AD HOC NETWORKS

NOTES FOR 7TH SEMESTER COMPUTER SCIENCE

SUBJECT CODE: 19CST732

MODULE 1 NOTES

TEXT BOOK

AD HOC WIRELESS NETWORKS –
C Siva Ram Murthy & B S Manoj, 2nd Edition, Pearson Education, 2005

MODULE 1 INTRODUCTION

CELLULAR AND AD HOC WIRELESS NETWORKS

The current cellular wireless networks are classified as the infrastructure dependent network.

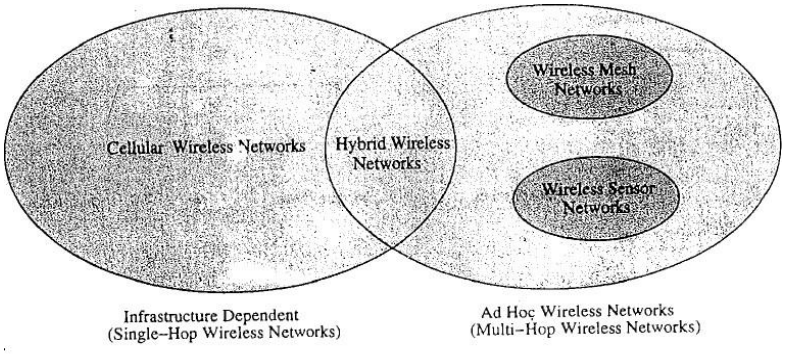


Figure : Cellular and ad hoc wireless networks.

The path setup for a call between two nodes, say, node C to E, is completed through base station as illustrated in figure below.

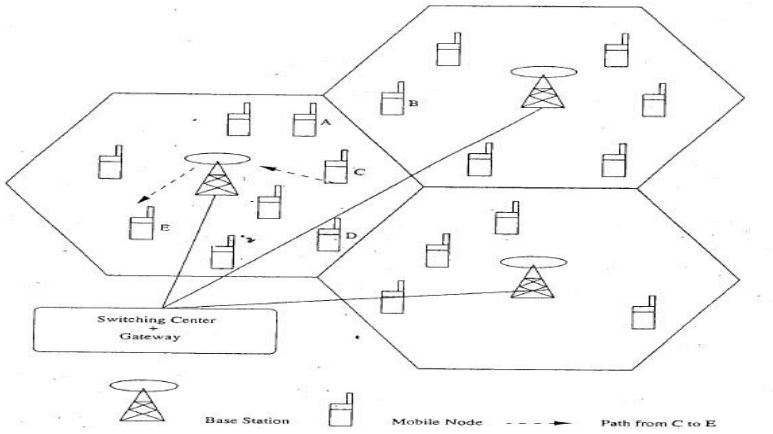


Figure 5.2 A cellular network

- Adhoc wireless networks are defined as a category of wireless network that utilize multi-hop radioreplaying and are capable of operating without the support of any fixed infrastructure.
- Absence of any central co-ordinator or base station makes the routing complex.
- Adhoc wireless network topology for the cellular network shown in above figure is illustrated below.
- The path setup for a call between 2 nodes, say, node C to E , is completed through the intermediate mobile node F.
- Wireless mesh network and Wireless sensor networks are specific examples of adhoc wireless networks.

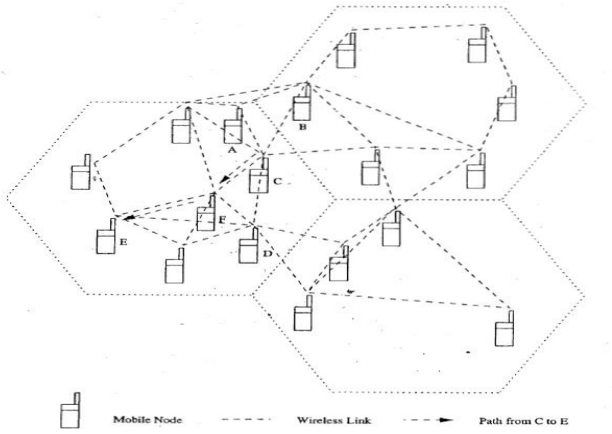


Figure 5.3: An ad hoc wireless network

- The presence of base station simplifies routing and resource management in a cellular network.
- But in adhoc networks, routing and resource management are done in a distributed manner in which allnodes co-ordinate to enable communication among them.

The following table shows the difference between cellular networks and adhoc wireless networks.

Cellular Networks	Ad Hoc Wireless Networks
Fixed infrastructure-based	Infrastructure-less
Single-hop wireless links	Multi-hop wireless links
Guaranteed bandwidth (designed for voice traffic)	Shared radio channel (more suitable for best-effort data traffic)
Centralized routing	Distributed routing
Circuit-switched (evolving toward packet switching)	Packet-switched (evolving toward emulation of circuit switching)
Seamless connectivity (low call drops during handoffs)	Frequent path breaks due to mobility
High cost and time of deployment	Quick and cost-effective deployment
Reuse of frequency spectrum through geographical channel reuse	Dynamic frequency reuse based on carrier sense mechanism
Easier to achieve time synchronization	Time synchronization is difficult and consumes bandwidth
Easier to employ bandwidth reservation	Bandwidth reservation requires complex medium access control protocols
Application domains include mainly civilian and commercial sectors	Application domains include battlefields, emergency search and rescue operations, and collaborative computing
High cost of network maintenance (backup power source, staffing, etc.)	Self-organization and maintenance properties are built into the network
Mobile hosts are of relatively low complexity	Mobile hosts require more intelligence (should have a transceiver as well as routing/switching capability)
Major goals of routing and call admission are to maximize the call acceptance ratio and minimize the call drop ratio	Main aim of routing is to find paths with minimum overhead and also quick reconfiguration of broken paths
Widely deployed and currently in the third generation of evolution	Several issues are to be addressed for successful commercial deployment even though widespread use exists in defense

APPLICATIONS OF AD HOC WIRELESS NETWORKS

Military Application

- Adhoc wireless networks can be very useful in establishing communication among a group of soldiers for tactical operations.
- Setting up of a fixed infrastructure for communication among group of soldiers in enemy territories or in inhospitable terrains may not be possible.
- In such a case, adhoc wireless networks provide required communication mechanism quickly.
- The primary nature of the communication required in a military environment enforces certain important requirements on adhoc wireless networks namely, Reliability, Efficiency, Secure communication & Support for multicast routing.

Collaborative & Distributed computing

- Adhoc wireless network helps in collaborative computing, by establishing temporary communication infrastructure for quick communication with minimal configuration among a group of people in a conference.
- In distributed file sharing application reliability is of high importance which would be

provided by adhoc network.

- Other applications such as streaming of multimedia objects among participating nodes in ad hoc wireless networks require support for soft real-time communication
- Devices used for such applications could typically be laptops with add-on wireless interface cards, enhanced personal digital assistants (PDAs) or mobile devices with high processing power

Emergency Operations

- Ad hoc wireless networks are very useful in emergency operations such as search and rescue, crowd control and commando operations
- The major factors that favour ad hoc wireless networks for such tasks are self-configuration of the system with minimal overhead, independent of fixed or centralised infrastructure, the freedom and flexibility of mobility, and unavailability of conventional communication infrastructure.
- In environments, where the conventional infrastructure based communication facilities are destroyed due to a war or due to natural calamities, immediate deployment of adhoc wireless networks would be a good solution for co-ordinating rescue activities.
- They require minimum initial network configuration with very little or no delay

Wireless Mesh Network

- Wireless mesh networks are adhoc wireless network that are formed to provide an alternate communication infrastructure for mobile or fixed nodes/users, without the spectrum reuse constraint & requirement of network planning of cellular network.
- It provides many alternate paths for a data transfer session between a source & destination, resulting inquick reconfiguration of the path when the existing path fails due to node failure.
- Since the infrastructure built is in the form of small radio relaying devices, the investment required in wireless mesh networks is much less than what is required for the cellular network counterpart.
- The possible deployment scenarios of wireless mesh networks include: residential zones, highways, business zones, important civilian regions and university campuses
- Wireless mesh networks should be capable of self-organization and maintenance.
- It operates at license-free ISM band around 2.4 GHz & 5 GHz.
- It is scaled well to provide support to large number of points.
- Major advantage is the support for a high data rate, quick & low cost of deployment, enhanced services, high scalability, easy extendability, high availability & low cost per bit.

Wireless Sensor Networks:

- Sensor networks are special category of Adhoc wireless network that are used to provide a wireless communication infrastructure among the sensors deployed in a specific application domain.
- Sensor nodes are tiny devices that have capability of sensing physical parameters processing the data gathered, & communication to the monitoring system.
- The issue that make sensor network a distinct category of adhoc wireless network are the following:Mobility of nodes :

- ✓ Mobility of nodes is not a mandatory requirement in sensor networks.
- ✓ For example, the nodes used for periodic monitoring of soil properties are not required to be mobile & the nodes that are fitted on the bodies of patients in a post-surgery ward of a hospital are designed to support limited or partial mobility.
- ✓ In general, sensor networks need not in all cases be designed to support mobility of sensor nodes.

Size of the network :

- ✓ The number of nodes in sensor network can be much larger than that in a typical ad hoc wireless network.

Density of deployment :

- ✓ The density of nodes in a sensor network varies with the domain of application.
- ✓ For example, Military applications require high availability of the network, making redundancy a high priority.

Power constraints :

- ✓ The power constraints in sensor networks are much more stringent than those in ad hoc wireless networks. This is mainly because the sensor nodes are expected to operate in harsh environmental or geographical conditions, with minimum or no human supervision and maintenance.
- ✓ In certain case, the recharging of the energy source is impossible.
- ✓ Running such a network, with nodes powered by a battery source with limited energy, demands very efficient protocol at network, data link, and physical layer.
- ✓ The power sources used in sensor networks can be classified into the following 3 categories:
  - *Replenishable Power source*: The power source can be replaced when the existing source is fully drained.
  - *Non-replenishable Power source*: The power source cannot be replenished once the network has been deployed. The replacement of sensor node is the only solution.
  - *Regenerative Power source:* Here, Power source employed in sensor network have the capability of regenerating power from the physical parameter under measurement.

Data / Information fusion :

- ✓ Data fusion refers to the aggregation of multiple packets into one before relaying it.
- ✓ Data fusion mainly aims at reducing the bandwidth consumed by redundant headers of the packets and reducing the media access delay involved in transmitting multiple packets.
- ✓ Information fusion aims at processing the sensed data at the intermediate nodes and relaying the outcome to the monitor node.

Traffic Distribution :

- ✓ The communication traffic pattern varies with the domain of application in sensor networks.
- ✓ For example, the environmental sensing application generates short periodic packets indicating the status of the environmental parameter under observation to a central monitoring station.
- ✓ This kind of traffic requires low bandwidth.

- ✓ Ad hoc wireless networks generally carry user traffic such as digitized & packetized voice stream or data traffic, which demands higher bandwidth.

Hybrid Wireless Networks

- One of the major application area of ad hoc wireless network is in the hybrid wireless architecture such as Multi-hop Cellular Network [MCN] & Integrated Cellular Adhoc Relay [iCAR].
- The primary concept behind cellular networks is geographical channel reuse.
- Several techniques like cell sectoring, cell resizing and multi tier cells increase the capacity of cellular networks.
- MCNs combine the reliability & support of fixed base station of cellular network with flexibility & multi- hop relaying adhoc wireless networks.
- Major advantages are as follows:
  - Higher capacity than cellular networks due to the better channel reuse.
  - Increased flexibility & reliability in routing.
  - Better coverage & connectivity in holes of a cell can be provided by means of multiple hops through intermediate nodes in a cell.

ISSUES IN AD HOC WIRELESS NETWORKS

The major issues that affect the design, deployment, & performance of an ad hoc wireless network system are :

- Medium Access Scheme.
- Transport Layer Protocol.
- Routing.
- Multicasting.
- Energy Management.
- Self-Organisation.
- Security.
- Addressing & Service discovery.
- Deployment considerations.
- Scalability.
- Pricing Scheme.
- Quality of Service Provisioning

Medium Access Scheme

The primary responsibility of a Medium Access Control (MAC) protocol in adhoc wireless networks is the distributed arbitration for the shared channel for transmission of packets. The major issues to be considered in designing a MAC protocol for adhoc wireless networks are as follows:

1. *Distributed Operation:*

- The ad hoc wireless networks need to operate in environments where no centralized coordinationis possible.
- The MAC protocol design should be fully distributed involving minimum control overhead.

2. *Synchronization:*
   - The MAC protocol design should take into account the requirement of time synchronization.
   - Synchronization is mandatory for TDMA-based systems for management of transmission andreception slots.
3. *Hidden Terminals:*
   - Hidden terminals are nodes that are hidden(or not reachable) from the sender of a data transmission session, but are reachable to the receiver of the session.
4. *Exposed terminals:*
   - Exposed terminals, the nodes that are in the transmission range of the sender of an on-goingsession, are prevented from making a transmission.
5. *Throughput:*
   - The MAC protocol employed in adhoc wireless networks should attempt to maximize thethroughput of the system.
   - The important considerations for throughput enhancement are
     - Minimizing the occurrence of collisions.
     - Maximizing channel utilization and
     - Minimizing control overhead.
6. *Access delay:*
   - The average delay that any packet experiences to get transmitted.
   - The MAC protocol should attempt to minimize the delay.
7. *Fairness:*
   - Fairness refers to the ability of the MAC protocol to provide an equal share or weighted share of thebandwidth to all competing nodes.
   - Fairness can be either *node-based* or *flow-based.*
8. *Real-time Traffic support*:
   - In a contention-based channel access environment, without any central coordination, with limited bandwidth, and with location-dependent contention, supporting time- sensitive traffic such as voice, video, and real-time data requires explicit support from the MAC protocol.
9. *Resource reservation*:
   - The provisioning of QoS defined by parameters such as bandwidth, delay, and jitter requires reservation of resources such as *bandwidth*, *buffer space*, and *processing power*.
10. *Ability to measure resource availability:*
    - In order to handle the resources such as bandwidth efficiently and perform call admission control based on their availability, the MAC protocol should be able to provide an estimation of resource availability at every node.
    - This can also be used for making *cogestion control decisions*.
11. *Capability for power control:*
    - The transmission power control reduces the energy consumption at the nodes, causes a decrease in interference at neighboring nodes, and increases frequency reuse.

12. *Adaptive rate control:*

- This refers to the variation in the data bit rate achieved over a channel.
- A MAC protocol that has adaptive rate control can make use of a high data rate when the sender andreceiver are nearby & adaptively reduce the data rate as they move away from each other.

13. *Use of directional antennas:*

- This has many advantages that include
  - Increased spectrum reuse.
  - Reduction in interference and
  - Reduced power consumption.

Routing

The responsibilities of a routing protocol include exchanging the route information; finding a feasible path to a destination. The major challenges that a routing protocol faces are as follows:

1. *Mobility :*

- The Mobility of nodes results in frequent path breaks, packet collisions, transient loops, stalerouting information, and difficulty in resource reservation.

2. *Bandwidth constraint :*

- Since the channel is shared by all nodes in the broadcast region, the bandwidth available perwireless link depends on the number of nodes & traffic they handle.

3. *Error-prone and shared channel :*

- The Bit Error Rate (BER) in a wireless channel is very high [10^{-5} to 10^{-3}] compared to that in its wired counterparts [10^{-12} to 10^{-9}].
- Consideration of the state of the wireless link, signal-to-noise ratio, and path loss for routing in ad hoc wireless networks can improve the efficiency of the routing protocol.

4. *Location-dependent contention :*

- The load on the wireless channel varies with the number of nodes present in a given geographical region.
- This makes the contention for the channel high when the number of nodes increases.
- The high contention for the channel results in a high number of collisions & a subsequent wastage ofbandwidth.

5. *Other resource constraints :*

- The constraints on resources such as computing power, battery power, and buffer storage also limitthe capability of a routing protocol.

The major requirements of a routing protocol in adhoc wireless networks are the following.

1. *Minimum route acquisition delay :*

- The route acquisition delay for a node that does not have a route to a particular destination nodeshould be as minimal as possible.
- The delay may vary with the size of the network and the network load.

2. *Quick route reconfiguration :*

- The unpredictable changes in the topology of the network require that the routing protocol be ableto quickly perform route reconfiguration in order to handle path breaks and subsequent packet losses.

3. *Loop-free routing :*
   - This is a fundamental requirement to avoid unnecessary wastage of network bandwidth.
   - In adhoc wireless networks, due to the random movement of nodes, transient loops may form in theroute thus established.
   - A routing protocol should detect such transient routing loops & take corrective actions.
4. *Distributed routing approach :*
   - An adhoc wireless network is a fully distributed wireless network & the use of centralized routing approaches in such a network may consume a large amount of bandwidth.
5. *Minimum control overhead :*
   - The control packets exchanged for finding a new route, and maintaining existing routes should bekept as minimal as possible.
6. *Scalability :*
   - Scalability is the ability of the routing protocol to scale well in a network with a large number ofnodes.
   - This requires minimization of control overhead & adaptation of the routing protocol to the networksize.
7. *Provisioning of QoS:*
   - The routing protocol should be able to provide a certain level of QoS as demanded by the nodes orthe category of calls.
   - The QoS parameters can be bandwidth, delay, jitter, packet delivery ratio, & throughput.
8. *Support for time-sensitive traffic :*
   - Tactical communications & similar applications require support for time-sensitive traffic.
   - The routing protocol should be able to support both hard real-time & soft real-time traffic.
9. *Security and privacy :*
   - The routing protocol in adhoc wireless networks must be resilient to threats and vulnerabilities.
   - It must have inbuilt capability to avoid resource consumption, denial-of-service, impersonation, andsimilar attacks possible against an ad hoc wireless network.

Multicasting

It plays important role in emergency search & rescue operations & in military communication. Use of single- link connectivity among the nodes in a multicast group results in a tree-shaped multicast routing topology. Such a tree-shaped topology provides high multicast efficiency, with low packet delivery ratio due to the frequency tree breaks. The major issues in designing multicast routing protocols are as follows:

1. *Robustness :*
   - The multicast routing protocol must be able to recover & reconfigure quickly from potential mobility-induced link breaks thus making it suitable for use in high dynamic environments.
2. *Efficiency :*
   - A multicast protocol should make a minimum number of transmissions to deliver a data packet to all the group members.

3. Control overhead :

- The scarce bandwidth availability in ad hoc wireless networks demands minimal control overhead for the multicast session.

4. Quality of Service :

- QoS support is essential in multicast routing because, in most cases, the data transferred in a multicast session is time-sensitive.

5. Efficient group management :

- Group management refers to the process of accepting multicast session members and maintaining the connectivity among them untill the session expires.

6 . *Scalability :*

- The multicast routing protocol should be able to scale for a network with a large number of node

7. Security :

- Authentication of session members and prevention of non-members from gaining unauthorized information play a major role in military communications.

Transport Layer Protocol

- The main objectives of the transport layer protocols include :
  - ✓ Setting up & maintaining end-to-end connections,
  - ✓ Reliable end-to-end delivery of packets,
  - ✓ Flow control &
  - ✓ Congestion control.

Examples of some transport layers protocols are,

a. *UDP (User Datagram Protocol) :*

- It is an unreliable connectionless transport layer protocol.
- It neither performs flow control & congestion control.
- It do not take into account the current network status such as congestion at the intermediate links,the rate of collision, or other similar factors affecting the network throughput.

b. *TCP (Transmission Control Protocol):*

- It is a reliable connection-oriented transport layer protocol.
- It performs flow control & congestion control.
- Here performance degradation arises due to frequent path breaks, presence of stale routing information, high channel error rate, and frequent network partitions.

Pricing Scheme

- Assume that an optimal route from node A to node B passes through node C, & node C is notpowered on.
- Then node A will have to set up a costlier & non-optimal route to B.
- The non-optimal path consumes more resources & affects the throughput of the system.
- As the intermediate nodes in a path that relay the data packets expend their resources such as battery charge & computing power, they should be properly compensated.

- Hence, pricing schemes that incorporate service compensation or service reimbursement are required.

Quality of Service Provisioning (QoS)

- QoS is the performance level of services offered by a service provider or a network to the user.
- QoS provisioning often requires ,
  - ✓ Negotiation between host & the network.
  - ✓ Resource reservation schemes.
  - ✓ Priority scheduling &
  - ✓ Call admission control.
- ***QoS-aware routing :***
  - i. Finding the path is the first step toward a QoS-aware routing protocol.
  - ii. The parameters that can be considered for routing decisions are,
    - ➢ Network throughput.
    - ➢ Packet delivery ratio.
    - ➢ Reliability.
    - ➢ Delay.
    - ➢ Delay jitter.
    - ➢ Packet loss rate.
    - ➢ Bit error rate.
    - ➢ Path loss.
- *QoS parameters :*

Applications	Corresponding QoS parameter
1.Multimedia application	1.Bandwidth & Delay.
2.Military application	2. Security & Reliability.
3.Defense application	3. Finding trustworthy intermediate hosts & routing.
4.Emergency search and rescue Operations	4. Availability.
5.Hybrid wireless network	5.Maximum available link life, delay, bandwidth & channelutilization.
6.communication among the nodes in a sensor network	6. Minimum energy consumption, battery life & energyconservation

- *QoS framework :*
  - I. A framework for QoS is a complete system that attempts to provide the promised services toeach user or application.
  - II. The key component of QoS framework is a QoS service model which defines the way userrequirements are served.

Self-Organization

- One very important property that an ad hoc wireless network should exhibit is organizing &maintaining the network by itself.
- The major activities that an ad hoc wireless network is required to perform for self-organization are,
  - ✓ Neighbour discovery.
  - ✓ Topology organization &
  - ✓ Topology reorganization (updating topology information)

Security

1) Security is an important issue in ad hoc wireless network as the information can be hacked.
2) Attacks against network are of 2 types :
   I. *Passive attack* → Made by malicious node to obtain information transacted in the network withoutdisrupting the operation.
   II. *Active attack* → They disrupt the operation of network.Further active attacks are of 2 types :
   - *External attack*: The active attacks that are executed by nodes outside the network.
   - *Internal attack:* The active attacks that are performed by nodes belonging to the same network.

3) The major security threats that exist in ad hoc wireless networks are as follows :
   ★ ***Denial of service*** – The attack affected by making the network resource unavailable for service to other nodes, either by consuming the bandwidth or by overloading the system.
   ★ ***Resource consumption*** – The scarce availability of resources in ad hoc wireless network makes it aneasy target for internal attacks, particularly aiming at consuming resources available in the network.
   The major types of resource consumption attacks are,
   - ✓ Energy depletion :
     - Highly constrained by the energy source
     - Aimed at depleting the battery power of critical nodes.
   - ✓ Buffer overflow :
     - Carried out either by filling the routing table with unwanted routing entries or byconsuming the data packet buffer space with unwanted data.
     - Lead to a large number of data packets being dropped, leading to the loss of criticalinformation.

   ★ ***Host impersonation*** – A compromised internal node can act as another node and respond with appropriate control packets to create wrong route entries, and can terminate the traffic meant for the intended destination node.
   ★ ***Information disclosure*** – A compromised node can act as an informer by deliberate disclosure of confidential information to unauthorized nodes.
   ★ ***Interference*** – A common attack in defense applications to jam the wireless communication by creating a wide spectrum noise.

Addressing and service discovery

- Addressing & service discovery assume significance in ad hoc wireless network due to the absence of any centralised coordinator.
- An address that is globally unique in the connected part of the ad hoc wireless network is required for anode in order to participate in communication.
- Auto-configuration of addresses is required to allocate non-duplicate addresses to the nodes.

Energy Management

- Energy management is defined as the process of managing the sources & consumers of energy in a node or inthe network for enhancing the lifetime of a network.
- Features of energy management are :
  →Shaping the energy discharge pattern of a node's battery to enhance battery life.
  →Finding routes that consumes minimum energy.
  →Using distributed scheduling schemes to improve battery life.
  →Handling the processor & interface devices to minimize power consumption.
- Energy management can be classified into the following categories :

a. *Transmission power management* :

- The power consumed by the Radio Frequency (RF) module of a mobile node is determined byseveral factors such as
  * The state of operation.
  *The transmission power and
  *The technology used for the RF circuitry.
- The state of operation refers to transmit,receive, and sleep modes of the operation.
- The transmission power is determined by
  * Reachability requirement of the network.
  * Routing protocol and
  * MAC protocol employed.

b. *Battery energy management :*

- The battery management is aimed at extending the battery life of a node by taking advantage of its chemical properties,discharge patterns, and by the selection of a battery from a set of batteries that is available for redundancy.

c. *Processor power management :*

- The clock speed and the number of instructions executed per unit time are some of the processorparameters that affect power consumption.
- The CPU can be put into different power saving modes during low processing load conditions.
- The CPU power can be completely turned off if the machines is idle for a long time.In such a cases,interrupts can be used to turn on the CPU upon detection of user interaction or other events.

d. *Devices power management :*

- Intelligent device management can reduce power consumption of a mobile node significantly.

- This can be done by the operating system(OS) by selectively powering down interface devicesthat are not used or by putting devices into different power saving modes, depending on their usage.

Scalability

- Scalability is the ability of the routing protocol to scale well in a network with a large number of nodes.
- It requires minimization of control overhead & adaptation of the routing protocol to the network size.

Deployment Considerations

The deployment of a commercial ad hoc wireless network has the following benefits when compared to wired networks

a) *Low cost of deployment :*

- The use of multi-hop wireless relaying eliminates the requirement of cables & maintenance indeployment of communication infrastructure.
- The cost involved is much lower than that of wired networks.

b) *Incremental deployment :*

- Deployment can be performed incrementally over geographical regions of the city.
- The deployed part of the network starts functioning immediately after the minimum configuration is done.

c) *Short deployment time :*

- Compared to wired networks, the deployment time is considerably less due to the absence of anywired links.

d) *Reconfigurability :*

- The cost involved in reconfiguring a wired network covering a Metropolitan Area Network(MAN) isvery high compared to that of an ad hoc wireless network covering the same service area.

The following are the major issues to be considered in deploying an ad hoc wireless network :

a) *Scenario of deployment* :

- The scenario of deployment has significance because the capability required for a mobile node varies with the environment in which it is used.
  The following are some of the different scenarios in which the deployment issues vary widely
  - *military deployment :*
    It can be either,
    - ✓ Data-centric network : Handle a different pattern of data traffic & can be partially comprised ofstatic nodes.
      Eg : a wireless sensor network.
    - ✓ User-centric network: Consists of highly mobile nodes with or without any support from anyinfrastructure.
      Eg :soldiers or armored vehicles carrying soldiers equipped with wirelesscommunication devices.

- *Emergency operations deployment* :
  - Demands a quick deployment of rescue personnel equipped with hand-held communicationequipment.
  - The network should provide support for time-sensitive traffic such as voice & video.
  - Short data messaging can be used in case the resource constraints do not permit voicecommunication.
- *Commercial wide-area deployment :*
  - Eg : wireless mesh networks.
  - The aim of the deployment is to provide an alternate communication infrastructure for wireless communication in urban areas & areas where a traditional cellular base stationcannot handle the traffic volume.
- *Home network deployment :*
  - Deployment needs to consider the limited range of the devices that are to be connected bythe network.
  - Eg : short transmission range avoid network patitions.

b) Required longevity of network :

- If the network is required for a short while, battery-powered mobile nodes can be used.
- If the connectivity is required for a longer duration of time, fixed radio relaying equipment withregenerative power sources can be deployed.

c) Area of coverage :

- Determined by the nature of application for which the network is set up.
- Eg : the home area network is limited to the surroundings of a home.
- The mobile nodes' capabilities such as the transmission range & associated hardware, software, &power source should match the area of coverage required.

d) Service availability :

- Defined as the ability of an ad hoc wireless network to provide service even with the failure of certainnodes.
- Has significance in a Fully mobile ad hoc wireless network used for tactical communication & in partially fixed ad hoc wireless network used in commercial communication infrastructure such as wireless mesh networks.

e) Operational integration with other infrastructure :

- Considered for improving the performance or gathering additional information, or for providing betterQoS.
- In military environment, integration of ad hoc wireless networks with satellite networks or unmannedaerial vehicles(UAVs) improves the capability of the ad hoc wireless networks.

f) ***Choice of protocol :***

- The choice of protocols at different layers of the protocol stack is to be done taking into considerationthe deployment scenario.
- A TDMA-based & insecure MAC protocol may not be the best suited compared to a CDMA-based MACprotocol for a military application.

AD HOC WIRELESS INTERNET

- Ad hoc wireless internet extends the services of the internet to the end users over an ad hoc wirelessnetwork.
- Some of the applications of ad hoc wireless internet are :
  - ✓ Wireless mesh network.
  - ✓ Provisioning of temporary internet services to major conference venues.
  - ✓ Sports venues.
  - ✓ Temporary military settlements.
  - ✓ Battlefields &
  - ✓ Broadband internet services in rural regions.

- **The major issues to be considered for a successful ad hoc wireless internet are the following** :

❖ Gateway :

- They are the entry points to the wired internet.
- Generally owned & operated by a service provider.
- They perform following tasks ,
  - Keeping track of end users.
  - Bandwidth management.
  - Load balancing.
  - Traffic shaping.
  - Packet filtering.
  - Width fairness &
  - Address, service & location discovery.

❖ Address mobility :

This problem is worse here as the nodes operate over multiple wireless hops.

- Solution such as Mobile IP can provide temporary alternative.

❖ Routing :

- It is a major problem in ad hoc wireless internet, due to dynamic topological changes, the presenceof gateways, multi-hop relaying, & the hybrid character of the network.
- Possible solution is to use separate routing protocol for the wireless part of ad hoc wirelessinternet.

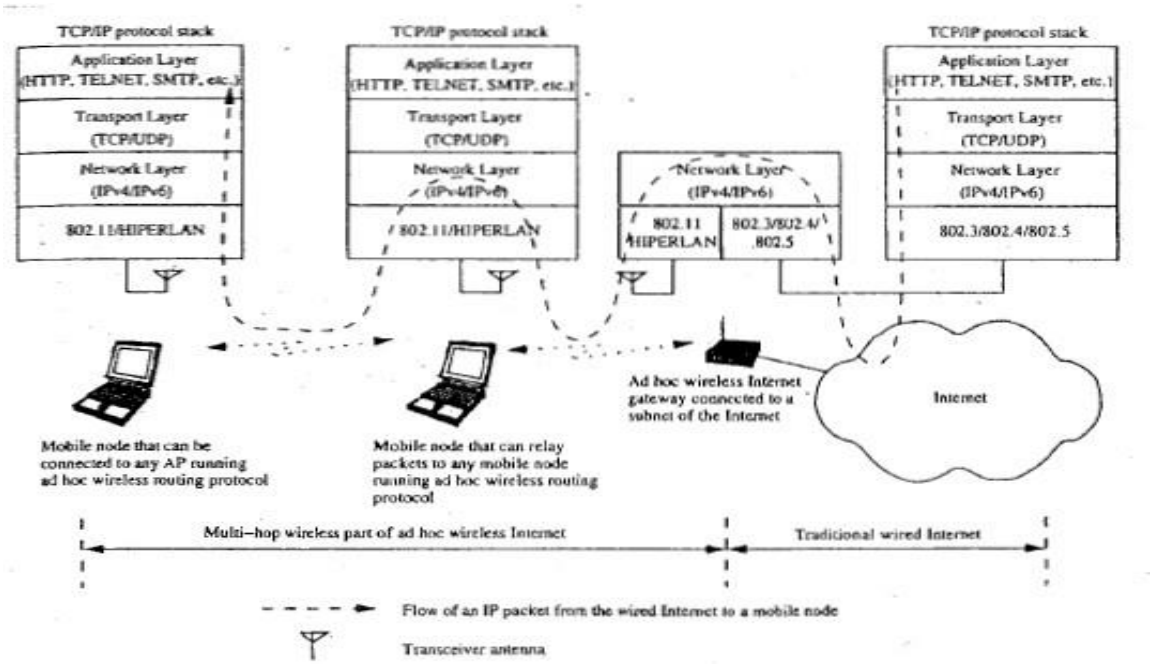


Figure 5.7 Schematic diagram of ad hoc wireless internet

- Transport layer protocol :
  - Several factors are to be considered here, the major one being the state maintenance overhead at the gateway nodes.
- Load balancing :
  - They are essential to distribute the load so as to avoid the situation where the gateway nodes become bottleneck nodes.
- Pricing / Billing :
  - Since internet bandwidth is expensive, it becomes very important to introduce pricing/billing strategies for the ad hoc wireless internet.
- Provisioning of security :
  - Security is a prime concern since the end users can utilize the ad hoc wireless internet infrastructure to make e-commerce transaction.
- QoS support :
  - With the widespread use of voice over IP(VOIP) & growing multimedia applications over the internet, provisioning of QoS support in the ad hoc wireless internet becomes a very important issue.
- Service, address & location discovery :
  - Service discovery refers to the activity of discovering or identifying the party which provides service or resource.
  - Address discovery refers to the services such as those provided by Address Resolution Protocol (ARP) or Domain Name Service (DNS) operating within the wireless domain.
  - Location discovery refers to different activities such as detecting the location of a particular mobile node in the network or detecting the geographical location of nodes.

MODULE 2
MAC PROTOCOLS FOR AD-HOC WIRELESS NETWORKS

ISSUES IN DESIGNING MAC PROTOCOL FOR AD HOC WIRELESS NETWORK

The main issues in designing MAC protocol for ad hoc wireless network are:

Bandwidth efficiency

- Bandwidth must be utilized in efficient manner
- Minimal Control overhead
- BW = ratio of BW used for actual data transmission to the total available BW

Quality of service support

- ★ Essential for supporting time-critical traffic sessions
- ★ They have resource reservation mechanism that takes into considerations the nature of wireless channel and the mobility of nodes

Synchronisation

- ★ MAC protocol must consider synchronisation between nodes in the network
- ★ Synchronisation is very important for BW (time slot) reservation by nodes
- ★ Exchange of control packets may be required for achieving time synchronisation among nodes

Hidden and exposed terminal problems

- ★ The 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.

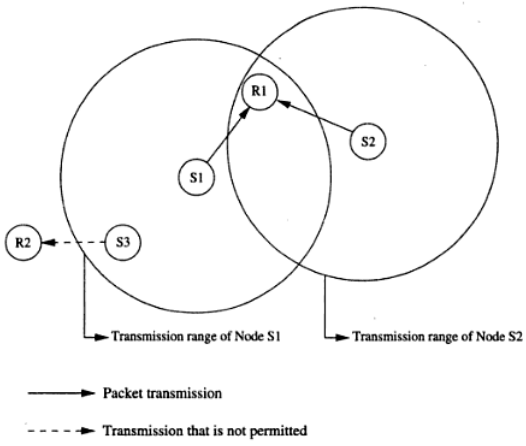


Figure 6.1. Hidden and exposed terminal problems.

- ★ S1 and S2 are hidden from each other & they transmit simultaneously to R1 which leads to collision
- ★ The 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
- ★ If S1 is already transmitting to R1, then S3 cannot interfere with on-going transmission & it cannot transmit to R2.
- ★ The hidden & exposed terminal problems reduce the throughput of a network when traffic load is high

Error-prone shared broadcast channel

- ★ When a node is receiving data, no other node in its neighbourhood should transmit
- ★ A node should get access to the shared medium only when its transmission do not affect any ongoing session
- ★ MAC protocol should grant channel access to nodes in such a manner that collisions are minimized
- ★ Protocol should ensure fair BW allocation

Distributed nature/lack of central coordination

- ★ Do not have centralised coordinators
- ★ Nodes must be scheduled in a distributed fashion for gaining access to the channel
- ★ MAC protocol must make sure that additional overhead, in terms of BW consumption, incurred due to this control information is not very high

Mobility of nodes

- ★ Nodes are mobile most of the time
- ★ The protocol design must take this mobility factor into consideration so that the performance of the system is not affected due to node mobility

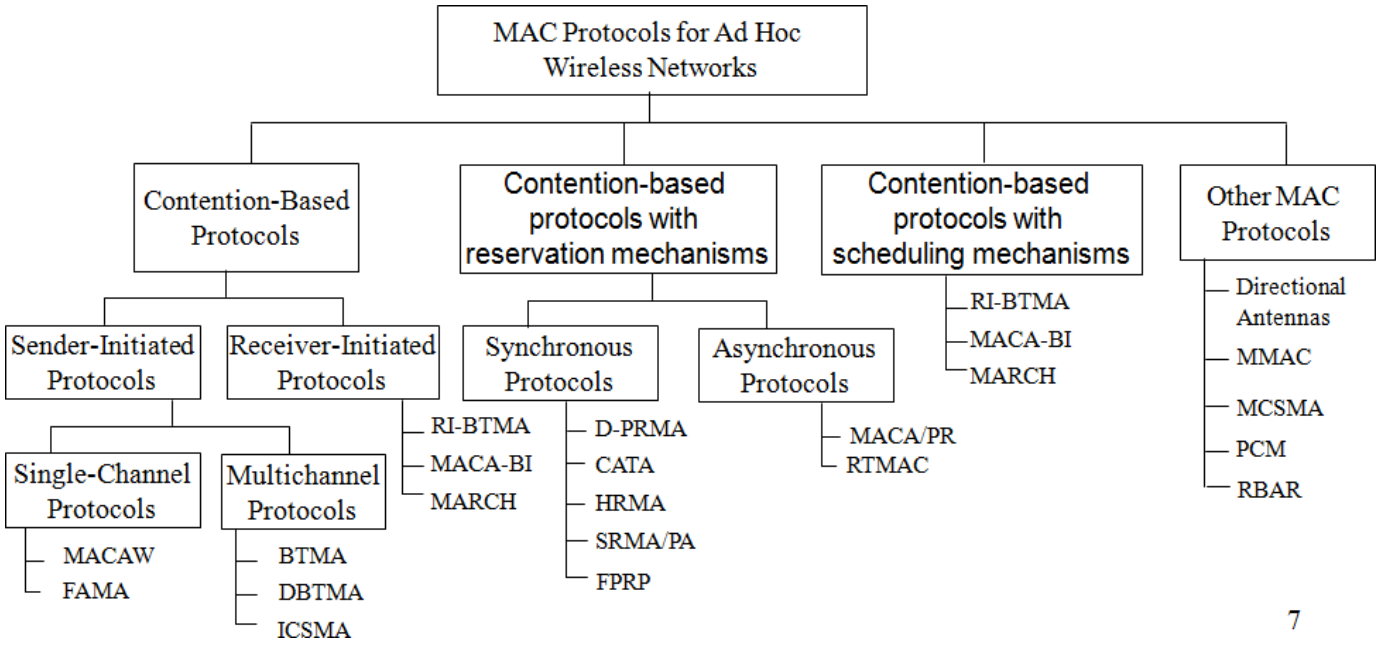
DESIGN GOALS OF A MAC PROTOCOL FOR AD HOC WIRELESS NETWORKS

- The operation of a protocol should be distributed
- The protocol should provide QoS support for real-time traffic
- The access delay, which refers to the average delay experienced by any packet to get transmitted, must be kept low
- The available bandwidth must be utilised efficiently
- The protocol should ensure fair allocation of bandwidth to nodes
- Control overhead must be kept as low as possible
- The protocol should minimise the effects of hidden and exposed terminal problems
- The protocol must be scalable to large networks
- It should have power control mechanisms in order to efficiently manage energy consumption of the nodes
- The protocol should have mechanisms for adaptive data rate control
- It should try to use directional antennas which can provide advantages such as reduced interference, increased spectrum reuse, and reduced power consumption
- The protocol should provide time synchronisation among nodes

CLASSIFICATION OF MAC PROTOCOLS

Ad hoc network MAC protocols can be classified into three basic types:

i. Contention-based protocols
ii. Contention-based protocols with reservation mechanisms
iii. Contention-based protocols with scheduling mechanisms
iv. Other MAC protocols [protocols which do not fall under above 3 categories]



NOTE: Only Contention-based Protocols with Reservation Mechanisms is for the syllabus

- Contention-based protocols
  - ***Sender-initiated protocols***: Packet transmissions are initiated by the sender node.
    - Single-channel sender-initiated protocols: A node that wins the contention to the channel can make use of the entire bandwidth.
    - Multichannel sender-initiated protocols: The available bandwidth is divided into multiplechannels.
  - ***Receiver-initiated protocols*****:** The receiver node initiates the contention resolution protocol.
- Contention-based protocols with reservation mechanisms
  - ***Synchronous protocols***: All nodes need to be synchronized. Global time synchronization isdifficult to achieve.
  - ***Asynchronous protocols:*** These protocols use relative time information for effecting reservations.
- Contention-based protocols with scheduling mechanisms
  - Node scheduling is done in a manner so that all nodes are treated fairly and no node is starvedof bandwidth.
  - Scheduling-based schemes are also used for enforcing priorities among flows whose packets arequeued at nodes.
  - Some scheduling schemes also consider battery characteristics.

Other protocols : are those MAC protocols that do not strictly fall under the above categories.

CONTENTION BASED PROTOCOLS WITH RESERVATION MECHANISMS

Distributed Packet Reservation Multiple Access Protocol (D-PRMA)

- It extends the centralized packet reservation multiple access (PRMA) scheme into a distributed scheme that can be used in ad hoc wireless networks.
- PRMA was designed in a wireless LAN with a base station.
- D-PRMA extends PRMA protocol in a wireless LAN.
- D-PRMA is a TDMA-based scheme.
- The channel is divided into fixed- and equal-sized frames along the time axis.

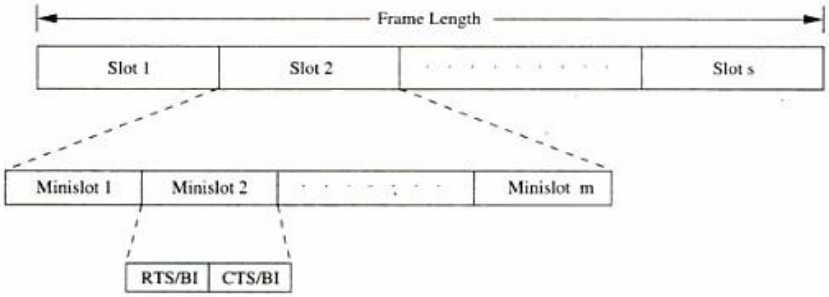


Figure 6.15. Frame structure in D-PRMA.

- Each frame is composed of s slots and each slot consists of m minislots
- Each minislot is further divided into two control fields, RTS/BI and CTS/BI
- These control fields are used for slot reservation and for overcoming the hidden terminal problem
- All nodes having packets ready for transmission contend 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 this winning terminal until it completes its packet transmission session
- Within a reserved slot, communication between the source and receiver nodes takes by means of either time division duplexing (TDD) or frequency division duplexing (FDD)
- Any node that wants to transmit packets has to first reserve slots
- A certain period at the beginning of each minislot is reserved for carrier sensing
- In order to prioritize nodes transmitting voice traffic over nodes transmitting normal data traffic, two rules are followed in D-PRMA
    - 1st rule voice nodes are allowed to start contending from minislot 1 with probabilityp=1. Others with p<1
    - 2nd rule only if the node winning the minislot contention is a voice node, it ispermitted to reserve the same slot in each subsequent frame until the end of the session
- In order to avoid the hidden terminal problem, all nodes hearing the CTS sent by the receiver are notallowed to transmit during the remaining period of that same slot
- In order to avoid the exposed terminal problem, a node hearing the RTS but not the CTS is still allowed to transmit
- Requirement 1 when a node wins the contention in minislot 1, other terminals must be preventedfrom using any of the remaining (m-1) minislots in the same slot for contention
- Requirement 2 when a slot is reserved in subsequent frames, other nodes should be prevented from contending for those reserved slots
- D-PRMA is more suited for voice traffic than for data traffic applications

Collision Avoidance Time Allocation Protocol (CATA)

- It is based on dynamic topology-dependent transmission scheduling
- Nodes contend for and reserve time slots by means of a distributed reservation and handshakemechanism.
- Support broadcast, unicast, and multicast transmissions.
- The operation is based on two basic principles:
  - The receiver(s) of a flow must inform the potential source nodes about the reserved slot on which it is currently receiving packets. The source node must inform the potential destination node(s) about interferences in the slot.
  - Usage of negative acknowledgements for reservation requests, and control packet transmissions at the beginning of each slot, for distributing slot reservation information to senders of broadcast or multicast sessions.
- Time is divided into equal-sized frames, and each frame consists of S slots.
- Each slot is further divided into five minislots.
- The first 4 minislots are used for transmitting control packets and are called control minislots (CMS)
- The last minislot is called data minislot (DMS)

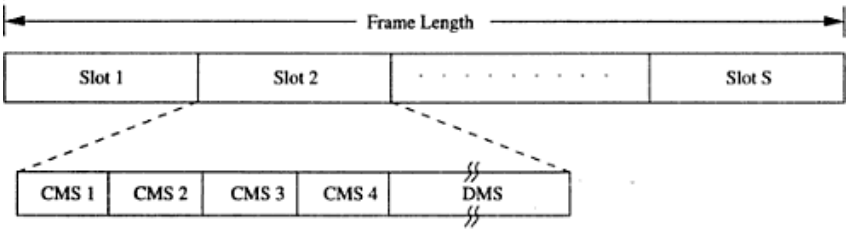


Figure 6.16. Frame format in CATA.

- Each node that receives data during the DMS of the current slot transmits a slot reservation (SR) packet during the CMS1 of the slot
- This serves to inform other neighboring potential sender nodes about the currently active reservations
- The SR packet is either received without error at the neighboring nodes or causes noise at thosenodes, preventing them from attempting to reserve the current slot
- Every node that transmits data during the DMS of the current slot transmits a request-to-send packet
- The receiver node of a unicast session transmits a clear-to-send packet
- On receiving this packet, the source node clearly understands that the reservation was successful and transmits data during the DMS of that slot until unicast flow gets terminated.
- Once the reservation has been made successfully in a slot, from the next slot onward, both the sender and receiver do not transmit anything during CMS3 and during CMS4 the sender node alone transmits anot-to-send (NTS) packet
- The not-to-send (NTS) packet serves as a negative acknowledgement
- A potential multicast or broadcast source node that receives the NTS packet or that detects noise, understands that its reservation request has failed & does not transmit during DMS of current slot
- The length of the frame is very important in CATA
- The worst case value of the frame-length = $Min(d^2+1, N)$, where d is the maximum degree of a node inthe network and N is the total number of nodes in the network
- CATA works well with simple single-channel half-duplex radios
- It is simple and provides support for collision-free broadcast and multicast traffic.

Hop Reservation Multiple Access Protocol

- A multichannel MAC protocol which is based on half-duplex, very slow frequency-hopping spread spectrum (FHSS) radios
- Uses a reservation and handshake mechanism to enable a pair of communicating nodes to reserve a frequency hop, thereby guaranteeing collision-free data transmission.

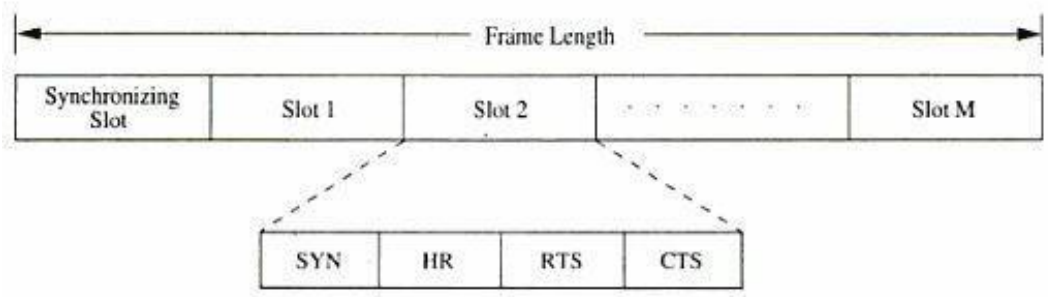


Figure 6.17. Frame format in HRMA.

- There are L frequency channels available
- HRMA uses one frequency channel, denoted by f_0 as a dedicated synchronising channel
- The nodes exchange synchronisation information on f_0
- The remaining L-1 frequencies are divided into M=(L-1)/2 frequency pairs
- f_i is used for transmitting and receiving hop-reservation packets, RTS, CTS and data packets
- f_i^* is used for sending and receiving acknowledgement (ACK) packets
- The data packets transmitted can be of any size.
- Data transmission can take place through a single packet or a train of packets.
- In HRMA, time is slotted and each slot is assigned a separate frequency hop
- Each time slot is divided into four periods, namely, synchronising period, HR period, RTS period, and CTS period
- Each period meant for transmitting or receiving the synchronising packet, FR packet, RTS packet, and CTS packet respectively.
- During the synchronising period of each slot, all idle nodes hop to the synchronising frequency f_0 and exchange synchronisation information

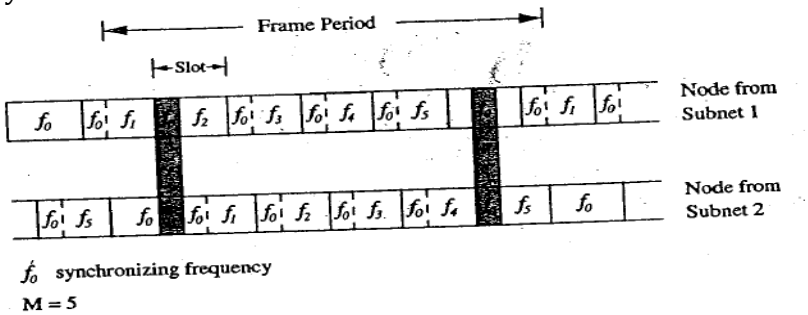


Figure Merging of subnets.

- When a new node enters the network, it remains on the synchronising frequency f_0 for a long enough period of time so as to gather synchronisation information such as the hopping pattern and the timing of the system
- If it receives no information, it assumes that it is the only node in the network, broadcasts its own synchronisation information and forms a one-node system
- Figure above depicts the worst-case frequency overlap scenario
- When a node receives data to be transmitted, it first listens to the HR period of the immediately following slot

- If it finds the channel to be free during the SR period, it transmits an RTS packet to the destination during the RTS period of the slot and waits for the CTS packet
- On receiving the RTS, the destination node transmits the CTS packet during the CTS period of the same slot and waits for the data packet
- If the source node receives the CTS packet correctly, it implies that the source and receiver nodes have successfully reserved the current hop
- After transmitting each data packet, the source node hops onto this acknowledgement frequency.
- The receiver sends an ACK packet back to the source.

Soft Reservation Multiple Access with Priority Assignment

- Developed with the main objective of supporting integrated services of real-time and non-real-time application in ad hoc networks, at the same time maximizing the statistical multiplexing gain.
- Nodes use a collision-avoidance handshake mechanism and a soft reservation mechanism
- Unique frame structure
- Soft reservation capability for distributed ad dynamic slot scheduling
- Dynamic and distributed access priority assignment and update policies
- Time constrained back-off algorithm
- Time is divided into frames, with each frame consisting of a fixed number of slots
- Each slot is further divided into 6 different fields (figure) namely SYNC, soft reservation (SR),reservation request (RR), reservation confirm (RC), data sending (DS) and acknowledgement (ACK)

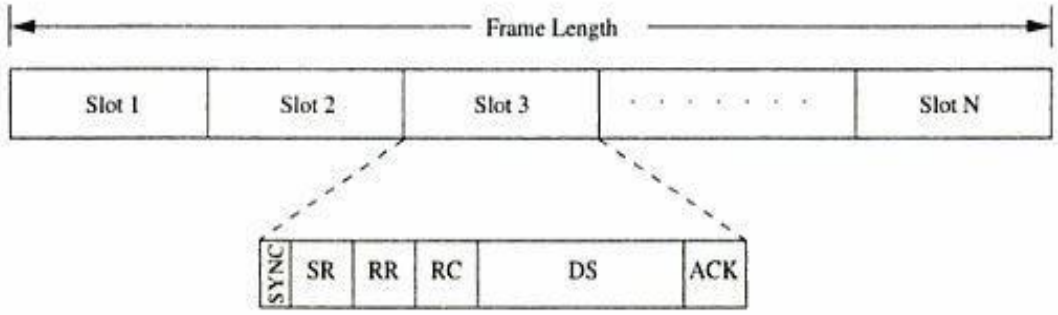


Figure 6.19. Frame structure in SRMA/PA.

- The SYNC field is used for synchronisation purposes
- The SR, RR, RC, and ACK fields are used for transmitting and receiving the corresponding controlpackets
- 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
- SR packet also carries the access priority value assigned to the node that has reserved the slot
- When an idle node receives a data packet for transmission, the node waits for a free slot and transmits the RR packet in the RR field of that slot
- A node determines whether or not a slot is free through the SR field of that slot
  In case of a voice terminal node, the node tries to take control of the slot already reserved by a dataterminal if it finds it 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
- It is required that priority of voice terminal $p_v^{(R)}$ > priority of data terminal $p_d^{(R)}$ such that delay-sensitive voice applications get preference over normal data applications

- A node that is currently transmitting is said to be in active state
- A node that is said to be in the idle state if it does not have any packet to be transmitted
- In the active state itself, nodes can be in one of the two states: access state and reserved state
- Access state is one in which the node is backlogged and is trying to reserve a slot for transmission
- The access priorities are assigned to nodes and updated in a distributed and dynamic manner
- This allows dynamic sharing of the shared channel
- In order to avoid collisions, a binary exponential back-off algorithm is used for non-real time connections and a modified binary exponential back-off algorithm is used for real time connections.

Five-Phase Reservation Protocol

- A single-channel time division multiple access (TDMA)-based broadcast scheduling protocol.
- Nodes use a contention mechanism in order to acquire time slots.
- 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

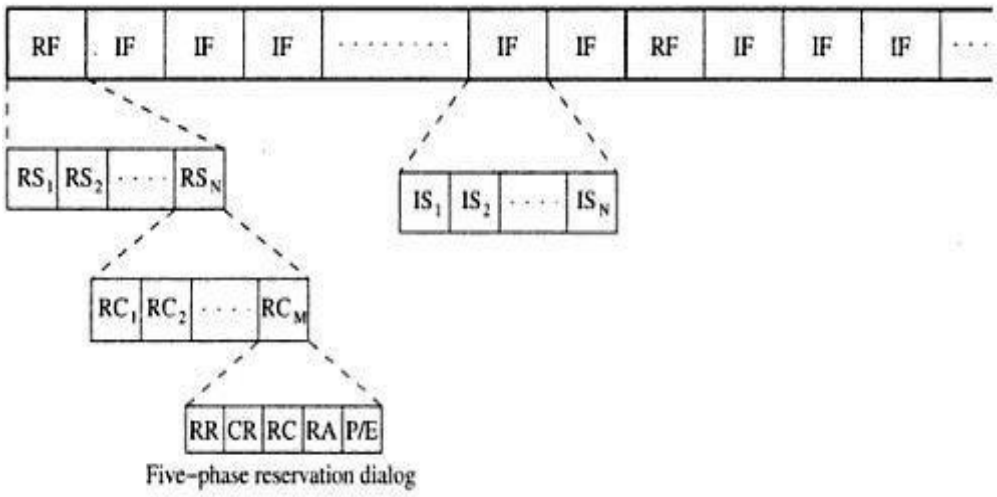


Figure 6.21. Frame structure in FPRP.

- Time is divided into frames
- There are two types of frames namely reservation frame and information frame
- Each RF is followed by a sequence of Ifs
- Each RF has N reservation slots (RS)
- Each IF has N information slots (IS)
- In order to reserve an IS, a node needs to contend during the corresponding RS
- Based on these contentions, a TDMA schedule is generated in the RF and is used in the subsequent Ifs until the next RF.
- Each RS is composed of M reservation cycles
- During the corresponding IS, a node would be in one of the three states: transmit(T), receive(R) or blocked(B)
- The protocol assumes the availability of global time at all nodes.
- The reservation takes five phases: reservation, collision report, reservation confirmation, reservationacknowledgement, and packing and elimination phase.

1. Reservation request phase: Nodes 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 nodes, upon receiving the CR packet, take necessary action.

3. Reservation confirmation phase: A source node is said to have won the contention for a slot if it does not receive any CR messages in the previous phase. In order to confirm the reservation request made in the reservation request phase, it sends a reservation confirmation (RC) message to the destination node in this phase.

4. Reservation acknowledgment phase: In this phase, the destination node acknowledges reception of the RC by sending back a reservation acknowledgment (RA) message to the source. The hidden nodes that receive this message defer their transmissions during the reserved slot.

5. Packing and elimination (P/E) phase: Two types of packets are transmitted during this phase: packing packet and elimination packet.

In this phase, a packing packet (PP) is sent by each node that is located within two hops from a TN, and that had made a reservation since the previous P/E phase. A node receiving a PP understands that there has been a recent success in slot reservation three hops away from it, and because of this some of its neighbors would have been blocked during this slot. The node can take advantage of this and adjust its contention probability p, so that convergence is faster.

MACA with Piggy-Backed Reservation

- Provide real-time traffic support in multi-hop wireless networks
- Based on the MACAW protocol with non-persistent CSMA
- The main components of MACA/PR are:
  - ✓ A MAC protocol
  - ✓ A reservation protocol
  - ✓ A QoS routing protocol
- Differentiates real-time packets from the best-effort packets
- Provide guaranteed BW support for real-time packets
- Provides reliable transmission of best efforts packets
- Time is divided into slots

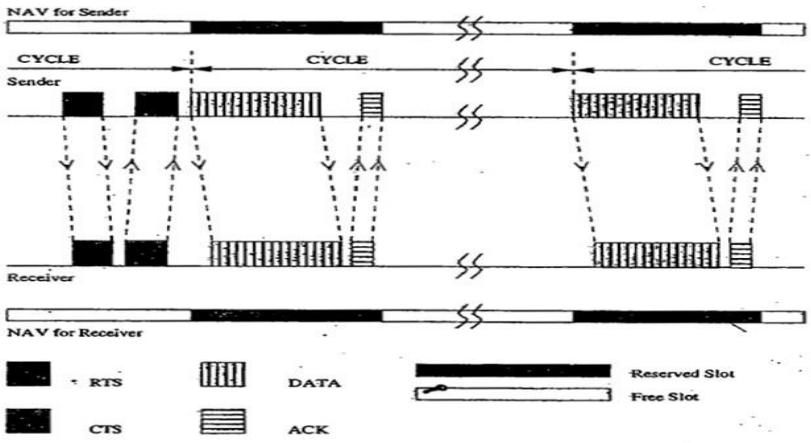


Figure 6.23. Packet transmission in MACA/PR.

- Slots are defined by the reservations made at nodes
- They are asynchronous in nature with varying lengths
- Each node in the network maintains a reservation table (RT) that records all the reserved transmit and receive slots/windows of all nodes within its transmission range
- The sender is assumed to transmit real-time packets at certain regular intervals, say, every CYCLE time period
- The first data packet of the session is transmitted in the usual manner
- The source node first sends an RTS packet, for which the receiver responds with a CTS packet
- Now the source node sends the first DATA packet of the real-time session
- Reservation information for the next DATA packet to be transmitted is piggy-backed on this current DATA packet.
- On receiving this DATA packet, the receiver node updates its reservation table with the piggy-backed reservation information
- It then sends ACK packet back to the source
- Receiver node piggy-backs the reservation confirmation information on the ACK packet
- Slot reservation information maintained in the reservation tables is refreshed every cycle
- Thus, MACA/PR is an efficient bandwidth reservation protocol that can support real-time trafficsessions
- Advantage it does not require global synchronisation among nodes
- Drawback a free slot can be reserved only if it can fit the entire RTS-CTS-DATA-ACK exchange

Real-Time Medium Access Control Protocol

- Provides a bandwidth reservation mechanism for supporting real-time traffic in ad hoc wireless networks
- RTMAC has two components
  - A MAC layer protocol is a real-time extension of the IEEE 802.11 DCF.
    - A medium-access protocol for best-effort traffic
    - A reservation protocol for real-time traffic
  - A QoS routing protocol is responsible for end-to-end reservation and release of bandwidth resources.

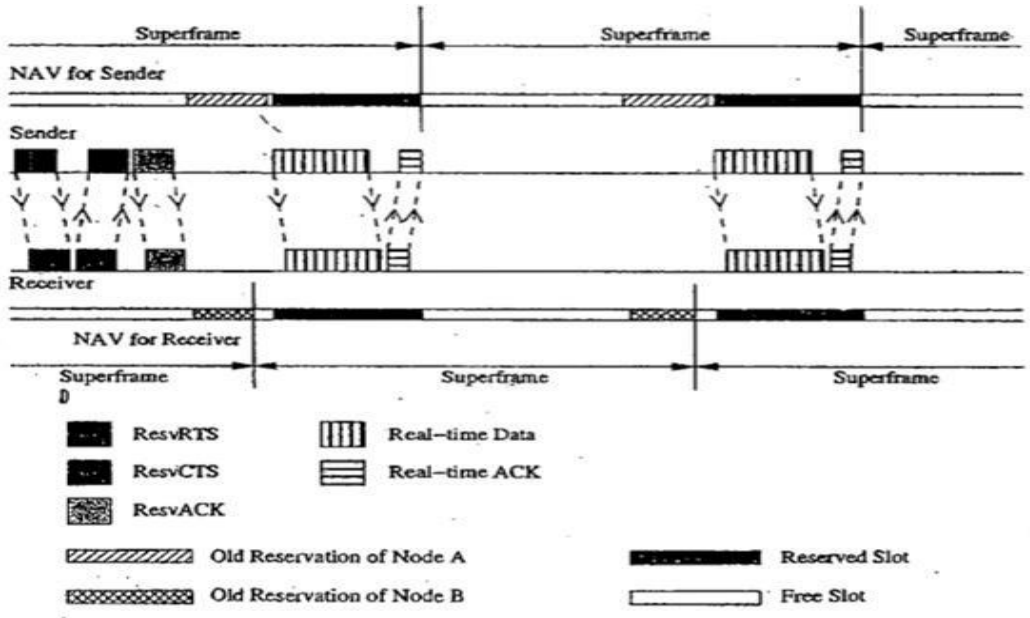


Figure 6.24. Reservation mechanism in RTMAC.

- A separate set of control packets, consisting of ResvRTS, ResvCTS, and ResvACK, is used for effecting BW reservation for real-time packets
- RTS, CTS and ACK control packets are used for transmitting best effort packets
- Time is divided into superframes. (figure)
- Bandwidth reservations can be made by a node by reserving variable-length time slots on superframes
- The core concept of RTMAC is the flexibility of slot placement in the superframe
- Each superframe consists of a number of reservation-slots
- The time duration of each resv-slot is twice the maximum propagation delay
- Data transmission normally requires a block of resv-slots
- A node that needs to transmit real-time packets 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
- Each node maintains a reservation table containing information such as the sender id, receiver id, and starting and ending times of reservations that are currently active
- In RTMAC, no time synchronisation is assumed
- The protocol uses relative time for all reservation purpose
- A three way handshake protocol is used for effecting the reservation
- In the figure, NAV indicates the network allocation vector maintained at each node
- Main advantage is Bandwidth efficiency
  Another advantage is asynchronous mode of operation where nodes do not require any global timesynchronisation