

UNIT - 3

MAC PROTOCOLS FOR WIRELESS SENSOR NETWORKS

Introduction:

Nodes in an ad-hoc wireless network share a common broadcast radio channel. Since the radio spectrum is limited, the bandwidth available for communication in such network is also limited. Access to this shared medium should be controlled in such a manner that all nodes receive a fair share of the available bandwidth, and that bandwidth is utilized efficiently.

Since the characteristics of the wireless medium are completely different from those of the wired medium, and it need to address unique issues such as

- * node mobility
- * limited bandwidth availability
- * hidden and exposed node problem
- * Synchronization between nodes
- * Broadcast channel characteristics
- * Power constraints

So, a different set of protocols is required for controlling access to the shared medium in such networks. This chapter focuses on Media access control (MAC) protocol for wireless networks.

Issues in designing a MAC protocol for ad-hoc wireless networks:

The following are the main issues in wireless networks.

Bandwidth Efficiency:

Since the radio spectrum is limited, the bandwidth available for communication is also very limited. The MAC protocol must be designed in such a way that the limited bandwidth is utilized in an efficient manner.

$$\text{Bandwidth efficiency} = \frac{\text{Bandwidth used for actual data transmission}}{\text{Total Available Bandwidth}}$$

The MAC protocol must try to maximize this bandwidth efficiency.

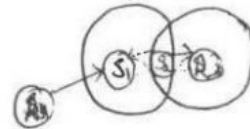
QoS Support:

Due to inherent nature of ad-hoc wireless network, where nodes are usually mobile most of the time, providing quality of service (QoS) to data transmission in such network is very difficult. Bandwidth reservation made at one point of time may become invalid once the node moves out of the region where the reservation was made. QoS support is essential for supporting time-critical traffic sessions such as in military communication. The MAC protocol for ad-hoc wireless networks that are to be used in such applications must have some kind of reservation mechanism that takes into consideration of the wireless channel characteristics and node mobility.

Synchronization:

Synchronization is very important for Bandwidth (time slot) reservation by nodes. Exchange of control packets may be required for achieving time synchronization among nodes. The control packets must not consume too much of network bandwidth.

Hidden and Exposed node problem:



The hidden node problem refers to the collision of packets at a receiving node due to the simultaneous transmission of those nodes that are not within the direct transmission range of sender, but are within the transmission range of the receiver. Collision occurs when both nodes transmit packet at the same time without knowing about the transmission of each other.

The exposed node problem refers to the inability of a node, which is blocked due to transmission by a nearby transmitting node, to transmit to another node. [refer unit-3]

The hidden and exposed node problem significantly reduce the throughput of a network when the traffic load is high. It is therefore desirable that the MAC protocol be free from the hidden and exposed terminal problem.

Broadcast nature of radio channel:

Another important factor in the design of MAC protocol is the broadcast nature of the radio channel.

The transmission made by a node are received by all nodes within its direct transmission range. When a node is receiving data, no other nodes in its neighborhood, apart from the sender should transmit. Since multiple nodes may contend for the channel simultaneously, the possibility of packet collisions is quite high in (WSN) wireless networks. A MAC protocol must be designed in such a way that it should minimize the collision. Also protocol should ensure that all nodes are treated fairly with respect to bandwidth allocations.

Distributed Nature:

Ad hoc wireless networks do not have centralized coordinators, which allocate bandwidth to mobile terminal. But this is not possible in wireless network, where the nodes are keep moving continuously. Therefore, nodes must be scheduled in a distributed fashion for gaining access to the channel. This may need exchange of control information. The MAC protocol must ensure that the additional overhead due to this control information exchange is not very high.

Mobility of Nodes:

Nodes in an ad-hoc wireless network are mobile most of the time. If the node mobility is very high, the bandwidth reservation made or control packet exchange may no use. The MAC protocols also has no role to play in the mobility of nodes. The protocol design must take this mobility factor into consideration so that the performance of the system is not significantly affected.

Design Goals of MAC Protocol:

The following are the important design goals of MAC protocol, for ad-hoc wireless networks:

- *. Distributed operation of the protocol.
- *. The protocol should provide QoS support for real-time traffic.
- *. Low access delay, which refers to the average delay experienced by any packet to get transmitted, must be kept low.
- *. The available bandwidth must be utilized efficiently.
- *. The protocol should ensure fair allocation (either equal allocation or weighted allocation) of bandwidth to nodes.
- *. The protocol should minimize the effects of hidden & exposed node problem.
- *. The protocol must be scalable to large networks.
- *. Control overhead must be kept as low as possible.
- *. It should have power control mechanism in order to efficiently manage energy consumption of the nodes.
- *. Support for mechanism that control data rate.
- *. The protocol should provide time synchronization among nodes.
- *. It should try to use directional antennas which can provide advantages such as, reduced interference, increased spectrum reuse, and reduced power consumption.

Classification of MAC Protocols:

Ad-hoc network MAC Protocols have been classified into the following

1. Contention-based protocols
2. Contention-based protocols with reservation mechanisms
3. Contention-based protocols with scheduling mechanisms.

1. Contention-based protocols:

These protocols follow a contention-based channel access policy. A node does not make any resource reservation a priori. Whenever it receives a packet to be transmitted, it contends with its neighbor node for access to the shared channel. These protocols cannot provide QoS support since nodes are not guaranteed regular access to the channel. Random access protocols can be further divided into two types

i) sender initiated protocols:

Packet transmissions are initiated by the sender node.

This can be further divided into two

a) Single-channel sender-initiated protocols:

In these protocols, the total available bandwidth is used as it is, without being divided. A node that wins the contention to the channel can make use of the entire bandwidth.

b) multichannel sender-initiated protocols:

In that, the available channel bandwidth is divided

into multiple channels. This enables several nodes to simultaneously transmit data, each using a separate channel.

ii) Receiver - initiated protocols:

The receiver node initiated the contention resolution protocols.

2. Contention-based protocols with Reservation Mechanisms:

In order to support real-time traffic, these protocols have mechanisms for reserving bandwidth a priori. It provide QoS support to time-sensitive traffic sessions. These protocols can be further divided into two types

i) Synchronous protocols:

Synchronous protocols need time synchronization among nodes in the network, so that reservation made by a node are known to other nodes in its neighborhood.

ii) Asynchronous protocols:

These protocols do not require any global synchronization among nodes in the network. These protocols usually use relative time information for effecting reservation.

3. ^{ten}Contention-based protocols with Scheduling Mechanisms:

These protocols focus on packet scheduling at nodes, and also scheduling nodes for access to the channel.

Scheduling of the nodes is accomplished in a way that the no node has to wait for the bandwidth allocation and all nodes are should be treated equally or fairly. Some Scheduling Mechanism depends upon priority of data transmission. While Scheduling the node, the battery power also take into consideration.

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Contention-based Protocols:

Contention-based protocols do not have any bandwidth reservation Mechanism. All ready to transmit nodes check the channel availability simultaneously, and the winning node gains access to the channel. Since nodes are not guaranteed bandwidth, these protocols cannot be used for transmitting real-time traffic.

MACAW: A Media Access Protocol for wireless LANs.

It is based on MACA (multiple access collision Avoidance) protocol.

MACA Protocol:

→ MACA does not make use of carrier-sensing for channel access.

→ When a node wants to transmit a data packet, it first transmit a RTS (Request to send) frame.

→ The receiver node, on receiving the RTS packet, if it is ready to receive the data packet, transmits a CTS (Clear to send) packet.

→ Once the sender receives the CTS packet without any error, it starts to transmitting data packet.

→ If a packet transmitted by node is lost, the node uses the binary exponential back-off algorithm to back off a random interval of time before retrying. (BEB Algorithm)

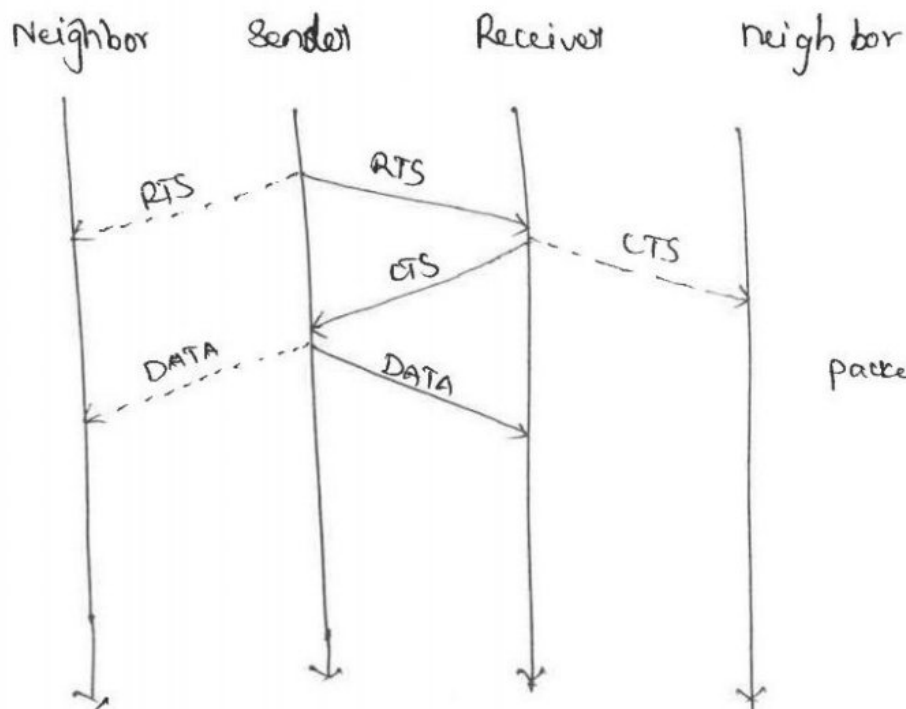


fig:
packet transmission in
MACA

The MACA protocol can overcome both hidden node and exposed node problem. Because of using control frame (RTS + CTS) normally the hidden node problem gets solved.

Both the RTS and CTS packets carry the expected duration of packet transmission.

A node near the receiver, upon hearing the CTS packets defers (postpone) its transmission till the receiver receives the data packet. Thus MACA overcomes the hidden node problem.

Similarly, a node receiving an RTS defers only a short period of time till the sender could receive the CTS. If no CTS is heard by the node during its waiting period, it is free to transmit packets once the waiting interval is over.

Thus, a node that hears only the RTS packet is free to transmit simultaneously when the sender of the RTS is transmitting data packet. Hence the exposed terminal problem is also overcome in MACA. But MACA still has certain problems, which is why we go for MACAW.

MACAW Protocol: A Media Access Protocol for wireless LANs.

The binary Exponential back-off mechanism used in MACA is not efficient because which increase back-off time double when a node collision occur. To overcome this MACAW used modified Algorithm MILD - multiplicative increase and linear decrease back-off mechanism. Here, upon a collision, the backoff is increased by a multiplicative factor 1.5 and upon a successful transmission, it is decremented by one.

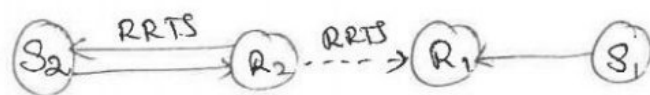
This MACAW protocols used additional signals (ie) RTS, CTS, DS, ACK and RRTS in order to avoid collisions.

An extra control packet ACK used in MACAW. The receiver sends an ACK for the packet received. If ACK is not received by sender, the sender would retry by transmitting an RTS for the same packet.

Next control packet is DS - (Data Sending) packet to ensure RTS-CTS exchange successful. Before transmitting data packet, the source node has to send this DS packet.

Another control packet : RRTS (Request for request to send)

If a node had received an RTS previously for which it was not able to respond because there exists on-going transmission, then it wait for the next contention period and transmits RRTS.



If node R2 had received RTS previously for which it was not able to respond immediately because of on-going transmission between nodes S1 & R1, then node R2 waits for the next contention period and transmits the RRTS packet. The source node receiving RRTS packet, transmits the regular RTS packet to node R2 and normal packet exchange (RTS-CTS-Data-ACK) continues from here.

In order to access the channel effectively by the nodes, the synchronization information need to be propagated to the concerned nodes at appropriate time. This is done by DS and RRTS packets. Figure shows the operation of the MACAW protocol. In that S is source, R is receiver, N1 & N2 are neighbor nodes.

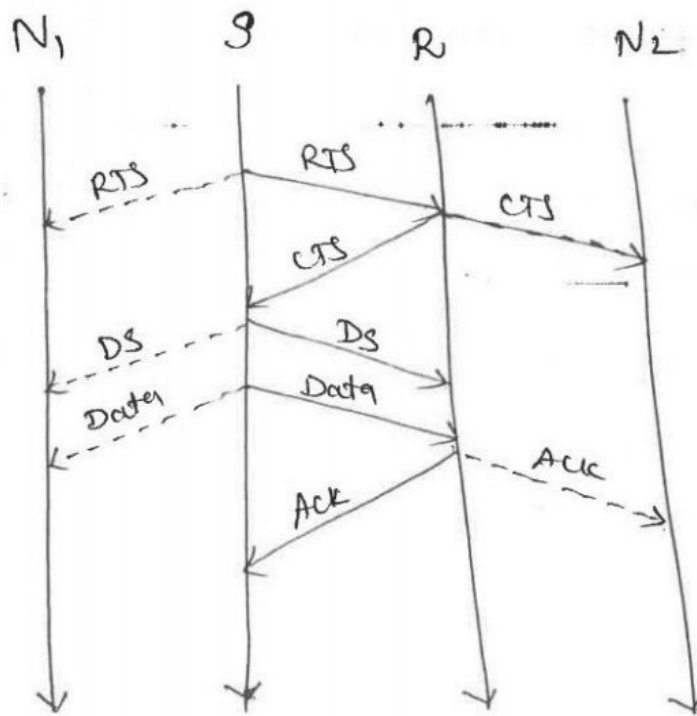


fig: Packet exchange in MACAW.

MACAW is a revision of MACA protocol.

→ The sender senses the carrier to see and transmits a RTS frame if no nearby station transmits a RTS.

→ If Receiver is Ready to receive, it send CTS.

→ Neighbors

→ See CTS, then keep quiet

→ See RTS but not CTS, then keep quiet until the CTS is back to the sender.

→ On receiving this CTS packet, node S immediately transmit the DS message carrying the expected duration of the data packet transmission. On hearing this packet, node N1 back off until the data packet is transmitted.

→ Finally after Receiving data packet, node R send ack packet, in order to ensure correct reception of data packets.

Floor Acquisition Multiple Access Protocols:

FAMA protocols are based on CSMA-CA, which consists of carrier-sensing operation and a collision Avoidance Mechanism.

Floor Acquisition refers to process of gaining control of channel. At any given point of time, the control of the channel is assigned to only one node, and this node is guaranteed to transmit one or more data packets to different destination without suffering from packet collision.

FAMA requires a node that wishes to transmit packet, first to acquire the floor (channel) before starting to transmit the packets. The floor is acquire by exchange of RTS-CTS control packets.

Though the control packets themselves may collide with other control packets, it is ensure that data packets sent by the node that has acquired the channel are always transmitted without any collisions.

Two FAMA protocol variants:

- RTS-CTS exchange with no carrier sensing (MACA)
- RTS-CTS exchange with non-persistent carrier sensing (FAMA - NTR)

According to FAMA principle, in order for collision free,

data transmission, the duration of an RTS must be at least twice the maximum channel propagation delay.

FAMA - NTR: —

- Before sending a packet, the sender senses the channel.
- If channel is busy, the sender back-off a random time and retries later.
- If channel is free, the sender sends the RTS and waits for a CTS packets
- If sender cannot receive a CTS, it takes a random back-off and retries later.
- If sender receives a CTS, it can start transmission of data packet.
- In order to allow the sender to send a burst of packets, the receiver is made to wait a time duration 2 seconds after a packet is received.

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Busy Tone multiple Access protocols: BTMA

The transmission channel is split into two: a data channel and a control channel.

- a data channel for data packet transmissions
- a control channel used to transmit the busy tone signal.

- When a node is ready for transmission, it senses the channel to check whether the busy tone is active. If not, it turns on the busy tone signal and starts data transmissions. If channel is busy, it reschedules the packet for transmission after some random rescheduling delay.

Any other node which senses the carrier on the incoming data channel also transmits the busy tone signal on the control channel, thus prevent two neighboring nodes from transmitting at the same time.

Though the probability of collisions is very low in BTMA, the bandwidth utilization is very poor.

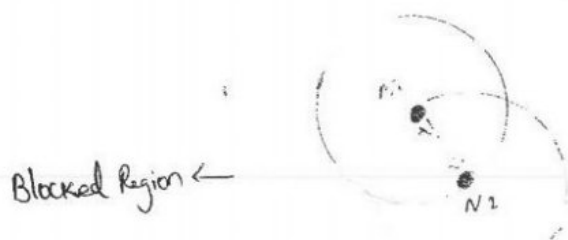


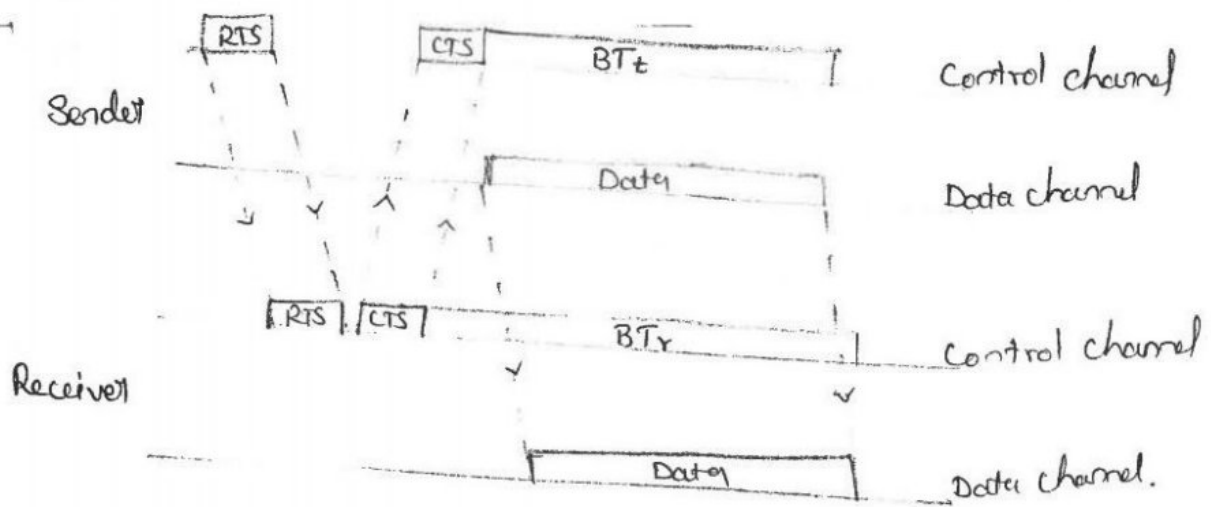
Figure shows the worst-case scenario where the node density is very high; the dotted circle shows the region in which nodes are blocked from simultaneously transmitting when node N_1 is transmitting packets.

Dual Busy tone multiple Access protocol: D-BTMA

- The transmission channel is divided into:
 - data channel → data packet transmission
 - control channel → control packet transmission (RTS & CTS and also for transmitting busy tone).
- Use two busy tones on the control channel: BT_t and BT_r
 - BT_t : indicate that it is transmitting on the data channel.

→ BT_r : indicate that it is receiving on the data channel.

→ Two busy tone signals are two sine waves at different frequencies



• when a node is ready to transmit a data packet

→ First sense the channel to determine where the BT_r signal is active. If no BT_r signal → Transmit RTS packet

→ on receiving RTS packets, check whether the BT_t tone is active. If no BT_t signal → Transmit CTS packet and turn on the BT_r signal.

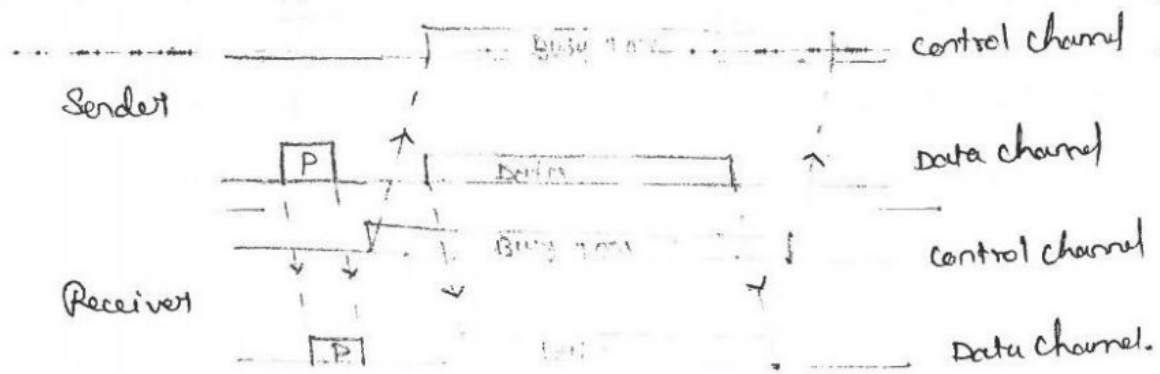
→ sender which receive CTS, turn on BT_t signal and start to send the data. After transmission, it should turn-off BT_t .

→ Receiver which receive data, turn-off BT_r signal.

→ In DBTMA, when a node is transmitting or receiving, only the reverse or forward channels, respectively are blocked. Hence the bandwidth utilization of DBTMA is nearly twice that of other RTS/CTS based schemes.

Receiver-Initiated Busy tone Multiple Access protocol: RI-BTMA

- * The transmission channel is split into two:
 - a data channel for data packet transmissions
 - a control channel for transmitting the busy tone signal
- * A node can transmit on the data channel only if it finds the busy tone to be absent on the control channel.
- * The data packet is divided into two portions: a preamble and the actual data packets. The preamble carries the identification of the intended destination node.
- * Data transmission consists of two steps. First, the preamble needs to be transmitted by the sender. Once the receiver node acknowledges the reception of this preamble by transmitting the busy tone signal on the control channel, the actual data packet is transmitted.
- * This busy tone signal continues as long as it is receiving data from the sender.
- * If Preamble transmission fails, the receiver does not acknowledge with the busy tone, and the sender node waits for the next free slot and tries again.
- * The busy tones serve two purposes
 - It acknowledges the sender about the successful reception of the preamble.
 - It informs the nearby hidden nodes about the impending transmission so that they do not transmit at the same time.



where $\rightarrow$ P - Preamble packet.

There are two types of RI-BTMA protocols: The basic protocol and control protocol.

$\rightarrow$ In the basic protocol, nodes do not have backlog buffers to store packet. If collision occur, packets cannot be retransmitted.

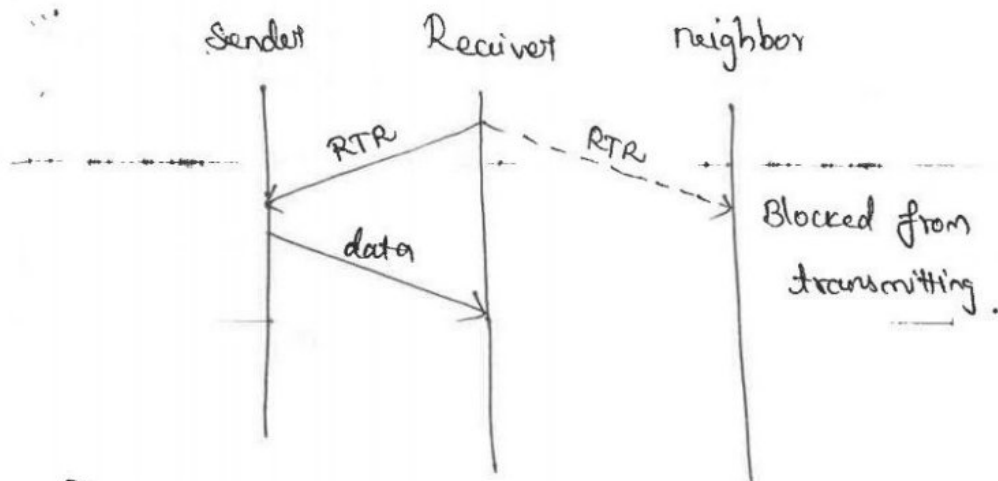
$\rightarrow$ In the controlled protocol, nodes consist of backlog buffer, when collision occur, the packets are put into buffer and transmit later.

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MACA-BY Invitation:

MACA-BI is a receiver initiated MAC protocol. It reduces the number of control packets in MACA protocol. It eliminates the needs of RTS-CTS packets.

In MACA-BI the receiver node initiates the data transmission by transmitting ready to receive (RTR) control packet to the sender. If it is ready to transmit, the sender node responds by sending a data packet.



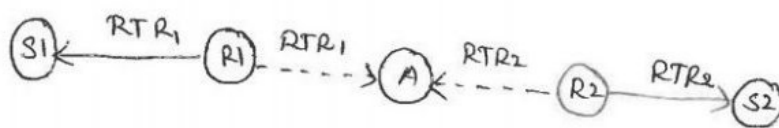
Problems:

→ Receiver may not have an exact knowledge about the traffic rate.

→ So, the Receiver needs to estimate the average arrival rate of packets. For providing necessary information, the Data packets are modified into carry control information regarding no. of packets and packet length.

→ Collision among Data packets is impossible.

→ However, the hidden terminal problem still affects the control packet transmission. This leads to protocol failure.



Here, RTR packets transmitted by receiver nodes R_1 & R_2 , collide at node A.

MACA-BI eliminates the problem hidden terminals and avoid collision between the data packet. But control packet transmission get affected by hidden terminal problem resulting in protocol failure.

Media access with reduced handshake protocol (MARCH)

This protocol, as the name suggest reduces the number of handshakes required for data transmission by employing broadcast nature of traffic with the help of omnidirectional antennas. This protocol make use of RTS packet during transmission only for the first packet of stream and the CTS packet stream from the second packet onwards. MARCH uses the property of the broadcast channel to reduce the two-way handshake into a single CTS-only handshake.

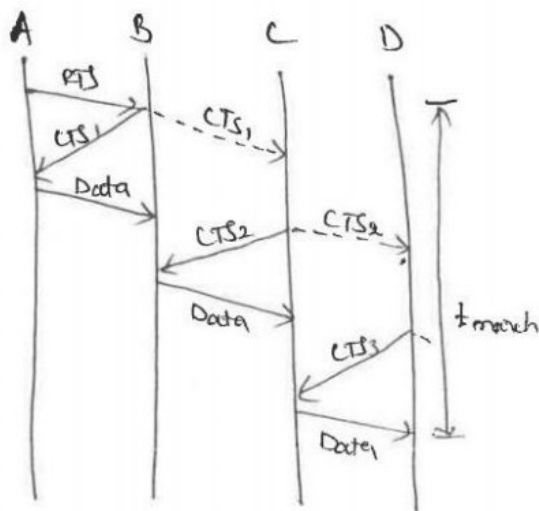


Figure shows the handshake mechanism of MARCH. Here, when node B transmits the CTS₁ packets, this packet is also heard by node C. A CTS packet carries information regarding the duration of the next data packet. Node C therefore determines the time at which the next

data packet would be available at node B. It sends the CTS₂ packet at the point of the time. On receiving CTS₂ packet, node B sends the data packet directly to node C. It can be observed from the figure that time taken for a packet transmitted by node A to reach node D in MARCH is less compare to MACA. (Time taken by protocol

The Through-put of MARCH is significantly high when compared to MACA, while control overhead is much less. Bandwidth consumed by control traffic is also less.

Contention-based protocols with reservation Mechanism:

Distributed Packet Reservation Multiple Access Protocol (D-PRMA)

D-PRMA is a TDMA-based scheme. The channel is divided into fixed and equal sized frames along the time axis. Each frame is composed of S slots, and each slot consists of m minislots. Each minislots can be further divided into two control fields RTS/BI and CTS/BI (BI stands for busy Indicator), as shown in the figure.

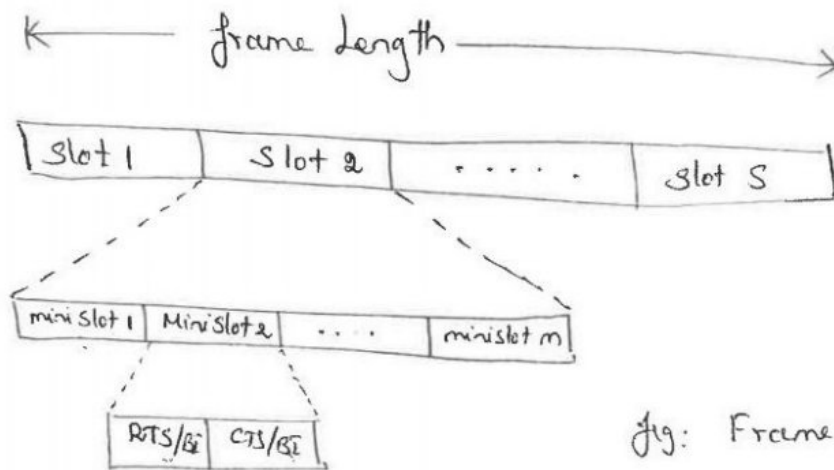


Fig: Frame structure in D-PRMA.

The RTS/BI and CTS/BI are used for slot reservation and for overcoming the hidden terminal problem. All the nodes having packets ready for transmission compete for the first minislot of each slot. The remaining $(m-1)$ minislots are granted to the node that wins the contention. Also, the same slot in each subsequent frame can be reserved for the same node until it completes its packet transmission.

Any node that wants to transmit, it has to first reserve slots, if they have not been reserved already. First the node sense the carrier. If a sender node detects the channel to be idle at the beginning of a slot (minislot 1), it transmit RTS packet to the intended destination through the RTS/ST part of the current minislot. The receiver node responds by sending a CTS packet through the CTS/ST of the same minislot. If the sender node receives this CTS successfully, then it gets the reservation for the current slot and can use the remaining minislots (ie) minislots 2 to n. D-PRMA is more suited for voice traffic than for data traffic application.

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Collision Avoidance Time Allocation Protocol : (CATA)

CATA protocol is based on dynamic topology-dependent scheduling transmission. It support broadcast, unicast and multicast transmissions simultaneously. It is also TDMA scheme. The channel is divided into equal size frame. Each frame consists of 3 slots and each slots is further divided into five minislots. The first four minislots are used for transmitting control packets and are called Control Minislots (CMS) and fifth minislot is called as data Minislots (DMS), is meant for data transmission.

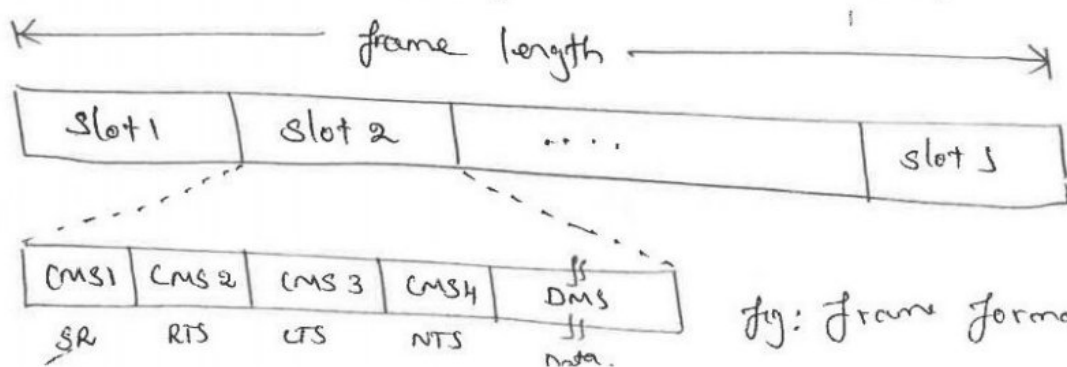


fig: Frame format in CATA

Five minislots:

1) CMS1: Slot Reservation (Receiver send SR packet to other source)

2) CMS2: RTS

3) CMS3: CTS

4) CMS4: Not to send (NTS)

5) DMS: Data transmission.

Each node that receives data during DMS of the current slot transmits a slot reservation (SR) packet during CMS1 of the slot. This inform other neighbors about the current reservation. After that ~~At~~ slot CMS2, the sender node send RTS command packet to receiver. Then receiver transmit a CTS in CMS3 slot.

If the reservation was successful the data can transmit in current slot and the same slot in subsequent frames, until the unicast flow get terminated. During CMS4 the sender transmits a NTS - Not to send. It act as a negative ACK. It informs that the transmission was completed and reservation is failed/terminated.

Hop Reservation Multiple Access Protocol (HRMA):

It is a multichannel MAC protocol, based on simple half duplex, very slow FHSS (Frequency hopping spread spectrum) radios. HRMA can be viewed as a time slot reservation protocol where each time slot is assigned a separate frequency channel.

Available frequency channels L , HRMA uses one frequency channel (f_0) as a dedicated synchronization channel, where nodes exchange synchronization information.

The remaining $L-1$ frequency channels are divided into

$M = \frac{(L-1)}{2}$ frequency pairs, denoted by

$$(f_i, f_i^*) \Rightarrow i = 1, 2, 3 \dots M$$

f_i is used for transmitting and receiving Hop reservation (HR), RTS packets, CTS packets and data packet.

f_i^* is used for transmitting ACK packets.

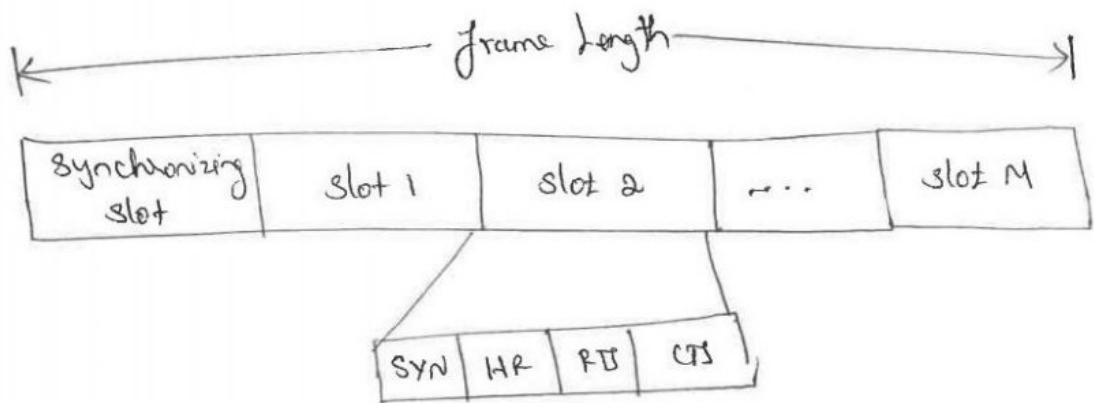


Fig: Frame format in HRMA.

→ In HRMA, Time is slotted and each slot is assigned a separate frequency hop.

→ Each time slot is divided into four period, namely SYN, HR, RTS and CTS period for transmitting syn packet, HR packet, RTS packet and CTS packets respectively.

→ Synchronizing slot: It is used to identify

→ The beginning of a frequency hop and

→ The frequency to be used is the immediately following

→ A node ready to transmit data,

- It sense the HA period of current slot
- If the channel is idle during HA period; it transmits the RTS during RTS period and wait for CTS during CTS period.
- On Receiving the RTS, the destination node transmits the CTS packets and wait for data packet.
- If the source receives the CTS packet correctly, it implies that the source and receiver nodes have successfully reserved the current hop.

→ As mentioned earlier, a separate frequency f_x is used for transmitting ACK from Receiver to transmitter. Once ACK packet transmission / Reception is over both source and receiver hop back to the reserved frequency to continue with the data transmission. The data packets transmitted can be of any size, may be single packet or train of packets.

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Soft Reservation Multiple Access with priority Assignment:

SRMA / PA :

It is developed with the main objective of supporting integrated services of real-time and non real-time application in ad-hoc networks.

Node uses a collision-Avoidance mechanism and soft reservation mechanism.

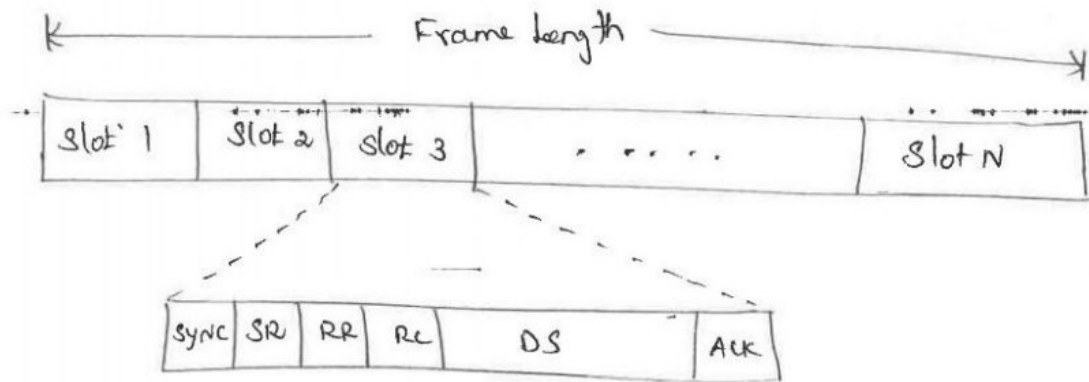


Fig: frame structure in SRMA/PA.

- Time is divided into frames, with each frame consisting of fixed number of slots.
- Each slot is further divided into 6 different fields namely sync, Soft Reservation (SR), Reservation Request (RR), reservation confirm (RC), data sending (DS) and acknowledgement (Ack).
 - The sync field is used for synchronization purpose.
 - The SR, RR, RC, & Ack fields are used for transmitting and receiving the corresponding control packets.
 - The DS field is used for data transmission
 - The SR packet serves as a busy tone. It informs the nodes about the reservation of the slot. It also carries the Access priority value assigned to the node that has reserved the slot.
- A node determine whether or not a slot is free through the SR field of that slot.
- When an idle node receives a data packet for transmission,

(114)

The node waits for a free slot and transmits the RR packet in the RR field of the slot.

- In the case of a voice terminal node, the node tries to take control of the slot already reserved by a data terminal if it finds its priority level to be higher than that of the data terminal. This process is called soft reservation.

- Priority levels are initially assigned to nodes based on the service classes in a static manner.

- Priority of voice terminal $>$ Priority of data terminal.

- A node can be in one of the two states:

- Active state = currently transmitting

- Idle state = does not have any packet to be transmitted

- In the active state itself, nodes can be in one of the two states

- Access state → The node is backlogged and is trying to

- reserved state reserve a slot for transmission

- In order to avoid collisions

- A binary Exponential back-off algorithm is used for non-real time connections

- A modified binary Exponential ^{back-off} algorithm used for real time connection.

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Five-phase Reservation Protocol (FPRP):

- It is a single-channel TDMA-based broadcast protocol.
- The protocol is fully distributed; that is, multiple reservations can be simultaneously made throughout the network.
- No ordering among nodes is followed.
- Nodes need not wait for making time slot reservations.

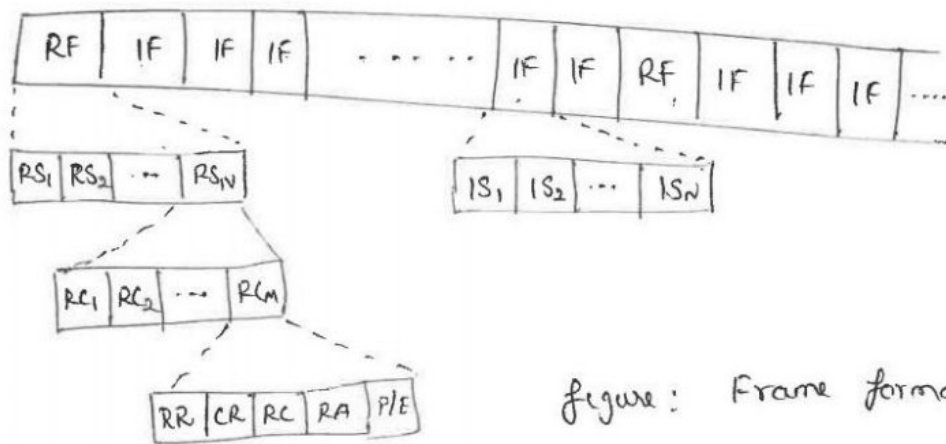


figure: Frame format FPRP

- Time is divided into frames: Reservation frame and information frame (IF). ^(RF)
- Each RF has N Reservation slots (RS) and each IF has N information slots (IS).
- Each RS is composed of M reservation cycles (RCs).
- Each RF is followed by a sequence of IFs.

In order to reserve an IS , a node needs to contend during the corresponding RS . Based on these contentions, a TDMA is generated in the RF and is used in the subsequent IFs until the next RF.

During the corresponding IS, a node would be in one of the three state : Transmit (T), receive (R), or Blocked (B).

The reservation takes following five phases:

1. Reservation Request phase:

Node that need to transmit packets send reservation request (RR) packets to their destination nodes.

2. Collision report phase:

If a collision is detected by any node during the reservation request phase, then that node broadcasts a collision report (CR) packet. The corresponding source node, upon receiving the CR packet, take necessary action.

3. Reservation confirmation phase:

A source node does not receive any CR packet, then it wins the contention for a slot. In order to confirm the reservation request, it sends a reservation Confirmation (RC) message to the destination node in this phase.

4. Reservation Acknowledgement phase:

In this phase, the destination node acknowledges reception of the RC by sending back a reservation acknowledgement (RA) message to the source.

5) packing and elimination phase: Two types of packets are transmitted during this phase : packing packet and Elimination packet.

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MACA with Piggy-Backed Reservation (MACA/PR):

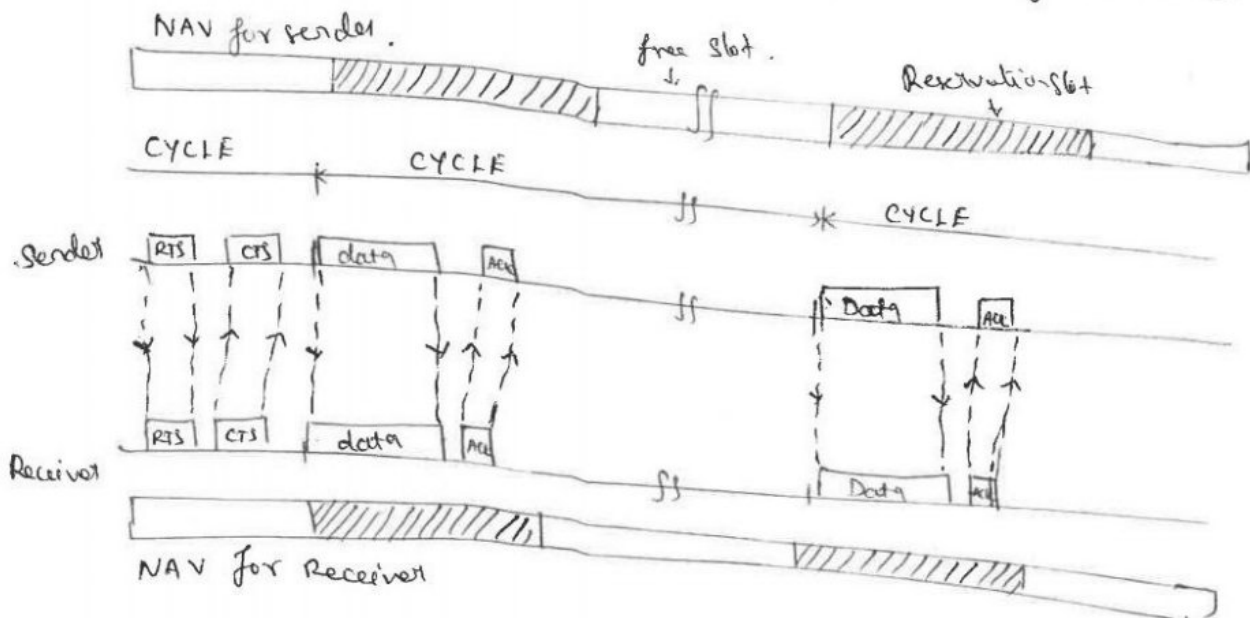
→ MACA/PR is used to provide real time traffic support.

→ The main components:

→ A MAC Protocol; A reservation Protocol and A QoS routing Protocol.

→ It provides guaranteed bandwidth support for real-time packets, and also it provides reliable transmission of best efforts packets.

→ Each node maintains a reservation Table (RT) that records all the reserved transmit and receive slots / windows of all nodes.



For real time traffic:

→ The source first sends an RTS packet, for which the receiver responds with CTS packet.

→ Now the source sends the first Data packet of the real-time session

→ Reservation information of the next Data is piggy-backed on this current data packet.

- On receiving this data packet, the receiver updates its reservation table with the piggy-backed reservation information.
- The receiver then sends back Ack packet to the source.
- Receiver piggy-backs the reservation confirmation information on this Ack packet.

For non real time traffic:

- A node that wants to transmit a non-real time packet, finds a free slot in the table.
- Then, it waits for the same slot the next time around.
- If it is still free, it sends a RTS packet in the slot, expects a CTS packet, then sends the data and receives the ack still in the same slot.
- The RTS and CTS packets contains the amount of time that the data transmission is going to take place.
- In this way, the neighbors of the source and destination nodes can update their tables.

— x —

Real time Medium Access Control Protocol (RTMAC)

* It provides a bandwidth reservation Mechanism for supporting real-time traffic. It has two components

- 1) Rts routing protocol
- 2) MAC protocol.

*. For transmitting best effort packets : RTS, CTS and ACK are used. For transmitting real-time packets : Resv RTS, Resv CTS and Resv ACK are used.

*. Time is divided into super frames (shown in figure).

*. Each Superframe consist of a number of reservation-slots.

*. A node that needs to transmit real-time packet, first reserves a set of resv-slots.

*. The set of resv-slots reserved by a node for a connection on a superframe is called a connection-slot.

*. The duration of each resv-slot is twice the maximum propagation delay.

*. Each node maintains a reservation table (RT), RT contains information such as

→ Sender id & Receiver-id

→ starting and ending time of active reservation.

Main Advantage:

→ Bandwidth efficiency

→ Asynchronous mode of operation where nodes do not require any global time synchronization

→ Flexibility of slot placement in the superframe.

— x

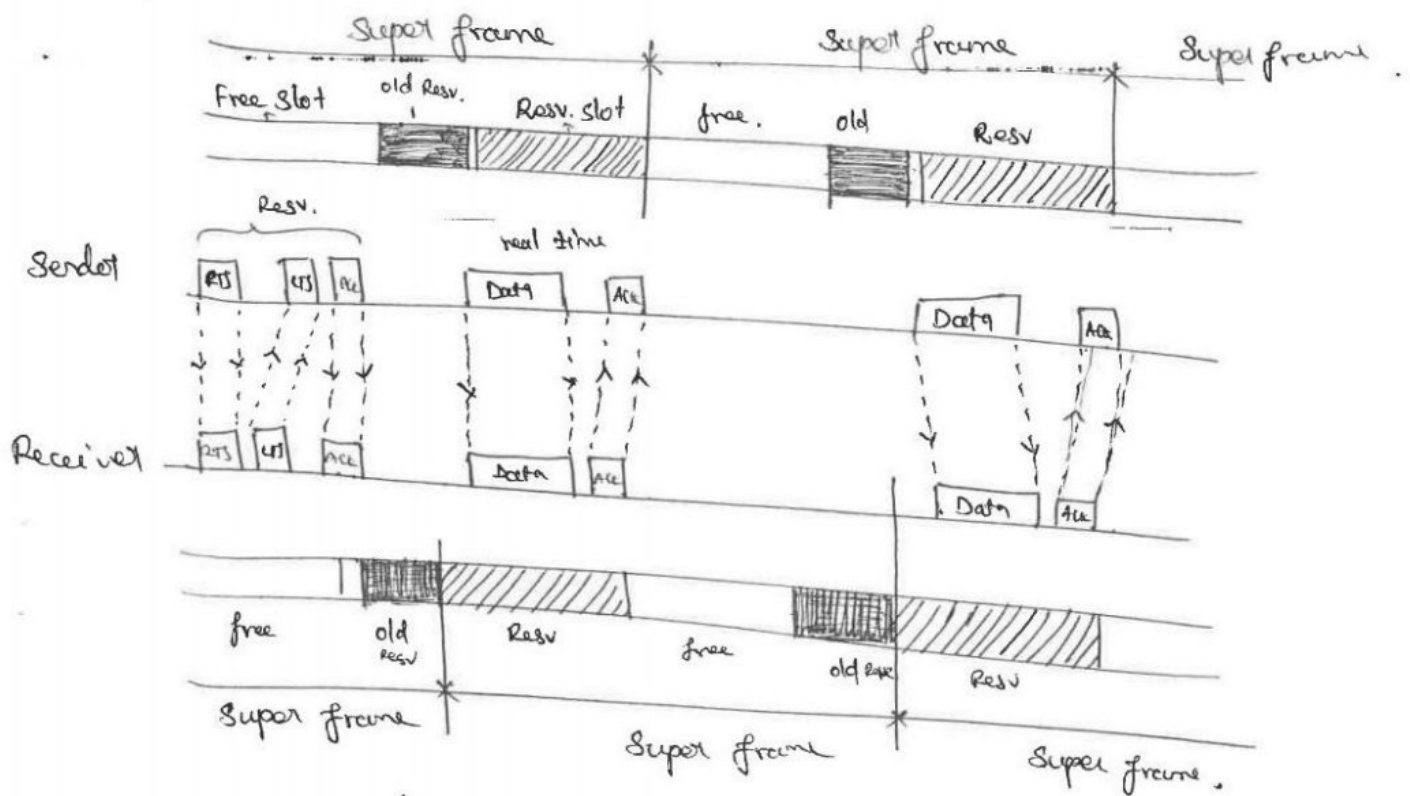


fig: Reservation mechanism in RTMAC.

CONTENTION BASED PROTOCOLS WITH SCHEDULING MECHANISMS:

Protocols that fall under this category focus on packet scheduling at the nodes and transmission scheduling of the nodes.

Distributed priority scheduling and Medium Access in Ad-hoc Networks:

There are two Mechanisms for providing quality of service support for connections in ad hoc wireless networks

1. Distributed priority scheduling
2. Multi-hop co-ordination.

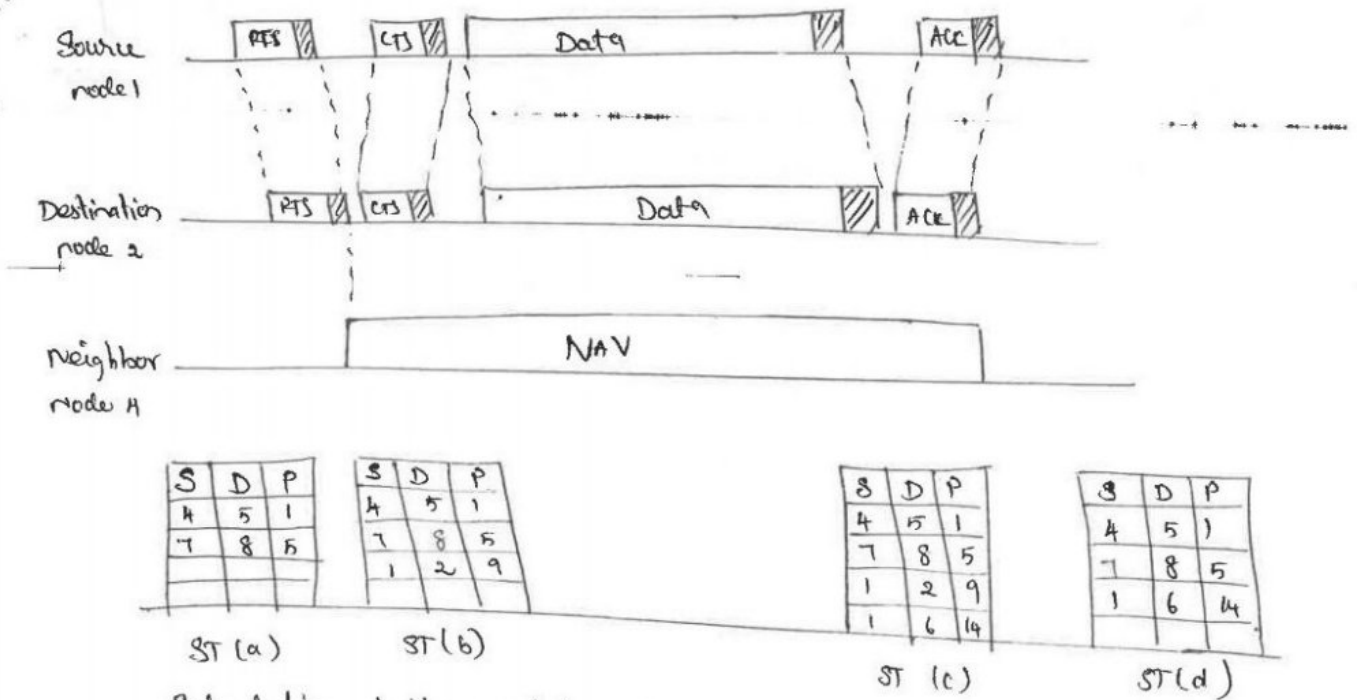
Distributed Priority Scheduling: DPS

- It uses the basic RTS-CTS-DATA-ACK packet exchange mechanism.
- The protocol works as follows:
 - i) When source transmits a RTS, Priority-tag of current Data is piggy-backed on RTS.
 - ii) On receiving RTS, the receiver responds with CTS packets.
 - iii) The receiver node copies priority-tag from the received-RTS and piggy-backs it along with the source node id, on the CTS packet.
 - iv) Neighbors receive the RTS or CTS packets, retrieve the piggy-backed priority tag information and make the corresponding entry in their Scheduling table (ST). STs contain the information about packets, which were originally piggy-backed on control and data packets.
- When source transmits DATA, its Head-Of-Line (HOL) packet information about packet to be transmitted next by the node is piggy-backed on the Data.
- On receiving Data, A receiver responds with ACK packet.
- The receiver copies the HOL information from the received DATA and piggy-backs it along.
- Neighbors receive the Data or ACK packet and retrieve the piggy-backed information and make a corresponding entry in their STs.
- When a node hears an ACK, it removes its entry from its ST any entry made earlier for corresponding data.

mechanism

Figure shows piggy-backing and scheduling table update in

DPS



Scheduling table updates at neighbor node 4

S - Source Id, D - Destination Id, P - Priority Index.

▨ - Piggy backed priority information

MULTI-HOP COORDINATION:

→ The excess delay incurred by the packet at the upstream-nodes is compensated for at the downstream-nodes.

→ When a node receives a packet, it would have already received the priority-index of the packet piggy-backed on the previous RTS packet.

→ In case the node is an intermediate-node (which has to further forward the packet), the node calculates the new priority-index of the Data packet based on the received value of the priority index.

→ If a packet suffers due to excess delay at the upstream-nodes, then the downstream-nodes increase priority of packet so that packet is able to meet its end-to-end delay target.

→ Similarly, if a packet arrives very early due to lack of contention at the upstream node, then the priority of the packet would be reduced at the downstream nodes.

Distributed Wireless Ordering Protocol (DWOP)

- packet access the medium according to order specified by an ideal reference scheduler such as FIFO (First In First Out)
- In FIFO, packet priority-indicator are set to the arrival-time of packets.
- Each node builds up a Scheduling Table ordered according to the Overheard arrival-times.
- It may not suffer due to information asymmetry. Since in most networks all nodes are not within the radio range of each other, a transmitting node might not be aware of the arrival times of packets queued at another node which is not within its direct transmission range.
- Control packets used in DWOP to piggy-back priority information regarding head-of-line packets of nodes.

Key concept: A node is made eligible to contend for the channel only if its locally queued packet has a smaller arrival-time compared to all other arrival times in its ST.

Following two additional table Mechanism are used in FIFO.

- 1) Receiver Participation Mechanism
- 2) Stale Entry Elimination.

A) Receiver Participation Mechanism:

1) When receiver finds that the source is transmitting out-of-order an "out-of-order (OON) notification" is piggy-backed by the receiver on the control packets (CTS/Ack) and it sends to the source

2) On receive OON, the source goes into a back-off state after completing the transmission of its current packet.

3) The back-off period $T_{\text{back-off}}$ is given by

$$T_{\text{back-off}} = R * (EIFS + DIFS + T_{\text{success}} + (W_{\text{min}}))$$

Where T_{success} - Longest possible time required to transmit a packet successfully.

B) Stale Entry Elimination:

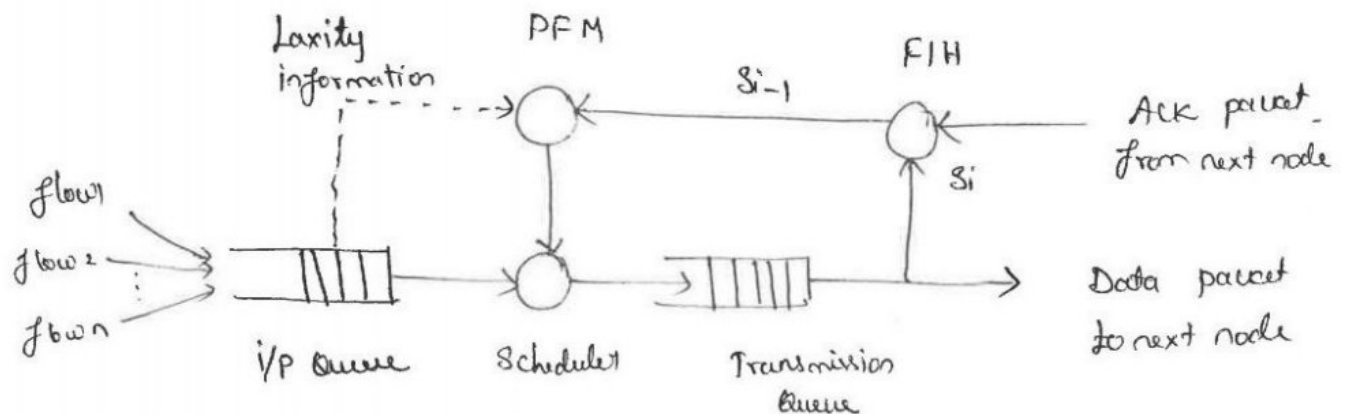
- 1) This makes sure that the STs are free of stale entries
- 2) An entry is deleted from the ST only after an Ack packet for the corresponding entry is heard by the node.

Distributed Latency Based Priority Scheduling Schemes (DLPS):

It is a packet scheduling scheme, depends upon the states of neighboring nodes and feedback from destination nodes regarding packet losses. Each node maintains two tables

- 1) Scheduling Table (ST)
- 2) Packet delivery ratio table. (PDT)

The Scheduling table (ST) contains information about packets to be transmitted by the node and packet overhead by the node. The PBT contains the count of Data packets transmitted & The Count of Ack packets received.



FIH $\rightarrow$ Feedback information Handler

PFM $\rightarrow$ Priority function Module.

- $\rightarrow$ Incoming packets to a node are queued in the node's input-queue according to their arrival-times (shown in figure).
- $\rightarrow$ The Scheduler
 - $\rightarrow$ Sorts packets according to their priority values and
 - $\rightarrow$ Inserts them into the queue of transmission.
- $\rightarrow$ The highest priority packet from this queue is selected for transmission.
- $\rightarrow$ On receiving data packet, Destination node initiates a feedback by means of sending Ack packets towards source node.
- $\rightarrow$ These two pieces of information are received by the feedback ^{info.} Handler
- $\rightarrow$ The FIH sends the previous state information S_{i-1} to the PFM.
- It assign priority value to the incoming pack along with Lazity information.

Directional Busy tone Based MAC (BTMA) Protocol:

The nodes use directional antennas for transmitting and receiving data packets, thereby reducing their interference to other neighbor nodes. This leads to an increase in the throughput of the system.

The purpose of the busy tones (BTs) is as follows:

- 1) Before transmitting an RTS, the source makes sure that the BT_r tone is not active in its neighborhood, so that its transmissions do not interfere with packets being received at a neighboring receiver. Similarly, a receiver, before transmitting CTS, verifies that a BT_t is not active in its neighborhood.
- 2) The directional busy tones can permit simultaneous transmissions in the neighborhood of a source or a receiver.

The protocol works as follows

- 1) A Source transmits an RTS addressed to the receiver on all its antennas (omnidirectional transmission).
- 2) On receiving this RTS, the receiver determines the antenna-element on which the RTS is received with maximum gain.
- 3) The receiver then sends back a directional-CTS (DCTS) to the source using the selected antenna-element. It also turns on busy tone BT_r in the direction towards source.
- 4) On receiving the CTS, the source turns on busy tone BT_t in the direction towards receiver.
- 5) Once the packet transmission is over, the source turns off the BT_t signal.

6) After receiving the DATA packet, the receiver turns off the BTx signal).

For a unicast transmission, only a single antenna element is used. For broadcast transmission, all the N antenna elements transmit simultaneously).

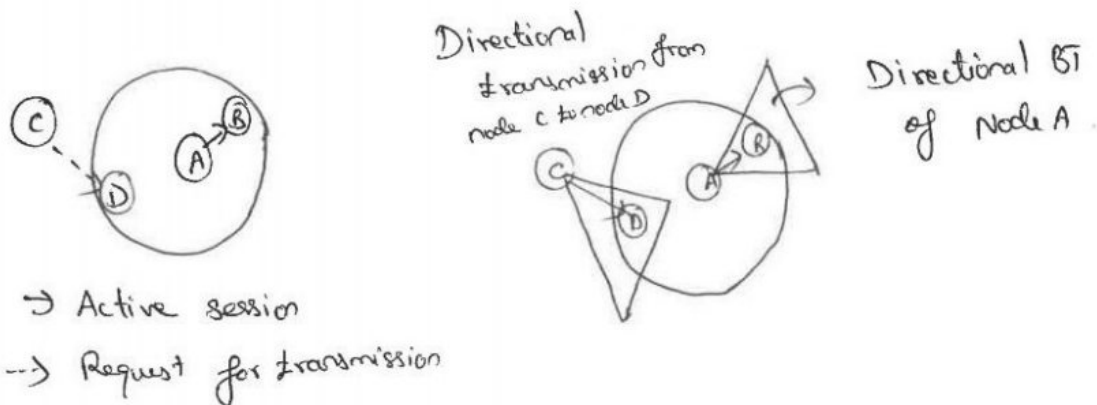


figure : Directional DBTMA.

Directional MAC Protocols for Adhoc wireless Networks:

- Key concept: Though a particular Antenna of a node may remain blocked, The remaining antennas of the node can be used for transmissions.
- It is assumed that each node knows about the location of its neighbors as well as its own location.

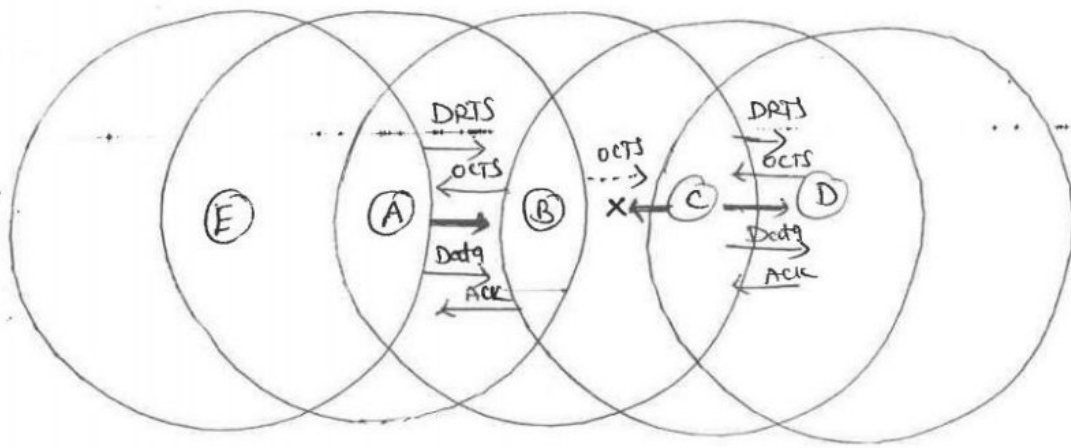
DMAC-1:

- A directional Antenna is used for transmitting RTS, DATA & ACK while an omnidirectional antenna is used for transmitting CTS.
- Consider figure, in that node A first transmit a Directional-RTS (DRTS) to node B.

- Node B responds by transmitting an omnidirectional-CTS (OCTS).
- Then, node A sends a Data using directional antenna.
- When node B receives the data, it immediately response with directional-ACK.
- When node C receives OCTS from node B, only the directional Antenna pointing toward node B would be blocked.
- Node C can freely transmit to node D using another directional Antenna.
- Drawback: The usage of DRTS may increase the probability of control packet collision.

DMAC-2

- In DMAC-2, both directional-RTS (DRTS) as well as omnidirectional-RTS (ORTS) transmissions are used.
- A node that wants to initiate a data transfer may send an ORTS or a DRTS as per the following two rules:
 - 1) If none of the directional Antennas at the node are blocked, then the node sends an ORTS.
 - 2) Otherwise, the node sends a DRTS, Provides the desired directional antenna is not blocked.
- Consider figure, Here when node A initiates the data transfer to node B assuming all its antennas are not blocked, it sends an ORTS to node B.
- Node B and now receive this packet, and the antenna on which the ORTS was received would remain blocked for the duration of the transmission from node A to node B.
- If node B want to send a packet to node A, it need to wait for the duration of the transmission between node A + B.



Operation of DMAC protocol.

OTHER PROTOCOLS:

Multi-channel MAC Protocol (MMAC):

- Each node maintains a data structure called PCL (Preferable channel List).
- PCL contains the usage of the channels within the transmission range of the node.
- Based on their usage, channels can be classified into three types:

1) High preference channel (High):

2) Medium Preference channel (MID):

3) Low Preference channel (Low):

High: The channel has been selected by the current node and is being used by the node in the current beacon-interval.

MID: The channel is free and is not being currently used in the transmission-range of the node.

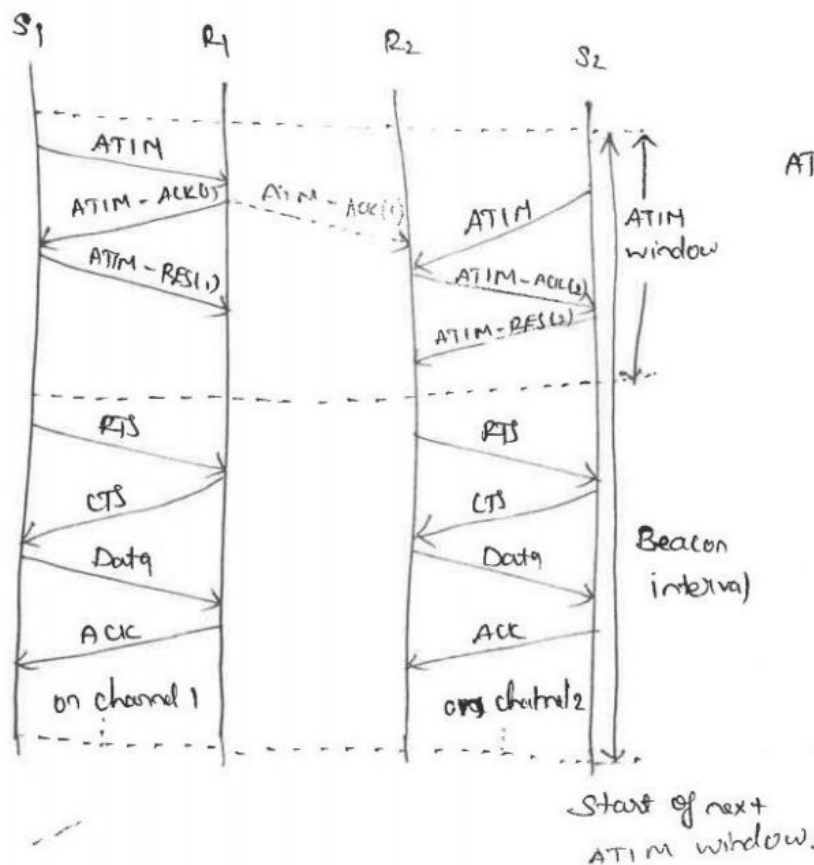
Low: The channel is already being used in the transmission-range of the node by other neighboring nodes. A counter is associated with each Low state channel.

Time is divided into beacon-intervals and every node is synchronized by periodic beacon transmissions.

At the start of every beacon-interval, there exists a time interval called the ATIM (ad hoc traffic indication Message) window.

The Protocol works as follows

- 1) A source send an ATIM to the intended receiver, which carries the PCL of the source.
- 2) On receiving this ATIM, the receiver uses the PCL carried on the ATIM and its own PCL to select a channel. It includes this channel information in the ATIM-ACK packet & sends to the source.
- 3) Then, source determines whether it can transmit on the channel indicated in the ATIM-ACK message. If so, It responds by sending the receiver an ATIM-RES (Reservation) packet.
- 4) At the end of ATIM window, source & receiver start communicating by exchanging RTS/CTS.



ATIM - Ad hoc Traffic Indication Message.

Multichannel CSMA MAC Protocol (M-CSMA):

- Select an idle channel randomly and employ the notion of soft channel reservation.
- The Available channel bandwidth is divided into several channels.
- Assumption : N channel : bandwidth = w/N , w is the total bandwidth for communication.
- The channels may created by FDMA or CDMA.
- An idle node continuously monitors all the channels.

Channel-Idle State : Total received signal strength (TRSS) $<$ sensing threshold of the node is marked by idle state by node. Such channels are put in the free channel list (FCL).

- Channel selection protocol.

- 1) If FCL is empty, it waits for any channel to become idle.
- 2) In case FCL is non-empty, the node first check whether the channel it used for its most recent successful transmission is included in the list. If so, the node uses this channel for its new transmission.
- 3) Otherwise, one among the idle channels available in the FCL is randomly chosen.

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POWER CONTROL MAC PROTOCOL (PCM) :

It allows node to vary their transmission power levels on the packet basis.

BASIC:

- The RTS and CTS packets are transmitted with power P_{max} .
- The RTS-CTS handshake is used for deciding upon the transmission power of the subsequent Data and Ack packet transmissions.

This can be done using two methods:

First Method:

- 1) Source transmits the RTS with maximum power P_{max} . This RTS is received at the receiver with signal level P_r .
- 2) The receiver B can calculate the minimum required transmission power level $P_{desired}$ for the DATA packet based on P_r , P_{max} and the noise level at the receiver B.
- 3) Receiver B then specifies this $P_{desired}$ in the CTS packet and send to Source A.
- 4) Source A transmit Data packet using Power level $P_{desired}$.

Second Method:

- 1) When the receiver B receives an RTS packet, it responds with a CTS packet at the usual maximum power level P_{max} .
- 2) When the Source A receives this CTS packet, it calculates $P_{desired}$ based on P_r , P_{max} as

$$P_{desired} = \frac{P_{max}}{P_r} * R_{x_thresh} * C$$

where R_{x_thresh} = min necessary received signal strength.
 C = constant.

- 3) Source uses power level $P_{desired}$ to transmit the Data packet.

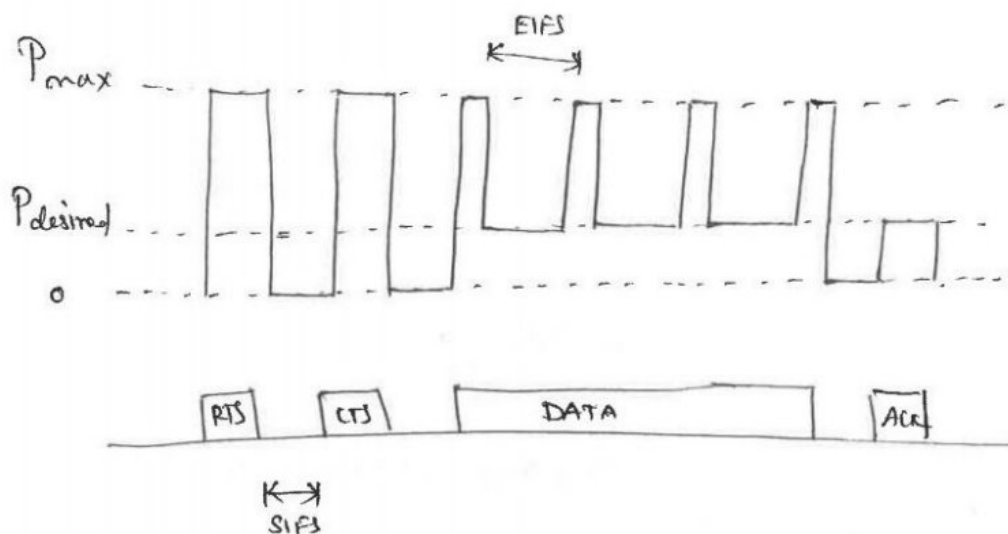
PCM:

The BASIC Scheme uses

- Maximum transmit power for RTS and CTS packets, and
- only necessary power levels for the Data & Ack packets.

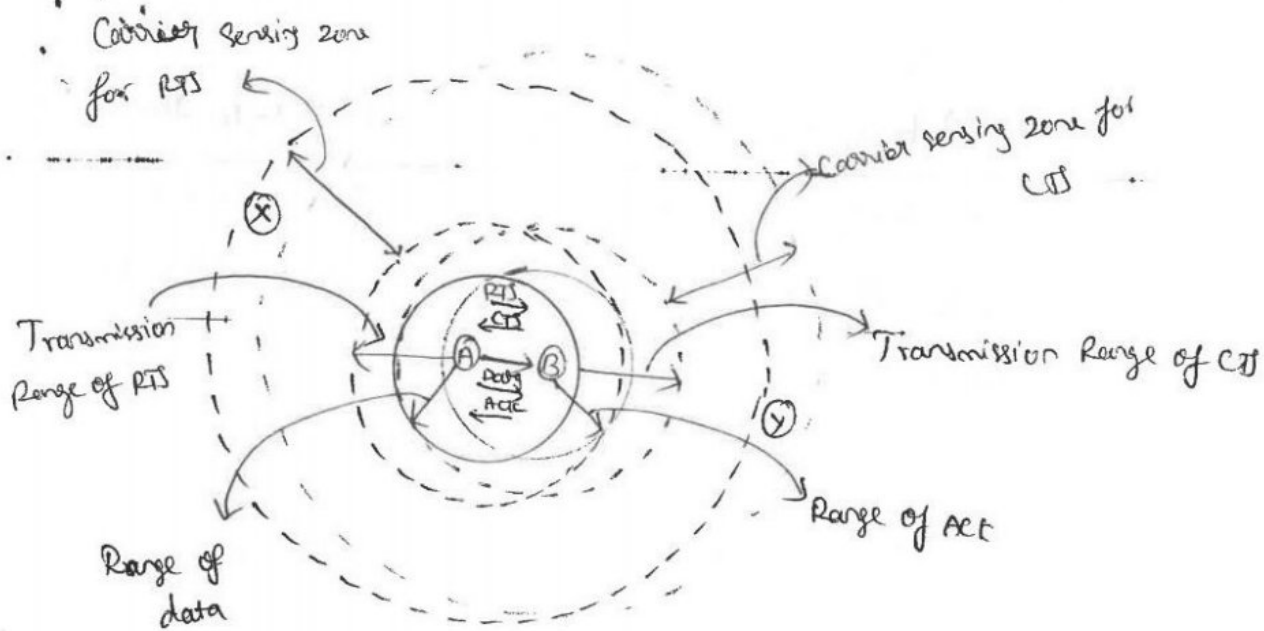
Drawback: Probability of collision may high. Since the Data & Ack transmissions use only Min necessary power, the Data transmitted by node A cannot be sensed by node X.

- PCM modifies this scheme so as to minimize the probability of collisions.
- The source and receiver node transmit the RTS and CTS packets with Maximum power P_{max} .
- Nodes in the carrier sensing zones of source and receiver nodes set their NAV for EIFS duration when they sense the signal but are not high enough to decode it correctly.
- So, Transmits the Data packet at Max power level P_{max} Periodically.
 - The duration of each such transmission must larger than the time required for physical Carrier sensing.



EIFS - Extended Interframe Space SIFS - Short interframe space.

Fig: Transmission Power pattern in PCM



Packet transmission in Basic scheme

Receiver - Based Auto Rate protocol

- It uses a novel rate adaptation approach.
- Rate adaptation is the process of dynamically switching data rates in order to match the channel conditions so that optimum throughput for the given channel conditions is achieved.
- Rate adaptation consists of two processes, namely, channel quality estimation and rate selection.
- Rate Selection is done at the receiver on a per-packet basis during the RTS-CTS packet exchange.
- The RTS and CTS packets consists of
 - the chosen data rate and
 - the size of the data packet

The protocol works as follows

- 1) The source choose a data rate based on some heuristic

and inserts the chosen data-rate and data-size into RTS.

2) When a neighbor receives this RTS, it calculates the duration of reservation DR_{RTS} using data rate and data-size carried on the RTS.

3) While receiving the RTS-packet, the receiver generates the estimate of the channel conditions for the impending data transfer. Based on this estimate, it chooses an appropriate data-rate.

4) The receiver stores the chosen data-rate and data-size in the CTS and transmits the CTS to the source.

5) On receiving the CTS, the source responds by transmitting the data-packet at the rate chosen by the receiver.

Problem: If the data-rates chosen by the sender and receiver are different, then the reservation duration DR_{RTS} calculated by the neighbors of the sender would not be valid. It is also referred to as tentative reservation.

→ In order to overcome this problem, the source sends the data-packet with a special MAC header containing RSH (Reservation Subheader).

→ The fields in RSH contain control information for determining the duration of the transmission.

→ A neighbor node with tentative reservation entries in its NAV, on hearing the data packet, calculates DR_{RSH} , the new reservation period, and updates its NAV to account for the difference between DR_{RTS} & DR_{RSH} .

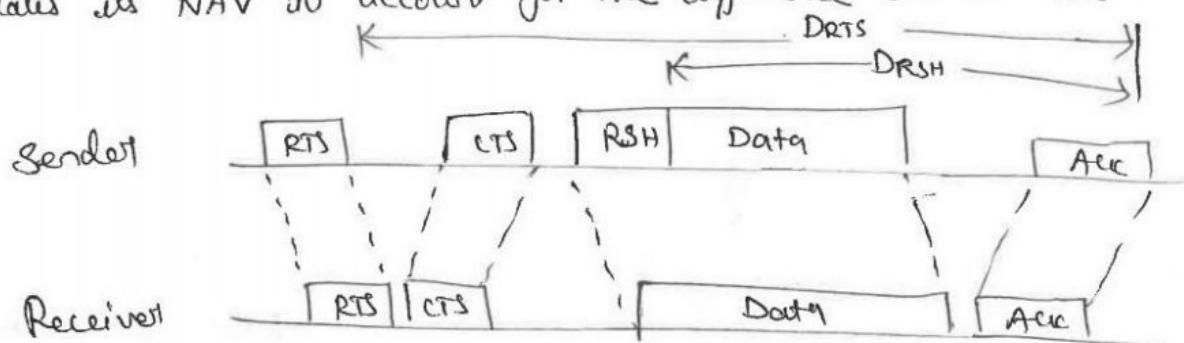


Fig: Packet transmission in RBAR

ICSMMA: Interleaved Carrier Sense Multiple Access Protocol:

- It efficiently Overcomes the exposed terminal problem.
- Consider figure, In that, when a transmission is going on from node A to node B, node C is called sender exposed and node E is called a receiver exposed node.
- The total available bandwidth is split into two equal channels (say, channel 1 and channel 2).
- The handshaking process is interleaved between the two channels
 - sender uses a channel 1 to send RTS and DATA while
 - Receiver uses another channel (channel 2) to send CTS and ACK

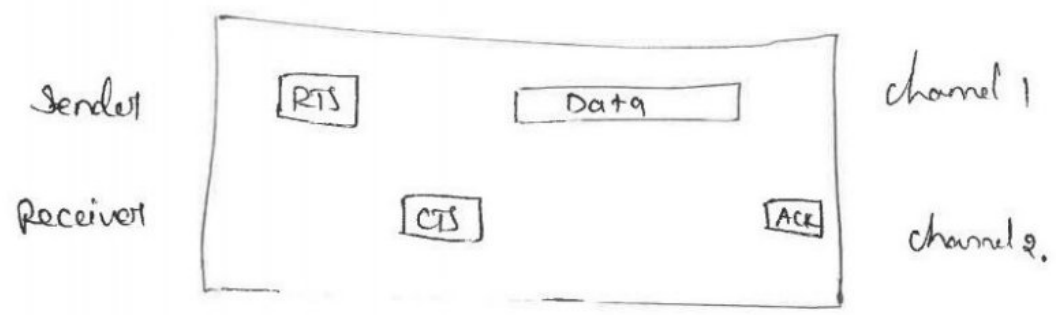
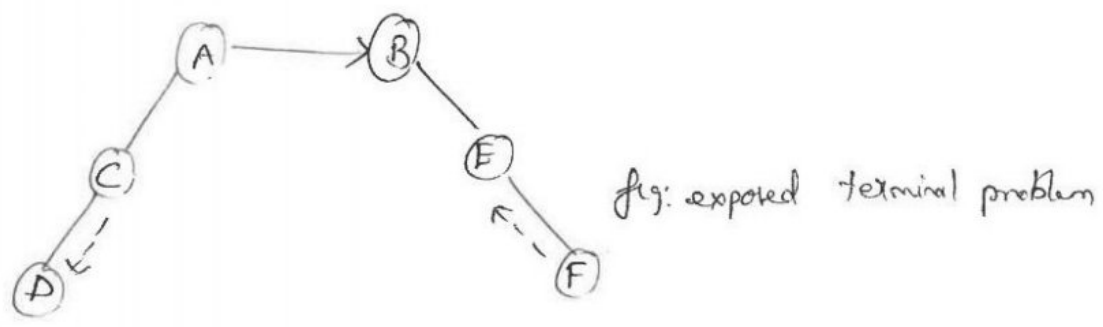


fig: Packet Transmission

The performance improvement factor:

A node hear RTS in a particular channel and don't hear CTS on the other channel, it can send RTS in the

Same channel.

→ A node hears CTS in particular channel and do not hear RTS on the other channel, it can send CTS in the same channel.

Due to this it over come exposed node problem.

— x —

Q11. What are the key features of S-MAC? Explain in detail.

April-15, Set-1, Q4(a)

OR

What are the causes behind energy wastage in wireless sensor networks? Explain.

Ans:

(Model Paper-I, Q4(a) | April-15, Set-2, Q4(b))

Key Features of S-MAC: Sensor MAC(S-MAC) protocol uses design consideration in order to conserve energy in MAC layer. The key features of s-mac is saving energy. It also incorporates combined scheduling and contention schemes to acquire good stability and collision avoidance.

The major causes behind energy waste in wireless sensor network are as follows,

- (i) Collision
 - (ii) Overhearing
 - (iii) Control packet overhead
 - (iv) Idle channel listening.
- (i) **Collision:** The collision corrupts the packet which must be rejected and retransmitted. This consumes high energy due to which there is a greater increase in latency.
- (ii) **Overhearing:** The sensor nodes can overhear the ongoing transmission of the other sensor nodes. Unlike unicast communication where the frames are generated from one source and reaches one destination, wireless medium performs broadcast communication. Here, the source's neighbors present at the receiver state can hear the packet and also drop it if it is not destined to their address. Here, the sensor nodes perform the process of overhearing, where in they overhear the ongoing transmission of other sensor nodes. On the other hand the process of overhearing causes loss in energy. The overhearing avoidance can be easily performed in higher node densities, saving large amount of energy.
- The overhearing is mostly useful for in assessment of current traffic load for management purposes and gathering neighborhood information.
- (iii) **Control Packet Overhead:** The overhead is occurred during the transmission and reception of control packet as they consume high amount of energy and also minimizes the payload. This extent of overhead raises as the node density increases. Beside this more energy is required to tolerate with the failure of sensor nodes by issuing more control messages so that the failed nodes can get self configured.
- (iv) **Idle Channel Listening:** The idle listening node occurs when the channels are empty. Due to this sensor nodes do not sense any data and remain idle for long time.

The mechanisms adopted for saving energy and improving performance are,

- ❖ Low duty cycle
- ❖ Adaptive listening
- ❖ Message passing
- ❖ Data aggregation.