EE 579: Wireless and Mobile Networks Design & Laboratory

Lecture 8

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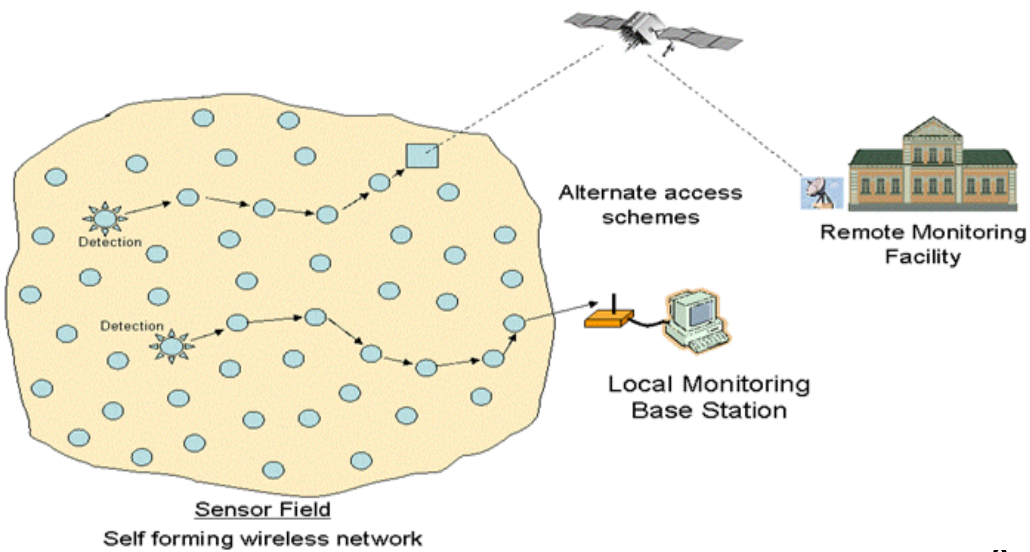
Lecture notes and course design based upon prior semesters taught by Bhaskar Krishnamachari and Murali Annavaram.

Outline

- Administrative Stuff
- MAC Protocols for Sensor Networks
- Data Gathering (Convergecast) - Throughput-Delay Trade-off

Recap

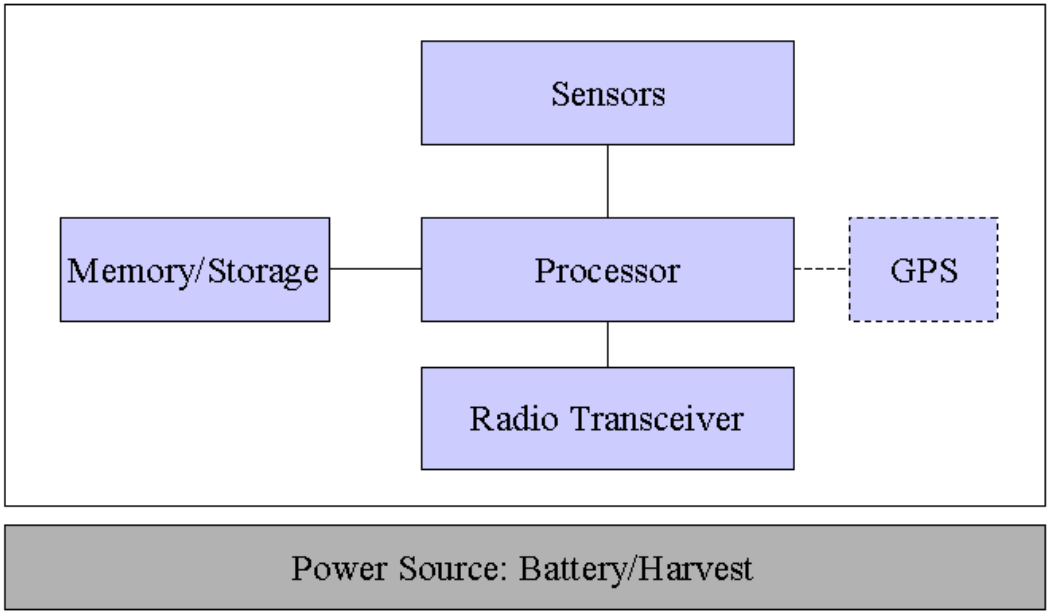
- ❑ Collection of low-power devices “sensor nodes”
- ❑ Small, inexpensive, with constrained power
- ❑ Organized in a cooperative network
- ❑ Communicate wirelessly in multi hop routing
- ❑ Heavy deployment
- ❑ Dynamic topology



Recap

Components and Schematic of a Node

- ❑ Processor
- ❑ Memory
- ❑ RF Radio
- ❑ Power Source
- ❑ Sensor
- ❑ GPS



Recap

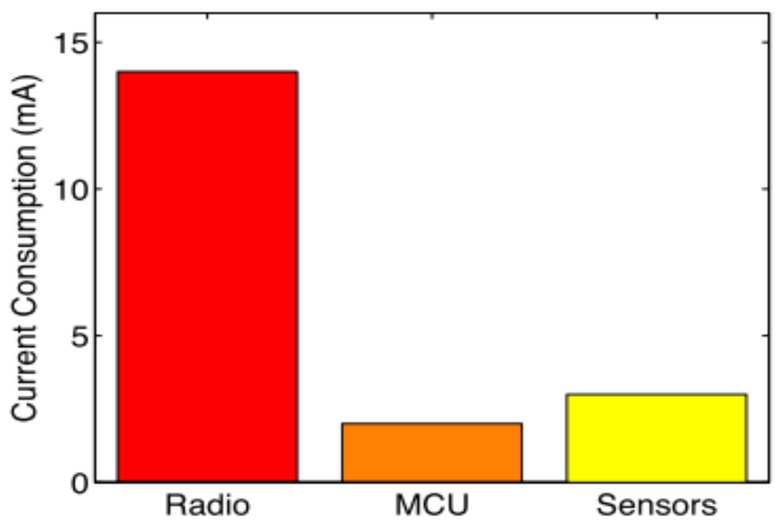
Communication Patterns

- Broadcast
  - Base station transmits message to all its immediate neighbors
- Convergecast
  - A group of sensors communicates to a specific sensor
- Local gossip
  - A sensor node sends a message to its neighboring nodes within a range

Power Consumption

One of the biggest challenges

- Sensors have a limited source of power and it’s hard to replace or recharge, e.g., sensors deployed in the battle field, sensors in a large forest



Radio mode	Power consumption (mW)
Transmit (T_x)	14.88
Receive (R_x)	12.50
Idle	12.36
Sleep	0.016

Sources of Power Consumption

Useful power consumption

- ❑ Transmitting or receiving data
- ❑ Processing queries requests
- ❑ Forwarding queries and data to the neighbours

Sources of Power Consumption

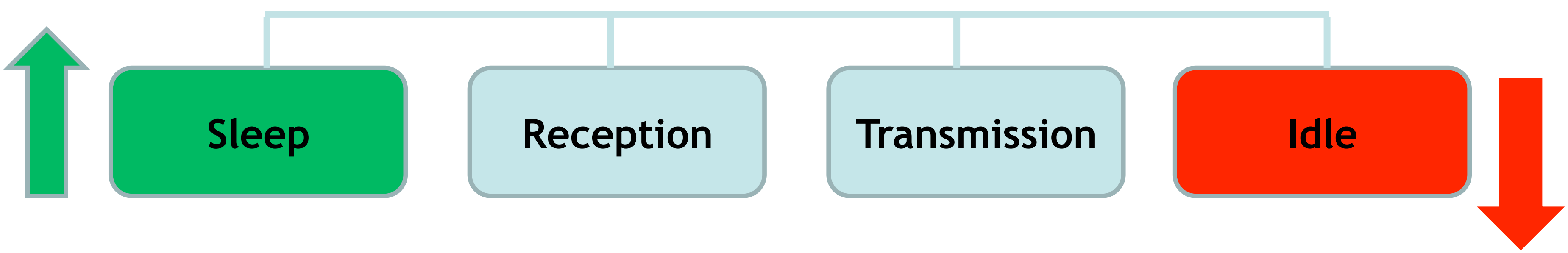
Wasteful power consumption

- Idle listening to the channel
  - Waiting for possible traffic
- Retransmitting because of collision
  - Two packets arrived at the same time at the same sensor
- Overhearing
  - When a sensor received a packet doesn't belong it
- Generating and handling control packets.

Sources of Power Consumption

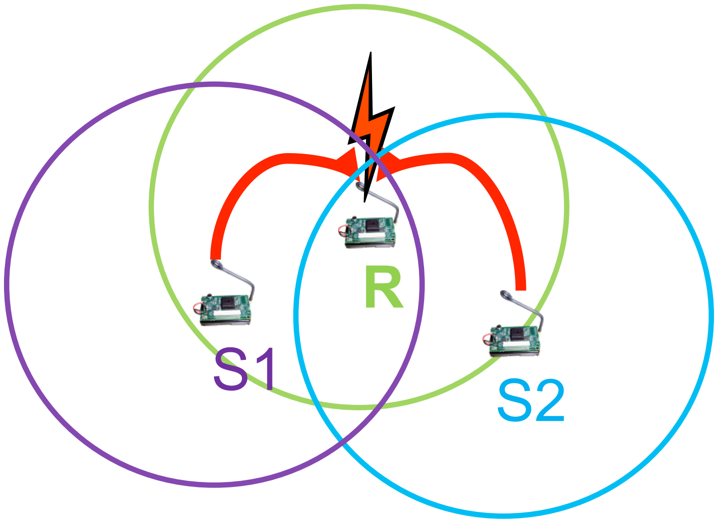
- How to minimize the energy consumption of sensor nodes while meeting application requirements?

- Use Protocols that aim mainly to increase the sleep periods as much as possible



Hidden Terminal Problem

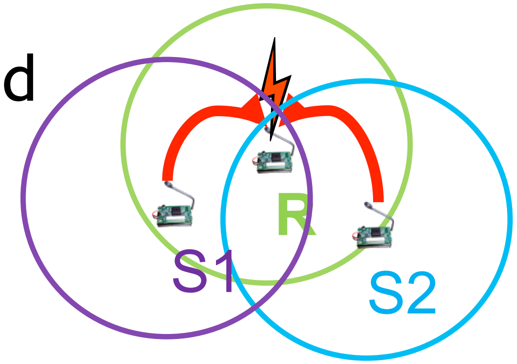
- Another sender's presence is hidden from the intended sender, and therefore simultaneous transmissions from both os them to the same receiver cause collision

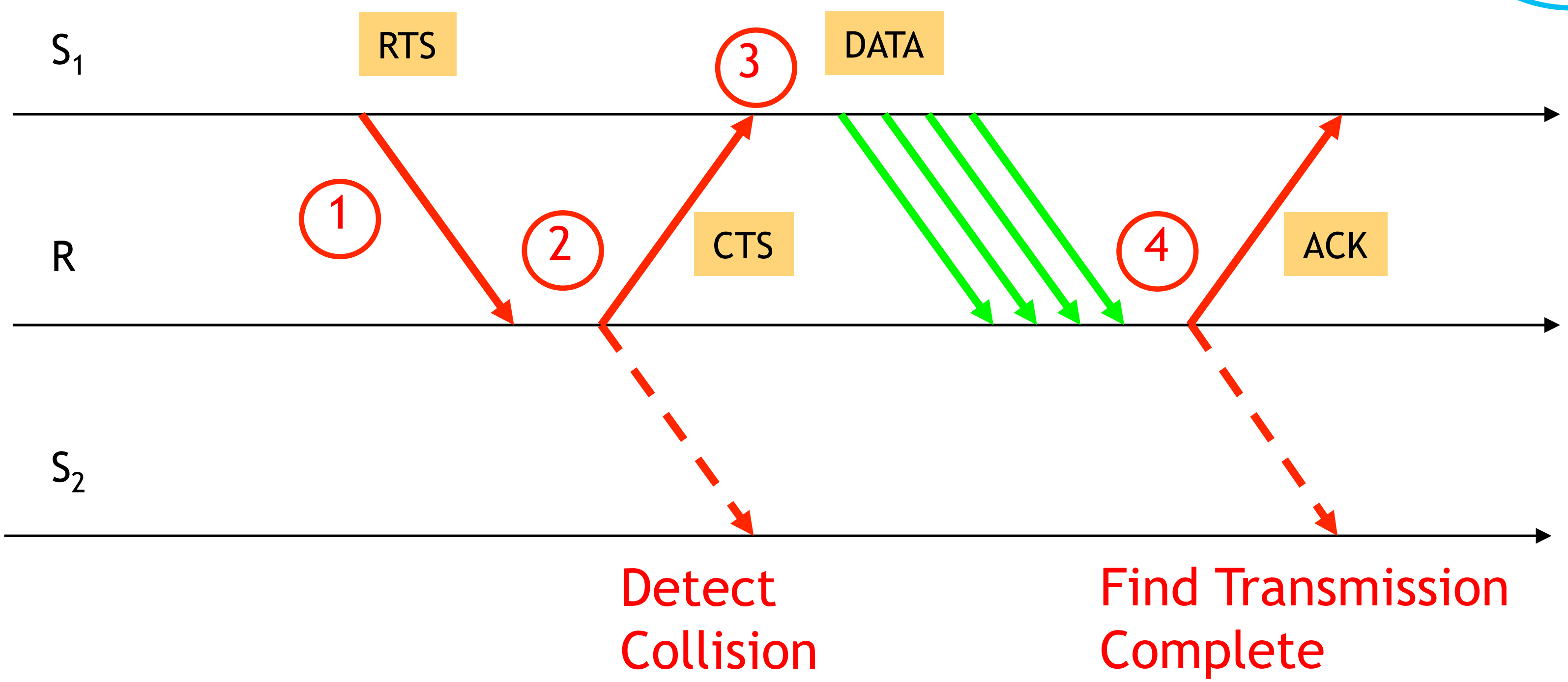


- How to avoid? – Use of additional signaling packets
  - Sender asks receiver whether it is able to receive a transmission - Request to Send (RTS)
  - Receiver agrees, sends out a Clear to Send (CTS)
  - Sender sends, receiver sends Acknowledgements (ACKs)

Hidden Terminal Problem

- A pictorial representation of how to avoid



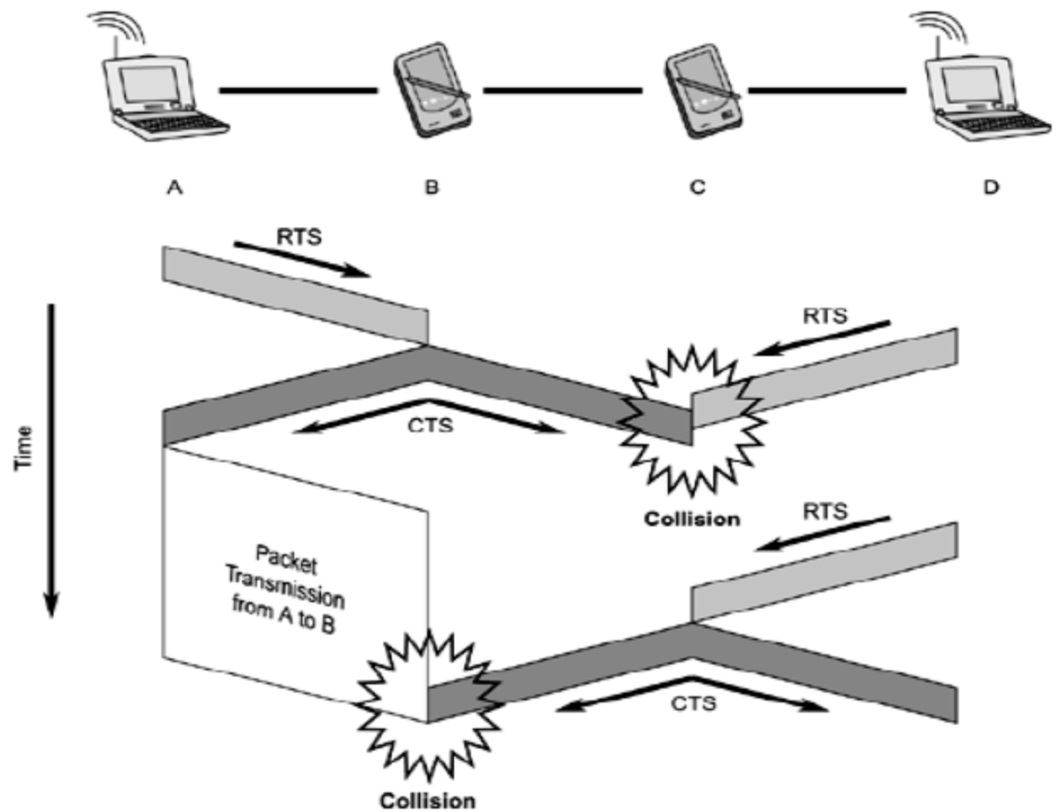


Hidden Terminal Problem

- Problems with RTS/CTS?

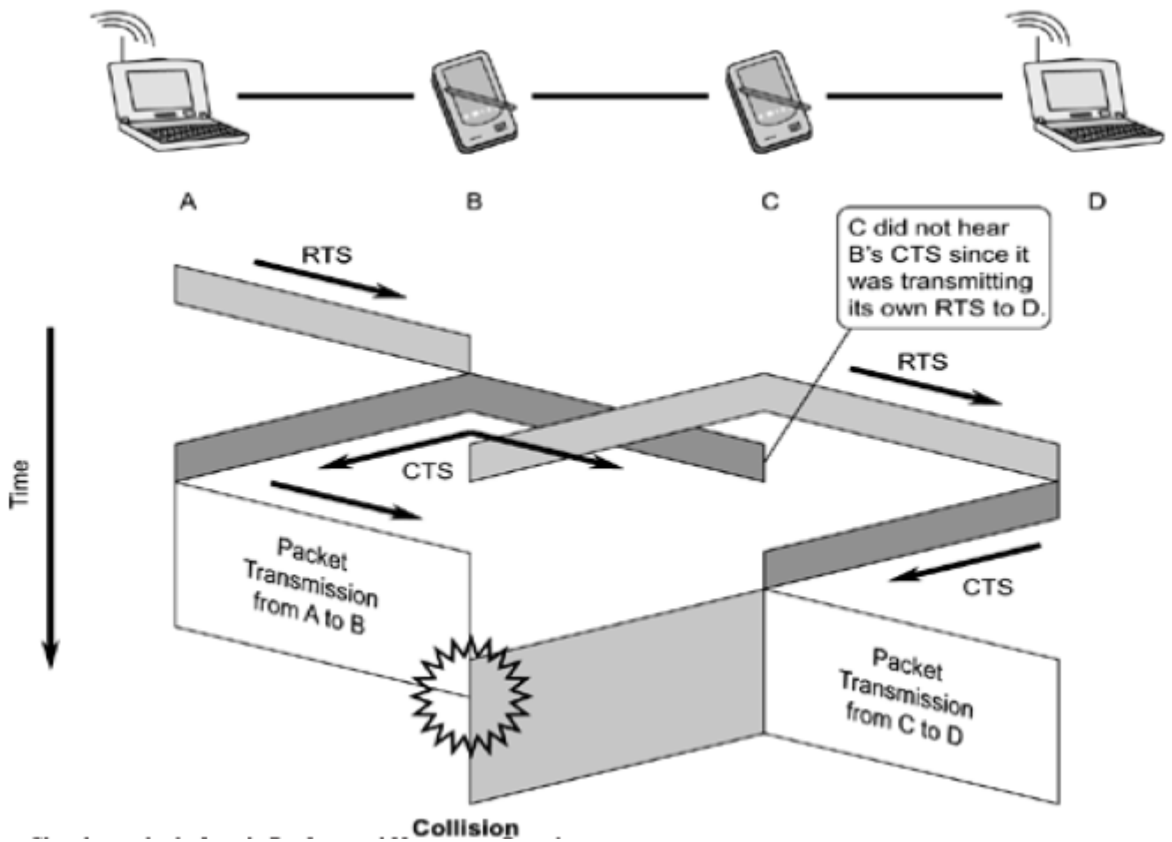
Hidden Terminal Problem

- Problems with RTS/CTS?
  - When RTS/CTS messages are sent by different nodes



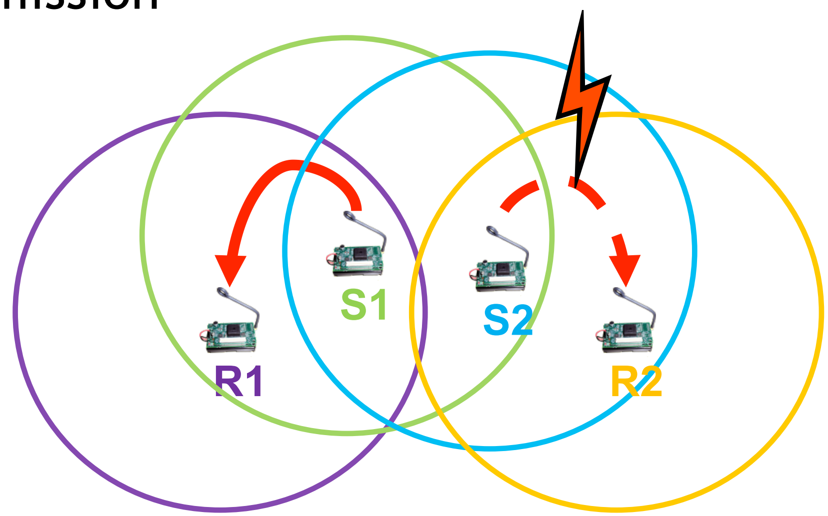
Hidden Terminal Problem

- Problems with RTS/CTS?
  - When RTS/CTS messages are sent by different nodes
  - When multiple CTS messages are granted to different neighboring nodes



Exposed Terminal Problem

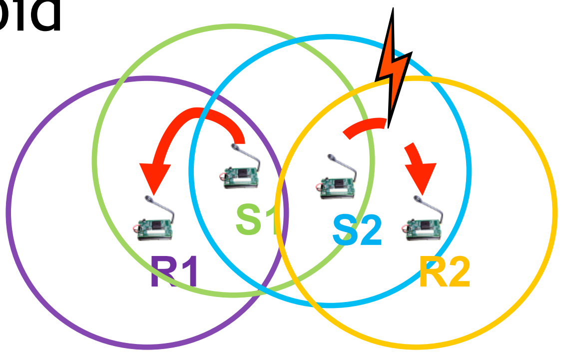
- An exposed node is one that is in the range of the transceiver but not the receiver
  - Sender mistakenly thinks that the medium is in use, and it unnecessarily defers transmission

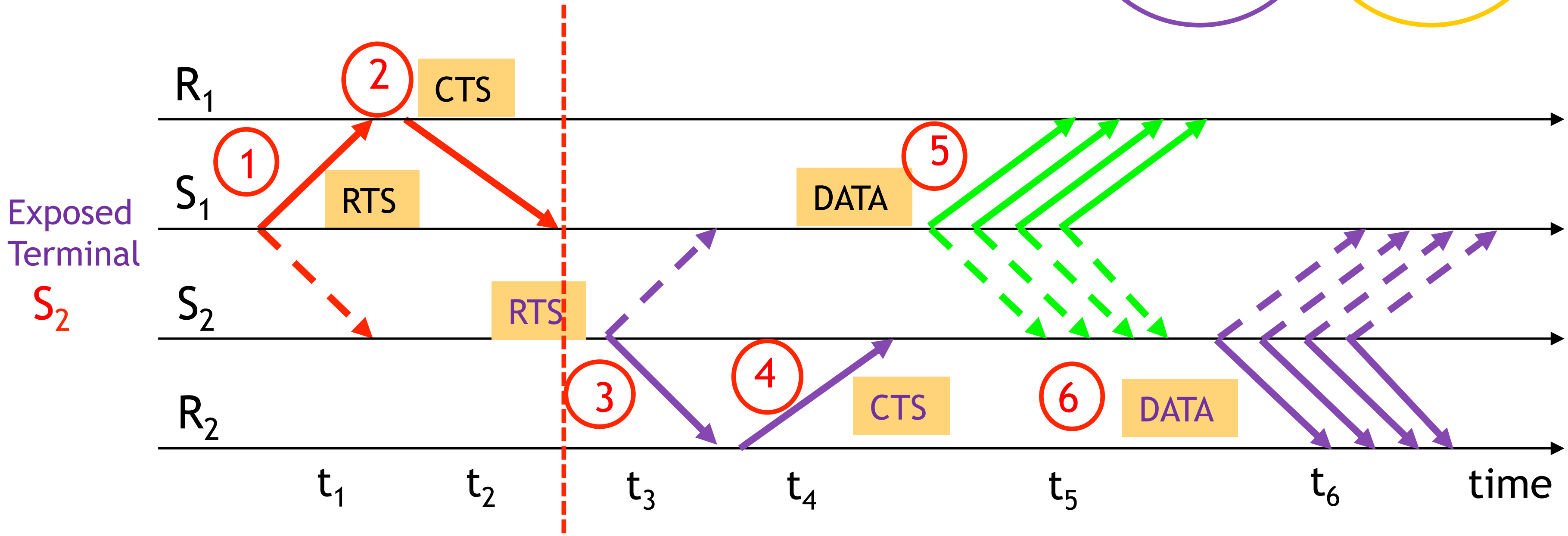


- How to avoid?
  - When a node hears an RTS but not a corresponding CTS, it can deduce that it is an exposed terminal and is permitted to transmit
  - Directional antennas

Exposed Terminal Problem

- A pictorial representation of how to avoid





Wireless MAC Protocols

Conventional of MAC Protocols

- CSMA
- CSMA/CA
- **IEEE 802.11**

Wireless MAC Protocols

CSMA

- Non Persistent: if the device detects activity on the channel, it performs a back-off by waiting before attempting to transmit

- P-persistent: if it detects an activity on the channel, it continues to sense the channel instead of delaying

- CSMA requires devices to remain in the “receive state” when not transmitting

Disadvantages

- Transceiver consumes energy too quickly

Wireless MAC Protocols

CSMA/CA

- Control messages were introduced such as (RTS/CTS) to reserve the channel
- Source first performs CSMA algorithm
- If it determines an appropriate time for transmission, it sends RTS
- Then, the destination responds with CTS

Disadvantages

- Might still have some collision in RTS

Wireless MAC Protocols

IEEE 802.11

- Infrastructure mode
  - Devices communicate through a central entity called an access point (AP) using the point coordination function (PCF)

- Ad hoc mode
  - Devices communicate with each other directly using the distributed coordination function (DCF)

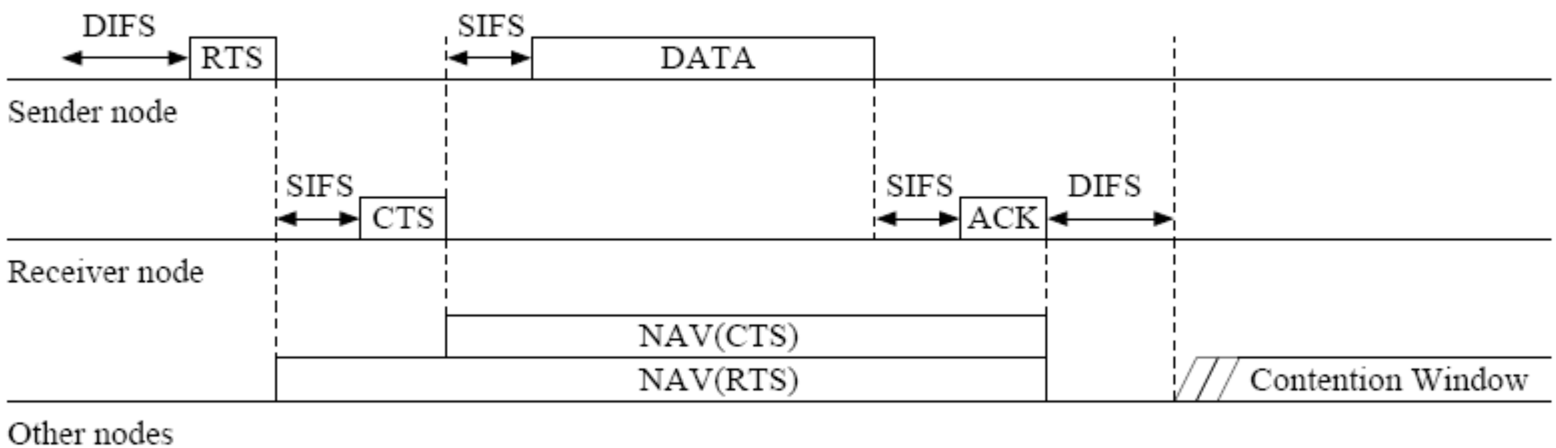
- Both the PCF and DCF use a channel access mechanism similar to CSMA/CA and use ACKs for reliability

- In addition to physical carrier sensing, IEEE 802.11 devices perform virtual carrier sensing “NAV”

Wireless MAC Protocols

IEEE 802.11 Disadvantages

- Devices consume large amounts of energy due to the high percentage of time spent listening without receiving messages



802.11 Data Transfer

Differences and Constraints

Traditional MAC protocol provides

- ❑ High throughput
- ❑ Low latency
- ❑ Fairness
- ❑ Mobility
- ❑ But have little consideration for energy

Improved MAC protocol provides

- ❑ Best performance of smallest amount of energy

Attributes of WSN MAC

More important

- ❑ Energy conservation
- ❑ Scalability and adaptively

Less important

- ❑ Throughput
- ❑ Fairness
- ❑ Latency

MAC protocol must achieve

- ❑ Establish communication link between the sensor nodes
- ❑ To share the communication medium fairly and efficiently

WSN MAC Protocols

Unscheduled WSN MAC Protocols

- Before sending a message, a sensor listens to the medium. If it's busy, wait a random time then retry again and if it's free then it will send the message

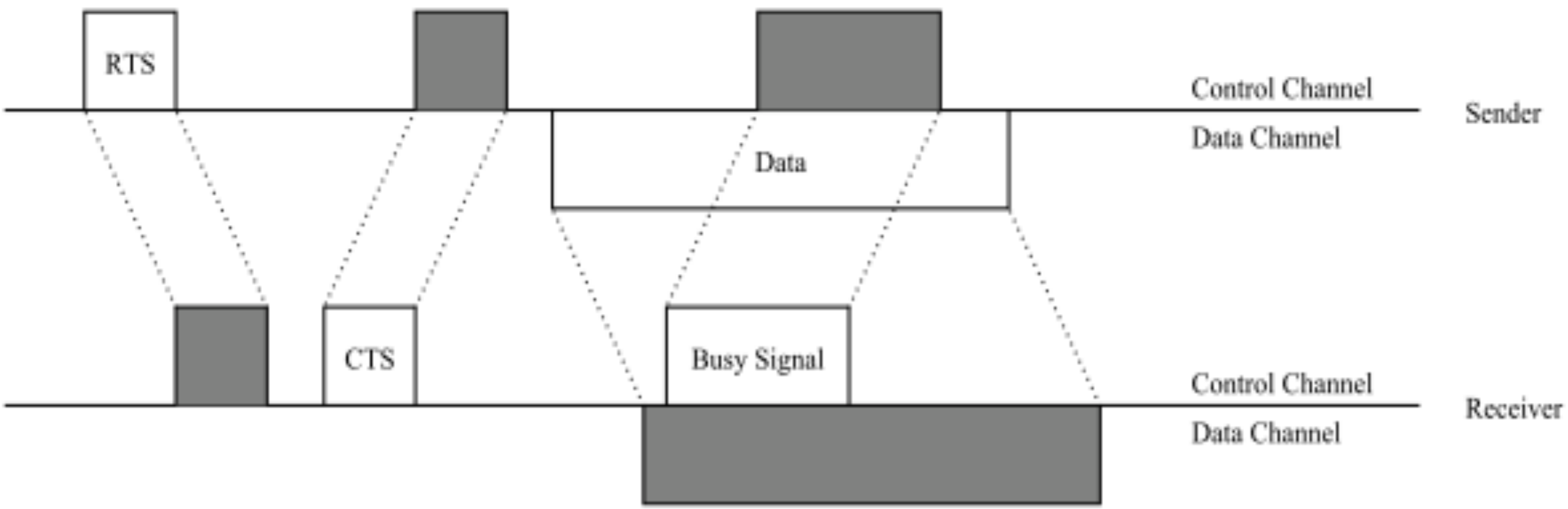
- **Advantages**
  - Can adapt for changes in the node density, traffic load, or the topology better than scheduled MAC protocols
  - Sensors don't have to be synchronized together

- **Disadvantages**
  - Worse than scheduled MAC protocols from power saving perspective since all sensors listen to the channel

Unscheduled WSN MAC Protocols

PAMAS (Power Aware Multi-Access)

- Uses multiple transceivers on each node
- Separate control and data channels



Unscheduled WSN MAC Protocols

Advantages

- ❑ Prevent collision
- ❑ Avoids exposed terminal problem

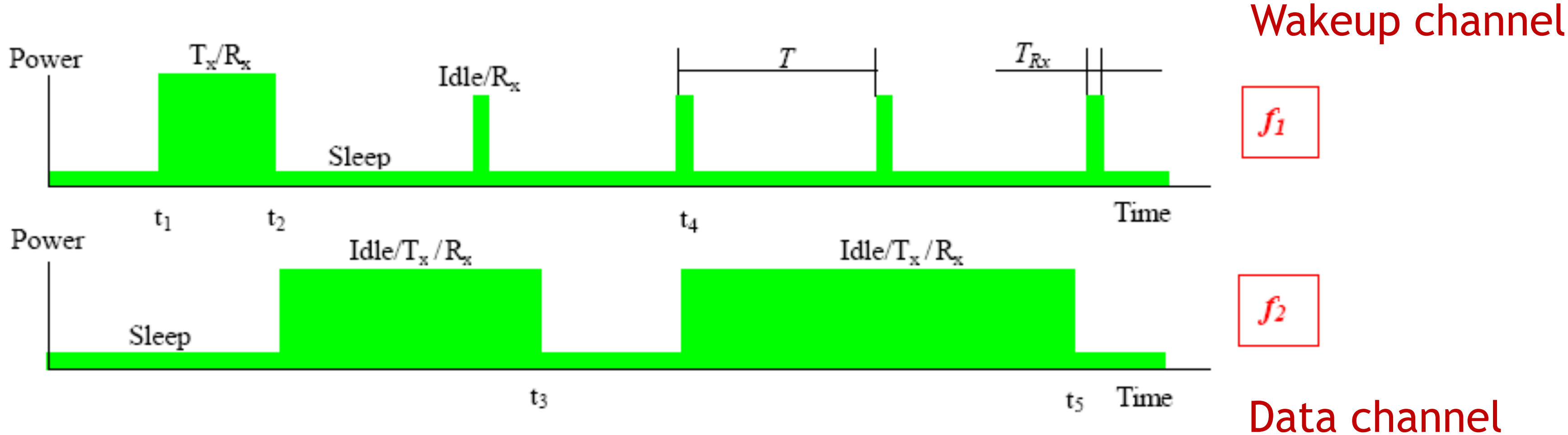
Disadvantages

- ❑ Multiple radio requirement
- ❑ Increase energy consumption
- ❑ Increase device complexity and cost

Unscheduled WSN MAC Protocols

STEM (Sparse Topology and Energy Management)

- ❑ Uses two channels, a wakeup channel and a data channel
- ❑ Requires two transceivers at each node



STEM duty cycle for single node

Unscheduled WSN MAC Protocols

STEM (Sparse Topology and Energy Management)

- Two flavors

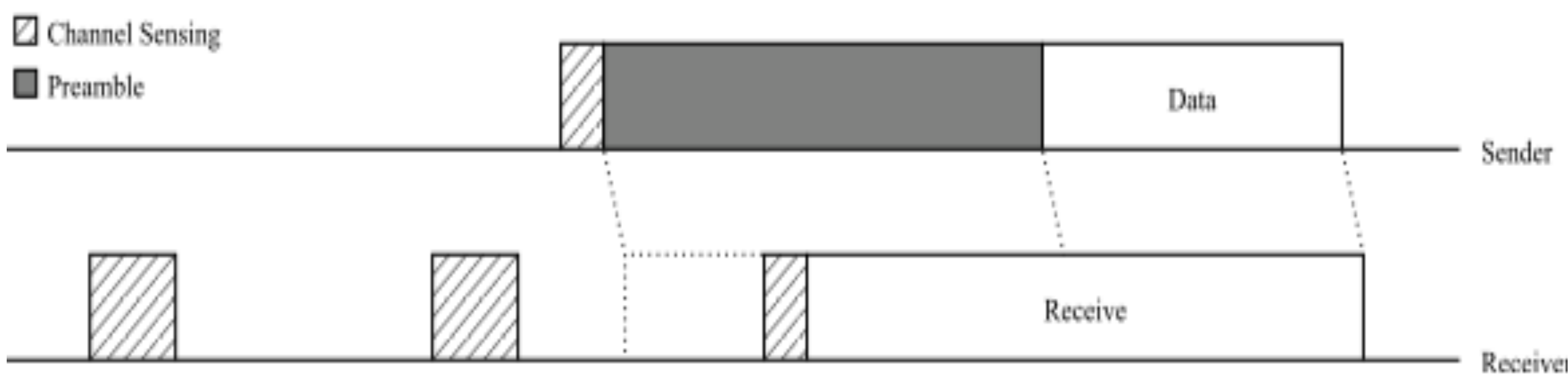
- STEM-B
  - Node which wishes to transmit sends beacon on the wakeup channel
  - Beacon contains both transmitter and receiver address
  - Low latency

- STEM-T
  - Tx sends busy tone on wakeup channel for long enough to hit the receiver's listen period
  - No address in busy tone – all nodes hearing "busy" shift to data channel, but only intended node replies
  - Higher latency and results in overhearing

Unscheduled WSN MAC Protocols

B-MAC

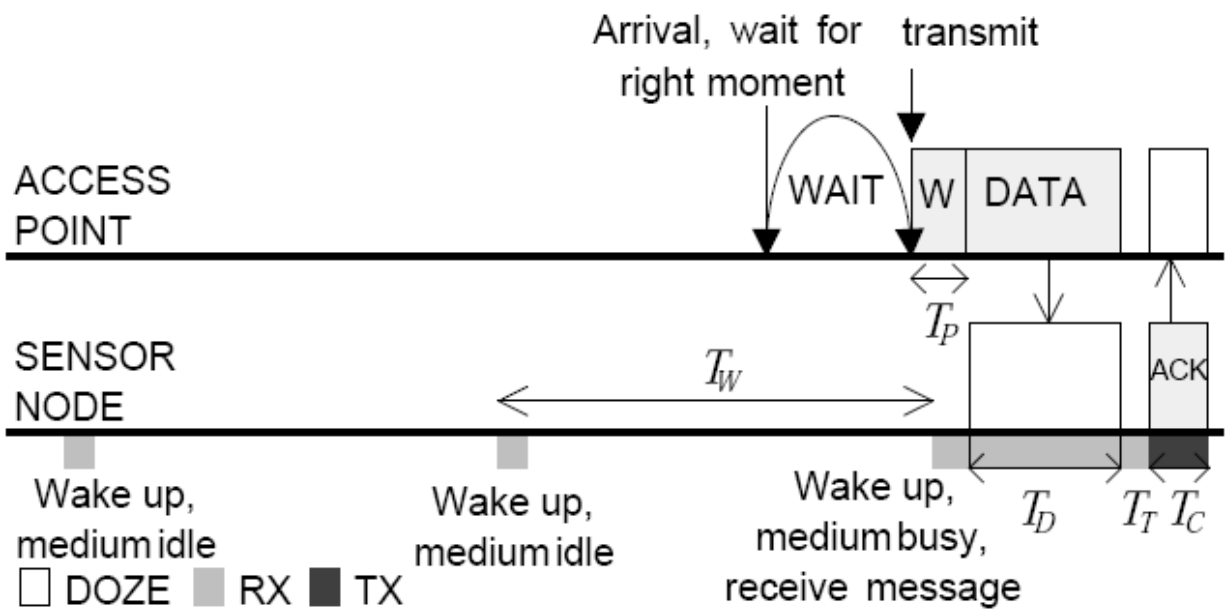
- ❑ Uses a tone to wake up sleeping neighbors, similar to STEM-T
- ❑ Uses very long preambles - dominates energy usage
- ❑ Suffers from overhearing problem



Unscheduled WSN MAC Protocols

Wise MAC

- Uses to B-MAC, but reduces energy consumption by
  - Minimizing (adaptive) preamble length
  - Having nodes remember the sampling schedules of neighbors
  - Disadvantage - cost of an extra field in the ACK message and the memory required to store neighbor's sampling offsets.



Scheduled WSN MAC Protocols

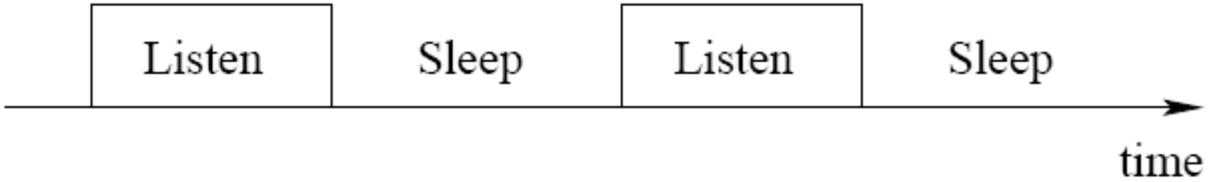
Scheduled WSN MAC Protocols

- Attempts to reduce the energy consumption by coordinating sensor nodes with a common schedule
- **Advantages**
  - Saves from wasting energy by turning off the radio outside the allocated time slot
  - Limits collision, idle listing, and overhearing
- **Disadvantages**
  - When new nodes join, they must wait till they learn – some delay
  - Cost of increased messages
  - Not flexible to changes in sensor density or movements
  - All sensors should be well synchronized

Scheduled WSN MAC Protocols

S-MAC (Sensor-MAC)

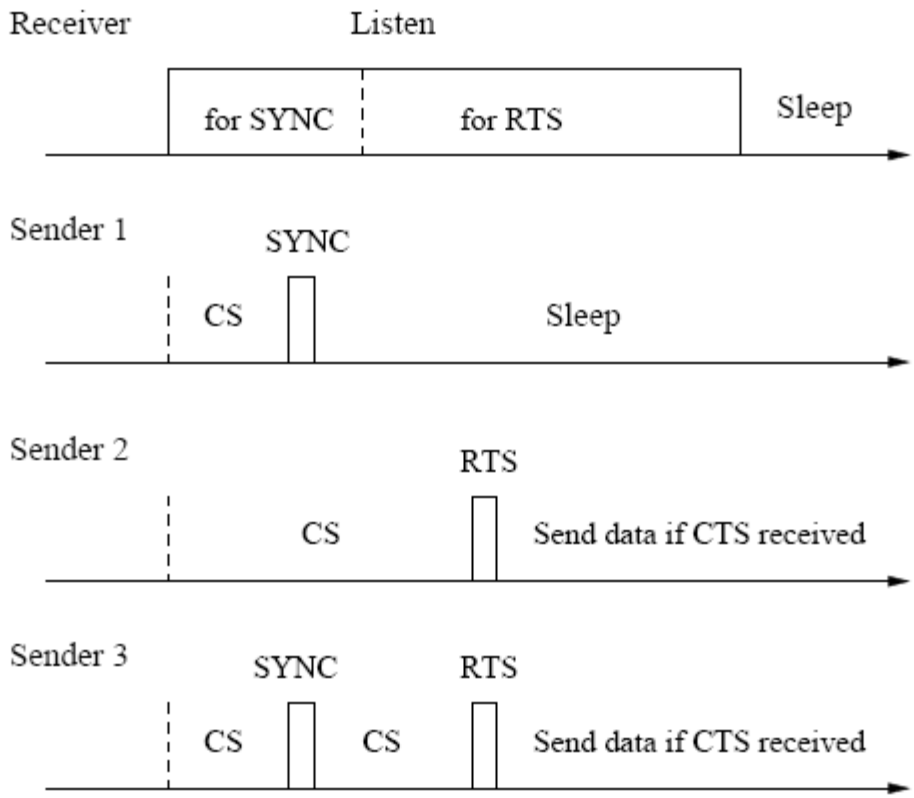
- ❑ Inspired by PAMAS, but in-channel signaling
- ❑ Nodes periodically go to a fixed listen/sleep cycle



- ❑ Virtual clustering to synchronize nodes on a common slot
- ❑ Energy is still wasted during listen period, as the sensor remains awake even if there is no reception/transmission

Scheduled WSN MAC Protocols

S-MAC (Sensor-MAC)



Timing relationship between different senders

Scheduled WSN MAC Protocols

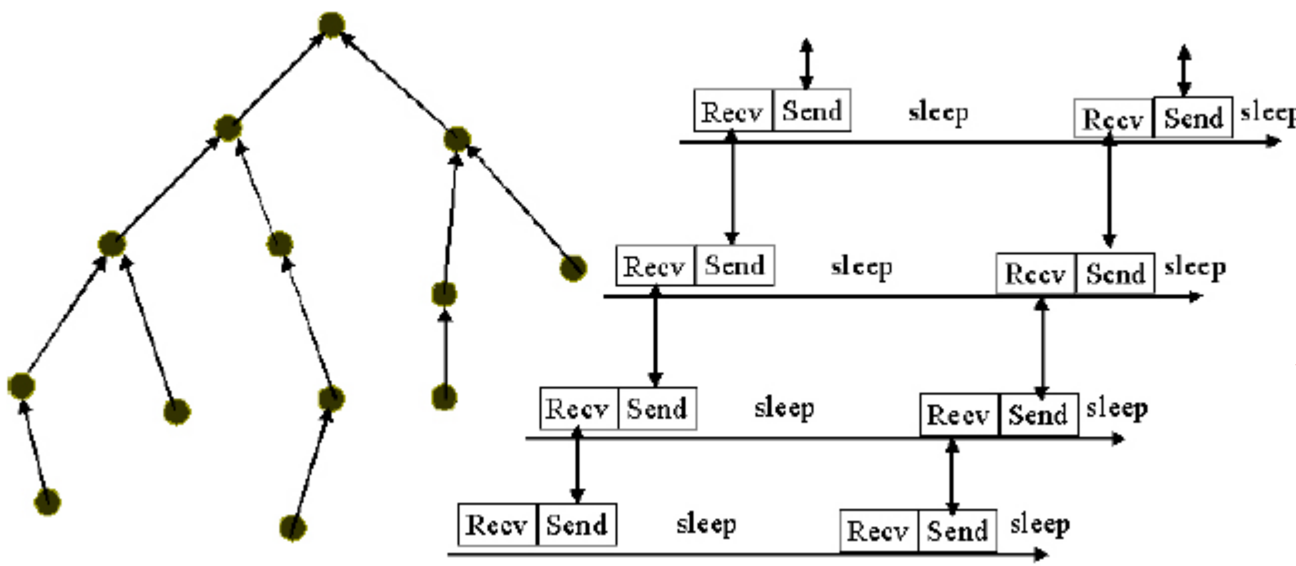
T-MAC (Timeout-MAC)

- Introduces adaptive duty cycling to improve S-MAC
  - Frees the application from the burden of selecting an appropriate duty cycle
  - Automatically adapts to traffic fluctuations
- Borrows virtual clustering from S-MAC for synchronization
  - Operates on a fixed length slot (615 ms)
  - Uses a time-out mechanism to dynamically determine the end of the active period
- Downside
  - Aggressive power-down policy (nodes often go to sleep too early)

Scheduled WSN MAC Protocols

D-MAC (Data Gathering-MAC)

- Uses adaptive duty cycling like T-MAC
  - 1 receive, 1 send, and n sleep slots
- Low node-to-sink latency: convergecast
- Divides time into short slots (10 ms) and runs CSMA/CA within each slot



Convergecast tree with matching, staggered DMAC slots

In Summary

There is no unique “best” MAC protocol for WSN. Each one is customized for specific applications.