Networked Embedded Applications

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CS 7 : (WSN MAC)

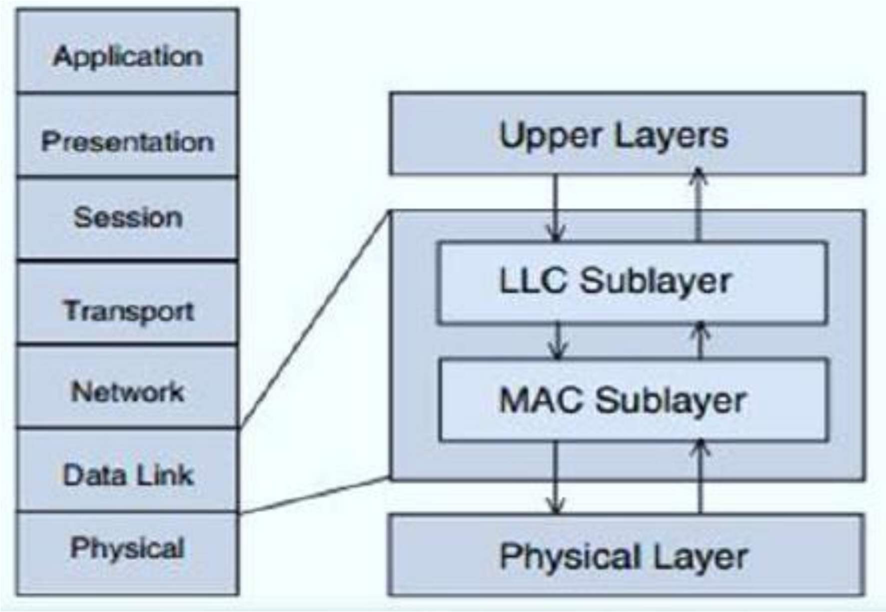
7	**WSN MAC** Introduction SMAC TMAC DMAC LMAC EMAC BMAC TRAMA **Mobility and Multi-Channel MAC**	

Introduction to MAC

- What is MAC?
  - Media access control (MAC) is a sublayer of the data link layer (DLL) in the seven-layer OSI network reference model. MAC is responsible for the transmission of data packets to and from the network-interface card, and to and from another remotely shared channel.
  - Media access control (MAC) layer is a very important layer in wireless sensor networks. Since this kind of network is self organizing and has different priorities than regular networks. Due to limited resources, WSN requires special MAC protocols.

Introduction to MAC

- What is MAC?
  - The MAC protocol functionalities are provided by the lower sublayer of the data link layer (DLL). The higher sublayer of the DLL is referred as the logical link control (LLC) layer.



Introduction to MAC

- Why do we need MAC?
  - Wireless channel is a shared medium
  - Radios transmitting in the same frequency band interfere with each other

Introduction to MAC

- The role of Medium Access Control
  - Controls when and how each node can transmit in the wireless channel
  - Solves the contention and collision
  - The MAC sublayer resides directly above the physical layer. It supports the following basic functions:
    - Framing – Define the frame format and perform data encapsulation and decapsulation for communication between devices.
    - Reliability – Ensure successful transmission between devices. (by sending acknowledgement (ACK) messages and retransmissions when necessary).

Introduction to MAC

- The role of Medium Access Control
  - Flow Control – Prevent frame loss (swamping) through overloaded recipient buffers.
  - Error Control – Use error detection or error correction codes to control the amount of errors present in frames delivered to upper layers.
  - Medium Access – Control which devices participate in communication at any time. Medium access becomes a main function of wireless MAC protocols since broadcasts easily cause data corruption through collisions.

Introduction to MAC

- While designing a MAC protocol for WSNs the traffic pattern to be dealt with has to be taken into account.
- *Broadcast*: A base station (or a sink node) sends data to all the sensor nodes in the WSN.
- *Local gossip*: Neighboring nodes communicate with each other locally, following the detection of an event.
- *Convergecast*: A group of sensors communicate what they perceived to a specific sensor (e.g., the sink, a cluster-head, etc.).
- *Multicast*: A sensor sends a message to a specific subset of sensors. An example of multicast communication can be found in cluster-based protocols where cluster-heads may need to send a message to a subset of their neighbors, i.e., the members of their cluster only.

Introduction to MAC

- Attributes of a Good MAC protocol
  - The good MAC protocol is energy efficient, reliable, low rate of access delay, and high throughput.
  - Energy efficiency
    - Large number of sensor nodes are deployed in the target region, which have limited battery and not possible to recharge or replace it. So it is necessary to use the energy efficient protocol at every layer.
  - Latency
    - All the data collected at a node are sent to the sink node so that immediate action should be taken at sink. Latency basically depends upon the traffic in the network, collision and bandwidth of the network.

Introduction to MAC

- Attributes of a Good MAC protocol
  - Throughput
    - Throughput requirement is also dependent upon the application. Some sensor application requires more data for that application throughput should be high.
  - Fairness
    - It is necessary to ensure that the sink node is receiving data from at the node fairly in low bandwidth WSN.
  - Security
    - WSN MAC protocols need to secure for any application of WSN. The unsecure MAC protocol can cause to energy wastage.

Design Issues of MAC Protocols in WSN

- Energy efficiency is the main requirement
- Small code size
- Reduced memory
- Adaptability to changes in network size, node density and network topology, which may be caused due to limited nodes' lifetime, addition of new nodes and varying interference.
- Traditional parameters like throughput and bandwidth utilization play a secondary role compared to energy efficiency and scalability
- Fairness among sensor nodes is generally not an issue.

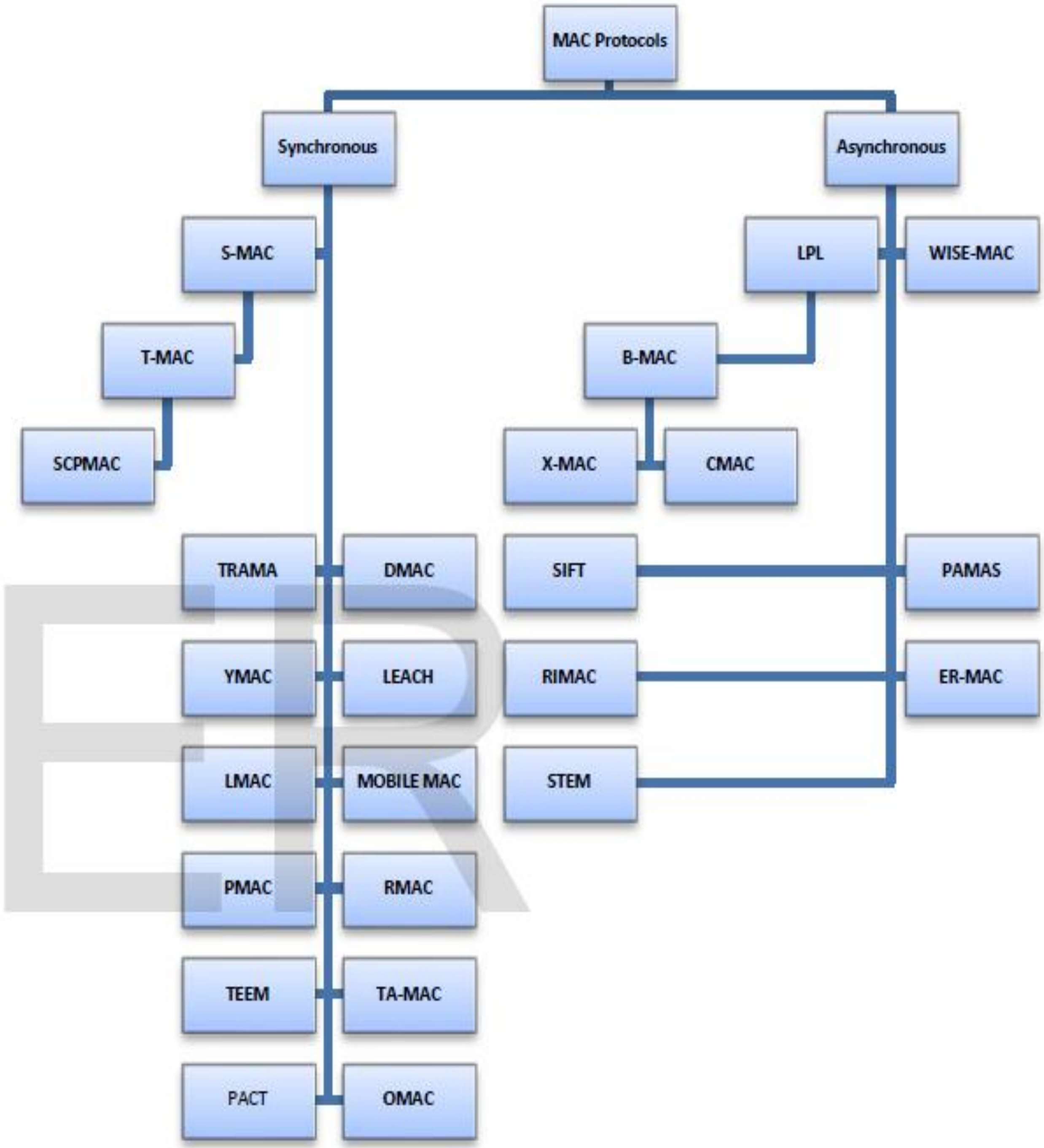
Cause of Energy Waste

- Collision
  - Collision occurs when multiple nodes try to transmit at the same time.
  - It result in back-off procedures.
  - It requires also sensing the medium.
  - All these activities consume energy.
- Overhearing
  - Since the medium is shared, nodes may receive the packets, that are not destined for.
- Protocol overheads
  - Overheads including sending and receiving of control packets like CTS/RTS, ACK, Beacons etc.

Cause of Energy Waste

- Idle listening
  - Nodes keep on listening, even though they may not receive messages, because they don't know when they will receive the message
  - It wastes energy
- Over-emitting:
  - A node sends a message and the destination node is not ready to receive (the receiving node may be in sleep state)

Classification of MAC protocols



Classification of MAC protocols

- **Synchronous MAC Protocols**
- Synchronous MAC Protocols are also called Schedule-Based or Slotted MAC Protocols.
- Unnecessary power consumption takes place on synchronization message exchanges.
- Schedule based medium access protocols in general require a mechanism to establish a non-conflicting schedule regulating which participant may use which resource at which time.
- Schedule can be fixed or computed on demand.
- Time synchronization is needed and time is divided into slots so that the time schedule can be fixed or computed on demand.

Classification of MAC protocols

- **Synchronous MAC Protocols**
- A traditional wakeup scheduling approach like SMAC uses fixed duty cycle (Duty Cycle is defined as Listen Interval divided by Frame Length).
- SMAC and TMAC use coordinated scheduling to reduce energy consumption, but require periodic synchronization, whereas CMAC avoids synchronization overhead while supporting low latency.
- CMAC uses unsynchronized sleep scheduling and allows operation at very low duty cycles.
- TMAC has advantage of dynamically ending active part, it uses adaptive duty cycle. This reduces energy wasted on idle listening.

- Sensor Media Access Control(S-MAC), Timeout MAC, Convergent MAC (CMAC)

Classification of MAC protocols

- Asynchronous MAC Protocols
  - Asynchronous MAC Protocols are also called as Contention-based or Random Access MAC Protocols.
  - Here randomization is used to gain access to the communication media.
  - Nodes do not synchronize time slots but contend for access to the radio channel.
  - To reduce idle listening, protocols in this class shift the costs from the receiver to the sender by extending the MAC header (i.e., the preamble).
  - Asynchronous MAC protocols allow nodes to check the channel periodically and otherwise sleep most of the time.

Classification of MAC protocols

- S-MAC (Sensor-MAC)
  - Trades energy efficiency for lower throughput and higher latency
  - Main Components
    - Periodic Listen and Sleep
    - Collision Avoidance
    - Overhearing Avoidance
    - Message Passing

Classification of MAC protocols

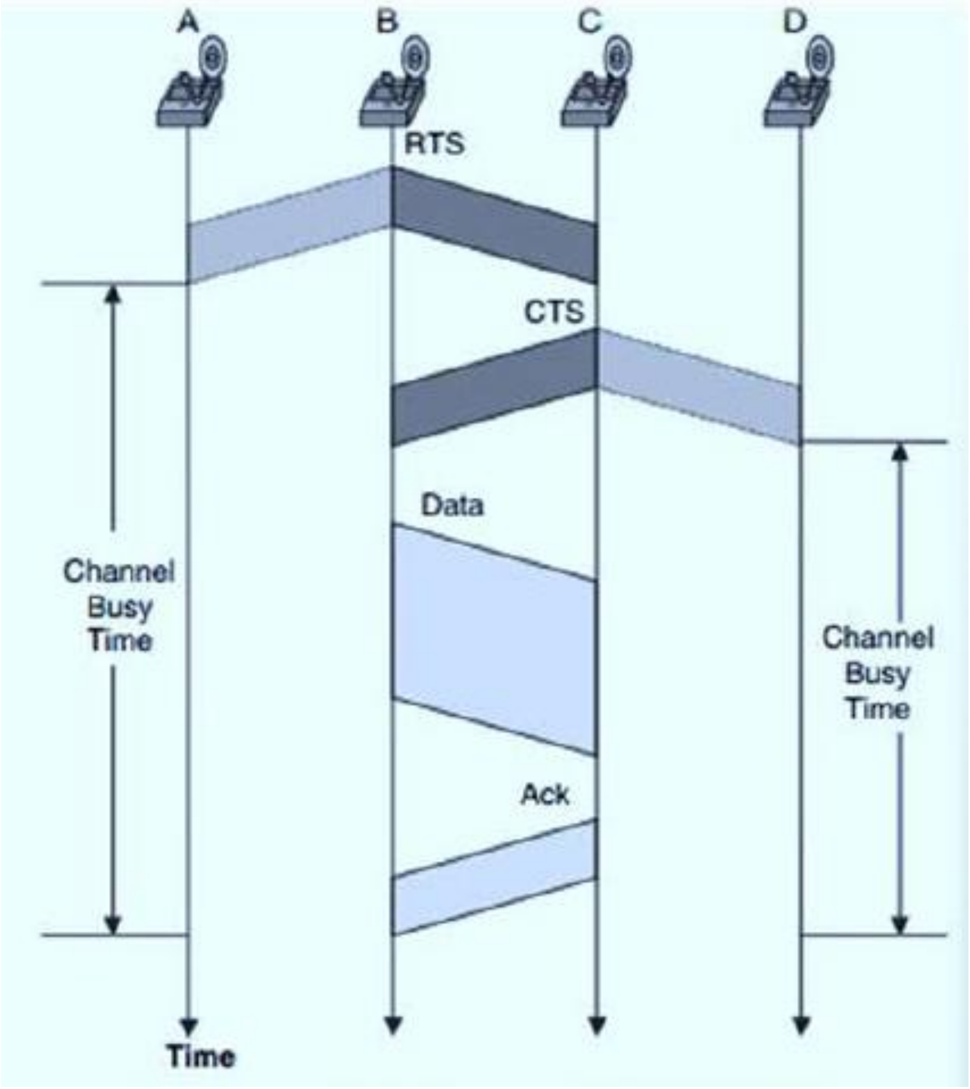
- S-MAC
  - Periodic Listen and Sleep
    - Nodes periodically sleep
    - Turn off radio when sleeping
    - Reduce duty cycle to ~10%
    - Trades energy efficiency for lower throughput and higher latency

Classification of MAC protocols

- S-MAC
- Collision Avoidance
  - Similar to IEEE 802.11 using RTS/CTS mechanism
  - Perform carrier sense before initiating a transmission
  - If a node fails to get the medium, it goes to sleep and wakes up when the receiver is free and listening again
  - Broadcast packets are sent without RTS/CTS
  - Unicast packets follow the sequence of RTS/CTS/DATA/ACK between the sender and receiver

Classification of MAC protocols

- S-MAC
  - Collision Avoidance



Classification of MAC protocols

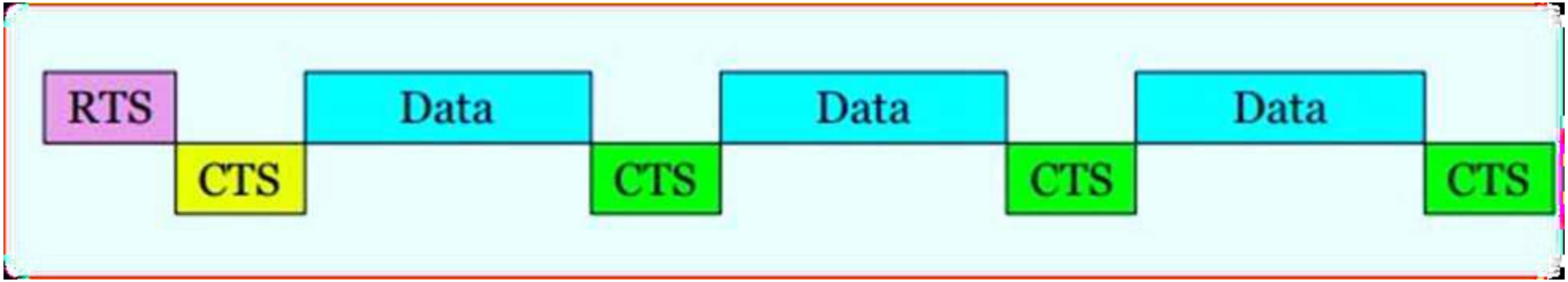
- S-MAC
  - Overhearing Avoidance
    - The Basic Idea is a node can go to sleep whenever its neighbor is talking with another node.
    - Who should sleep?
    - The immediate neighbors of sender and receiver.
    - How do they know when to sleep?
    - By overhearing RTS or CTS.
    - How long should they sleep?
    - NAV (Network Allocation Vector).

Classification of MAC protocols

- S-MAC
- The 'listen' interval of a node is divided into two parts:
  - First part is to receive SYNC packets
  - Second part is meant for receiving DATA packets
- Each node maintains a NAV (Network Allocation Vector) table and an associated timer
- When a node receives a RTS/CTS packet destined to other nodes, it updates the NAV by the duration field in the packet and goes to sleep till the end of the transmission.
- Disadvantage:
  - Latency increases due to periodic sleep of the nodes
  - Latency becomes more in the case of multi-hop transmissions

S- MAC

- S-MAC
  - Message Passing
    - How to transmit a long message?
      - Transmit it as a single long packet (Easy to be corrupted).
      - Transmit as many independent packets (Higher Control Overhead & Longer Delay).
      - Divide into fragments, but transmit all in burst.

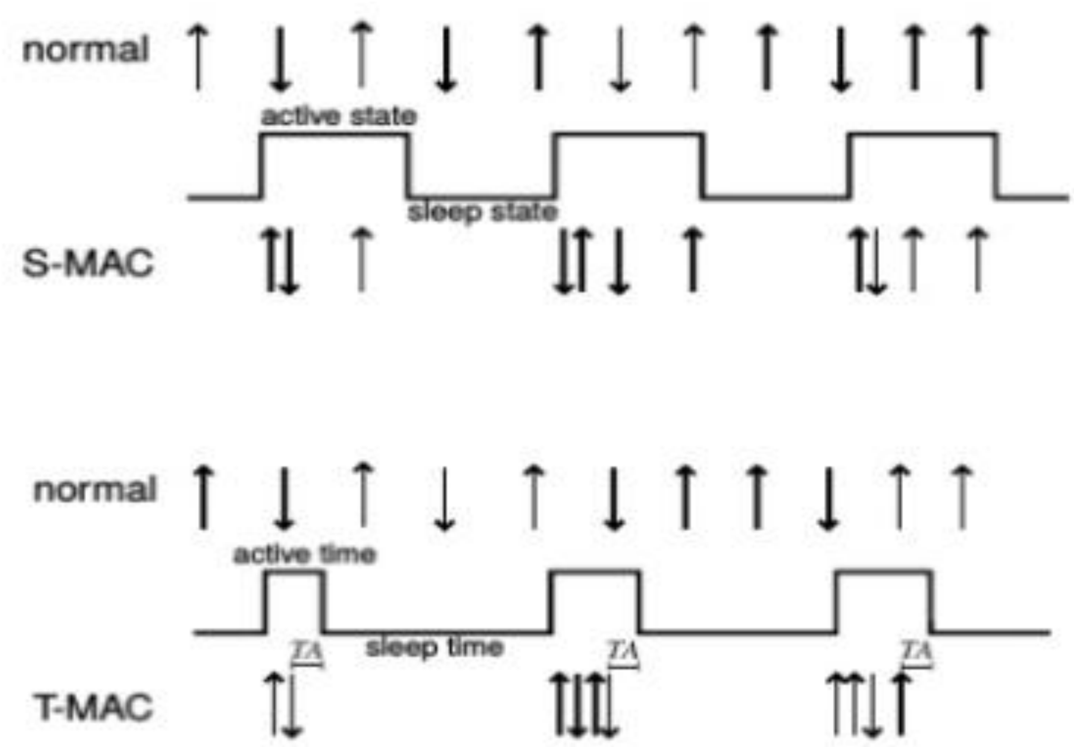


Timeout MAC (T-MAC)

- It is similar to S-MAC, with the following differences.
- Messages are transmitted in burst
- Instead of using a fixed length active period, it dynamically adapts the duty cycle to the network traffic.
- It uses a time-out mechanism to determine the end of the active period.
  - If a node doesn't detect any activity (incoming message or collision), within a timeout interval TA, it concludes that no neighbour is going to communicate. Hence, it enters into sleep mode.
  - Otherwise, it will start a new timeout after the on-going communication finishes.

Timeout MAC (T-MAC)

- Adaptive duty cycle to improve S-MAC based on traffic



- TA period- wait till CTS time

Timeout MAC (T-MAC)

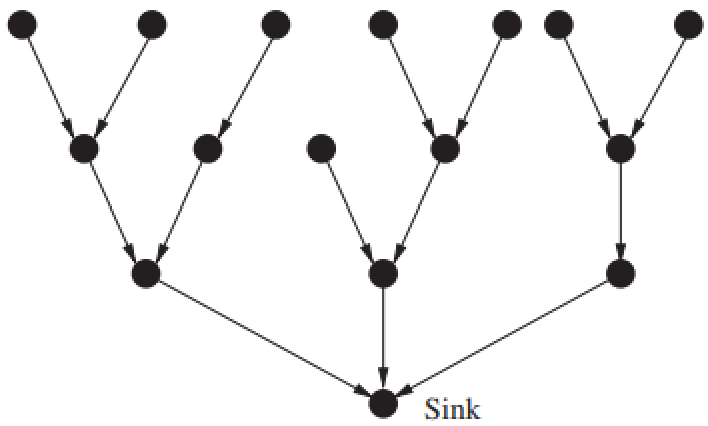
- When a node transmits, receives, or overhears a message, it remains awake for a brief period of time after completion of the message transfer to see if more traffic can be observed.

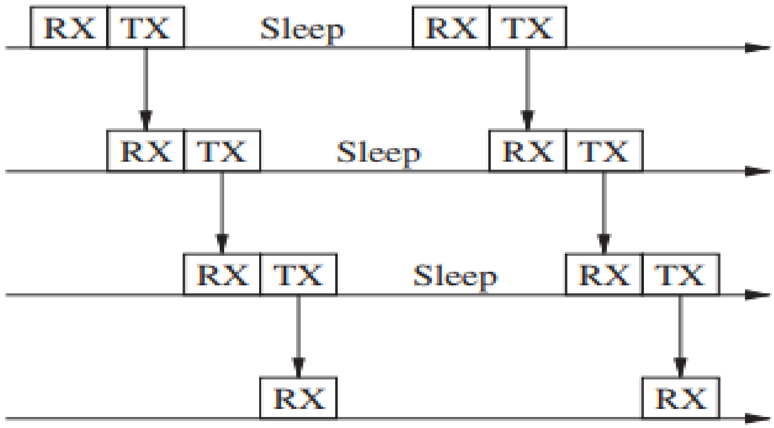
- This brief *timeout* interval allows a node to return to the sleep mode as quickly as possible.

- A node's awake times will increase with the heavier traffic and will be very brief if traffic is light.

Data-Gathering MAC-(DMAC)

- The Data-Gathering MAC (DMAC) is an energy-efficient low-latency protocol designed and optimized to solve the data forwarding interruption problem in convergecast WSNs.





- DMAC works best for networks in which transmission paths and rates are known in advance and do not change over time

Data-Gathering MAC-(DMAC)

- The key idea of DMAC in order to enable a continuous packet flow from sensor nodes to the sink is to stagger the wake-up scheme by giving the sleep schedule of a node an offset, which is a function of its level on the data-gathering tree.
- During the receive period of a node, all of its child nodes have transmit periods and contend for the channel.
- To reduce collisions during the transmit period of nodes on the same level in the tree, every node backs-off for a period plus a random time within a fixed contention window before packet transmission.
- DMAC can be viewed as an extension of the Slotted Aloha algorithm in which slots are assigned to the sets of nodes based on a data-gathering tree.

Data-Gathering MAC (DMAC)

- Low node-to-sink latency is obtained by assigning subsequent slots to the nodes that are consecutive in the data transmission path.
- Similarly to T-MAC, DMAC also adjusts the duty cycles adaptively according to the network workload.
- DMAC fits well for the scenarios in which data transmission paths are known in advance (so it is possible to build the data-gathering tree) and outperforms S-MAC in terms of latency (thanks to staggered schedules), throughput and energy efficiency (thanks to the adaptivity).
- However, when collisions are likely to occur, i.e., in event-triggered WSNs, DMAC performance degrades.

Berkeley MAC (B-MAC)

- B-MAC protocol is a carrier-sense configurable MAC protocol for WSNs that provides a flexible interface to combine low-power operation, effective collision avoidance, and high channel utilization.
- B-MAC consists of four main components, i.e.,
  - Clear channel assessment (CCA) and packet back-off, for channel arbitration
  - Link layer ACKs, for reliability
  - LPL, for low-power communication
- CCA is performed using a weighted moving average on a set of samples taken when the channel is idle to assess the ground noise, thus enabling a better detection of valid transmissions and collisions.
- The approach has proven to outperform thresholding methods used in a variety of wireless protocols which produce a large number of false negatives that reduce the channel bandwidth.

Berkeley MAC (B-MAC)

- Packet back-off is configurable and is chosen from a linear range instead of the usual exponential back-off approach.
- Optional packet-by-packet link layer ACKs are provided to reliably transfer important data.
- Finally, low-power operation is achieved through an adaptive preamble sampling scheme able to reduce duty cycle and minimize idle listening.
- A node cycles between awake and sleep states.
- While awake, it listens a long preamble to assess whether it has to remain awake or can go back to sleep.
- RTS/CTS packets, due to their high overhead, are not used.

Berkeley MAC (B-MAC)

- B-MAC supports on-the-fly reconfiguration and provides bidirectional interfaces for services to optimize performance in terms of throughput, latency, or power saving.
- While S-MAC and T-MAC are not just link protocols, but also network and organization protocols, the lightweight Berkeley MAC protocol only contains a small core of media access functionalities.
- Network services such as organization, synchronization, and routing build upon it.
- As B-MAC is very configurable, other MAC protocols for WSNs (e.g., S-MAC and T-MAC) may be implemented efficiently upon B-MAC and could benefit from its flexibility.

Traffic-Adaptive Medium Access (TRAMA)

- TRAMA provides energy-efficient collision free channel access in WSNs exploiting transmission schedules to avoid collisions of data packets at the receivers and an adaptive power switching policy to dynamically put nodes into low-power mode whenever they are not transmitting or receiving.
- TRAMA assumes a single, time-slotted channel for both data and signaling transmissions.
- Time is divided into sections of random and scheduled-access periods.
- Random-access slots are used for signalling, while scheduled-access slots are used for transmission.

Traffic-Adaptive Medium Access (TRAMA)

- During the random-access period, nodes go through contention-based channel access and thus signaling packets may experience collisions.
- On the contrary, transmission slots are used for collision-free data transmission and also for schedule propagation.
- Given the low data rates of a typical WSN, the duration of time-slots is much larger than typical clock drifts, so a timestamp mechanism is enough for node synchronization.
- TRAMA consists of three components:
    - Neighbor Protocol (NP)
    - Schedule Exchange Protocol (SEP)
    - Adaptive election algorithm (AEA)

Traffic-Adaptive Medium Access(TRAMA)

- The NP and SEP allow nodes to exchange two-hop neighbor information and their schedules.
- The AEA uses this information to select the transmitters and receivers for the current time-slot, thus enabling non involved nodes to switch to a low-power mode.
- NP propagates one-hop neighbor information among neighboring nodes during the random access period using the signalling slots.
- SEP is used to exchange schedules with neighbors, where a schedule contains information on traffic coming from a node, i.e., the set of receivers for the traffic originating at the node.
- Before transmitting, a node has to announce its schedule using SEP.
- This mechanism provides a consistent view of schedules across neighbors and periodic schedule updates.

Traffic-Adaptive Medium Access(TRAMA)

- AEA selects transmitters and receivers to achieve collision-free transmission using the information obtained from NP and SEP.
- AEA uses traffic information (i.e., which sender has traffic for which receivers) to improve channel exploitation.
- TRAMA provides support for unicast, broadcast, and multicast traffic and differs from S-MAC for two main aspects:
  - TRAMA is inherently collision-free, as its MAC mechanism is schedule-based, while S-MAC is contention-based.
  - TRAMA uses an adaptive approach based on current traffic to switch nodes to low-power mode, while S-MAC is based on a predefined static duty cycle.
- TRAMA achieves higher end-to-end throughput and energy saving than S-MAC and other contention-based MAC protocols, but also higher delays than random-selection protocols due to the scheduling overhead.

Lightweight Medium Access (LMAC)

- LMAC protocol aims to minimize the overhead of the physical layer reducing the number of transceiver state switches and the energy waste due to the preamble transmissions.
- LMAC uses TDMA to provide WSN nodes with a collision-free channel access.
- Unlike traditional TDMA-based protocols, the time-slots in LMAC protocol are not assigned to nodes by a central authority, but through a fully distributed slot assignment mechanism.
- Slots are organized in frames.
- Each node is given one time-slot per frame, during which the node will transmit a message consisting of two parts, a control message and a data unit.

Lightweight Medium Access (LMAC)

- The control message, which has a fixed size, carries:
  - ID of the time-slot controller
  - Distance (in hops) of the node to the gateway for routing purposes
  - Intended receiver(s)
  - Length of the data unit
- The control message is also used to maintain synchronization between the nodes, as it contains the sequence number of the time-slot in the frame.

Lightweight Medium Access (LMAC)

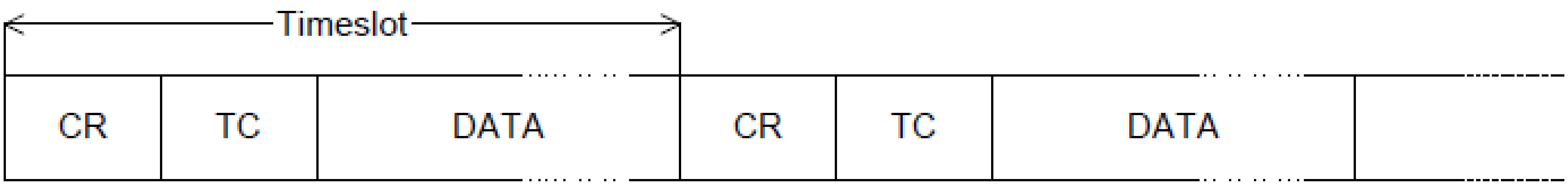
- All nodes listen to the control messages of their neighboring nodes.
- When a node is not the recipient of that message and the message is not a broadcast one, the node will switch off its transceiver only to wake at the next time-slot.
- Otherwise, if the node is the intended receiver, it will listen to the data unit.
- If the latter does not fill up the remaining portion of the time-slot, after the message transfer has completed, both transmitter and receiver(s) turn off their transceivers.

Lightweight Medium Access (LMAC)

- A short timeout interval ensures that nodes do not waste energy due to idle listening to free timeslots.
- To limit the number of time-slots in the network, slot reusing is allowed at a non-interfering distance.
- It is required that a slot is not reused within a two-hop neighborhood, so LMAC includes a bitmap with all the slots assigned to a node's neighbors in the header.
- By combining the bitmaps of all its neighbors, a node can assess which slots are free within a two-hop neighborhood.
- LMAC significantly improves the network lifetime as compared to S-MAC.

EYES Medium Access Protocol (EMAC)

- The TDMA-based EMACs protocol also eases the (local) synchronization between nodes.
- Time is divided into so called frames and each frame is divided into time slots
- Each timeslot in a frame can be owned by only one network node.
- This network node decides what communication should take place n its timeslot and denies or accepts requests from other nodes.



Frame format of the TDMA-based MAC protocol

communication request

traffic control

European research project EYES

EYES Medium Access Protocol (EMAC)

- Each node autonomously selects a timeslot it wants to own.
- A timeslot is selected based on the already occupied timeslots as submitted by neighboring nodes.
- This information includes the known timeslots of the surrounding nodes of a neighbor, so that information about the second order neighborhood is respected.
- The radio signal has already attenuated quite severely at the third order neighbors, so that timeslots can be reused.
- Nodes can ask for data or notify the availability of data for the owner of the timeslot in the communication request (CR) section.

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EYES Medium Access Protocol (EMAC)

- The owner of the slot transmits its schedule for its data section and broadcasts the above discussed table in the *traffic control* (TC) section, which tells to which other TC sections the node is listening.
- After the TC section, the transmission of the actual data packet follows either uplink or downlink. Both CR and TC sections consist of only a few bytes.
- Collisions can occur in the communication request section. Although we do not expect a high occurrence of collisions, we incorporate a collision handling mechanism in the EMACS protocol.
- When the time slot owner detects a collision, it notifies its neighbor nodes that a collision has occurred. The collided nodes retransmit their request in the data section after a random, but limited backoff time.
- Carrier sense is applied to prevent the distortion of ongoing requests.

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EYES Medium Access Protocol (EMAC)

- The EMACS protocol therefore supports two sleep modes of the sensor nodes:
- *Standby mode*: This sleep mode is used when at a certain time no transmissions are expected.
- The node releases its slot and starts periodically listening to a TC section of a frame to keep up with the network.
- When the node has to transmit some data (event-driven sensor node), it can just fill up a CR section of another network node and agree on the data transmission, complete it and go back to sleep.
- It can actively be woken up by other nodes to participate in the communication.
- Depending on the communication needs, it will start owning a timeslot.

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EYES Medium Access Protocol (EMAC)

- *Dormant mode*: This sleep mode is agreed on at higher layers.
- The sensor node goes to low power mode for an agreed amount of time.
- Then it wakes, synchronizes (rediscovers the network) and performs the communication.
- While in this sleep mode the synchronization with the network will be lost and all communication with the node will be impossible.
- This sleep mode is especially useful to exploit the redundancy in the network.
- In a clustered structure, the controlling instance, i.e. the cluster head, will usually decide on the sleeping pattern of redundant nodes.

EYES Medium Access Protocol (EMAC)

- Not every node in the network has to own a timeslot.
- It is clear that a node does not own a timeslot when it is in one of the sleep modes since being in a sleep mode is inherent to not transmitting a TC section every frame.
- However, event-driven nodes might also not redeem their right to own a timeslot.
- A drawback of not owning a timeslot is that the node only being able to receive multicast messages and not messages directly addressed to it.
- Transmitting data to nodes that own a timeslot is not a problem.
- Other protocol layers in the network may invoke listening to, or transmitting in a prior agreed (and free or not owned) data section.

European research project EYES

EYES Medium Access Protocol (EMAC)

- Before a node decides that it does not want to own a timeslot, it should check that sufficient TC sections are transmitted by neighbours to keep the network connected and to maintain synchronization.
- The fact that nodes do not necessarily need to own a timeslot eases the scalability of the network and reduces the power consumption of the nodes.

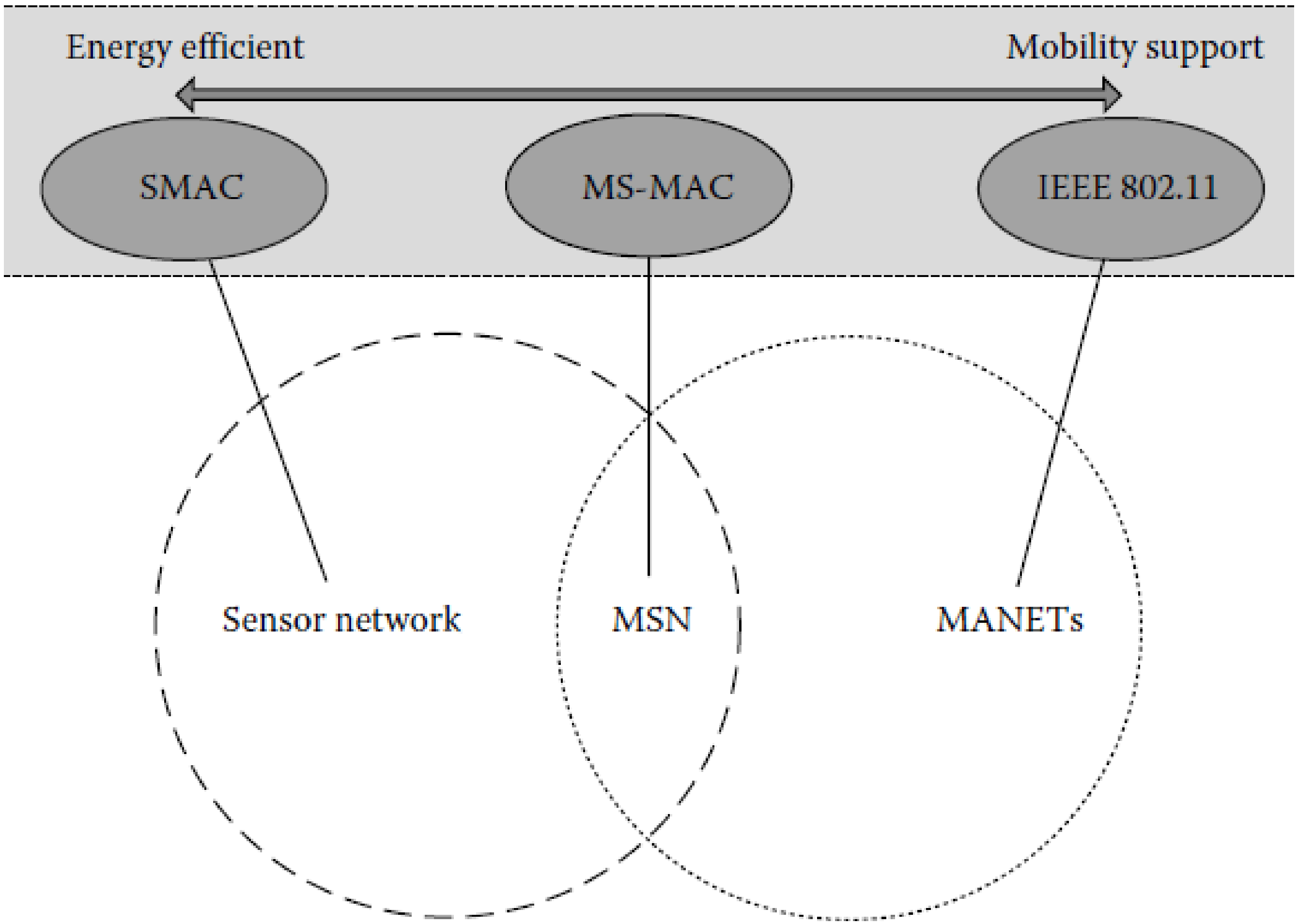
Mobility Support in WSNs

- In WSNs two kinds of mobility can be defined, i.e., weak and strong mobility.
- Weak mobility refers to network topology changes following either node failures (due to hardware failures or battery consumption) or node joins (due to the addition of new sensor nodes to cover a larger sensing area or to improve the network lifetime).
- Weak mobility can be found even in sensor networks with static nodes.
- Strong mobility refers to physical mobility combined with concurrent node joins/failures.
- WSN nodes may change their physical location for several reasons.
- For example, they may be moved by external weather conditions (such as, wind, rain, or waves) or following some mechanism introduced with the aim of enhancing the network performance or lifetime

Mobility-Aware MAC for Sensor Networks

- The Mobility-Aware MAC for Sensor Networks (MS-MAC) protocol extends the well known SMAC protocol to support mobile sensor nodes through an adaptive mobility handling mechanism which changes the duty cycle of nodes as a function of their estimated mobility.
- This protocol works in an energy-efficient SMAC-like fashion when nodes are stationary, while it works similarly to IEEE802.11 in the presence of mobility.
- Nodes estimate the presence of mobility within their neighborhood through the received signal strength of the periodical SYNC frames.
- When a variation on the signal level of a neighbor is detected, the node is assumed to be moving.
- When a mobile node is detected, the mobility information is included in the periodical SYNC frames.

Mobility-Aware MAC for Sensor Networks



Mobility-Aware MAC for Sensor Networks

- However, when multiple mobile nodes are detected, only information on the node with the highest estimated speed is included.
- The mobility information is used to create a so-called active zone around the moving node that is a region in which the synchronization period is smaller.
- This means that nodes within the active zone have a higher energy consumption, but also that the time needed to setup a new connection is shorter.
- This mechanism highly improves the performance of the WSN under mobility.
- In fact, using the standard synchronization periods, a mobile node might lose the connection with the old neighbors before it has setup a new schedule

Mobility-Aware MAC for Sensor Networks

- The node might stay therefore disconnected for a long time, until a new synchronization phase starts (the default period is 2 min).
- On the other hand, decreasing the synchronization periods, a node can speed up connection setup,
- so that a new schedule can be created before the old connections are lost.
- Under stationary conditions no active regions are created, so the node features low energy consumption, whereas when the mobility of a node is detected, only the surrounding nodes increase their synchronization rates.
- The nodes in the active zone adjust their duty cycles depending on the estimated speed of the moving nodes and will also stay awake all the time if a threshold speed is exceeded.
- This way, a trade-off between performance and energy consumption is obtained in both stationary and mobile scenarios.

Mobility-Adaptive Collision-Free MAC (MMAC)

- This protocol uses a dynamic frame containing both scheduled-access and random-access time-slots.
- The division between scheduled-access and random-access slots is adaptively changed according to the expected mobility changes, e.g., node joins or node failures.
- The MMAC protocol assumes that WSN nodes are location-aware.
- The location information is used to predict the mobility patterns of nodes, through a real-time mobility estimation scheme (AR-1) based on a first-order autoregressive model.
- The key idea is to use the information obtained from the mobility estimation model to reduce the frame time when a large number of nodes is expected to enter or leave the two-hop neighborhood, and vice-versa to increase the frame time when less node mobility is expected.

Mobility-Adaptive Collision-Free MAC (MMAC)

- The main issues of such an approach are how to obtain mobility information about all the current and potential two-hop neighbors, and how to perform synchronization between nodes, as they could independently calculate frame times different from each other.
- To overcome these issues, this protocol uses a cluster-based approach, in which nodes are grouped into clusters.
- A cluster-head node for each cluster is elected in rotation, with an election schema similar to the one used in low energy-adaptive cluster hierarchy (LEACH).
- Time is divided into rounds, and a different cluster-head is elected at each round. The predicted mobility information is put by nodes into the header of MAC packets

Mobility-Adaptive Collision-Free MAC (MMAC)

- The cluster-head is always on, so it collects all the information and it broadcasts all the mobility information to the member nodes during a dedicated time-slots at the end of the frame.
- This provides the nodes with a best-effort knowledge of the mobility information of the current and potential two-hop neighborhood.
- A similar solution is used to provide synchronization between nodes.
- They calculate independently their frame time, but, instead of setting-up the frame by themselves, nodes communicate their frame time to the cluster head, which collects the value for all its member nodes and calculates the average value.

Mobility-Adaptive Collision-Free MAC (MMAC)

- At the end of each round, cluster-head nodes exchange all the average values between themselves and the global mean value is disseminated along the whole network.
- So, at the end of each round, all the nodes adjust the frame time as well as the scheduled access slots and the random-access slots according to the global frame time.
- While the frame time remains the same for the whole round, at the end of each frame the number of random-access slots within a cluster may be increased or decreased, according to the mobility patterns of cluster nodes.

Mobility-Adaptive Hybrid MAC (MH-MAC)

- MH-MAC tries to combine the advantages of schedule-based and contention-based protocols.
- The WSN nodes are differentiated in mobile nodes and static nodes, and the most suitable medium access mechanism is used for each type of nodes.
- So, for static nodes a schedule-based channel access mechanism is adopted, while a contention-based approach is used for mobile nodes.
- Time is divided into time-slots and two different types of time-slots, i.e., static and mobile, are defined.
- Each node uses a mobility estimation algorithm to determine its mobility.

Mobility-Adaptive Hybrid MAC (MH-MAC)

- Based on its mobility, a node uses the static or mobile slot.
- Static slots are assigned in a LMAC-like fashion, while for the contention-based time-slots a Scheduled Channel Polling mechanism is used to limit the duty cycle in order to decrease energy consumption.
- According to such a mechanism, a sender node sends a short wake-up tone followed by the receiver ID, so that all the other nodes but the receiver can go to sleep.
- The MH-MAC protocol adapts to different levels of mobility by dynamically adjusting the ratio static/mobile slots as well as the frame time.
- When less nodes are mobile, more slots are reserved for schedule-based allocation and vice-versa.

Multichannel Protocols for WSNs

- Multichannel protocols are usually hybrid approaches that combine FDMA with TDMA and/or CSMA and use different frequencies for parallel communications.
- Typically, these approaches try to maintain all the benefits, in terms of energy consumption, of TDMA-based protocols by avoiding contentions and lowering the nodes' duty cycles.
- In addition, thanks to the use of multiple channels, these protocols enhance the network capacity and solve the scalability problems that affect schedule based protocols when applied to large and dense WSNs.

Multifrequency Media Access Control for WSNs

- The Multifrequency MAC for Wireless Sensor Networks (MMSN) protocol consists of two different parts, i.e., a frequency assignment schema and a medium access protocol.
- The frequency assignment schema aims to assign different frequencies to each neighbor or, if the number of frequencies is not large, to efficiently assign the available frequencies in order to limit the potential communication conflicts.
- four different assignment strategies are proposed, i.e.,
- *Exclusive frequency assignment*: The nodes exchange their IDs with the two-hop neighbors and then make the frequency decision in the increasing order of ID values, so that nodes with lower IDs have the lower frequencies.

Multifrequency Media Access Control for WSNs

- *Even selection*: The exclusive frequency assignment is extended to the case in which all frequencies have been already used by at least one node within two hops. In this case a random frequency is selected among the least used ones.
- *Eavesdropping*: Each node broadcasts its frequency decision and waits for a back-off interval.
- During such an interval the other decisions are recorded. When the back-off timer expires, a frequency is randomly selected from the least chosen ones. This mechanism only uses one-hop neighbor information, so it features less overhead, but also more conflicts.

Multifrequency Media Access Control for WSNs

- *Implicit-consensus:* The two-hop neighbors' IDs are collected as in exclusive frequency assignment, then each node calculates its frequency locally, using a pseudorandom number generator seeded by node IDs and a defined algorithm. This schema provides different channels for all two-hop neighbors, but it is effective only when the number of available frequencies is large.
- One of these schemes can be used to assign the frequency for data reception. Nodes are synchronized and the medium access divides the time into time-slots.
- A time-slot consists of a broadcast contention period Tbc, in which nodes contend for the same broadcast frequency, and a transmission period Ttran, in which nodes contend for shared unicast frequencies

Multichannel LMAC

- The proposed technique works in two phases.
- In the first phase, nodes select their time-slot according to the classic LMAC protocol,
- while in the second phase nodes select the radio channels.
- In fact, while in LMAC a time-slot can be reused only after at least two hops, in the multichannel approach proposed in the same time-slot may be reused on a different radio channel.
- Thus, a node which finds its time-slot already occupied by a two-hop neighbor can use the same time-slot but on a different channel. Bridge nodes are used to maintain the whole network connected.
- Simulation results shown that applying a similar approach to a classical MAC protocol, such as LMAC, denser networks can be supported. In addition, the number of collisions is significantly decreased.

Multichannel MAC

- This protocol introduces network clusterization and exploits the existence of cluster-head nodes that collect request messages from the cluster members, select the radio channels and communicate them to both source and destination nodes.
- In this way, node pairs can communicate using the received schedule and the designated radio channel.
- Although this approach can increase the sleeping times of nodes, thus lowering their power consumption, it introduces a significant overhead, due to the high number of signaling messages sent from/to the cluster-head.

Thank You