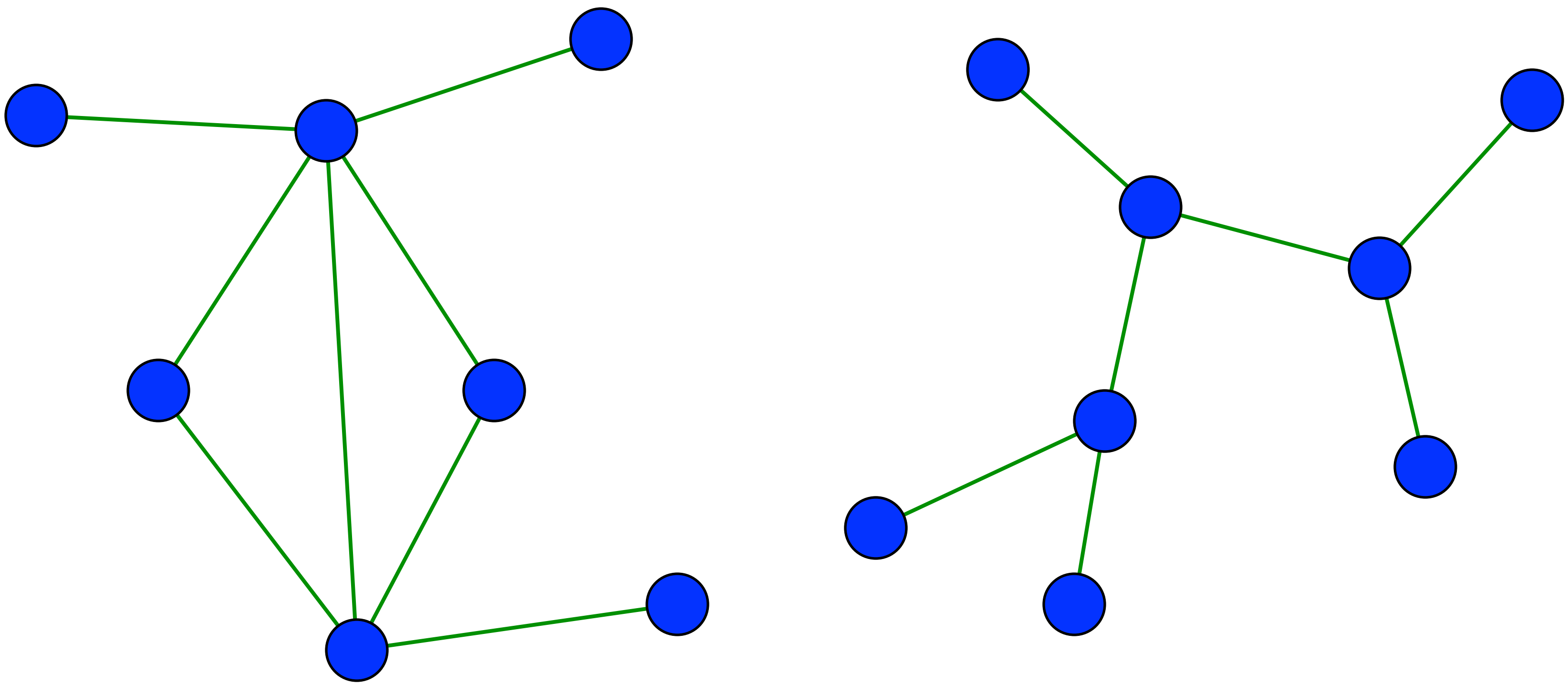
IEEE 802.15.4 MAC Overview

Star Topology



IEEE 802.15.4 MAC Overview

Peer-Peer Topology

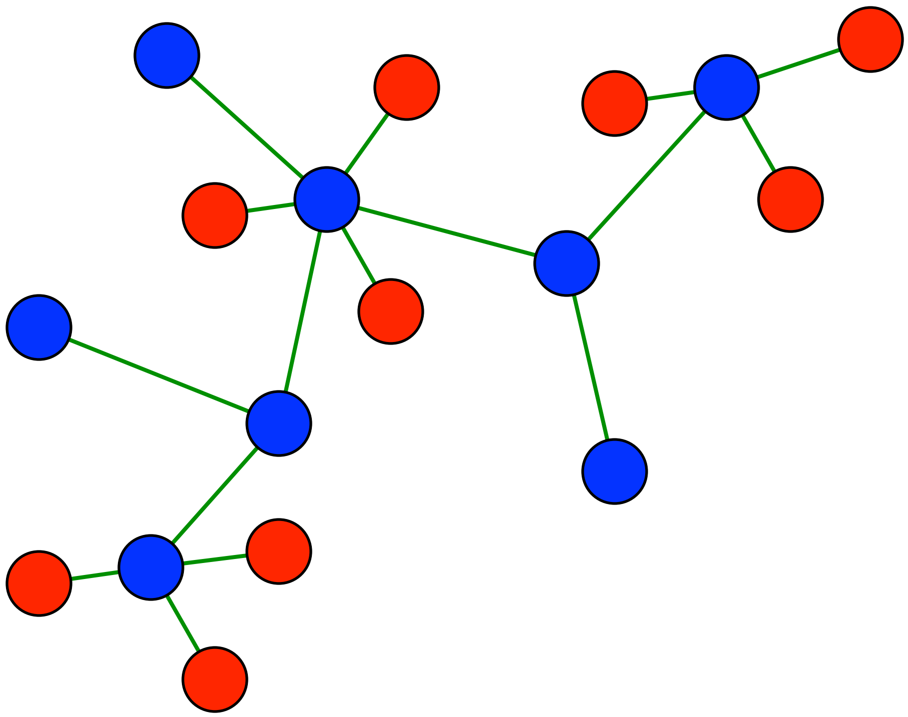


Point to point

Cluster tree

IEEE 802.15.4 MAC Overview

Combined Topology



Clustered stars - for example, cluster nodes exist between rooms of a hotel and each room has a star network for control.

Full function device

Reduced function device

Communications flow

Frame Types

- Data
- Acknowledgement
- Beacon
- MAC command

- Slotted or unslotted CSMA/CA

- Data transfer = beacon sync + data in slots + optional ack = request + confirm + response

General MAC Frame Format

Octets:2	1	0/2	0/2/8	0/2	0/2/8	variable	2
Frame control	Sequence number	Destination PAN identifier	Destination address	Source PAN identifier	Source address	Frame payload	Frame check sequence
		Addressing fields					
MAC header						MAC payload	MAC footer

Bits: 0-2	3	4	5	6	7-9	10-11	12-13	14-15
Frame type	Sequrity enabled	Frame pending	Ack. Req.	Intra PAN	Reserved	Dest. addressing mode	Reserved	Source addressing mode

Frame control field

Beacon Frame Format

Octets:2	1	4 or 10	2	variable	variable	variable	2
Frame control	Beacon sequence number	Source address information	Superframe specification	GTS fields	Pending address fields	Beacon payload	Frame check sequence
MAC header			**MAC payload**				**MAC footer**

Bits: 0-3	4-7	8-11	12	13	14	15
Beacon order	Superframe order	Final CAP slot	Battery life extension	Reserved	PAN coordinator	Association permit

MAC Command Frame

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

- Command Frame Types
  - Association request
  - Association response
  - Disassociation notification
  - Data request
  - PAN ID conflict notification
  - Orphan Notification
  - Beacon request
  - Coordinator realignment
  - GTS request

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**

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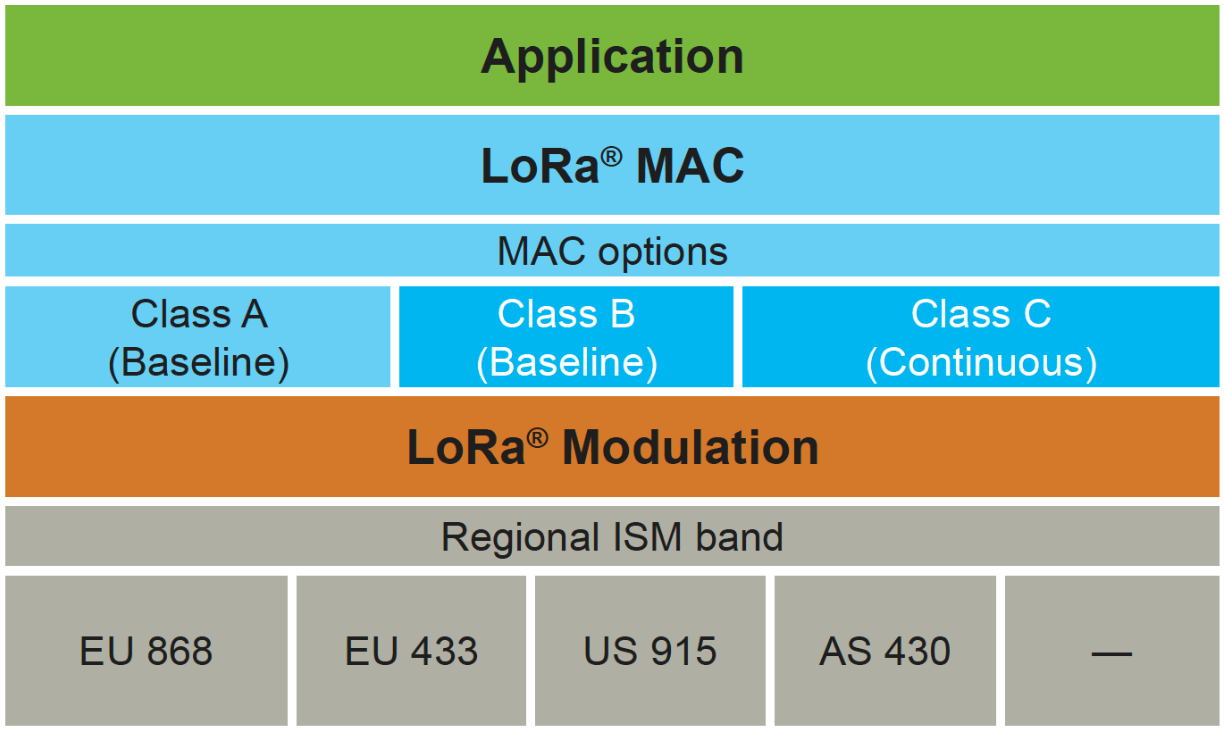
LoRaWAN

LoraWAN

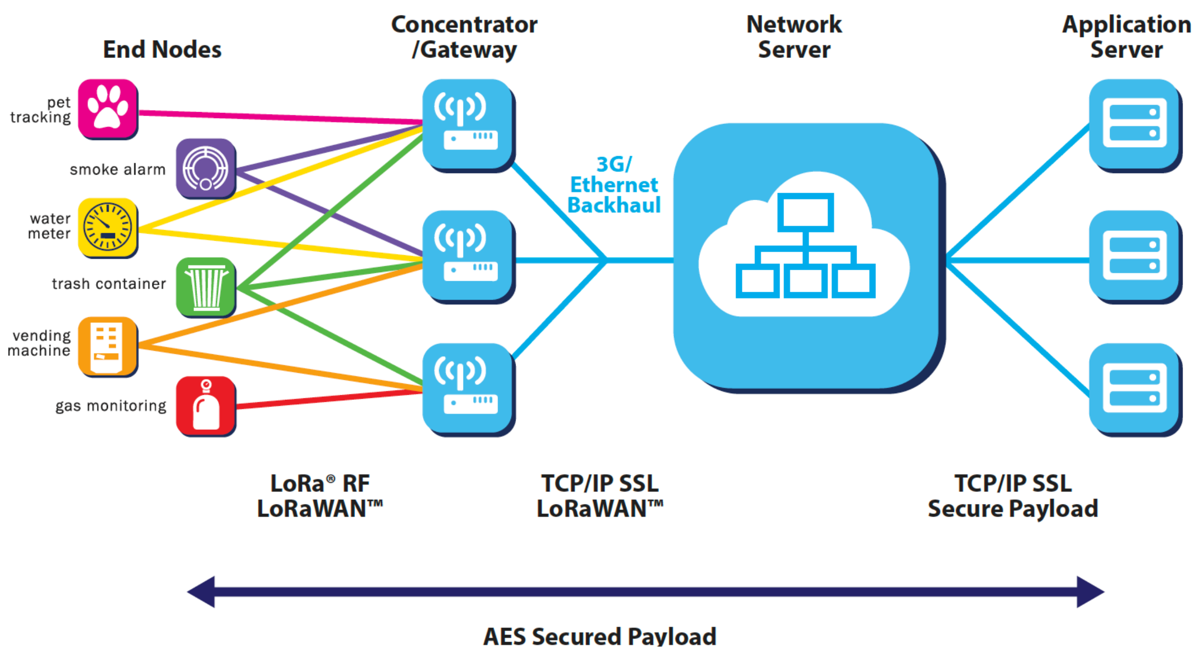

Application
LoRa® MAC
MAC options
Class A
(Baseline)
Class B
(Baseline)
Class C
(Continuous)
LoRa® Modulation
Regional ISM band
EU 868
EU 433
US 915
AS 430
—

Mesh Network

- Mesh network: individual end-nodes forward the information of other nodes to increase the communication range and cell size of the network. While this increases the range, it also adds complexity, reduces network capacity, and reduces battery lifetime

Star Network

- Single hope from sensor nodes to a gateway
- Long range star architecture makes the most sense for preserving battery lifetime when long-range connectivity can be achieved



LoRa-Alliance.org

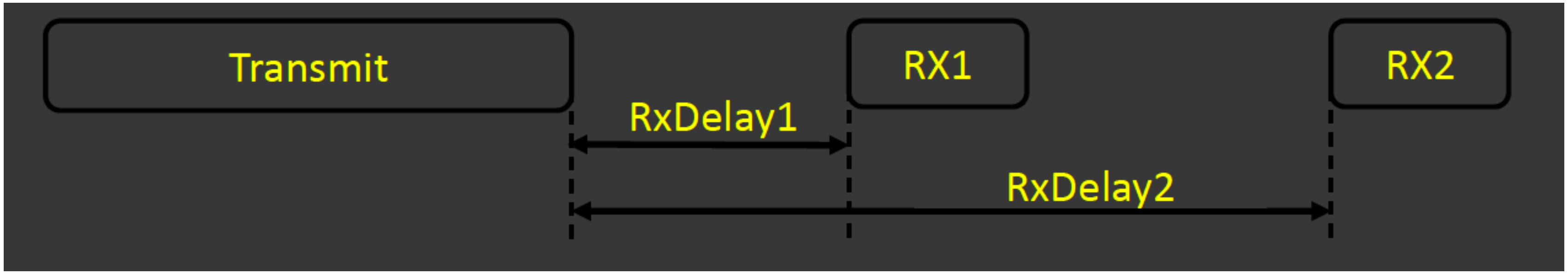
End-devices

Each end-device class has different behavior depending on the choice of optimization:

- Battery Powered – Class A
- Low Latency – Class **B**
- No Latency – Class **C**

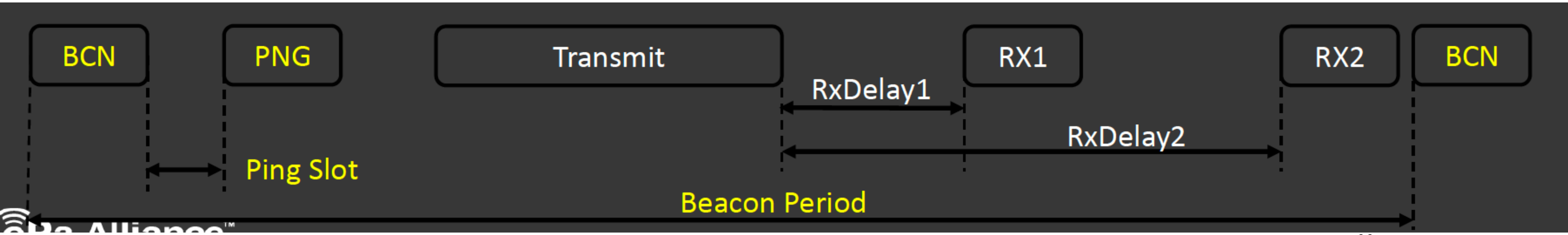
Battery Powered – Class A

- Bidirectional communications
- Unicast messages
- Small payloads, long intervals
- End-device initiates communication (uplink)
- Server communicates with end-device (downlink) during predetermined response windows:



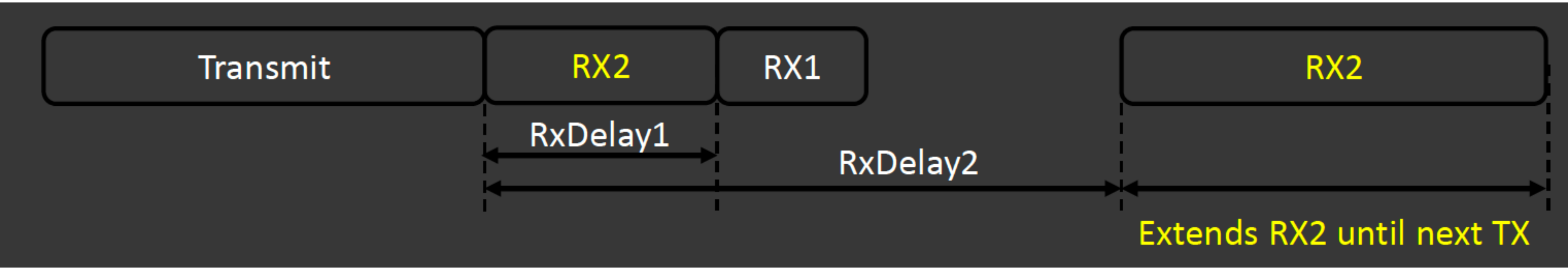
Low Latency – Class B

- Bidirectional with scheduled receive slots
- Unicast and Multicast messages
- Small payloads, long intervals
- Periodic beacon from gateway
- Extra receive window (ping slot)
- Server can initiate transmission at fixed intervals



No Latency – Class C

- Bidirectional communications
- Unicast and Multicast messages
- Small payloads
- Server can initiate transmission at any time
- End-device is constantly receiving



TTN the things network

- Further reading
- https://www.thethingsnetwork.org/

Summary

- WSN MAC challenges
- Contention MACs – Aloha
- Scheduled MACs – SMAC, FlexiMAC
- Hybrid MACs - IEEE 802.15.4 MAC
- LoRaWAN