Mobile Adhoc Networks

MAC protocols for adhoc wireless networks

- nodes share common broadcast radio channel
- radio spectrum is limited, bandwidth is limited
- shared medium should be controlled in such a manner that all nodes receive a fair share
- node mobility, limited bandwidth, availability, error-prone broadcast channel,
- hidden and exposed terminal problem, power constraints issues compared to wired network
- needs different set of protocols for medium access

Issues: Designing MAC protocols

- bandwidth efficiency
- scarce bandwidth is utilized in an efficient manner
- control overhead involved must be kept as minimal as possible
- bandwidth efficiency defined as ratio of the bandwidth used for actual size data transmission to the total available bandwidth
- MAC protocol maximize the bandwidth efficiency

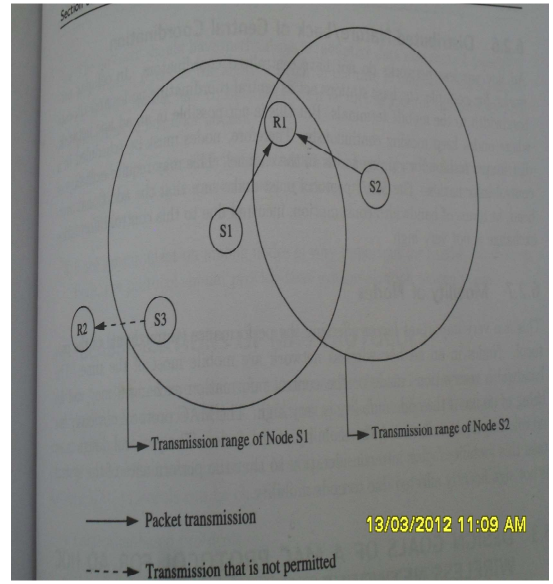
Issues: Designing MAC protocols

- QoS support
- mobility of nodes, bandwidth reservation made at one point of time may become invalid once the node moves out of the region where the reservation was made
- time critical traffic session - military application resource reservation
- synchronization between the node and network, for bandwidth reservation by nodes (time slots),
- exchange of control packets required for achieving time synchronization among nodes
- control packets must not consume too much of network bandwidth

Issues: Designing MAC protocols

- hidden and exposed terminal problems
- unique to wireless networks
- hidden terminal 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 the sender, but are within the transmission range of the receiver
  - collision occurs when both nodes transmit packets at the same time without knowing about the transmission of each other
  - transmit nodes S1 and S2 and receiver node R1

Hidden and Exposed terminal problems



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Issues: Designing MAC protocols

- exposed terminal problem refers to the inability of a node which is blocked due to transmission by a nearby transmitting node, to transmit to another node
  - transmission from node S1 to another node R1 is in progress,
  - node S3 can not transmit to node R2 as it concludes that its neighbor node S1 is in transmitting mode and hence it should not interfere with the on-going transmission
- both reduces throughput of a network when the traffic load is high
- MAC protocol should be free from these problems

Issues: Designing MAC protocols

- Error-prone shared broadcast channel
- broadcast nature of the radio channel, i.e.,

  transmission made by a node are received by all nodes within its direct transmission range
- when a node is receiving data, no other in its neighborhood, apart from the sender, should transmit
- node should get access to the shared medium only when its transmissions do not affect any on going session
- multiple nodes may contend for the channel simultaneously, the possibility of packet collision is quite high
- MAC protocol should grant channel access to nodes in such a manner that collisions are minimized
- all nodes are treated fairly with respect to bandwidth allocation

Issues: Designing MAC protocols

- distributed nature/lack of central coordination
- cellular network base station acts as central coordinating nodes and allocate bandwidth to mobile terminals
- nodes must be scheduled in a distributed fashion for gaining access to the channel
- require exchange of control information and it should not be high avoiding bandwidth consumption
- mobility of nodes
  - affecting the performance (throughput) of the protocol
  - the bandwidth reservation or control information exchanged may be of no use if the node mobility is very high
- MAC protocol should consider mobility factor

Design goals of MAC protocol

- operation of protocol should be distributed
- provide QoS for real-time traffic
- access delay for any packet to get transmitted should be low
- efficient utilization of available bandwidth
- fair allocation of bandwidth to nodes
- minimum control overhead
- minimize the effects of hidden and exposed terminal problems
- scalable to large networks

Design goals of MAC protocol

- power control mechanisms to manage energy consumption of the nodes
- adaptive data rate control -
  - ability to control the rate of outgoing traffic considering load in the network and status of neighbor nodes
- try to use directional antenna, reduces interferences, increased spectrum reuse and reduced power consumption
- synchronization among nodes for bandwidth reservation, should provide time synchronization

Classifications of MAC protocols

- several categories based on various criteria such as initiation approach, time synchronization, and reservation approaches
- three basic types
- contention based protocols
- contention based with reservation mechanisms
- contention based with scheduling mechanisms
- and other MAC protocols

Contention based MAC protocols

- contention based channel access policy
- node does not make any resource reservation a priori
- whenever it receives a packet to be transmitted, it contends with its neighbor nodes for access to the shared channel
- these protocols can not provide QoS guarantees to sessions since nodes are not guaranteed regular access to the channel
- random access protocols divided into two types
  - sender initiated protocols - packet transmissions are initiated by the sender node
  - receiver initiated protocols - receiver node initiates the contention resolution protocol

Contention based MAC protocols

- sender initiated protocols divided into two types
  - single channel sender initiated protocols
    - ★ 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
  - multichannel sender initiated protocols
    - ★ available bandwidth is divided into multiple channels,
    - ★ enables several nodes to simultaneously transmit data, each using separate channel
- some protocols dedicate a frequency channel exclusively for transmitting control information

Contention based MAC protocols with reservation mechanisms

- for supporting real-time traffic; requires QoS guarantees
- nodes are not guaranteed periodic access to the channel, they cannot support real time traffic
- for support real time traffic, need reserving bandwidth a priori, can provide QoS support to time sensitive traffic sessions
- can be classified into two types
- synchronous protocols
  - require time synchronization among all nodes in the network, so that reservations made by a node are known to other nodes in its neighborhood
  - global time synchronization is difficult to achieve
- asynchronous protocols
  - do not require any global synchronization among nodes in the network
  - use relative time information for effecting reservations

Contention based MAC protocols with scheduling mechanisms

- focus on packet scheduling at nodes and scheduling nodes for access to the channel
- node scheduling done in a manner to that all nodes are treated fairly
- no node is starved of bandwidth
- scheduling based schemes are also used for enforcing priorities among flows whose packets are queued at node
- some scheduling schemes also take into consideration battery characteristics, such as
- remaining battery power, while scheduling nodes for access to the channel

Contention based MAC protocols: Example

- do not have any bandwidth reservation mechanisms
- all ready nodes contend for the channel simultaneously and winning node gains access to the channel
- nodes are not guaranteed bandwidth,
- these protocols can not be used for transmitting real-time traffic which requires QoS guarantees from the system
- MACAW - A Media Access Protocol for Wireless LANs based on multiple access collision avoidance protocol (MACA)

Contention based MAC protocols: MACA

- MACA was proposed due to shortcoming of CSMA (used in wired network)
- in CSMA the sender first senses the channel for the carrier signal
- if carrier is present or not, it retries after a random period of time otherwise it transmits the packet
- CSMA senses the state of the channel only at the transmitter
- this protocol does not overcome the hidden terminal problem
- in adhoc network the transmitter and receiver may not be near each other at all times
- the packets transmitted by a node are prone to collisions at the receiver due to simultaneous transmissions by the hidden terminals
- bandwidth utilization in CSMA protocols is less because of the exposed terminal problem

Contention based MAC protocols: MACA

- MACA does not make use of carrier sensing for channel access
- it uses two additional signaling packets: request to send RTS and clear to send CTS packet
- when a node wants to transmit a data packet, it first transmits an RTS packet
- the receiver node, on receiving RTS packet if it is ready to receive the data packet, transmit a CTS packet
- once sender receives the CTS packet without any error, it starts transmitting the data packet
- if a packet transmitted by a node is lost, the node uses the binary exponential backoff (BFB) algorithm to back off for a random interval of time before retrying

Contention based MAC protocols: MACA

- in the binary exponential backoff mechanism, each time a collision is detected, the node doubles its maximum backoff window
- neighbor nodes near the sender that hear the RTS packet do not transmit for a long enough period of time so that the sender could receiver the CTS packet
- both RTS and CTS packets carry the expected duration of data packet transmission
- a node near the receiver upon hearing the CTS packet, defers its transmission till the receiver receives the data packet, thus,
- MACA overcomes the hidden node problem

Contention based MAC protocols: MACA

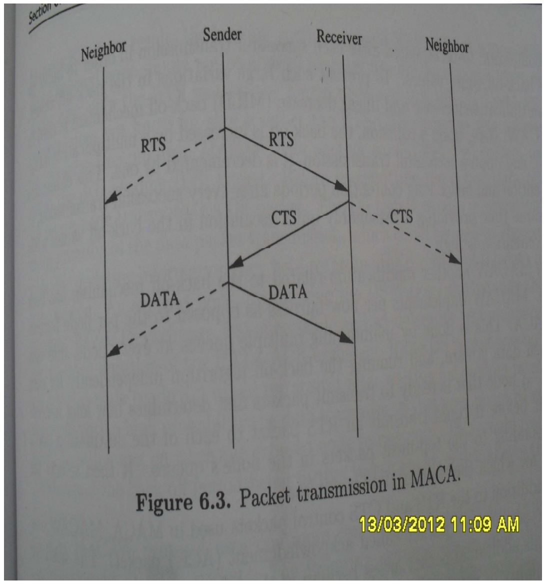

Figure 6.3. Packet transmission in MACA.

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Contention based MAC protocols: MACA

- node receiving an RTS defers only for 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 RTS is transmitting data packets, hence,
- the exposed terminal problem is also overcome in MACA
- MACA has certain problems and to overcome this MACAW was proposed
- the binary exponential back-off mechanism used in MACA at times starves flows

Contention based MAC protocols: MACAW

- for example, nodes S1 and S2 keep generating a high volume of traffic, the node that first captures the channel (say S1) starts transmitting packets
- the packets transmitted by the other node S2 get collided, and the node keeps incrementing its back-off window according to the BFB algorithm
- the probability of node S2 acquiring the channel keeps decreasing, and over a period of time it gets completely blocked
- to overcome this back-off algorithm has been modified in MACAW
- the packet header now has an additional field carrying the current back-off counter value of the transmitting node
- a node receiving the packet copies this value into its own back-off counter

Contention based MAC protocols: MACAW

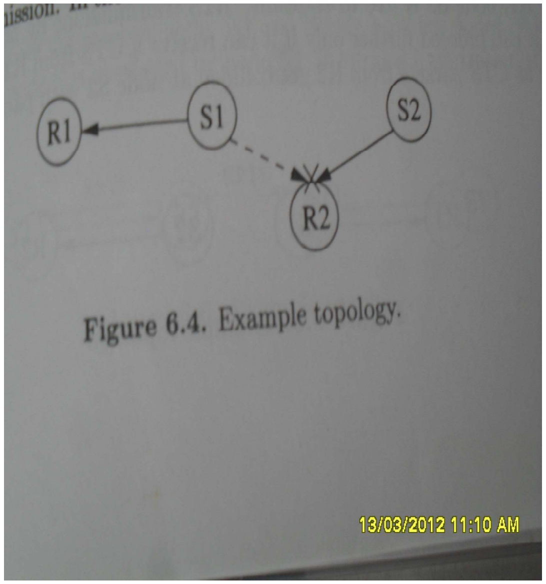

Figure 6.4. Example topology.

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Contention based MAC protocols: MACAW

- this mechanism allocates bandwidth in a fair manner
- another problem with BFB algorithm is that it adjusts the back-off counter value very rapidly, both when a node successfully transmits a packet and when a collision is detected by the node
- the back-off counter is reset to the minimum value after every successful transmission
- in the modified back-off process, this would require a period of contention to be repeated after each successful transmission in order to build up the back-off timer values
- to prevent such large variations in the back-off values a multiplicative increase and linear decrease (MILD) back-off mechanism is needed in MACAW

Contention based MAC protocols: MACAW

- upon a collision, the back-off is increased by a multiplication factor and upon a successful transmission it is decremented by one
- this eliminates contention and hence long contention periods after every successful transmission, at the same time providing a reasonably quick escalation in the back-off values when the contention is high
- another modification related to back-off mechanism
- implements per flow fairness as opposed to the per node fairness in MACA
- done by maintaining multiple queues at every node, one each for each data stream and running the back-off algorithm independently for each queue
- a node that is ready to transmit packets first determines how long it needs to wait before it could transmit an RTS packet to each of the destination nodes corresponding to the top-most packets in the node's queue

Contention based MAC protocols: MACAW

- it then selects the packet for which the waiting time is minimal
- in addition to RTS and CTS control packets in MACA, MACAW uses ACK packet also
- in MACA the responsibility of recovering from transmission errors lies with the transport layer,
- minimum timeout period of about 0.5 sec, significant delay is involved while recovering from errors
- in MACAW, the error recovery responsibility is given to the data link layer (DLL)
- in DLL, the recovery process can be made quicker as the timeout provides can be modified in order to suit the physical media being employed.

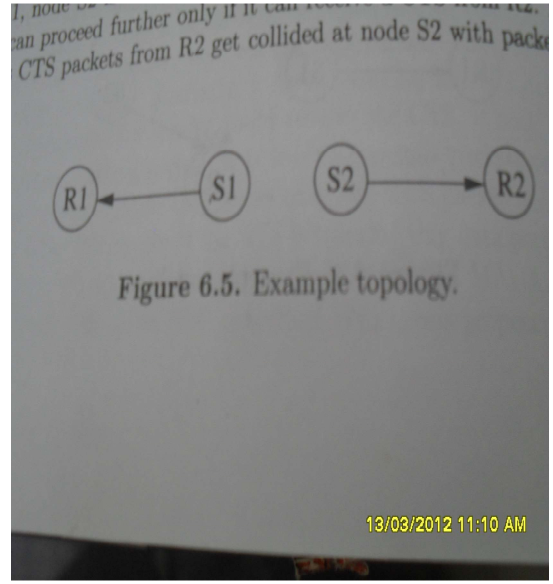
Contention based MAC protocols: MACAW

- in MACAW, after successful reception of each data packet, the receiver node transmits an ACK packet
- if the sender does not receive the ACK packet, it reschedules the same data packet for transmission
- the back-off counter is incremented if the ACK packet is not received by the sender
- if the ACK packet got lost in transmission, the sender would retry by transmitting an RTS for the same packet
- now the receiver, instead of sending back a CTS, sends an ACK for the packet received, and the sender moves onto transmit the next data packet

Contention based MAC protocols: MACAW

- In MACA, an exposed node (which received only RTS and not CTS packet) is free to transmit simultaneously when the source node is transmitting packets
- when a transmission is going on between nodes S1 and R1, node S2 is free to transmit
- RTS transmissions by node S2 are of no use, as it can proceed further only if it can receive a CTS from R2
- but this is not possible as CTS packets from R2 get collided at node S2 with packet transmitted by node S1
- as a result back-off counter at node S2 builds up unnecessarily
- so an exposed node (S2) should not be allowed to transmit

Contention based MAC protocols: MACAW



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Contention based MAC protocols: MACAW

- an exposed node since it can hear only the RTS sent by the source node and not the CTS sent by the receiver (R1), does not know for sure whether the RTS-CTS exchange was successful
- to overcome the problem, MACAW uses another small (30 bytes) control packet called the data sending (DS) packet,
- before transmitting the actual data packet the source node transmits this DS packet,
- the DS packet carries information such as the duration of the data packet transmission, which could be used by the exposed nodes for updating information they hold regarding the duration of the data packet transmission

Contention based MAC protocols: MACAW

- as exposed node, overhearing DS packet, understands that the previous RTS-CTS exchange was successful, and so defers its transmissions until the expected duration of DATA-ACK exchange
- if DS packet was not used, the exposed node (S2) would retransmit after waiting for random intervals of time, and with a high probability the data transmission (between S1 and R1) would be still going on when the exposed node retransmits, this would result in a collision and the back-off period being further incremented which affects the node even more

Contention based MAC protocols: MACAW

- MACAW uses another control packet request for request to send (RRTS) packet
- transmission going on between S1 and R1; node S2 wants to transmit to node R2
- but R2 is a neighbor of R1, it receives CTS packets from node R1 and therefore it defers its own transmissions
- node S2 has no way to learn about the contention periods during which it can contend for the channel and so it keeps on trying, incrementing its back-off counter after each failed attempt, hence,
- the main reason for this problem is the lack of synchronization information at source S2
- MACAW overcomes this problem by using the RRTS packet

Contention based MAC protocols: MACAW

- receiver node R2 contends for the channel on behalf of source S2, if R2 had received an RTS previously for which it was not able to respond immediately because of the on-going transmission between nodes S1 and R1 then node R2 waits for the next contention period and transmits RRTS packet
- neighbor node that hear RRTS packet including R1 are made to wait for two successive slots (for RTS-CTS exchange to take place)
- S2 on receiving the RRTS from node R2, transmits the regular RTS packet to node R2, and the normal packet exchange (RTS-CTS-Data-ACK) continues from here

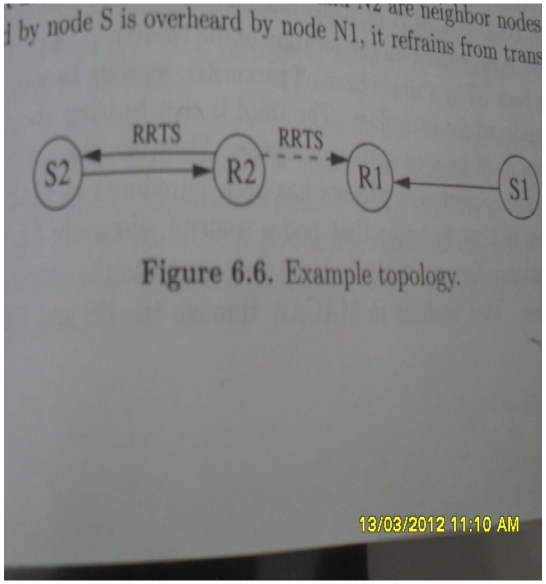
Contention based MAC protocols: MACAW

- S and R source and receiver N1 and N2 neighbor nodes
- RTS transmitted by S is over-headed by N1 and it refrains from transmitting S receives CTS
- when CTS transmitted by R is heard by neighbor node N2, it defers its transmissions until the data packet is received by receiver R
- on receiving this CTS, S immediately transmits 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 the data packet R sends ACK to S

Contention based MAC protocols: Summary of MACAW

- congestion occurs at receiver node and not at the sender
- CSMA unsuitable for adhoc networks
- improved by RTS-CTS-DS-DATA-ACK
- congestion is dependent on the location of receiver
- instead of single back-off, separate back-off parameters for each flow
- learning about congestion at various nodes must be collective enterprise
- the notion of copying back-off values from overheard packets has been introduced in MACA
- nodes contend for the channel, synchronization information needs to be propagated to concerned nodes at appropriate time
- this is done by DS and RRTS

Contention based MAC protocols: MACAW



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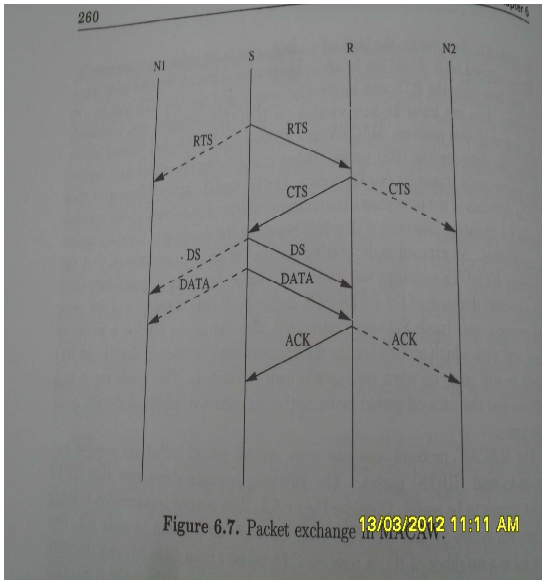
Contention based MAC protocols: MACAW



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