Module 5

Communication Protocols: Physical Layer and Transceiver Design Considerations, MAC Protocols for Wireless Sensor Networks, Low Duty Cycle Protocols And Wakeup Concepts **-** S-MAC , The Mediation Device Protocol, Wakeup Radio Concepts, Contention based protocols(CSMA,PAMAS), Schedule based protocols (LEACH, SMACS, TRAMA) Address and Name Management in WSNs, Assignment of MAC Addresses, Routing Protocols- Energy-Efficient Routing, Geographic Routing, Hierarchical networks by clustering.

Physical Layer for Wireless Sensor Networks

- The main concern of the physical layer is **modulation and demodulation** of digital data, i.e. **transmission and reception** of the data.
- The **transceivers** in the sensor nodes play a major role.
- The main functions of physical layer are **carrier frequency selection** and **generation, encryption and decryption, modulation and demodulation, transmission and reception of data**.
- The most important parameters which are to be considered while designing Physical layer in wireless sensor networks are
  - Low Power Consumption.
  - Low Transmission and Reception range.
  - Interference from other systems, working in the same band.
  - Low complexity.
  - Low duty cycle, i.e. most of the time sensor nodes are switched off.
  - Low data rates most of the time and high data rate only for a short period of time.
- The most challenging aspect in physical layer design for sensor networks is to find, low cost transceivers which consume less power, simple modulation schemes which are robust enough to provide required service.
- Usually the transceivers used in sensor network are only 10% efficient.
- To radiate a power of 1 mw the transceivers will consume at least 10 mw of power.
- The power consumed for reception is similar to power consumed for transmission.
- The transmission and reception of data are the most power consuming activity in the sensor node.
- So transmission and reception of data should be kept as less possible.

- The power consumed by the transceivers in idle mode will not be significantly less than the power consumed by transceivers in receive or transmit mode.
- It is always preferable to put the transceiver in sleep mode rather than in idle mode when not required.
- The power consumed during start up and time taken to startup the transceiver does not overcome the advantage of putting the transceiver in sleep mode.
- The choice of modulation scheme is another important aspect to be considered for design
- The data rate is another factor tells about the amount of data can be transmitted or received when the node is on.
- To save more and more energy the sensor node should be in sleep as much as possible and more the data rate more amount of data can be transmitted and received in small active period.
- The symbol rate is yet another important factor, as it has be found that more is the symbol rate more is the power consumption.
- The BER has also to be considered, because to keep BER low the power radiated has to be more.

Balance of requirements

- The importance of energy efficiency for the design of MAC protocols is relatively new and many of the "classical" protocols like ALOHA and CSMA contain no provisions towards goal.
- Typical performance figures like fairness, throughput, or delay tend to play a minor role in sensor networks.
- Since the WSN are competing for bandwidth, fairness is not an important parameter.
- The WSN also collaborate to achieve a common goal.
- The access/transmission delay performance is traded against energy conservation, and throughput is mostly not an issue either.
- The important requirements for MAC protocols are **scalability and robustness** against frequent topology changes.
- The need for scalability is evident when considering very dense sensor networks with dozens or hundreds of nodes in mutual range.

Q. Describe the energy problems and goals in WSN

Energy problems on the MAC layer

- A nodes transceiver consumes a significant share of energy.
- The four main states that the nodes operate are: **transmitting, receiving, idling, & sleeping.**
- The energy-consumption properties of some transceiver designs in the different operational states.
- Transmitting is costly, receive costs have the same order of magnitude as transmit costs, idling can be significantly cheaper but also about as expensive as receiving, and sleeping costs almost nothing but results in a "deaf" node.
- For the operations of a MAC protocols, the following energy problems and design goals are considered:

Collisions

- Collisions incur useless receive costs at the destination node, useless transmit costs at the source node, and the expenditure on energy upon packet retransmission.
- Hence, collisions should be avoided, either by design (fixed assignment/TDMA or demand assignment protocols) or by appropriate collision avoidance/hidden-terminal procedures in CSMA protocols.

Overhearing

- Unicast frames have one source and one destination node.
- The wireless medium is a broadcast medium and all the source's neighbors that are in receive state hear a packet and drop it when it is not destined to them; these nodes **overhear** the packet.

Protocol overhead

- Protocol overhead is induced by MAC-related control frames like RTS and CTS packets or request packets in demand assignment protocols.
- Also per-packet overhead like packet headers and trailers also are called packet overhead.

Idle listening

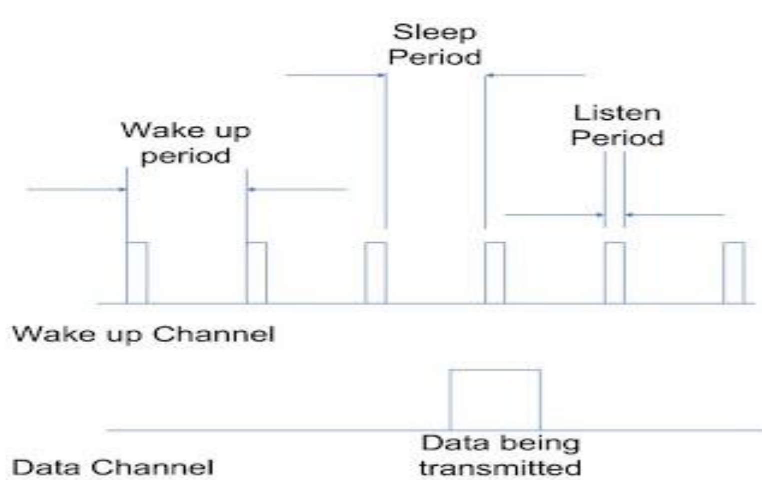
- A node being in idle state is ready to receive a packet but is not currently receiving anything.
- This readiness of the node is costly and useless in case of low network loads.

- Switching off the transceiver is a solution; but since mode changes also cost energy, their frequency should be kept at "reasonable" levels.
- **TDMA-based protocols** offer an implicit solution to this problem, since a node having assigned a time slot and exchanging (transmitting/receiving) data only during this slot can safely switch off its transceiver in all other time slots.

Q. Describe the STEM protocol.

STEM: Sparse Topology and Energy Management

- This protocol tries to save energy due to **idle listening**.
- This protocol does not provide a complete MAC protocol, a MAC protocol can be used along with it to give a complete MAC protocol.
- The protocol proposes to use two channels, **wake up channel** and **data channel**.
- Wake up channel is used to **inform** the receiver that a transmitter wants to transmit data to it.
- Data channel is used to transmit data, underlying MAC protocol is used for this data transmission.
- STEM is designed for applications which wait for an event and report that event, when the event takes place.
- In other words STEM is applicable where nodes have two states, monitor sate, where nodes monitor and no event takes place, and transfer state, where event is detected and data has to be transmitted.
- On the Wake up channel time is divided into sleep period and listen period, these together are called wake up period.
- This can be seen in the diagram below:



Q. With a neat diagram explain the channels in the STEM protocol.

Channels in STEM:

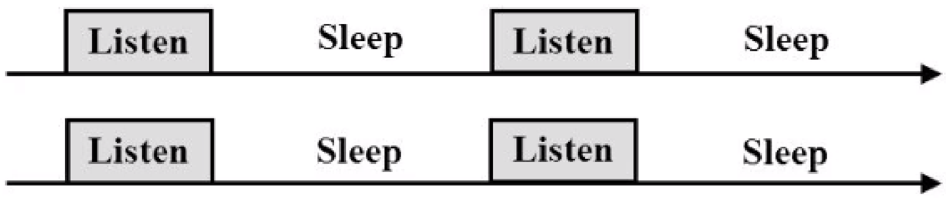
- There are two transceivers in every sensor node.
- One is for wake up channel and other is for data channel.
- The transceiver of the data channel will always be in sleep mode until some has to received or transmitted by the node and the transceiver of the wake up channel will be sleep in sleep period and be active in listen period.
- During the **listen period** the wake up channel receiver is switched on.
- The node waits to check if any data is to be received if so the data channel transceiver is switched on or else the wake up channel transceiver goes to sleep.
- The STEM protocol has two types: they are **STEM-B** and **STEM-T**.
- In **STEM-B** a node which wishes to transmit to another node, sends beacons periodically on the wake up channel.
- The beacon contains the address of transmitter and receiver.
- The receiver detects the beacons during its listen period and acknowledges the transmitter, and then both shift to data channel and exchange data.
- In **STEM-T** the transmitter sends busy tone on wake up channel for a long enough time to hit the receivers listen period.
- As there is no address of the receiver in the busy tone all neighboring nodes which hear busy shift to data channel, however on receiving the data, only the node for which the data was intended will reply and all others go back to sleep.

SMAC-Sensor MAC Protocol

- S-MAC is a medium-access control (MAC) protocol designed for wireless sensor networks.
- Wireless sensor networks use battery-operated computing and sensing devices.
- A network of these devices will collaborate for a common application such as environmental monitoring.
- Sensor networks are deployed in an ad hoc fashion, with individual nodes remaining largely inactive for long periods of time.
- They become suddenly active when an event is detected.
- These characteristics of sensor networks and applications motivate a MAC that is different from traditional wireless MACs such as IEEE

802.11 in almost every way: **energy conservation and self-configuration** are primary goals.

- The per-node fairness and latency are less important.
- To reduce energy consumption in listening to an idle channel, nodes periodically sleep as shown below:



- Neighboring nodes form virtual clusters to auto-synchronize on sleep schedules.
- S-MAC applies **message passing mechanism** to reduce contention latency for sensor-network applications that require store-and-forward processing as data move through the network.
- **Pros and Cons of SMAC:**

Pros:

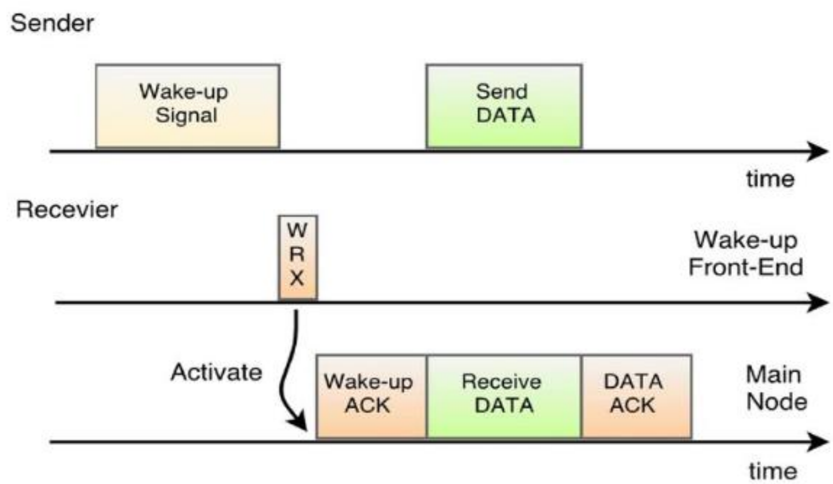
- Significant low power operation.
- Schedules sleep and transmit time to enable low power transmission with reasonable latency.

Cons:

- Implementation is quite complex for WSN.
- Significant state maintanence(Schedules).
- Neighbors synchronization.
- Sleep and listen periods are predefined and constant.

Wakeup radio concepts

- The lifetime of battery operated sensor nodes is a critical issue.
- In the case of event driven applications where events take place infrequently, most of the energy is wasted in idle listening by the sensor nodes.
- The sensor node in continuous idle listening mode drains the batteries approximately in two days.
- The ideal situation would be if a node were always in the receiving state when a packet is transmitted to it, in the transmitting state when it transmits a packet, and in the sleep state at all other times; the idle state should be avoided.
- The **wakeup radio** concept strives to achieve this goal by a simple, “powerless” receiver that can trigger a main receiver.

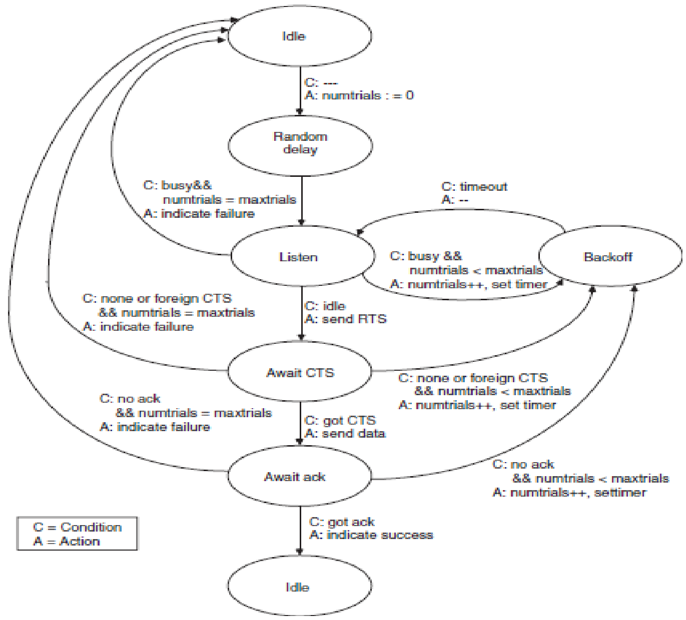


- A node wishing to transmit a data packet randomly picks one of the channels and performs a carrier sensing operation.
- If the channel is busy, the node makes another random channel choice and repeats the carrier-sensing operation.
- After a certain number of unsuccessful trials, the node backs off for a random time and starts again.
- If the channel is idle, the node sends a wakeup signal to the intended receiver, indicating both the receiver identification and the channel to use.
- The receiver wakes up its data transceiver, tunes to the indicated channel, and the data packet transmission can proceed.
- The receiver can switch its data transceiver back into sleep mode.
- This wakeup radio concept has the significant advantage that only the low-**power wakeup transceiver has to be switched on** all the time while the much more energy consuming data transceiver is non sleeping if and only if the node is involved in data transmissions.
- This scheme is naturally **traffic adaptive**, that is, the MAC becomes more and more active as the traffic load increases. Periodic wakeup schemes do not have this property.

CSMA protocols:

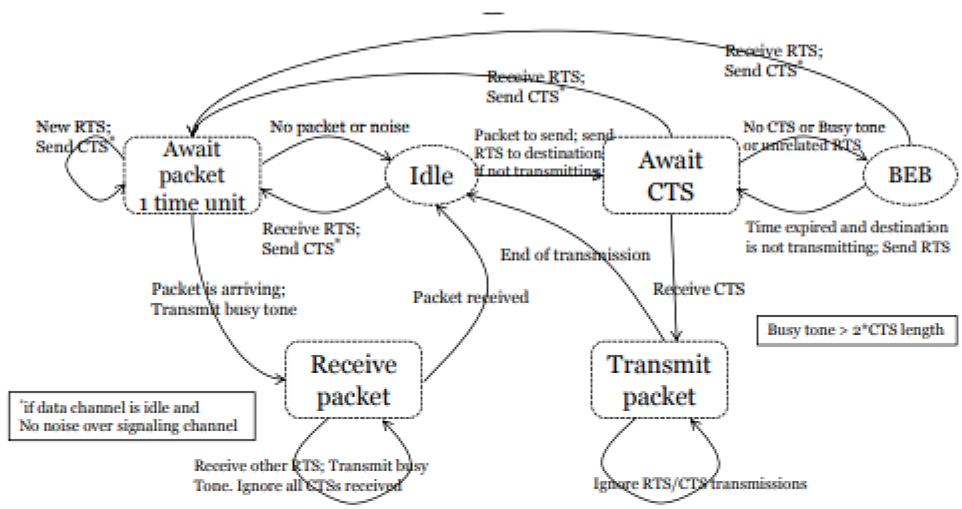
- A network that is idle for long times and starts to become active when triggered by an important external event.
- Upon the triggering event, all nodes wish to transmit simultaneously, potentially creating lots of collisions.
- In the case that the nodes want to send their packets periodically, the danger of collisions is repeated if no special measures are taken.
- The nodes are assumed to know an upstream neighbor to which they have to forward packets destined for the sink.
- This upstream neighbor is also called the *parent node*.

- Each node generates local sensor traffic and additionally works as a forwarder for downstream nodes.



- Figure shows the several steps a node passes through in case of a transmission as a finite state automaton.
- After a node gets a new packet for transmission from its upper layers, it starts with a random delay and initializes its trial counter num retries with zero.
- The purpose of the random delay is to desynchronize nodes that are initially synchronized by the external event.
- During this random delay, the node's transceiver can be put into sleep mode.
- During the listen period, the node performs carrier sensing.
- If the medium is found to be busy and the number of trials so far is smaller than the maximum number, the node goes into the backoff mode.
- In the backoff mode, the node waits a random amount of time, which can depend on the number of trials and during which the node can sleep (the protocol is thus a nonpersistent CSMA variant).
- The backoff mode can also be used by the application layer to initiate a "phase change" for its locally generated periodic traffic.
- This phase change aims to desynchronize correlated or periodic traffic of different nodes.

PAMAS- Power Aware Multiaccess with Signaling

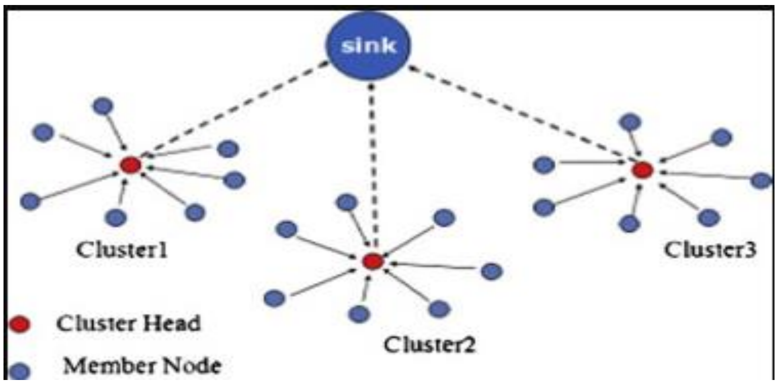


- The PAMAS protocol (Power Aware Multiaccess with Signaling) presented by Raghavendra and Singh is originally designed for ad hoc networks.
- It provides a detailed overhearing avoidance mechanism while it does not consider the idle listening problem.
- The protocol combines the busy-tone solution and RTS/CTS handshake similar to the MACA protocol (MACA uses no final acknowledgment packet).
- A distinctive feature of PAMAS is that it uses two channels: a **data channel** and a **control channel**.
- All the signaling packets (RTS, CTS, busy tones) are transmitted on the control channel, while the data channel is reserved for data packets.
- The operation of PAMAS is as depicted in the diagram above.
- Let us consider an idle node *x* to which a new packet destined to a neighboring node *y* arrives.
- First, *x* sends an RTS packet on the control channel without doing any carrier sensing.
- This packet carries both *x*'s and *y*'s MAC addresses. If *y* receives this packet, it answers with a CTS packet if *y* does not know of any ongoing transmission in its vicinity.
- Upon receiving the CTS, *x* starts to transmit the packet to *y* on the data channel.
- When *y* starts to receive the data, it sends out a **busy-tone** packet on the control channel.
- If *x* fails to receive a CTS packet within some time window, it enters the backoff mode, where a binary exponential backoff scheme is used (i.e., the backoff time is uniformly chosen from a time interval that is doubled after each failure to receive a CTS).

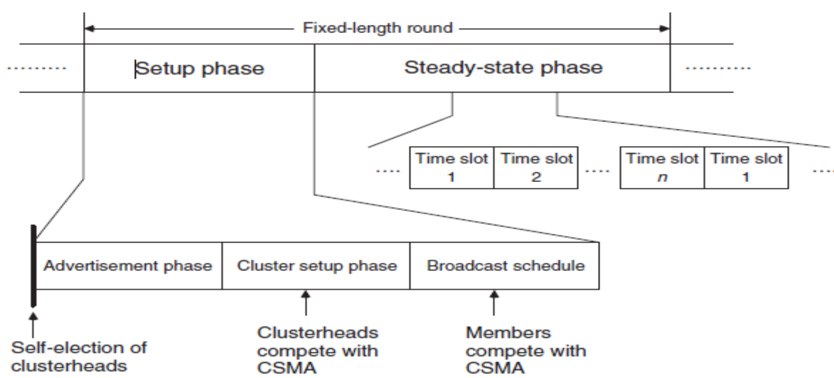
Schedule-based protocols

LEACH- Low-energy Adaptive Clustering Hierarchy

- The LEACH protocol (Low-energy Adaptive Clustering Hierarchy) assumes a dense sensor network of homogeneous, energy-constrained nodes, which shall report their data to a sink node.
- In LEACH, a TDMA-based MAC protocol is integrated with clustering and a simple "routing" protocol.
- LEACH partitions the nodes into **clusters** and in each cluster a dedicated node.



- The **cluster head**, is responsible for creating and maintaining a TDMA schedule; all the other nodes of a cluster are **member nodes**.
- Two phases of operation are defined: a) Set up phase- where the cluster heads are chosen, b) Steady state phase- where the cluster heads are maintained for the period of transmission of data.



- LEACH assumes that each node has a radio powerful enough to directly reach the base station or the nearest cluster head, but that using this radio at full power all the time would waste energy.
- To all member nodes, TDMA slots are assigned, which can be used to exchange data between the member and the clusterhead; there is no peer-to-peer communication.
- With the exception of their time slots, the members can spend their time in sleep state.

- The clusterhead aggregates the data of its members and transmits it to the sink node or to other nodes for further relaying.
- Since the sink is often far away, the clusterhead must spend significant energy for this transmission. For a member, it is typically much cheaper to reach the clusterhead than to transmit MAC protocols directly to the sink.
- The cluster heads role is energy consuming since it is always switched on and is responsible for the long-range transmissions.
- If a fixed node has this role, it would burn its energy quickly, and after it died, all its members would be "headless" and therefore useless.
- **Cons in LEACH**:Leach assumes that:
  a) It is only suitable for small networks.
  b) All nodes have data to send and so assign a time slot for a node even though some nodes might not have data to transmit.
  c) Overhead of clustering after a period of time.
  d) System stop situation at the time of cluster head failure.
  e) LEACH requires a Cluster Head to transfer data to sink node overba single hop link.

Properties of this algorithm include:

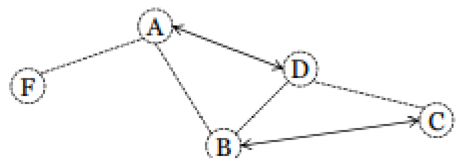
- Cluster based
- Random cluster head selection each round with rotation. Or cluster head selection based on sensor having highest energy
- Cluster membership adaptive
- Data aggregation at cluster head
- Cluster head communicate directly with sink or user
- Communication done with cluster head via TDMA
- Threshold value

SMACS - Self-organizing Medium Access Control for Sensor Networks:

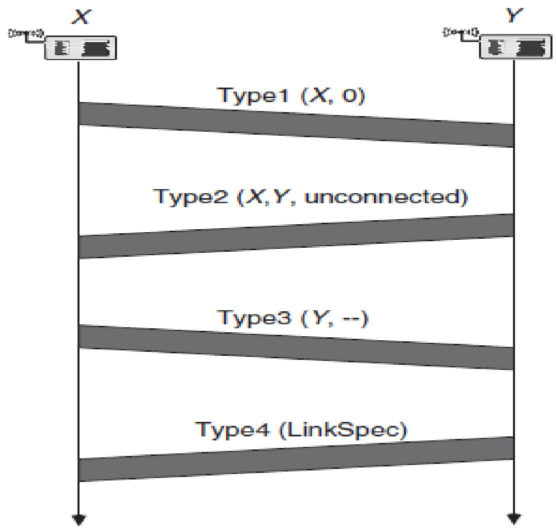
- It is a protocol in a suite for organization, routing, management for MANETs to optimize for QoS.
- It is an infrastructure-building protocol that forms a flat topology for sensor networks
- SMACS is a distributed protocol which enables a collection of nodes to discover neighbors and establish schedules for communicating with them without the need of a "master" node.
- Neighbor discovery and channel assignment phases are combined

SMACS—Assumptions

- The available spectrum is subdivided into many channels (and many CDMA codes are available)
- Each node can tune to an arbitrary channel
- Most of the nodes are stationary and remain as such for a long time
- Each node divides its time locally into fixed-length superframes of Tframe length
- Superframes are subdivided into timeslots

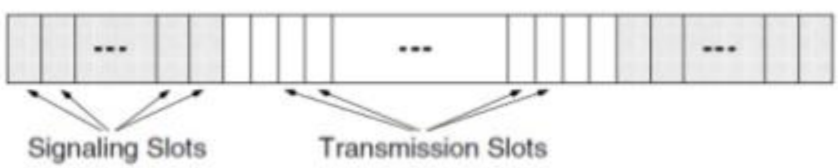


- Nodes wake up at random times, and listen to the channel for a random amount of time
- A node (C) will transmit an invitation (TYPE 1) by the end of its initial listen time if not heard the same from others
- Nodes hearing the invitation (B and G not shown) broadcast a response (TYPE 2) Nodes hearing the invitation (B and G, not shown), broadcast a response (TYPE 2) during the interval following the reception of TYPE 1 at a random time
- If responses don't collide and heard by C, C must chose only one respondent (first)
- Node C sends TYPE 3 immediately
- after the interval following TYPE 1 to notify all respondents of the chosen one
- Node G was not chose, it turns off its transmitter for a while and starts the search again
- If C is already attached it If C is already attached, it will transmit its schedule info along with the time its next 'll transmit its schedule info along with the time its next superframe will start in the body of TYPE 3
- Node B compares the schedules and time offsets and arrives at a set of two free time intervals as the slots assigned to the link between B and C
- B sends this information with the randomly selected frequency band to node C in the body of TYPE 4
- After a pair of short test messages, the link is added to the nodes' schedules permanently



Traffic-adaptive medium access protocol (TRAMA)

- The Traffic-Adaptive Medium Access (TRAMA) protocol creates schedules allowing nodes to access a single channel in a collision-free manner.
- The schedules are constructed in a distributed manner and on an on-demand basis.
- The protocol assumes that all nodes are time synchronized and divides time into **random access periods** and **scheduled-access periods**.
- A random access period followed by a scheduled-access period is called a **cycle**.
- The nodes broadcast their neighborhood information and, by capturing the respective packets from their neighbors, can learn about their two-hop neighborhood during signalling slots.



- The data is transmitted in the transmission slots allotted.
- Furthermore, they broadcast their schedule information, they periodically provide their neighbors with an updated list of receivers for the packets currently in a nodes queue.
- On the basis of this information, the nodes execute a distributed scheduling algorithm to determine for each time slot of the scheduled-access period the transmitting and receiving nodes and the nodes that can go into sleep mode.
- The protocol itself consists of three different components: the **neighborhood protocol**, the **schedule exchange protocol** and the **adaptive election algorithm**.

- The **neighborhood protocol** is executed solely in the random access phase, which is subdivided into small time slots.
- A node picks randomly a number of time slots and transmits small control packets in these without doing any carrier sensing.
- These packets indicate the node's identification and contain incremental neighborhood information, that is only those neighbor identifications are included that belong to new neighbors or neighbors that were missing during the last cycle.
- When a node does not transmit, it listens to pick up its neighbors' control packets.
- The length of the random access phase should be chosen such that a node receives its neighbors packets with sufficiently high probability to ensure consistent topology information.
- It depends thus on the node degree. All nodes' transceivers must be active during the random access period.
- **Schedule exchange protocol(SEP):** The schedule consists of intended receivers for future transmissions slots.
- Schedules are established based on the current traffic information at the node.
- The information is propagated to the neighbors periodically.
- Scheduled exchange protocol maintained consistent schedules for the one hop neighbors.
- **Adaptive Election Algorithm:** Decides the node state as either **transmit, receive or sleep.**
- Uses the schedule information obtained by SEP.
- Nodes without any data to send are removed from the election process, thereby improving the channel utilization.
- **Pros and Cons of TRAMA:**

Pros:

- Energy efficiency: increasing sleeping of the nodes.
- Decrease in collision rate.

Cons:

- Delay I the network
- Frequent message exchange
- High density network- overheads