MOBILE NETWORK PERVASIVE COMPUTING

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Materi

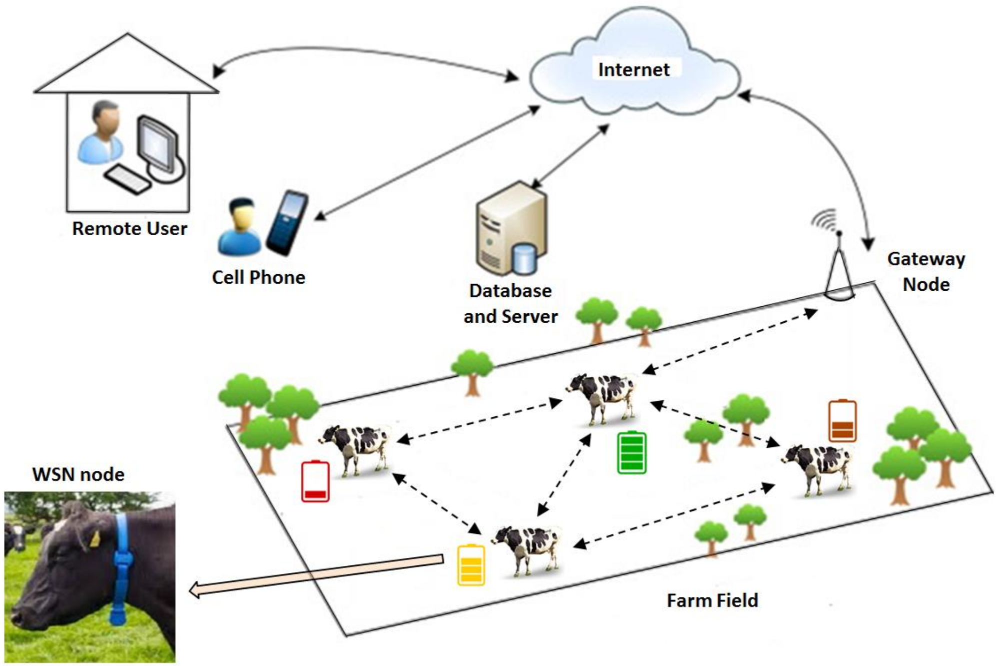
- MAC Protocol pada WSN
- Routing Protocol pada WSN
- Tipe Mobility
- MANET / VANET
- Mobility pada WSN
- Lingkungan 2 Dimensi dan 3 Dimensi

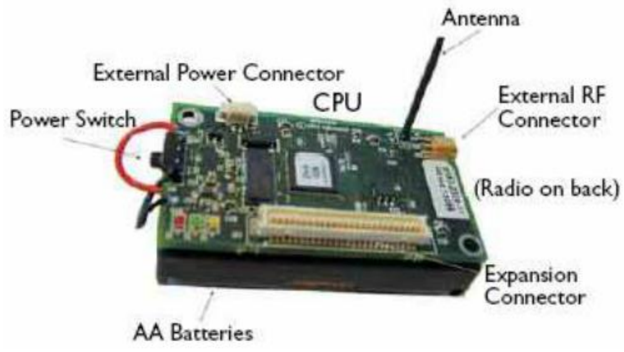
MEDIUM ACCESS CONTROL
Wireless Sensor Networks

Roadmap

- Introduction
- Characteristics of MAC Protocols in Sensor Networks
- Contention-Based MAC Protocols
- Contention-Free MAC Protocols
- Hybrid MAC Protocols

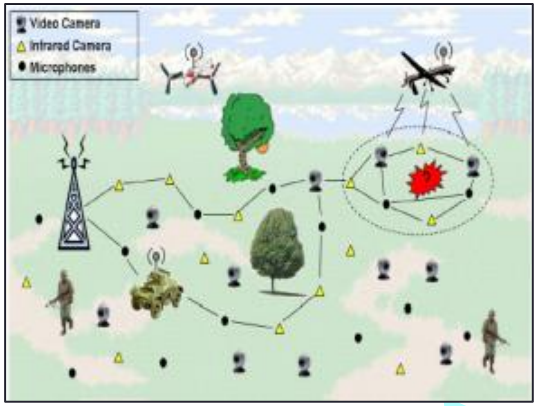
Wireless Sensor Networks (WSN)



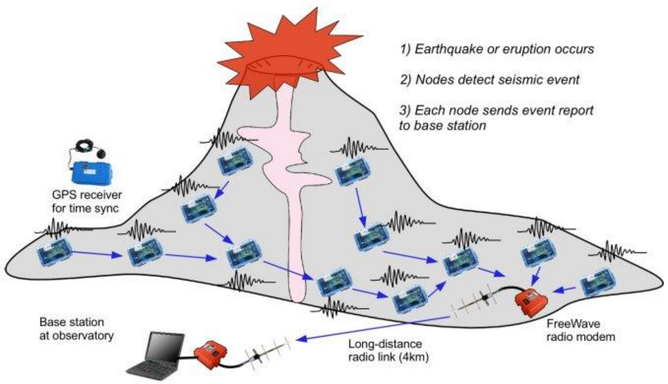


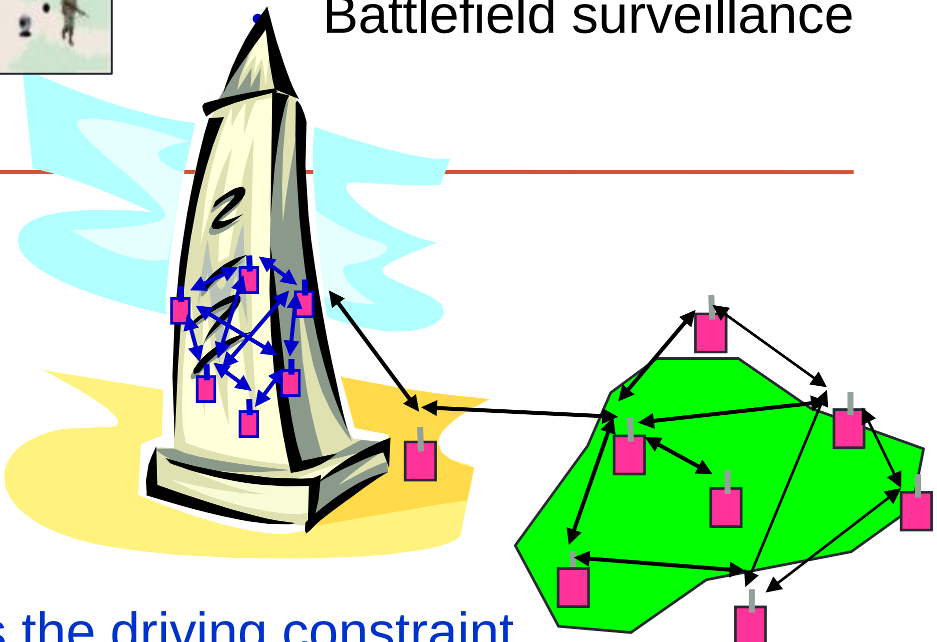
- Formed by hundreds or thousands of motes that communicate with each other and pass data along from one to another.
- Applications with considering mobility:
  - Animal Monitoring
  - Search-and-Rescue Operations
  - Healthcare Monitoring
  - Evacuation Systems

Wireless Sensor Networks



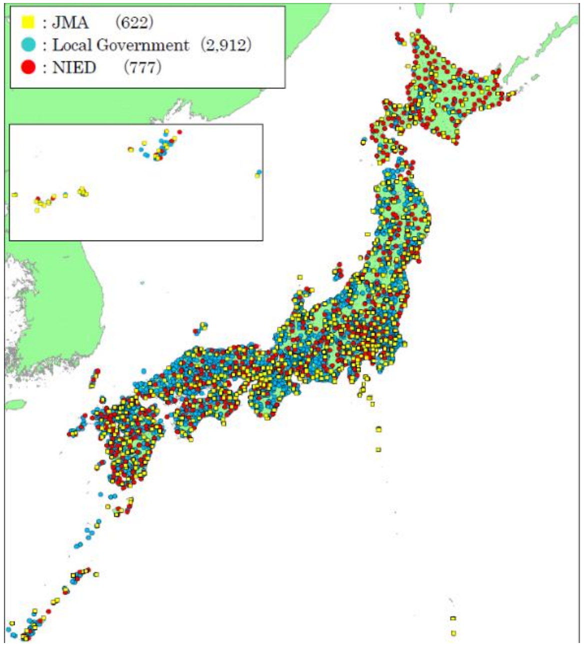
- Smart homes/buildings
- Smart structures
- Search and rescue
- Homeland security
- Event detection
- Battlefield surveillance

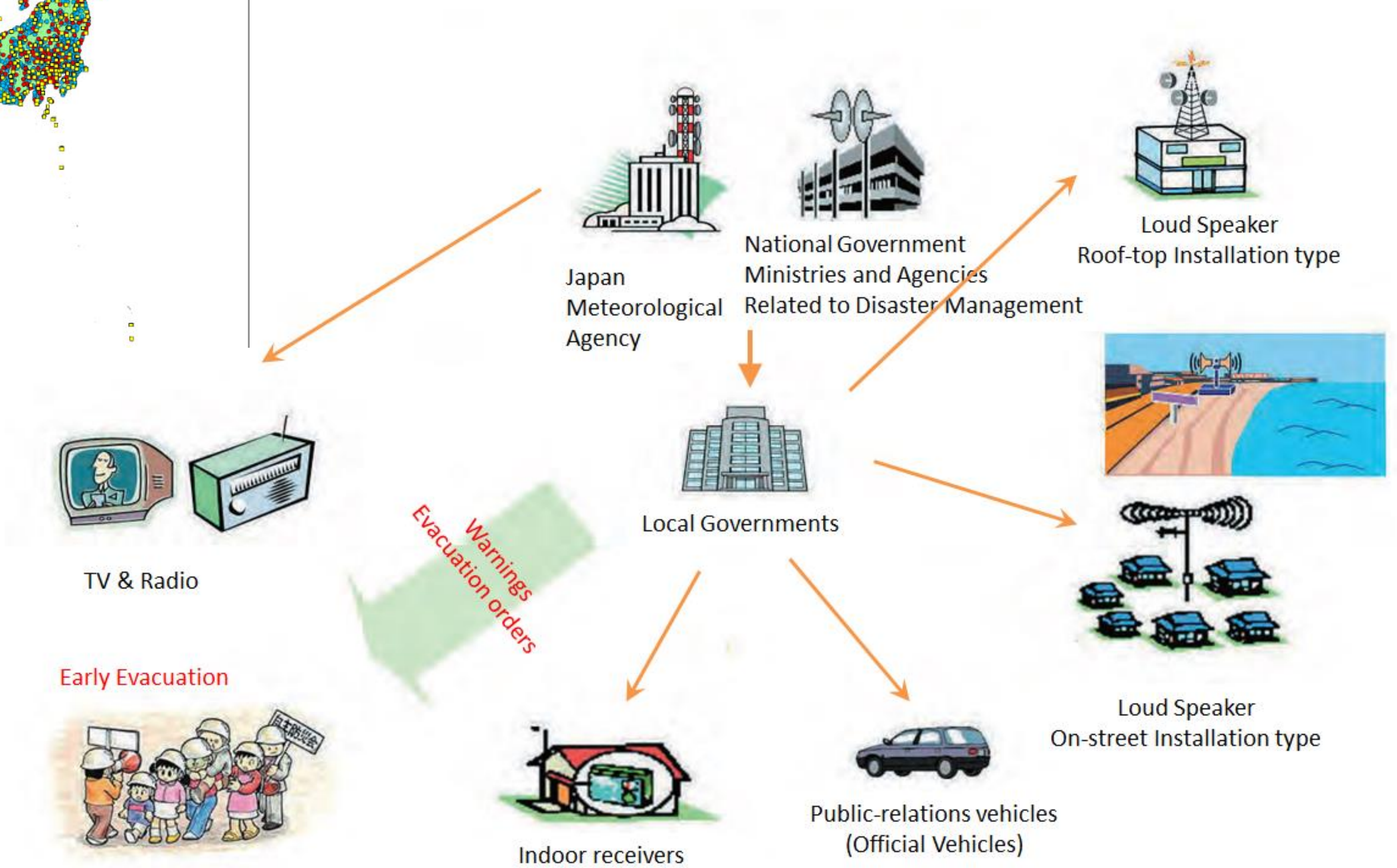




- Energy (transmit and processing) is the driving constraint
- Data generally flows to a centralized location for processing
- Intelligence is in the network rather than in the devices

Disaster Management





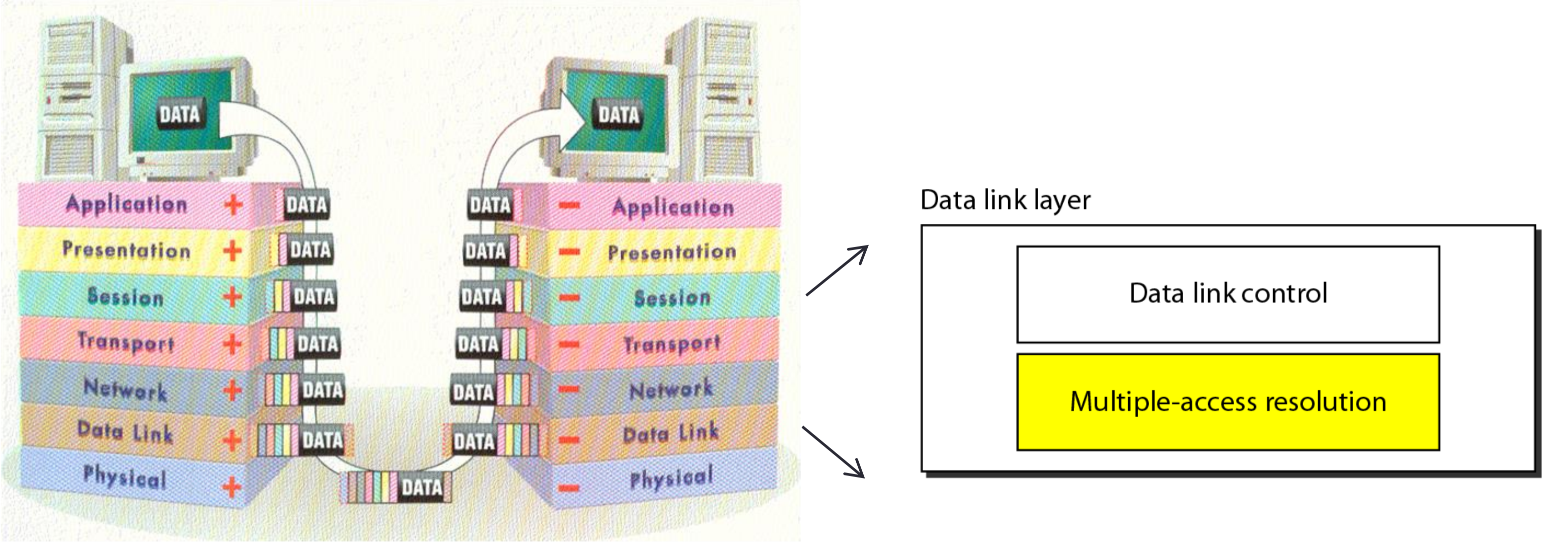
Source: Cabinet Office, *Disaster Management in Japan*

Introduction

- In most networks, multiple nodes share a communication medium for transmitting their data packets
- MAC protocol is primarily responsible for regulating access to the shared medium.
- Problem in MAC: hidden-terminal and exposed-terminal.
- Energy in MAC is for transmitting and receiving data, sensing the medium for activity (idle listening), data retransmission (e.g. due to collisions), packet overheads, control packet transmission, transmit power level are higher than necessary to reach a receiver.

Introduction

- Data link layer (IEEE 802 reference model) is divided into the logical link control layer and the MAC layer.
- The function of MAC:
  - decide when a node accesses a shared medium
  - resolve any potential conflicts between competing nodes
  - correct communication errors occurring at the physical layer
  - perform other activities such as framing, addressing, and flow control



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- Contention-Based MAC Protocols
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Characteristics of MAC Protocols in Sensor Networks

- Energy Efficiency
  - It uses finite energy sources (batteries)
  - Energy is used for transmitting, receiving, idle modes, low-power sleep mode
  - Reason for energy inefficiency: idle listening, inefficient protocol designs (e.g., large packet headers), reliability features (e.g., collisions requiring retransmissions or other error control mechanisms), and control messages to address the hidden-terminal problem., choice of modulation scheme and transmission rate
- Scalability
  - MAC protocols must be able to allow for efficient use of resources without incurring unacceptable overheads, particularly in very large area.

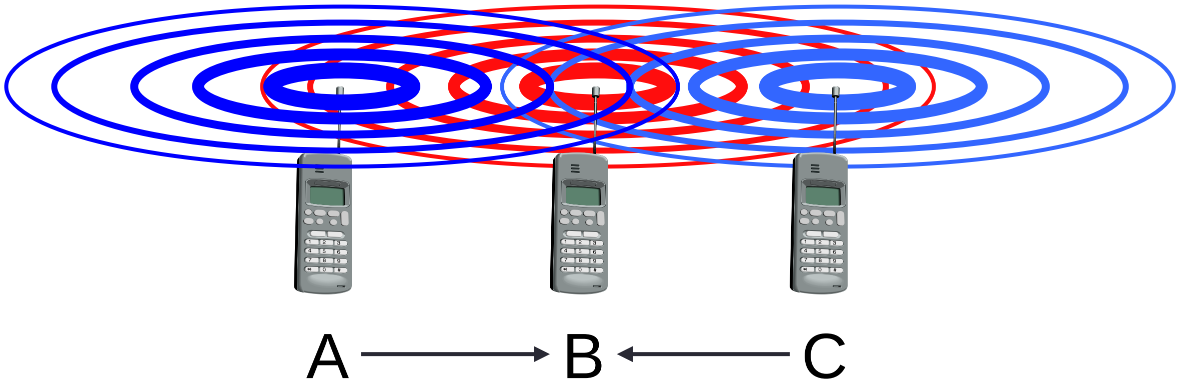
Characteristics of MAC Protocols in Sensor Networks

- Adaptability
  - Ability to self-manage and adapt to changes in the networks, including changes in topology, networks size, density, and traffic characteristics (without significant overheads).
- Low Latency
  - Many WSN applications have timeliness requirements: sensor data must be collected, aggregated, and delivered within certain latency constraints.
- Reliability
  - The design of the MAC protocol can contribute to increased reliability by detecting and recovering from transmission errors and collisions (e.g., using ACK and retransmit).
- Fairness
  - Every node should get an equal amount of resources
  - no node should receive special treatment

Problems in Wireless Channel Access

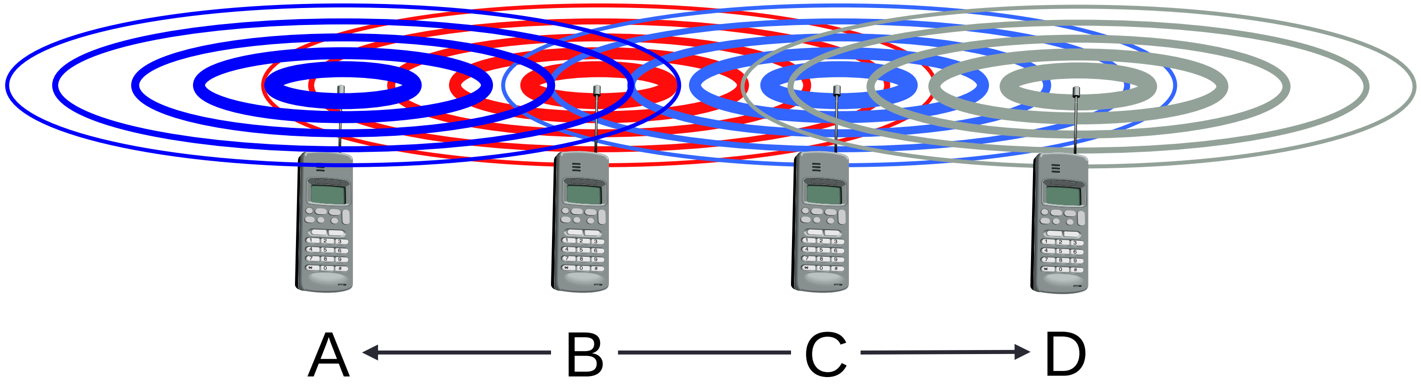
Hidden Terminal Problems

- senders A and C are able to reach B, but cannot overhear each other's signals
- it is possible for A and C to transmit data to B at the same time, causing a collision at B, without being able to directly detect this collision



Exposed-Terminal Problems

- C wants to transmit data D, but decides to wait because it overhears an ongoing transmission from B to A
- B’s transmission could not interfere with data reception at D since D is outside the transmission range of B. As a consequence, node C’s decision to wait delay its transmission unnecessarily.



Requirements for Energy-efficient MAC Protocols

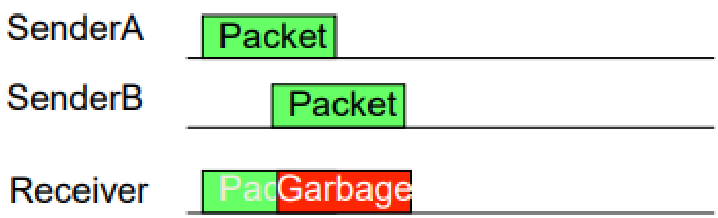
- Energy budget
  - Sending a packet is costly
  - Receiving a packet about as expensive as transmitting
  - Receiver must listen in order to be ready to receive

- Energy is wasted due to
  - 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

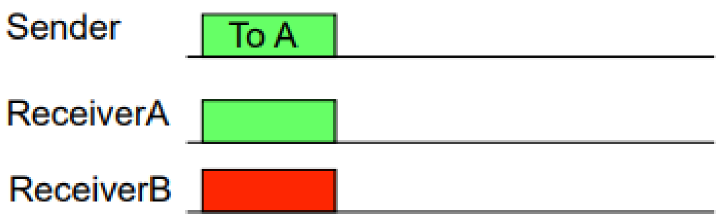
Energy Wastings

Idle listening

Collisions

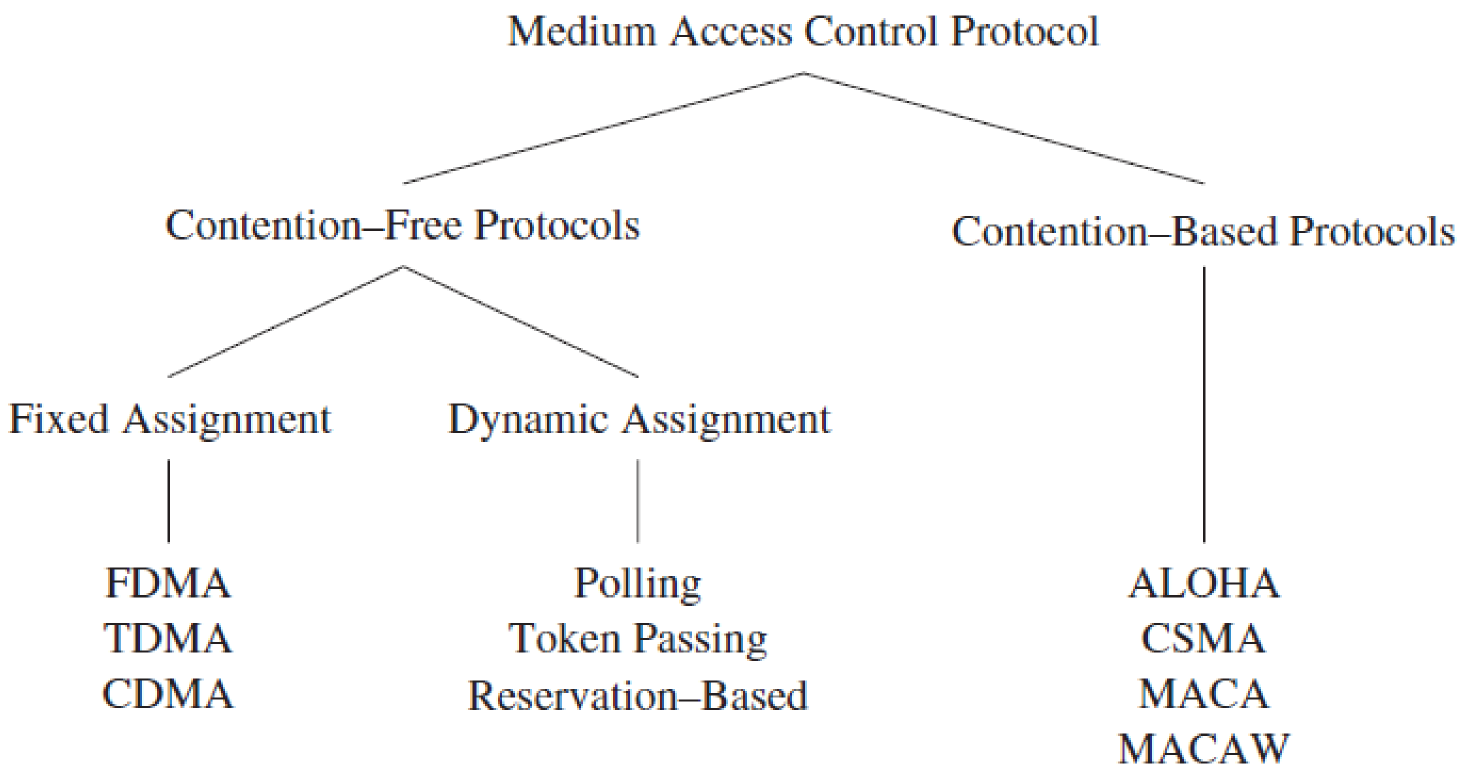


Overhearing



MAC protocol should reduce these wastings!

Categories of MAC



Contention-Free Medium Access

- Collisions can be avoided by allocating resources to nodes such that each node can use its resource exclusively.
- FDMA (Frequency Division Multiple Access) divide the frequency band into several smaller bands, which can be used for data transfer between a pair of nodes, while all other nodes that could potentially interfere with this transfer use a different frequency band.
- TDMA allows multiple devices to use the same frequency band, but it uses periodic time windows (called frames), consisting of a fixed number of transmission slots, to separate the medium access of different devices.
- CDMA, simultaneous accesses of the wireless medium are supported using different codes.
- Fixed assignment strategies are inefficient
  - generating schedules for an entire network can be a taunting task
  - these schedules may require modifications every time the network topology or traffic characteristics in the network change

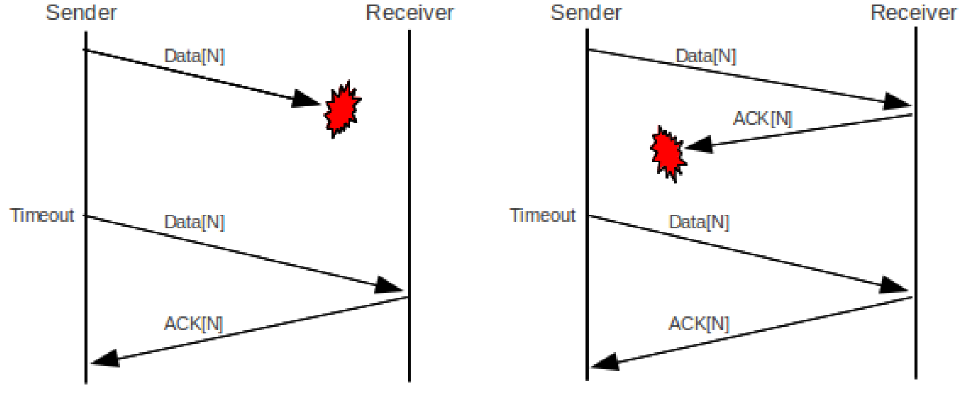
Contention-Free Medium Access

- To address the problem, it can use Dynamic assignment strategies: allow nodes to access the medium on demand
  - polling-based protocols
    - a controller device issues small polling frames in a round-robin fashion, asking each station if it has data to send
  - token passing
    - stations pass a polling request to each other (round-robin fashion) using a special frame called a token
    - a station is allowed to transmit data only when it holds the token
  - reservation-based protocols
    - static time slots used to reserve future access to the medium
    - e.g., a node can indicate its desire to transmit data by toggling a reservation bit in a fixed location (very complex protocols)

Contention-Based Medium Access

- This protocol allow nodes to contend to access the medium at the same time but provide mechanisms to reduce the number of collisions and to recover from collisions.
- Example: ALOHA protocol
  - uses ACK to confirm the success of a broadcast data transmission.
  - allows nodes to access the medium immediately but addresses collisions with approaches such as exponential back-off to increase the likelihood of successful transmissions.
- Example: slotted-ALOHA protocol
  - requires that a station may commence transmission only at predefined points in time (the beginning of a time slot)
  - increases the efficiency of ALOHA
  - introduces the need for synchronization among nodes

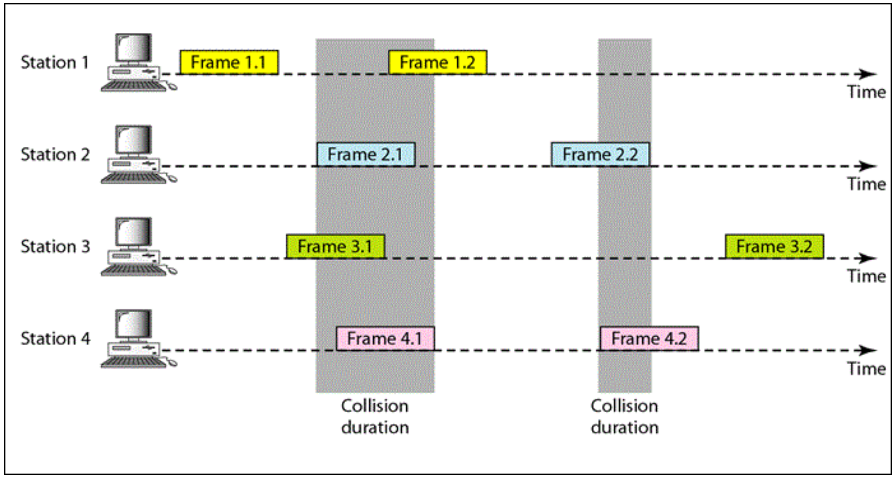
Contention-Based Medium Access



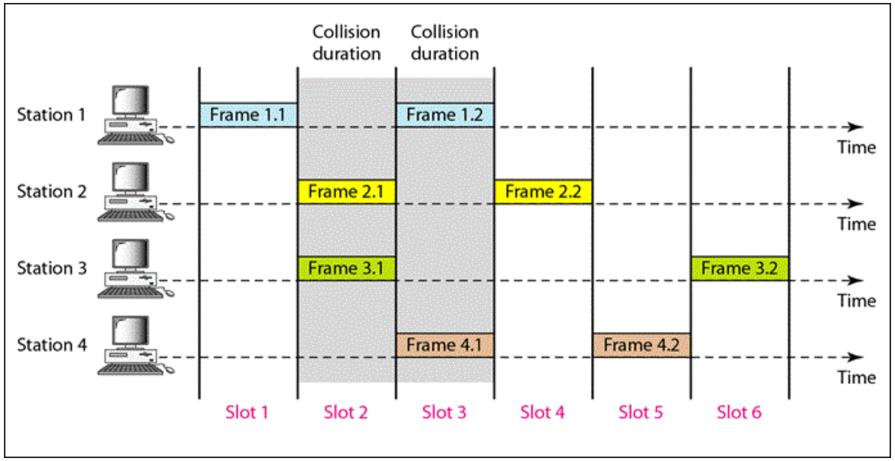
Lost Data

Lost ACK

ALOHA



SLOTTED-ALOHA



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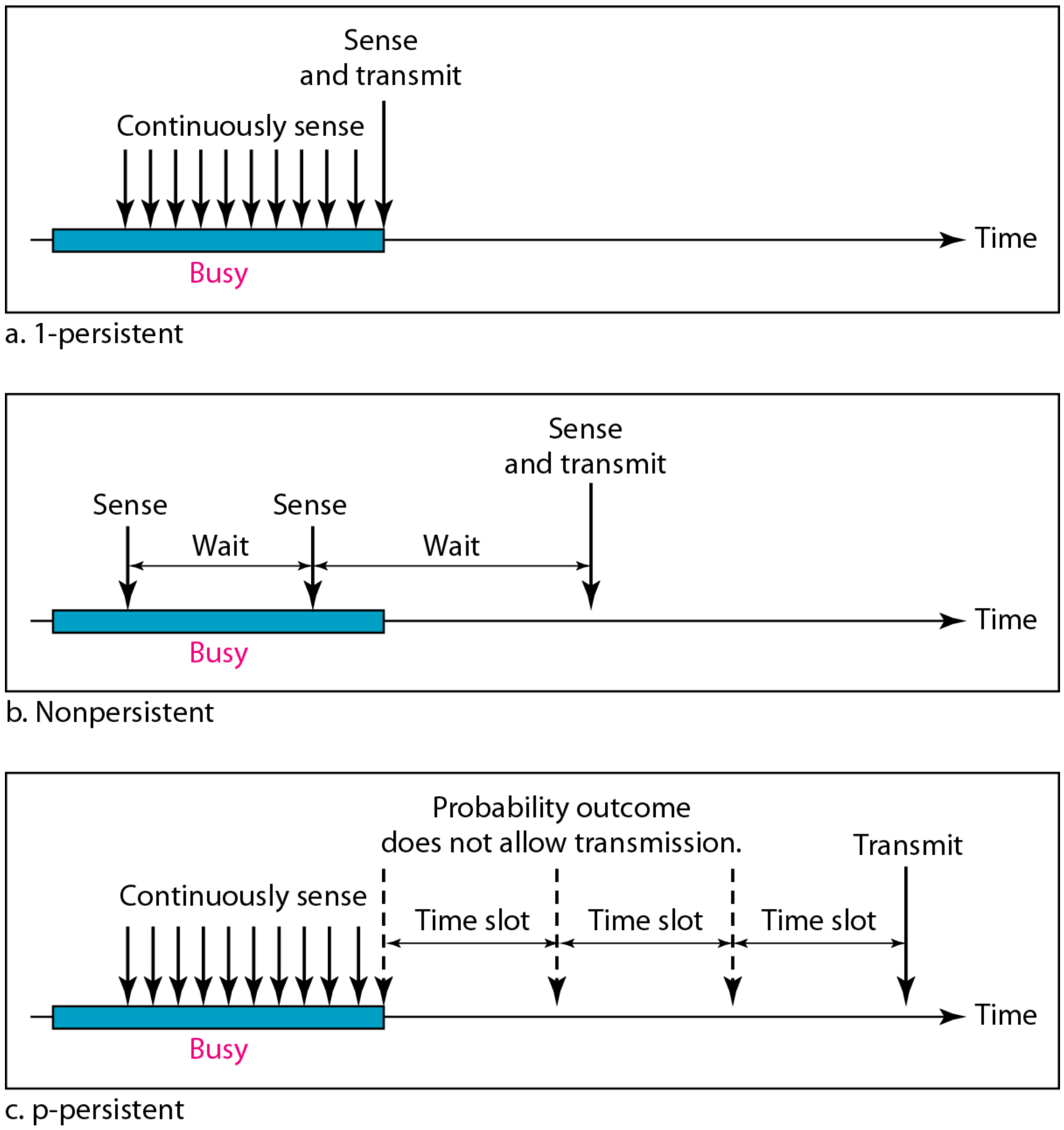
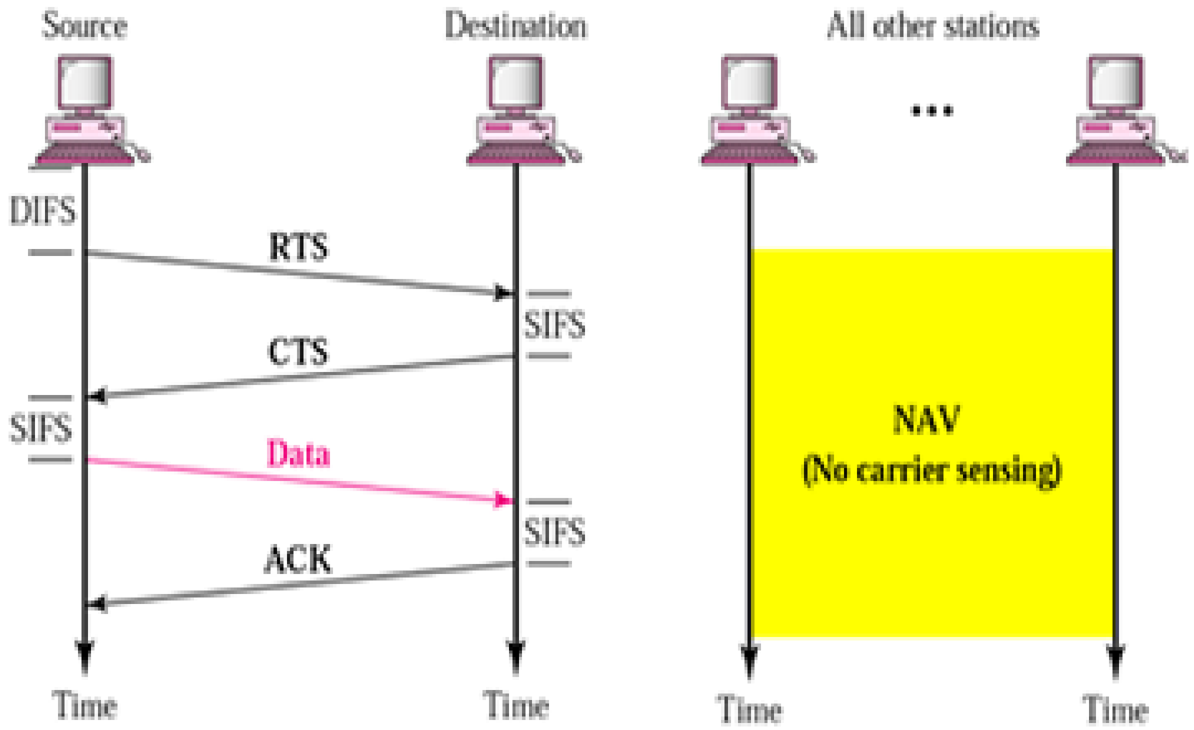
Contention-Based MAC Protocols

- These protocols do not rely on transmission schedules, instead they require other mechanisms to resolve contention when it occurs
- The main advantage of contention-based techniques is their simplicity compared to most schedule-based techniques
  - most contention-based protocols do not require to save, maintain, or share state information
  - this also allows contention-based protocols to adapt quickly to changes in network topologies or traffic characteristics
- However, they typically result in higher collision rates and overheads due to idle listening and overhearing (overheads usually refer to additional bits in a packet or additional packets such as control packets)
- They may also suffer from fairness issues (i.e., some nodes may be able to obtain more frequent channel accesses than others)
- Improvement of ALOHA protocol: Carrier Sense Multiple Access (CSMA) Protocols

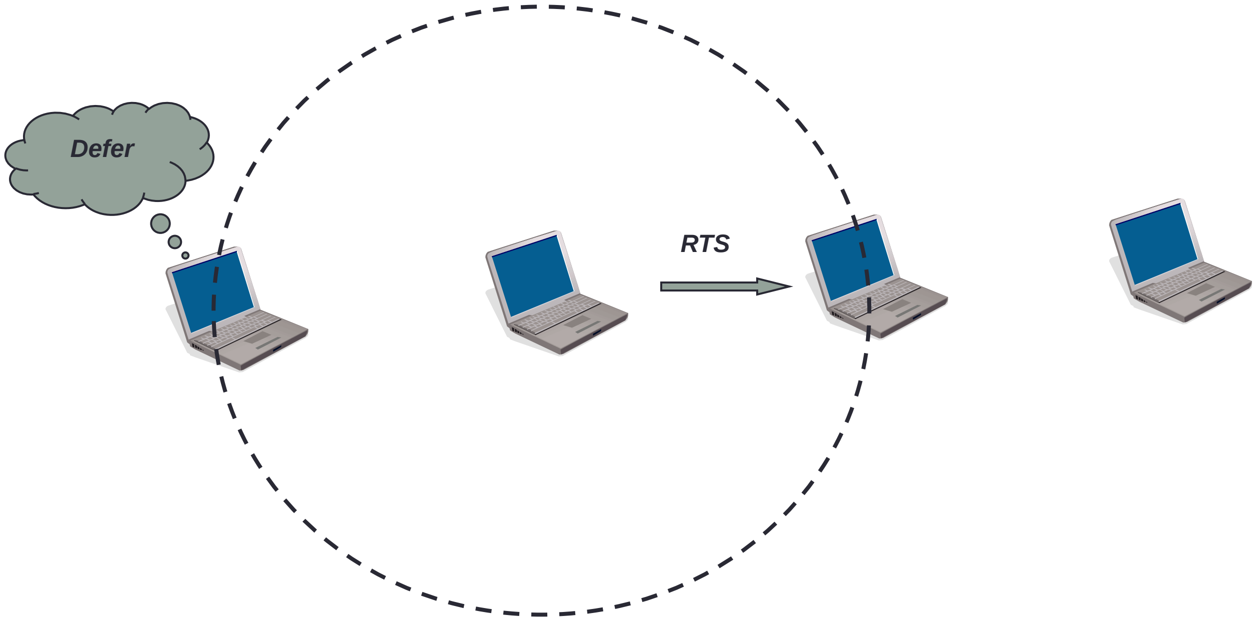
Behavior of three persistence methods (CSMA)



CSMA/CA
Collision Avoidance

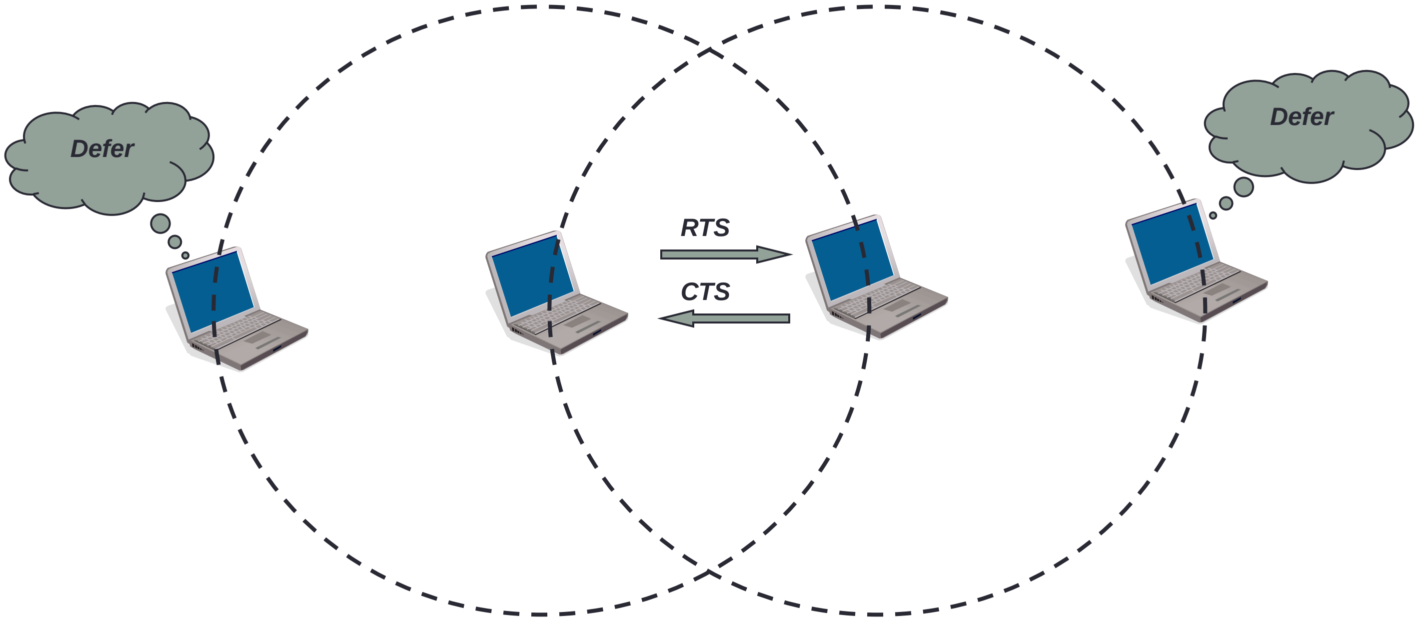


RTS/CTS dialog (1)



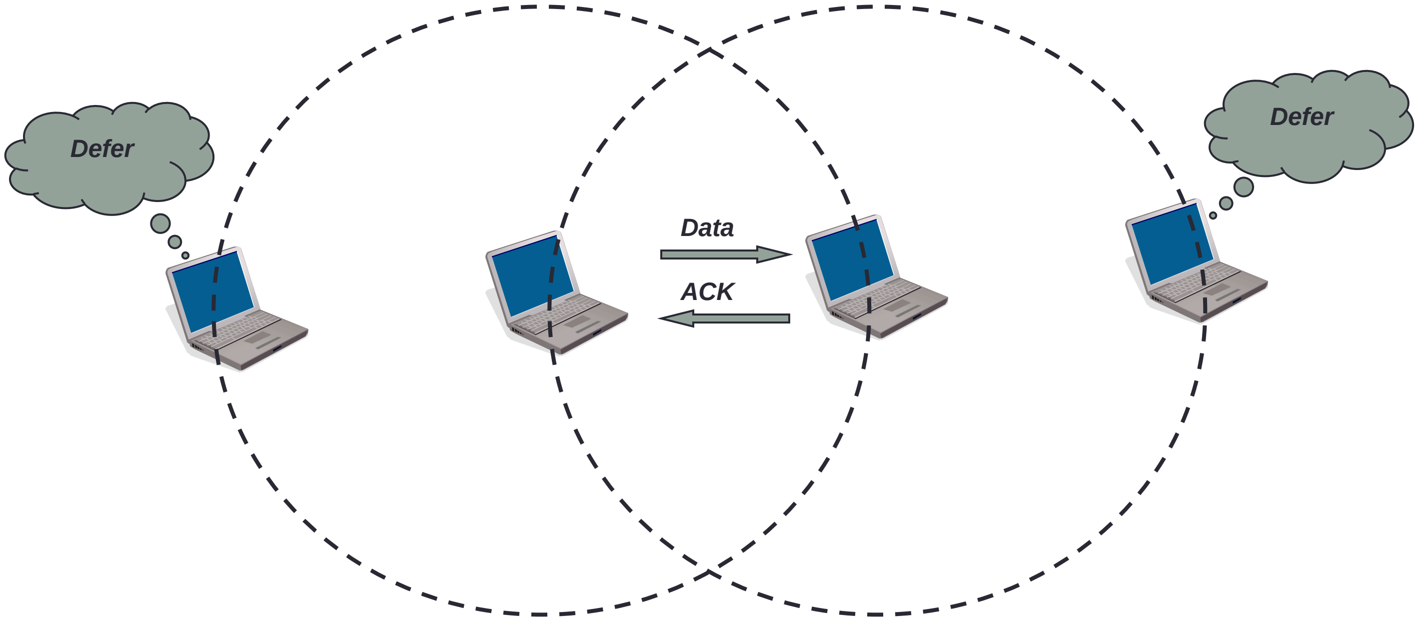
Any node hearing this RTS (RequestToSend) will defer medium access

RTS/CTS dialog (2)

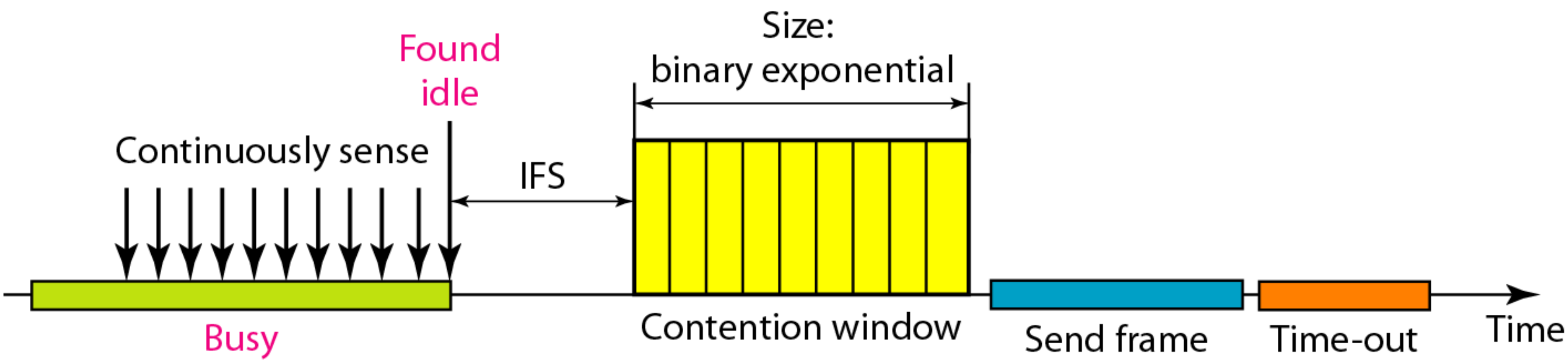


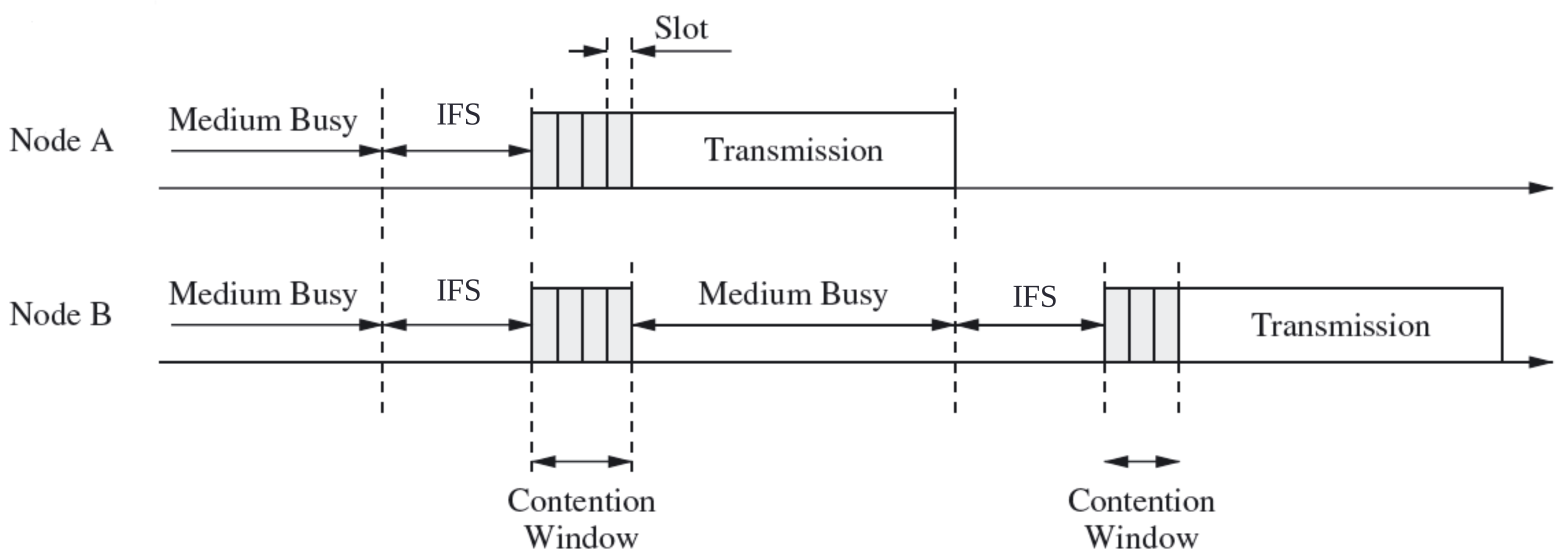
Any node hearing this CTS (ClearToSend) will defer medium access

RTS/CTS/DATA/ACK dialog



Timing in CSMA/CA



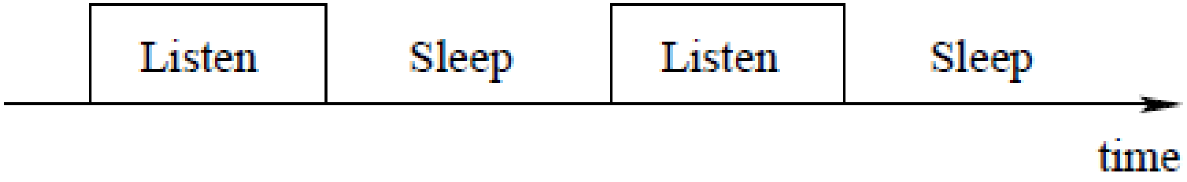


Contention-Based MAC Protocols

- Sensor MAC
- Timeout MAC
- Berkeley MAC

Sensor MAC

- The goal of the S-MAC protocol is
  - to reduce unnecessary energy consumption
  - providing good scalability and collision avoidance mechanism
- S-MAC adopts a duty-cycle approach
  - nodes periodically transition between a listen state and a sleep state to avoid idle listening
  - Sleep during other nodes transmission



Sensor MAC
Periodic Listen and Sleep

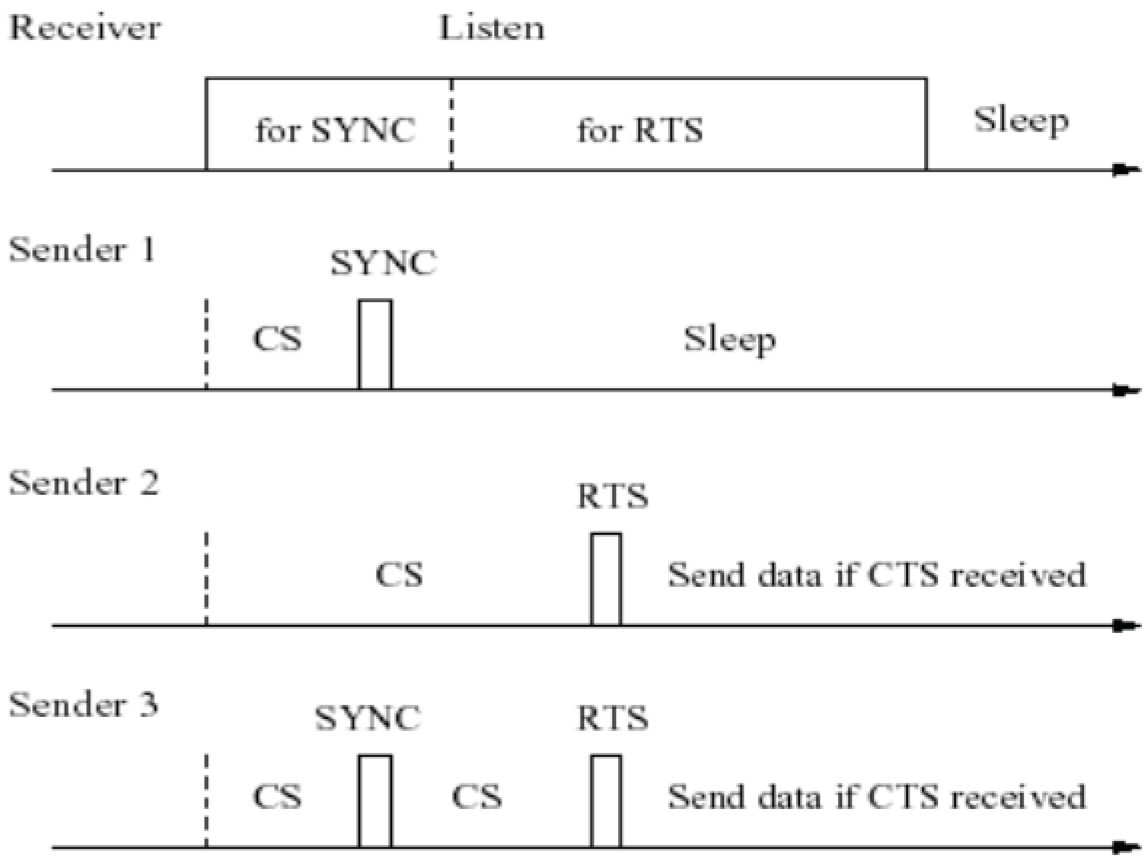
- If no sensing event happens, nodes are idle for a long time so it is not necessary to keep the nodes listening all the time
- Each node go into periodic sleep mode during which it switches the radio off and sets a timer to awake later
- When the timer expires it wakes up and listens to see if any other node wants to talk to it
- If a node A wants to talk to node B, it just waits until B is listening
- If multiple neighbors want to talk to a node, they need to contend for the medium using RTS/CTS scheme

Sensor MAC
Choosing and Maintaining Schedules

- In order to choose a schedule, a node initially listens to the medium for a certain amount of time
  - if this node receives a schedule from a neighbor, it chooses this schedule as its own and this node becomes a follower
  - the node broadcasts its new schedule after a random delay t_d to minimize the possibility for collisions from multiple new followers
- Nodes can adopt multiple schedules if a node receives a different schedule after it has broadcast its own schedule
  - it then adopts both schedules
- If a node does not hear a schedule from another node
  - it determines its own schedule
  - broadcasts this schedule to any potential neighbors
  - and this node becomes a synchronizer (in that other nodes will begin to synchronize themselves with it)

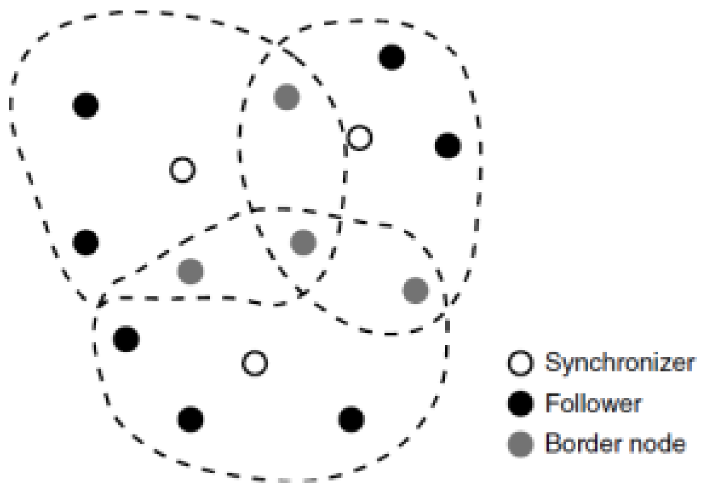
Sensor MAC
Timing Relationship

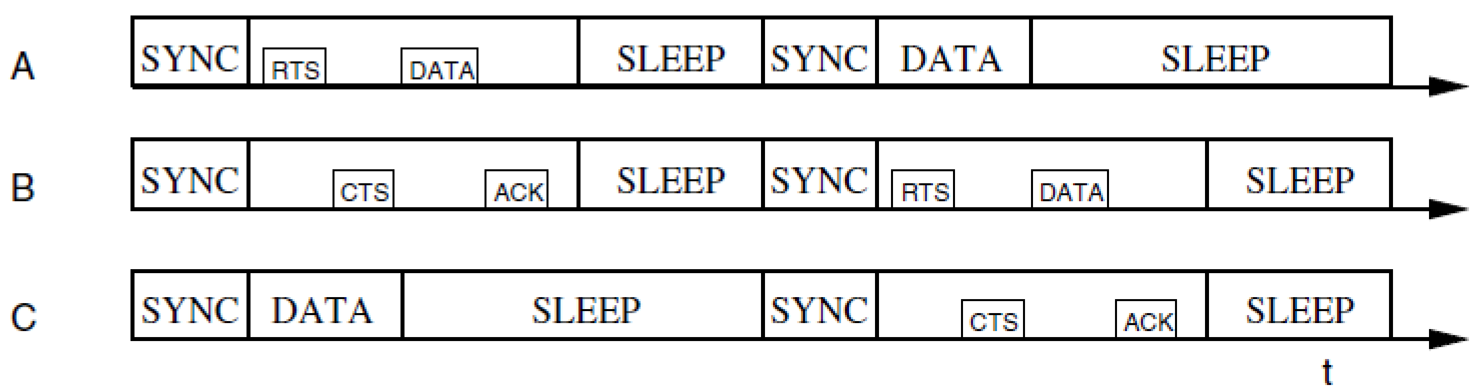
- S-MAC divides a node's listen interval further into
  - a part for receiving SYNC packets
  - a part for receiving RTS messages



cs: carrier sense

Sensor MAC
CSMA/CA in Sensor MAC



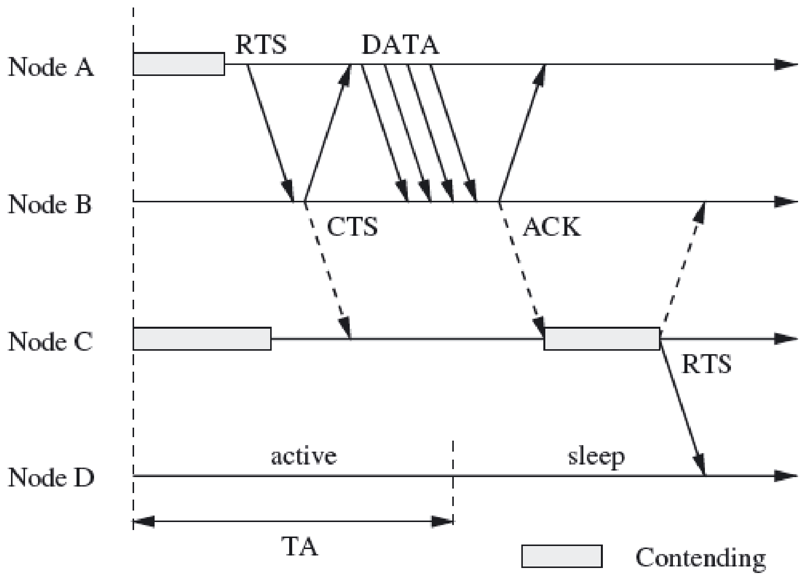


Timeout MAC

- If there is only little traffic, S-MAC can actually waste energy because the listening period of S-MAC is of fixed duration
- On the other hand, if traffic is heavy, the fixed duration may not be large enough
- Therefore, the T-MAC protocol is a variation of S-MAC that uses an active period that adapts to traffic density
- Nodes wake up during the beginning of a slot to listen very briefly for activity and return to the sleep mode when no communication has been observed
- When a node transmits, receives, or overhears a message, it remains awake for a brief period of time after completion of the message transfer to see if more traffic can be observed
  - this brief timeout interval allows a node to return to the sleep mode as quickly as possible
  - the end effect is that a node's awake times will increase with the heavier traffic and will be very brief if traffic is light

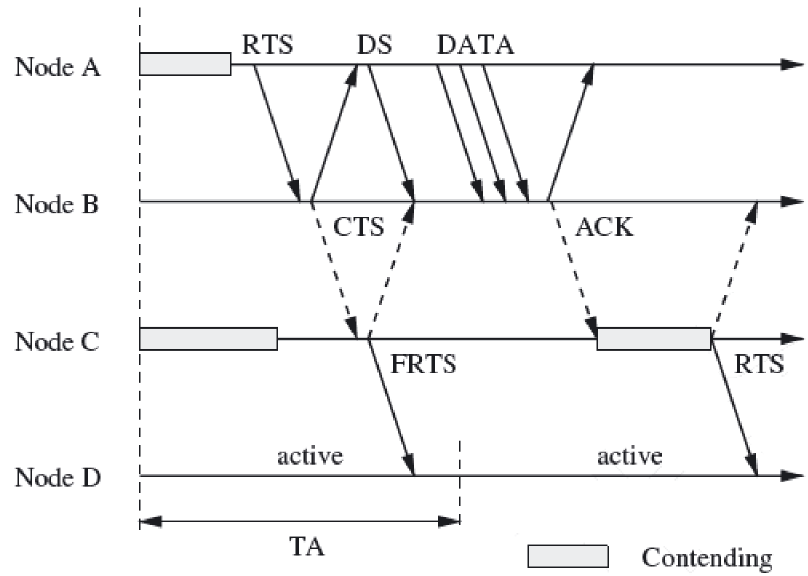
Timeout MAC

- To reduce potential collisions, each node waits for a random period of time within a fixed contention interval before the medium is accessed



(a)

Early sleeping problem



(b)

Future-request-to-send

Timeout MAC

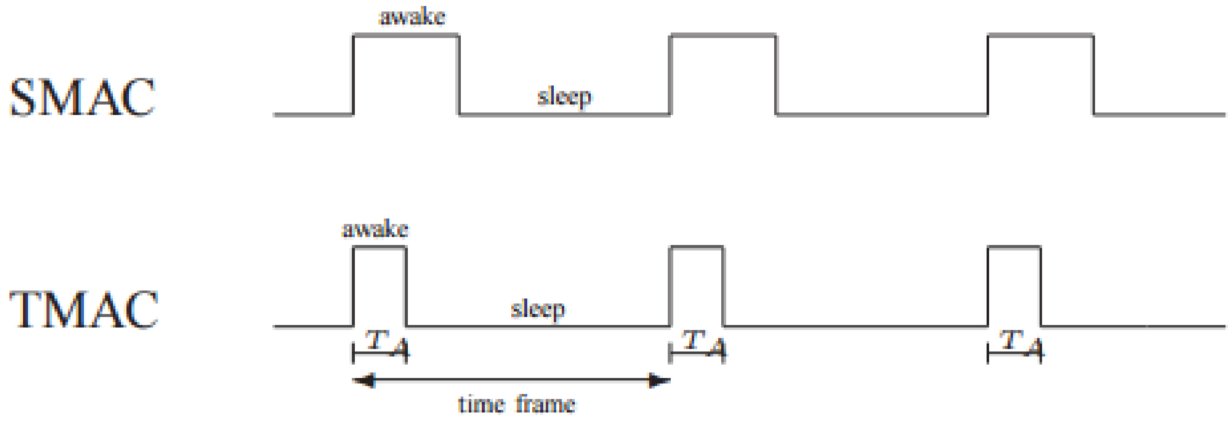
- Once a node hears a CTS, it knows that another node won the medium
- This node then stays awake until the end of the transmission, which can be observed by overhearing the acknowledgment (ACK) sent by node B
- This event initiates the beginning of the next contention interval and node C will have an opportunity to transmit its data if it wins the medium
- In figure, assume that messages flow from top to bottom
  - node A sends only to node B
  - every time node C wants to send a message to node D, C must contend for the medium
    - C may lose to node B (B may transmit an RTS before C does) or
    - C may lose to node A (C overhears a CTS transmitted by node B)
  - while node C stays awake after overhearing node B's CTS message, its intended receiver (node D) is not aware of C's intention to transmit data and therefore returns to the sleep mode after TA has expired

Timeout MAC

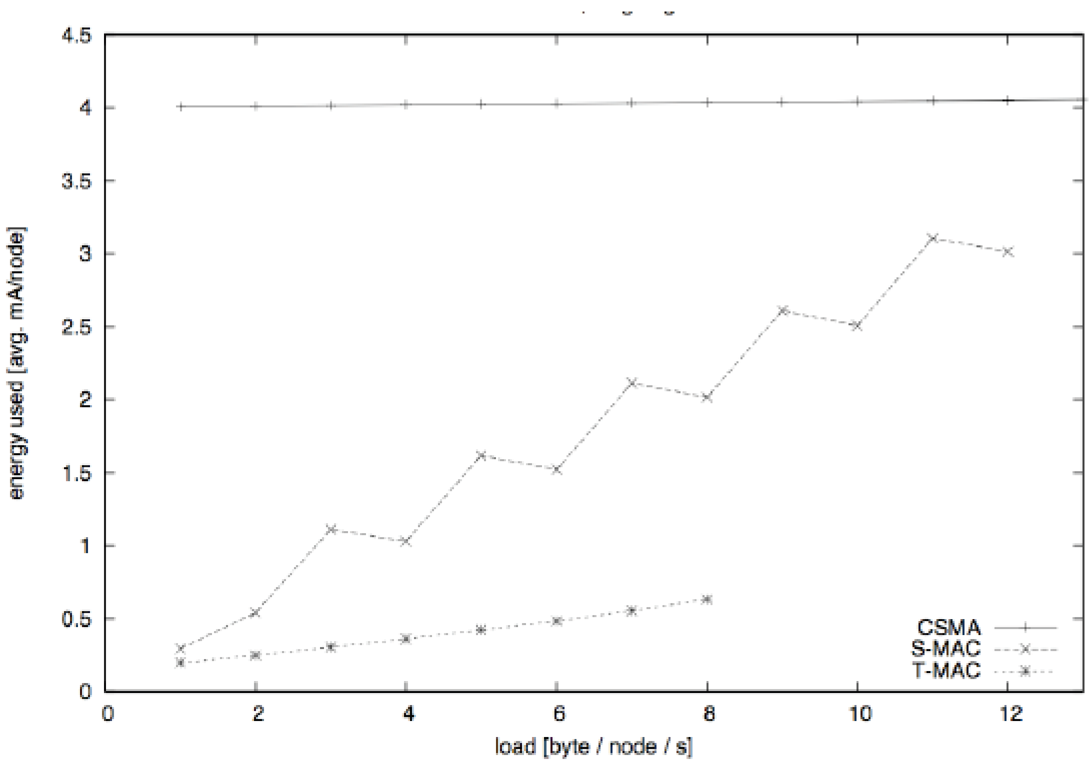
- Early sleeping problem
  - possible solution: future-request-to-send technique
    - a node with pending data can inform its intended receiver by transmitting a future-request-to-send (FRTS) packet immediately after overhearing a CTS message
    - node D, upon receiving the FRTS message, knows that node C will attempt to send data to it and will therefore remain active
    - however, sending an FRTS message immediately after CTS could interfere with node B's reception of node A's data
    - therefore, Node A first sends a dummy message called Data-Send (DS) to delay the transmission of the actual data
      - DS has the same size as FRTS
      - DS can collide with FRTS at node B, which is of no consequence since it does not contain any useful information

Timeout MAC

Comparison of the length of idle listening periods among SMAC and TMAC



Timeout MAC
Result

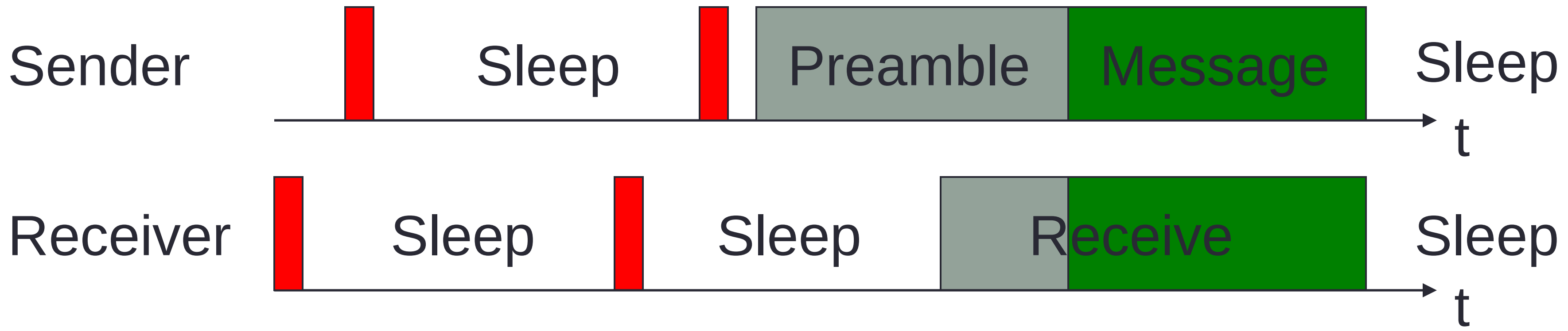


B-MAC (Berkeley MAC)

- B-MAC's Goals:
  - Low power operation
  - Effective collision avoidance
  - Simple implementation (small code)
  - Efficient at both low and high data rates
  - Reconfigurable by upper layers
  - Tolerant to changes on the network
  - Scalable to large number of nodes

B-MAC (Berkeley MAC)

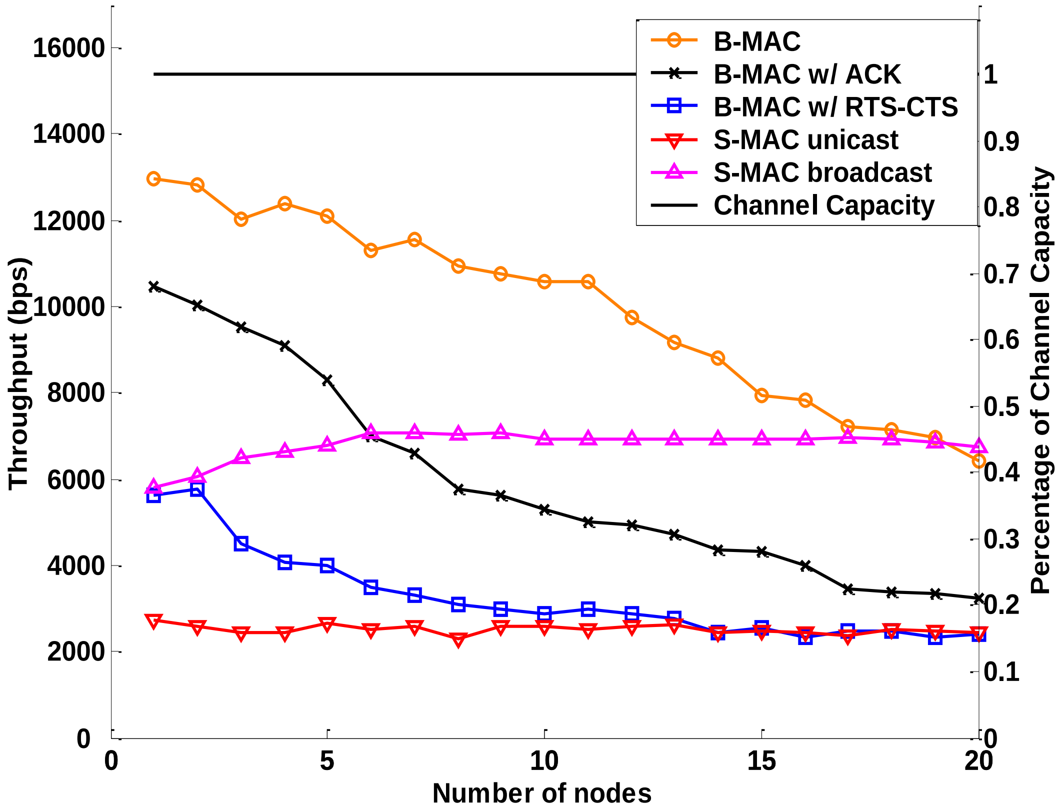
- Clear Channel Assessment (CCA)
  - Measure the SNR by taking a moving average when there seems to be no traffic
- Low Power Listening (LPL)
  - Periodic preamble sampling: Preamble > Sleep period
  - No sync between nodes
- Hidden terminal and multi-packet mechanisms not provided



Pros and Cons of B-MAC

- No need for every node to stay awake when there is no traffic
  - Just wake up for preamble sampling and go back to sleep
- Better power conservation, latency and throughput than S-MAC
- Simpler to implement -> no need a synchronization
- Low duty cycle → longer preamble
  - Little cost to receiver yet higher cost to sender
  - Longer delay
  - More contention

B-MAC
Result (comparison with S-MAC)



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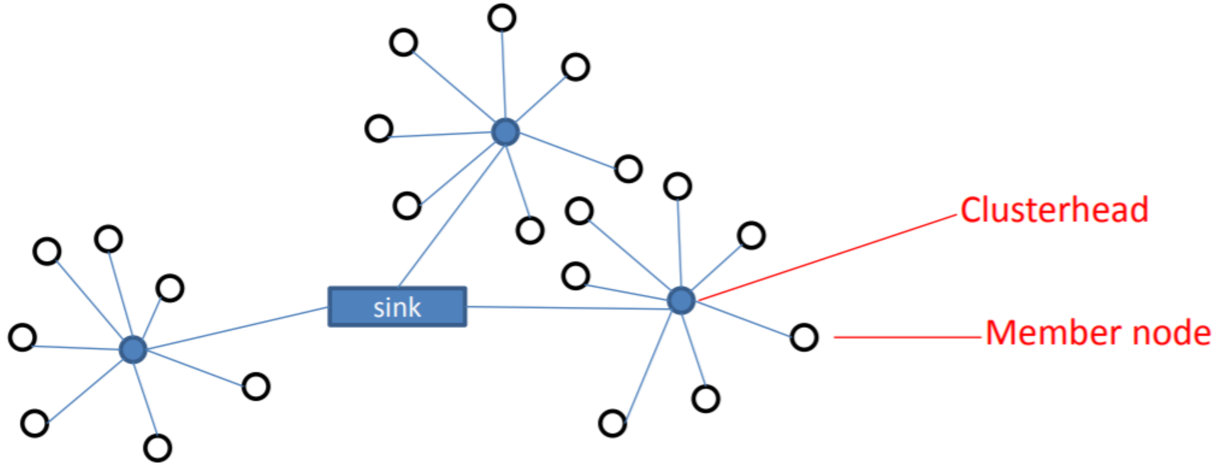
Contention-Free MAC Protocols

- Concept:
  - allow only one sensor node to access the channel at any given time
  - thereby avoiding collisions and message retransmissions
  - assuming a perfect medium and environment
- Contention-free protocols allocate resources to individual nodes to ensure exclusive resource access by only one node at any given time
- Exposes a number of desirable characteristics
  - node knows exactly when it has to turn on its radio
  - during all other times, radio can be turned off to preserve energy
  - fixed slot allocations impose upper bounds on delay
  - difficult to design schedules for large networks
  - difficult to handle changes in topology, density, traffic load

Low-Energy Adaptive Clustering Hierarchy (LEACH)

- The LEACH protocol combines TDMA-style contention-free communication with a clustering algorithm for wireless sensor networks
  - a cluster consists of a single cluster head and any number of cluster members, which only communicate with their cluster head
  - clustering is a popular approach for sensor networks
    - facilitates data aggregation and in-network processing at the cluster head
    - reduces the amount of data that needs to be transmitted to the base station



Low-Energy Adaptive Clustering Hierarchy (LEACH)

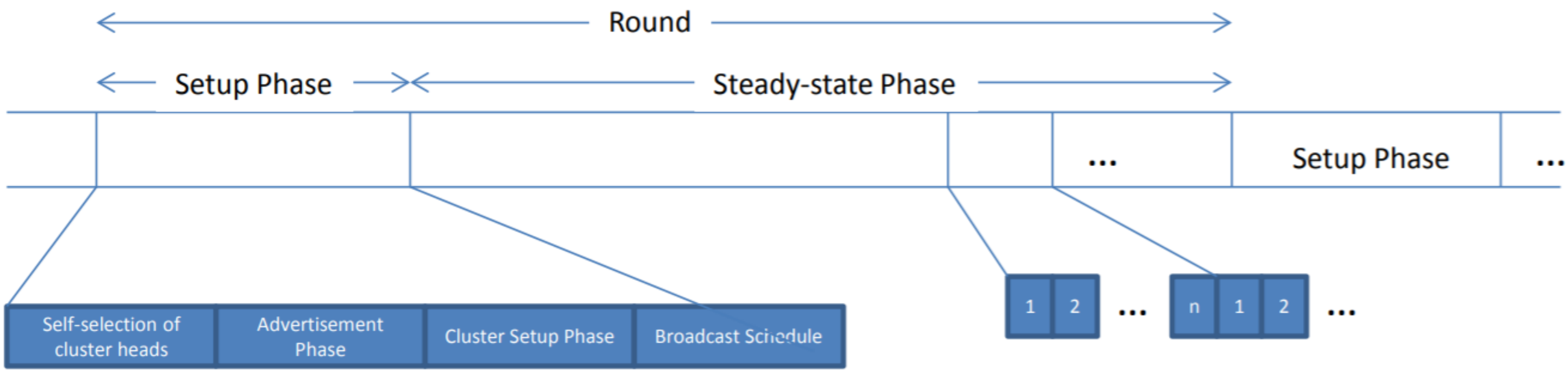
- LEACH is organized in rounds
- Each round is divided in two phases

a. Set-up phase

- Custer-heads (CHs) are randomly self-selected
- Advertisement-Phase: CHs announce their self (use CSMA)
- Setup: member nodes are assigned to clusters (CSMA)
- Schedule for each cluster is determined and distributed by the CH

b. Steady State phase

- Node send data to CH once per frame during the allocated time slot.



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Hybrid MAC Protocols

- Combines TDMA and CSMA features

CSMA
- Pros
  - Simple
  - Scalable
- Cons
  - Collisions due to hidden terminals
  - RTS/CTS is overhead

TDMA
- Pros
  - Naturally avoids collisions
- Cons
  - Complexity of scheduling
  - Synchronization needed

MAC	Channel Utilization	
	Low Contention	High Contention
CSMA	High	Low
TDMA	Low	High

Zebra MAC Initialization

- Neighborhood discovery through ping messages containing known neighbors
- Two-hop neighborhood used as input for a scheduling algorithm (DRAND-Distributed Random)
- The performance of DRAND is scalable and it produces a very efficient time schedule.

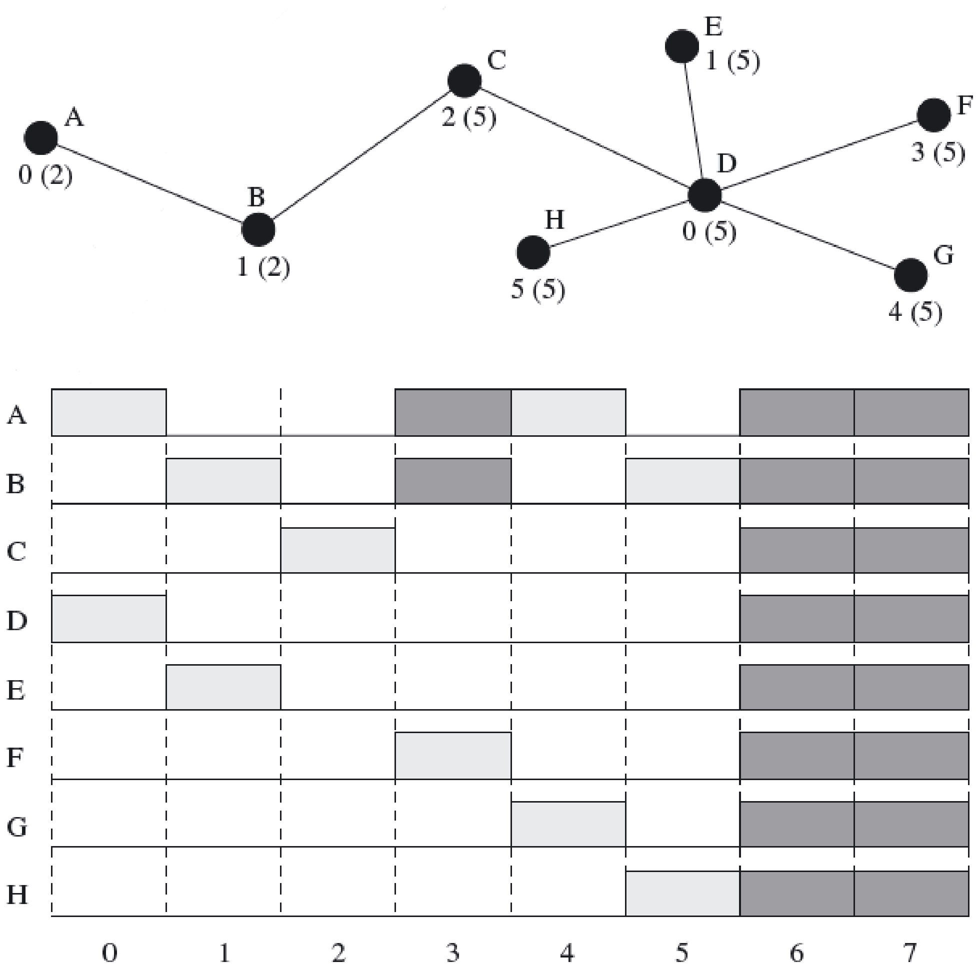
Zebra MAC
Time Slot Assignment

- Z-MAC allows nodes to select the periodicity of their assigned slots where different nodes can have different periods (time frames or TF)
- The advantage of this approach is that it is not necessary to propagate a maximum slot number (MSN) to the entire network

Zebra MAC
Time Slot Assignment

- Example with eight nodes
  - number indicates the assigned slot for each node
  - number in parenthesis is F_i (maximum slot number)
  - bottom part of the figure shows the corresponding schedule for all nodes
    - light-shaded slots are the ones used for transmissions
    - dark-shaded slots are the empty slots that are not used by any 1-hop or 2-hop neighbors

Zebra MAC
Time Slot Assignment

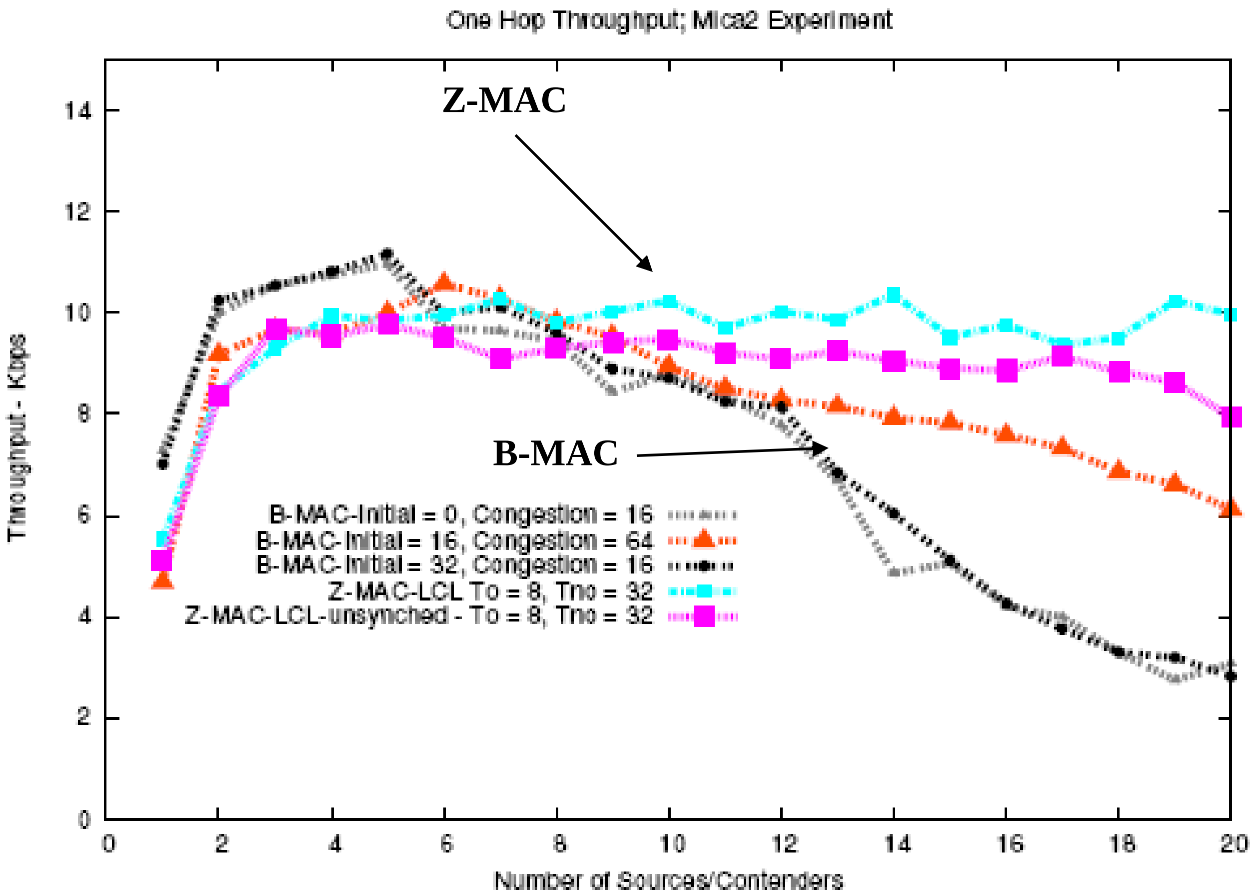


Zebra MAC
Transmission Control

The Transmission Rule (CSMA based):

- If owner of slot
  - Take a random backoff within To
  - Run CCA (Clear Channel Assignment) and, if channel is clear, transmit
- Else
  - Wait for To
  - Take a random backoff within [To,Tno]
  - Run CCA and, if channel is clear, transmit

Zebra MAC Result



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