UNIT 1
INTRODUCTION

CELLULAR AND AD HOC WIRELESS NETWORKS

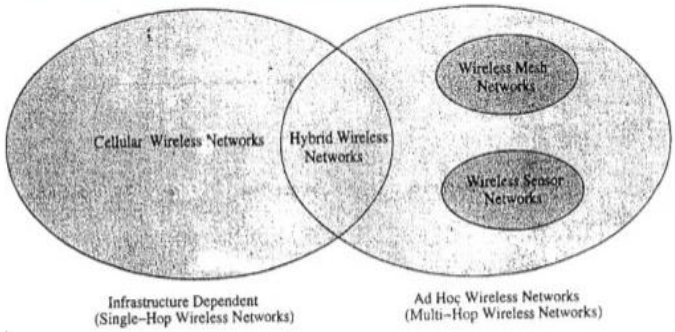

Figure : Cellular and ad hoc wireless networks.

The current cellular wireless networks are classified as the infrastructure dependent network. The path setup for a call between two nodes, say, node C to E, is completed through base station as illustrated in figure below.

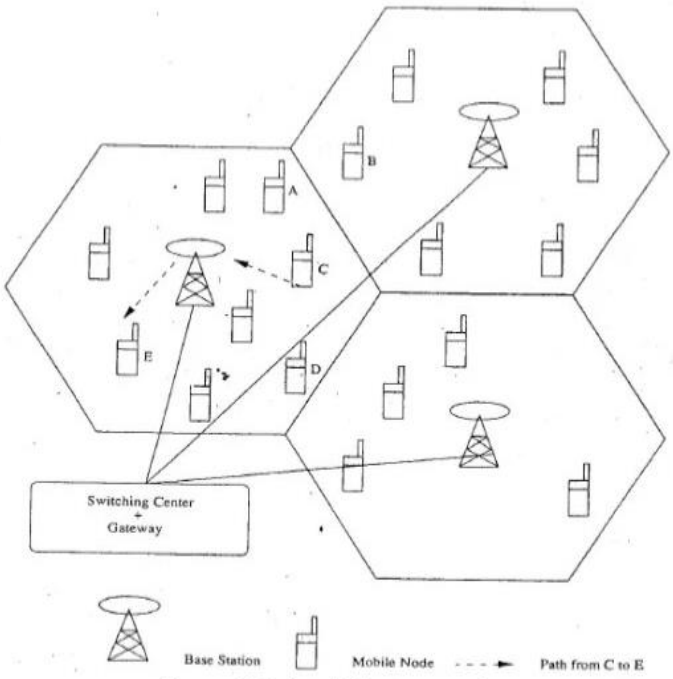

Figure 5.2 A cellular network

- Adhoc wireless networks are defined as a category of wireless network that utilize multi-hop radio replaying 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.

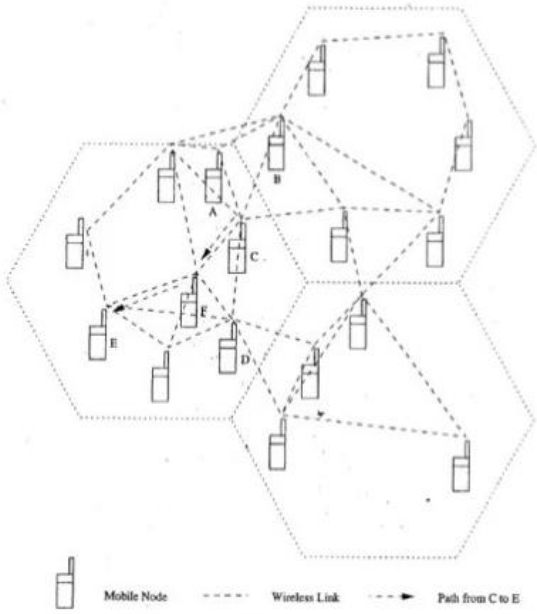

Figure 5.3: An ad hoc wireless network

- 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 all nodes 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 in quick 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 coordination is 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 and reception 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-going session, are prevented from making a transmission.
5. ***Throughput:***
   - The MAC protocol employed in adhoc wireless networks should attempt to maximize the throughput 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 the bandwidth 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 and receiver 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, stale routing information, and difficulty in resource reservation.
2. ***Bandwidth constraint :***
   - Since the channel is shared by all nodes in the broadcast region, the bandwidth available per wireless 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 of bandwidth.
5. ***Other resource constraints :***
   - The constraints on resources such as computing power, battery power, and buffer storage also limit the 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 node should 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 able to 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 the route 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 be kept as minimal as possible.
6. ***Scalability :***
   - Scalability is the ability of the routing protocol to scale well in a network with a large number of nodes.
   - This requires minimization of control overhead & adaptation of the routing protocol to the network size.
7. ***Provisioning of QoS:***
   - The routing protocol should be able to provide a certain level of QoS as demanded by the nodes or the 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, and similar 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 not powered 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 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 & channel utilization.
6.communication among the nodes in a sensor network	6.Minimum energy consumption, battery life & energy conservation

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

AD HOC WIRELESS INTERNET

- Ad hoc wireless internet extends the services of the internet to the end users over an ad hoc wireless network.
- 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 :**
    - o They are the entry points to the wired internet.
    - o Generally owned & operated by a service provider.
    - o They perform following tasks ,
      - Keeping track of end users.
      - Bandwidth management.
      - Load balancing.
      - Traffic shaping.
      - Packet filtering.
      - Width fairness &
      - Address, service & location discovery.

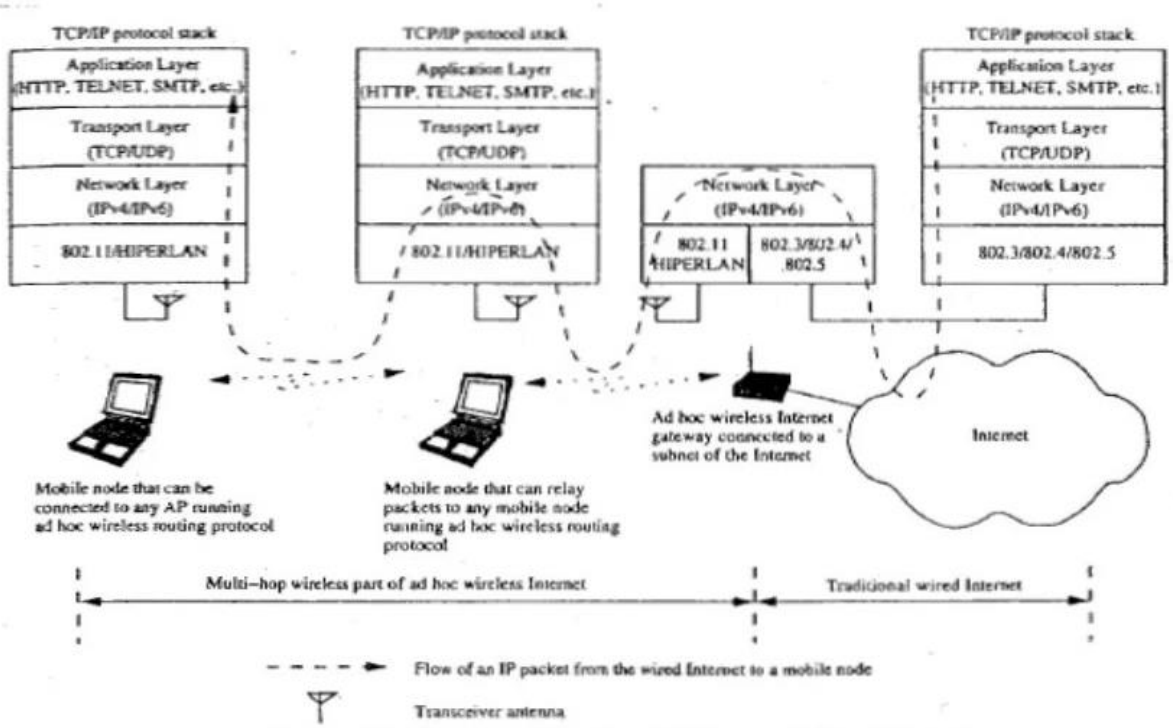

Figure 5.7 Schematic diagram of ad hoc wireless internet

- **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 presence of 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 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.