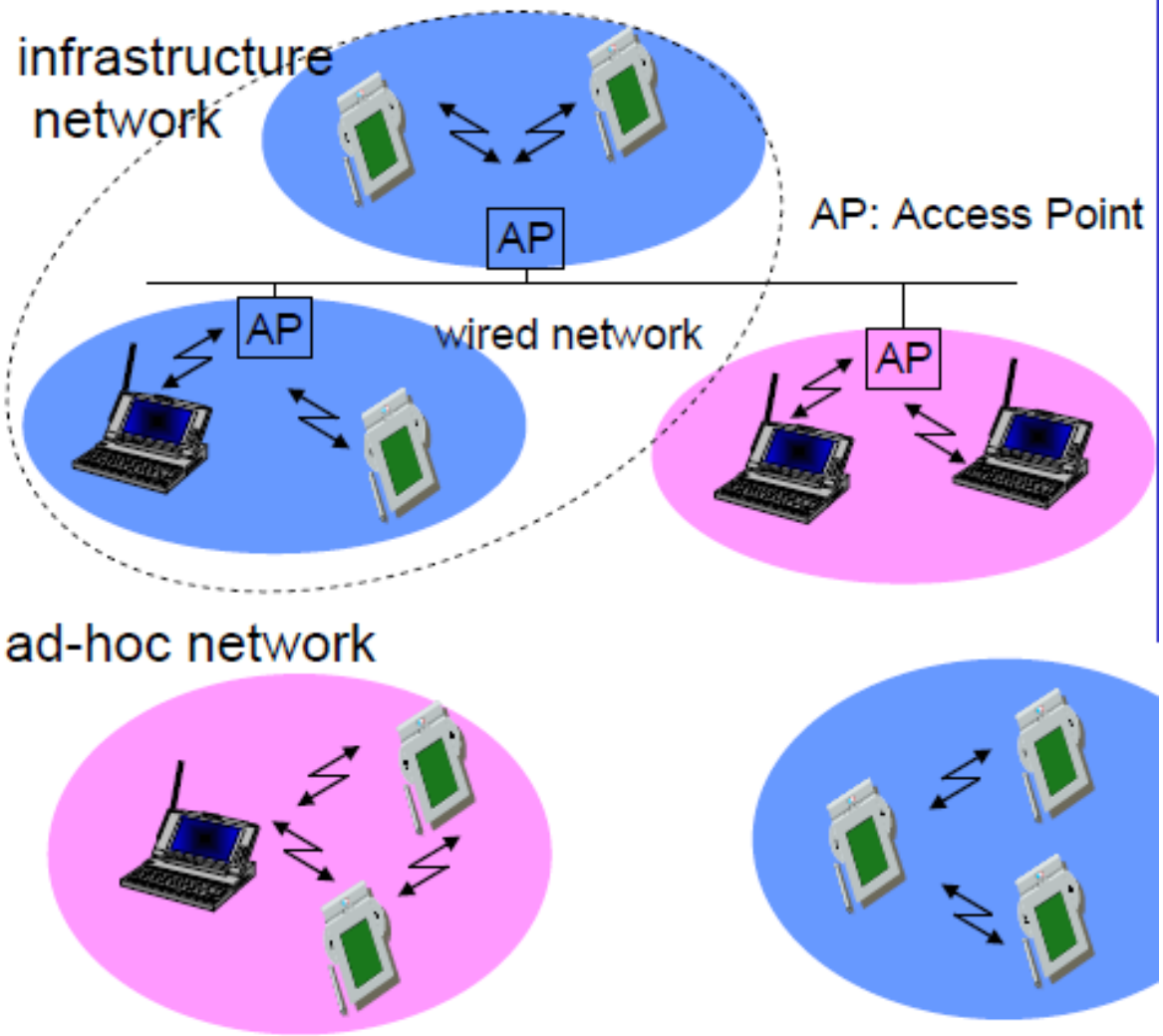
Ad Hoc Wireless Networks

Types of Wireless Network



Infrastructure Network

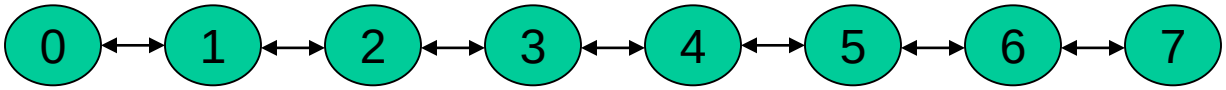
- Fixed, wired backbone
- Mobile devices communicate directly with access points
- Suitable for locations where access points can be placed
- Example - Cellular networks

Ad hoc Wireless Networks

- A network without any base stations “infrastructure-less” or multi-hop
- A collection of two or more devices equipped with wireless communications and networking capability
- Supports anytime and anywhere computing
- Heterogeneous – nodes with different capabilities
- Homogeneous (fully symmetric) - all nodes have identical capabilities and responsibilities

Ad hoc Wireless Networks

- Ad hoc network is a multi-hop relaying network in which messages are sent from the source to the destination by relaying through intermediate hops (nodes).
- Intermediate nodes may be mobile.
- Communication needs are primarily between nodes within the same network



- Why Ad hoc Networks?
  - Ease of deployment
  - Speed of deployment
  - Decreased dependence on infrastructure

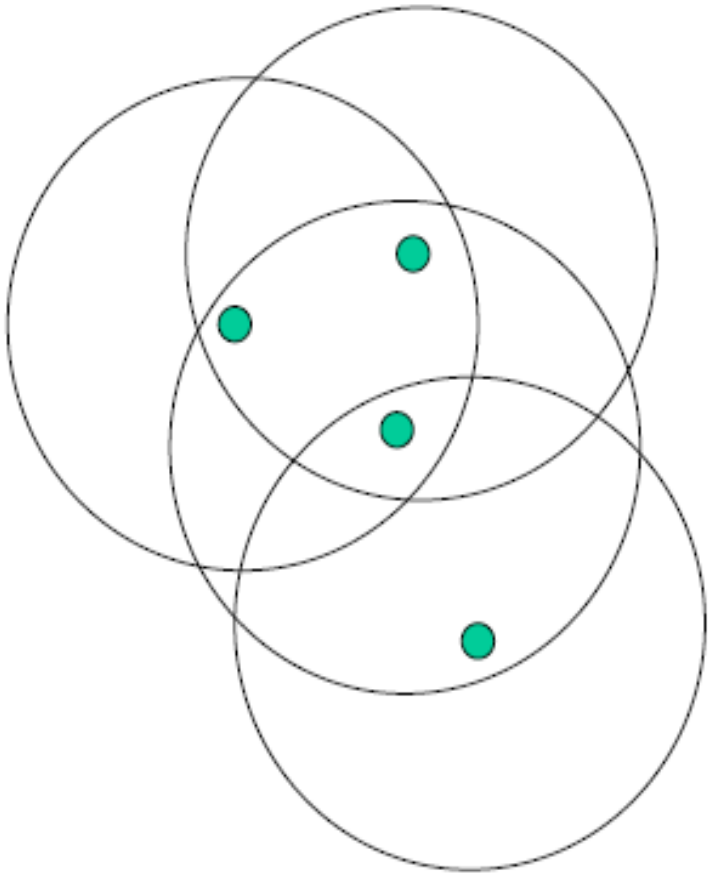
Ad hoc Wireless Networks

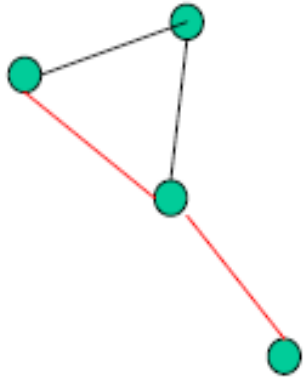
- Bluetooth – the first commercial realizations of ad hoc wireless networking developed by Bluetooth Special Interest Group (SIG):
  - A piconet formed by a group of nodes establishes a single-hop (master node) point-to-point wireless link.
  - A scatternet formed by multiple piconets (master nodes) can establish a multi-hop wireless network.
- IEEE 802.11 protocols developed for both, infrastructure and ad hoc wireless networks
  - However, they don’t function well in multi-hop networks.
- The mobile ad hoc networks (MANET) standards are being developed by the Internet Working Tasking Force (IETF) MANET working group.

Ad hoc Wireless Networks

- Self-organizing and adaptive
  - Allows spontaneous formation and deformation of mobile networks
- Each mobile host acts as a router
- Supports peer-to-peer communications
- Supports peer-to-remote communications
- Reduced administrative cost
- Ease of deployment

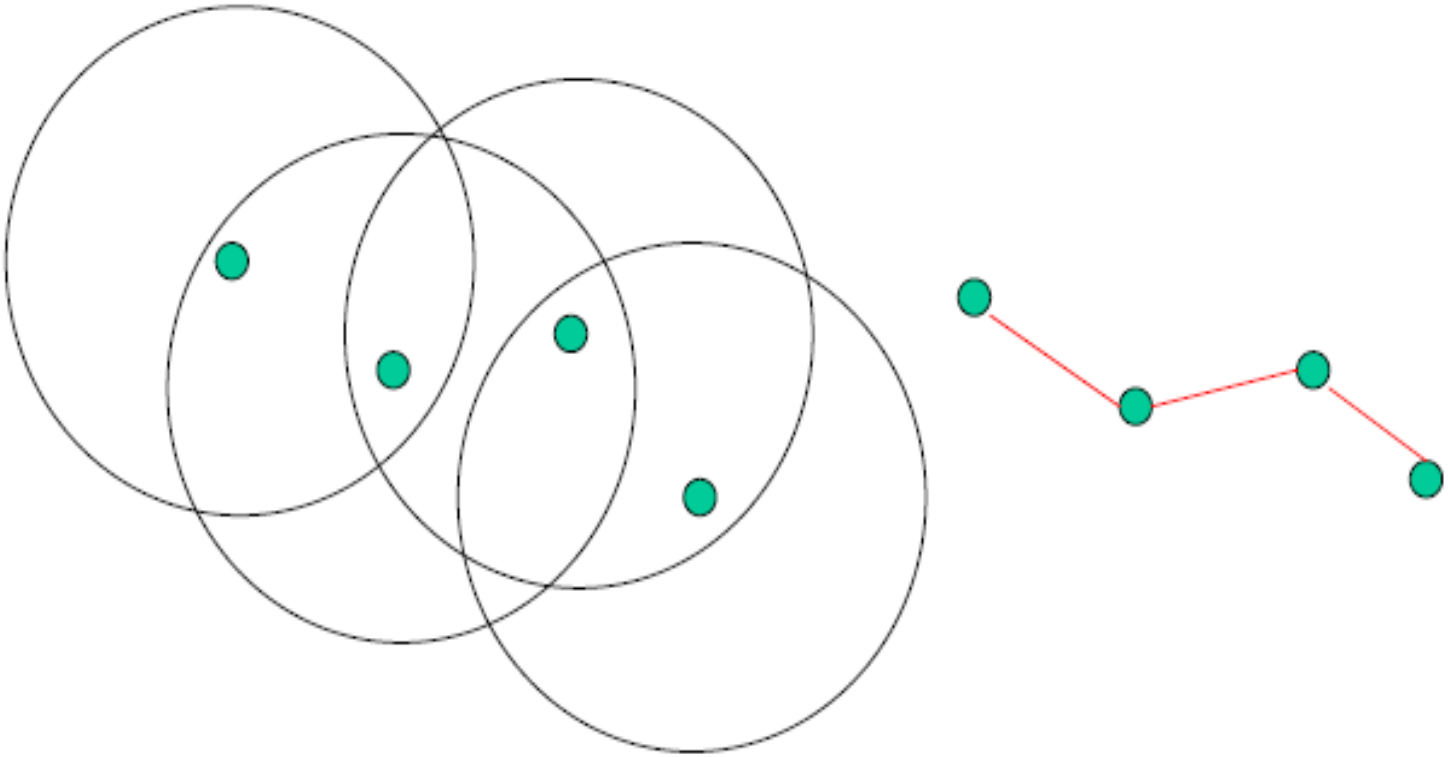
Mobile Ad Hoc Networks



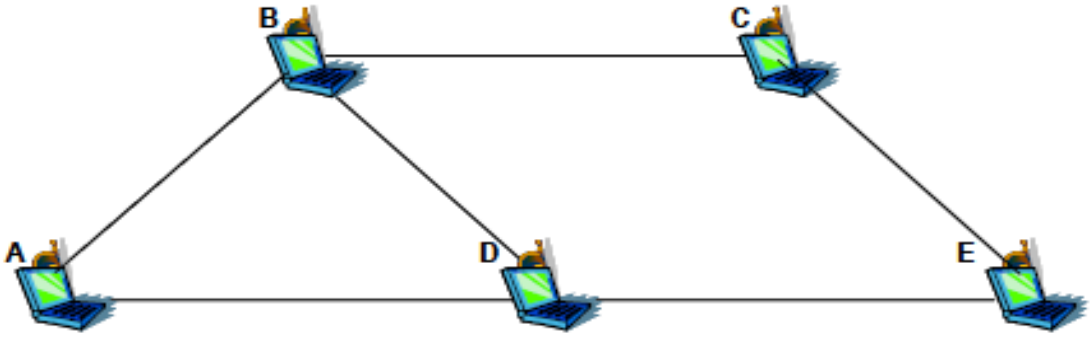


Mobile Ad Hoc Networks

Mobility causes route changes



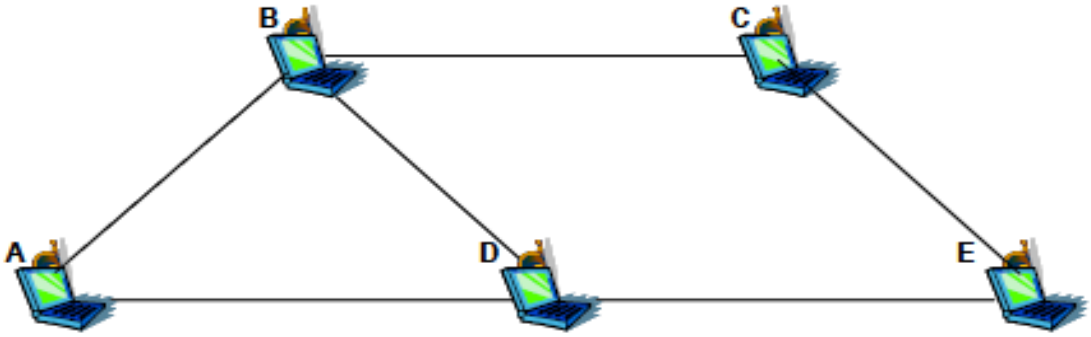
Ad Hoc Networks – Operating Principle



Example of an Ad Hoc Network

- A peer-to-peer multihop ad hoc network
- Mobile node A communicates directly with B (single hop) when a channel is available
- If Channel is not available, then multi-hop communication is necessary e.g. A->D->B
- For multi-hop communication to work, the intermediate nodes should route the packet i.e. they should act as a router
- Example: For communication between A-C, B, or D & E, should act as routers

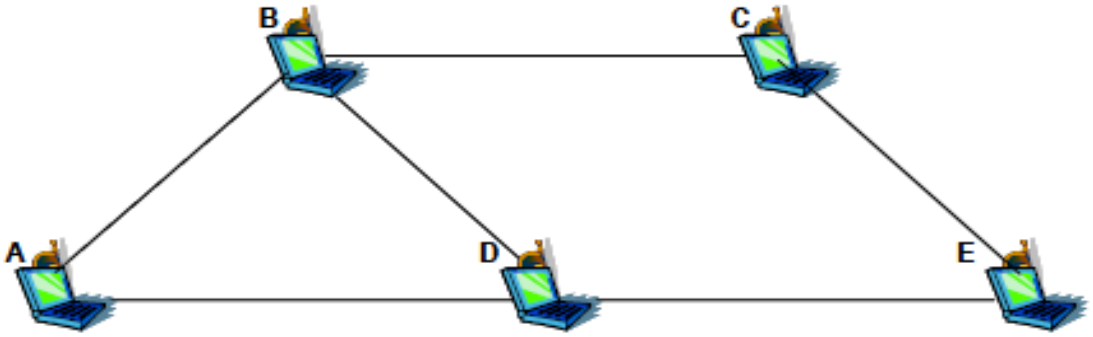
Bringing up an Ad hoc Network



Example of an Ad Hoc Network

- Ad hoc network begins with at least two nodes broadcasting their presence (beaconing) with their respective address information
  - They may also include their location info if GPS equipped
  - Beaconing messages are control messages
- If node A is able to establish a direct communication with node B verified by appropriate control messages between them, they both update their routing tables

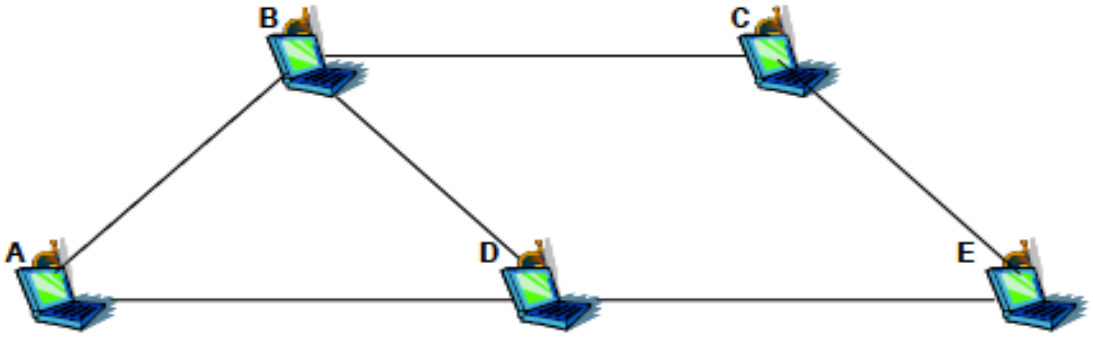
Bringing up an Ad hoc Network



Example of an Ad Hoc Network

- Third node C joins the network with its beacon signal. Two scenarios are possible:
  - (i) A & B both try to determine if single hop communication is feasible
  - (ii) Only one of the nodes e.g. B tries to determine if single hop communication is feasible and establishes a connection

Bringing up an Ad hoc Network

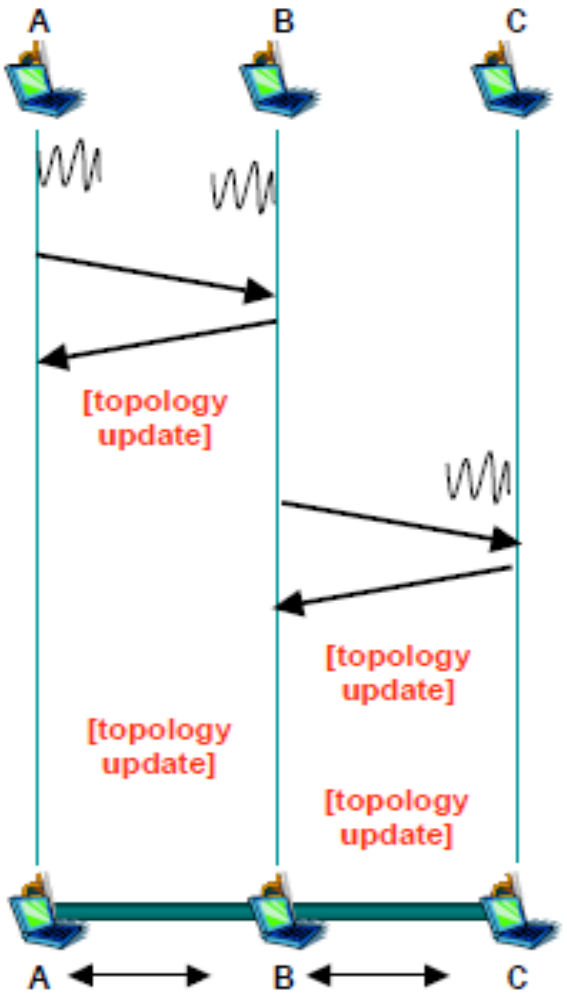


Example of an Ad Hoc Network

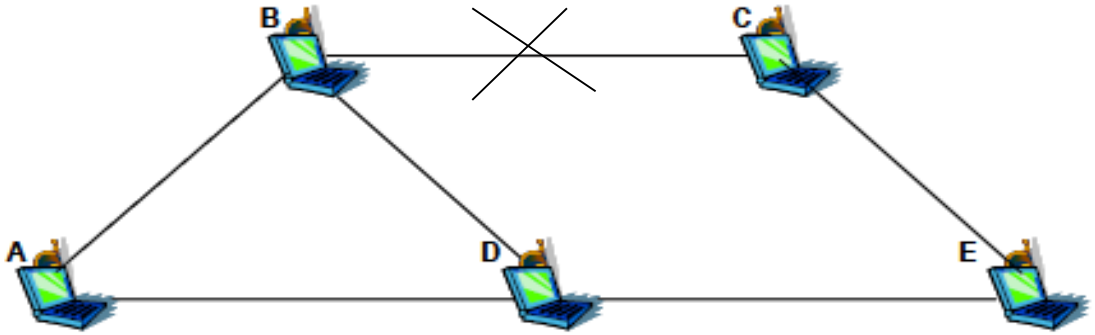
- The distinct topology updates consisting of both addresses and the route updates are made in three nodes immediately.
- In first scenario, all routes are direct i.e. A->B, B->C, and A->C (Lets assume bi-directional links)

Bringing up an Ad hoc Network

- In the second scenario, the routes are updated
  - First between B & C,
  - then between B & A,
  - Then between B & C again confirming that A and C both can reach each other via B



Bringing up an Ad hoc Network



Example of an Ad Hoc Network

- Mobility of nodes may cause link breakage requiring route updates
- Assume link between B & C breaks because of some reason
- Nodes A & C are still reachable via D and E
- So old route between A &C was A->B->C is to be replaced by

A->D->E->C

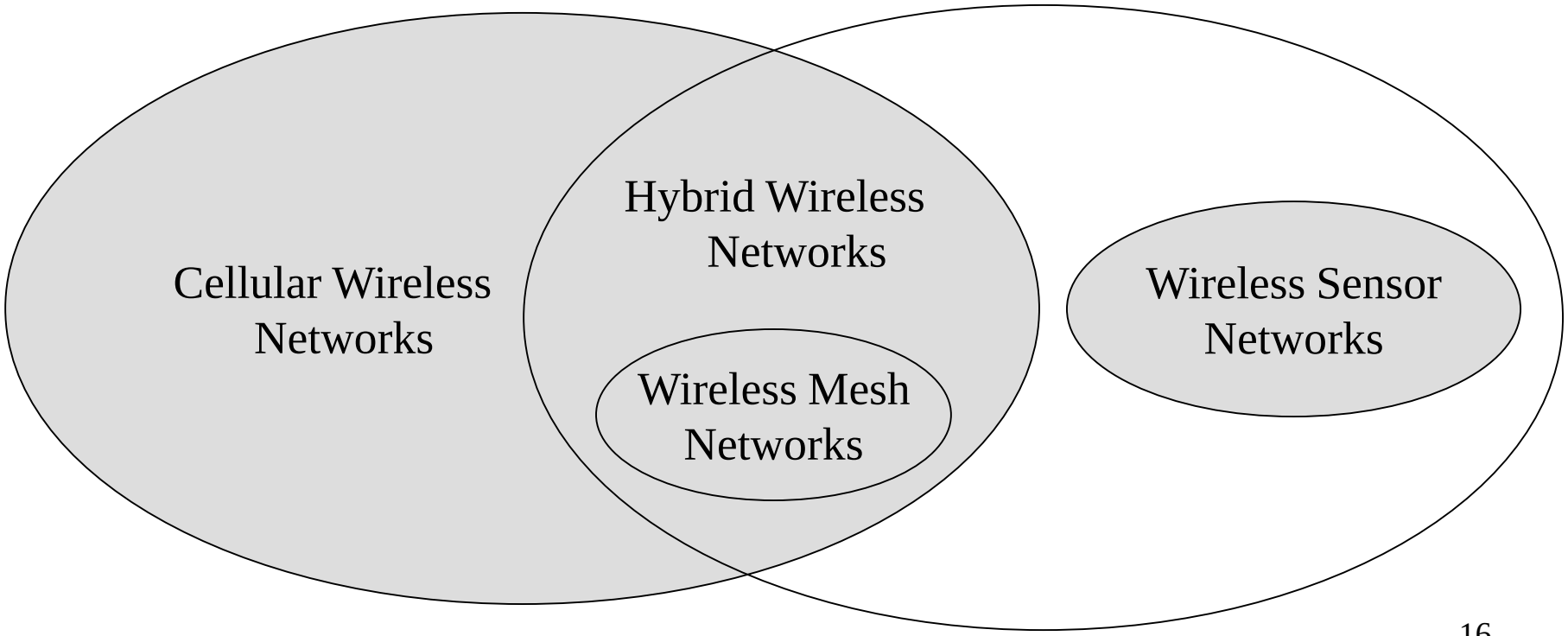
- All five nodes are required to incorporate this change in their routing table
  - This change will happen first in nodes B & C
  - Then A & E
  - Then D

Ad hoc Wireless Networks

- Ad hoc wireless networks are expected to work in the absence of any fixed infrastructure
- However, recent advances in wireless network architectures enable the mobile ad hoc nodes to function in the presence of infrastructure. Examples -
  - Multi-hop cellular networks (MCNs),
  - self-organizing packet radio ad hoc networks with overlay (SOPRANO), and
  - mesh networks.
- Mesh networks serve as access networks that employ multi-hop wireless forwarding by non-mobile nodes to relay traffic to and from the wired Internet.
- Hybrid technologies and/or hierarchical network organization can be used for ad hoc and infrastructure wireless links.

Cellular and Ad Hoc Wireless Networks

- Infrastructure: cellular wireless networks
- Ad hoc: wireless sensor networks
- Hybrid: mesh networks



Comparisons between Cellular and Ad Hoc Wireless Networks (I)

Cellular Networks	**Ad Hoc Wireless Networks**
Fixed infrastructure-based	Infrastructureless
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 employ bandwidth reservation	Bandwidth reservation requires complex medium access control protocols

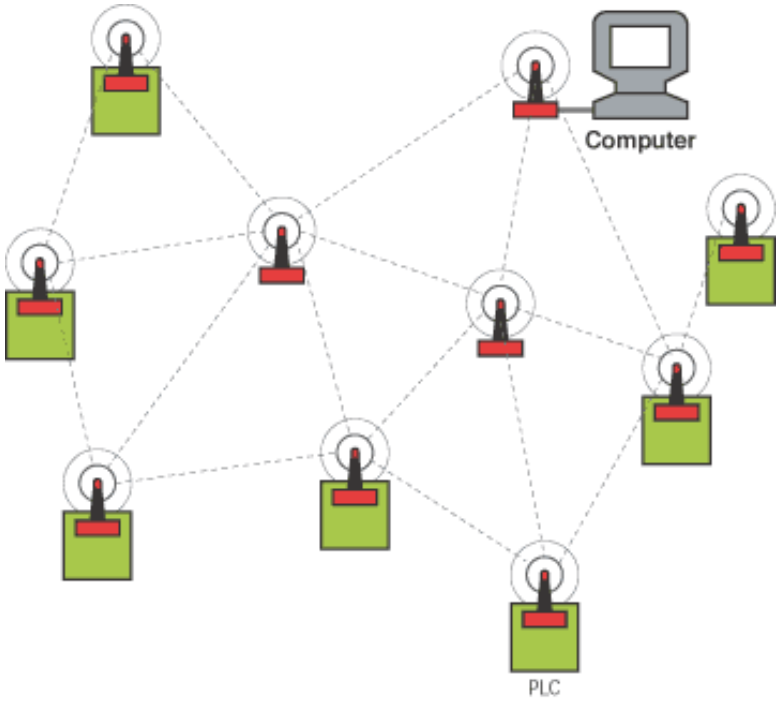
Comparisons between Cellular and Ad Hoc Wireless Networks (II)

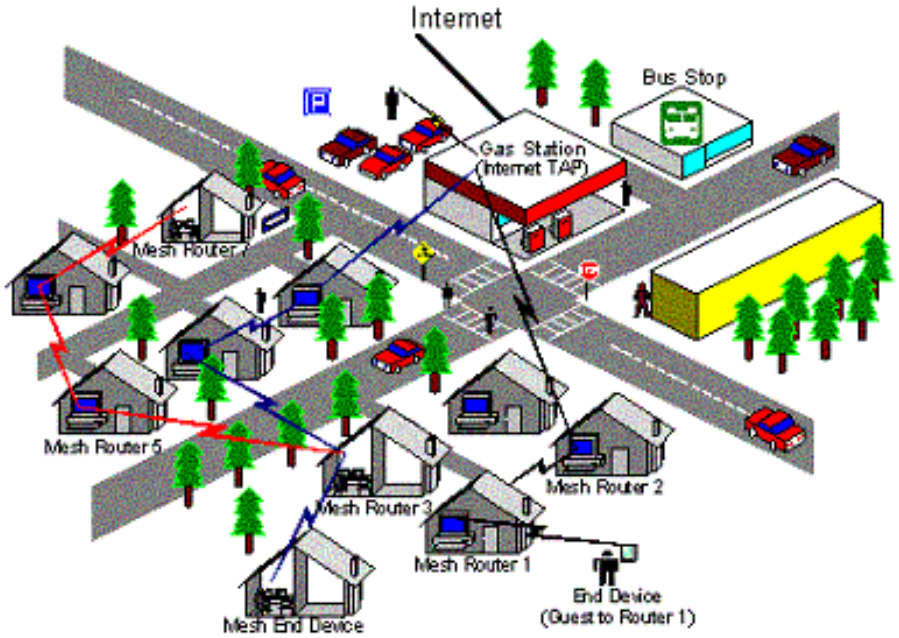
Cellular Networks	**Ad Hoc Wireless Networks**
Application domains include mainly civilian and commercial sectors	Application domains include battlefields, emergency search and rescue operations, and collaborative computing
High cost of network maintenance (backup power source, staffing, etc.)	Self-organization 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 applications
  - Ad hoc wireless networks is useful in establishing communication in a battle field.
- Collaborative and Distributed Computing
  - A group of people in a conference can share data in ad hoc networks.
  - Streaming of multimedia objects among the participating nodes.
- Emergency Operations
  - Ad hoc wireless networks are useful in emergency operations such as search and rescue, and crowd control.
- A **Wireless Mesh Network** is a mesh network that is built upon wireless communications and allows for continuous connections and reconfiguration around blocked paths by "hopping" from node to node until a connection can be established.

Wireless Mesh Networks





- In a wireless mesh network, multiple nodes cooperate to relay a message to its destination. The mesh topology enhances the overall reliability of the network, which is particularly important when operating in harsh industrial environments.

Wireless Mesh Networks

- The investment required in wireless mesh networks is much less than in the cellular network counterparts.
- Such networks are formed by placing wireless replaying equipment spread across the area to be covered by the network.
- The possible deployment scenarios include:
  - Residential zones (where broadband Internet connectivity is required)
  - Highways (where a communication facility for moving automobiles is required)
  - Business zones (where an alternate communication system to cellular networks is required)
  - Important civilian regions (where a high degree of service availability is required)
  - University campuses (where inexpensive campus-wide network coverage can be provided)

Wireless Mesh Networks

- Wireless mesh networks should be capable of self-organization and maintenance.
- Advantages
  - High data rate
  - Quick and low cost of deployment
  - Enhanced services
  - High scalability
  - Easy extendability
  - High availability
  - Low cost per bit
- It operates at 2.4 GHz or 5 GHz
- Data rates of 2 Mbps to 60 Mbps can be supported.

Wireless Sensor Networks

- Wireless Sensor Networks are a special category of ad hoc networks that are used to provide a wireless communication infrastructure among the sensors deployed in a specific application domain.
- A sensor network is a collection of a large number of sensor nodes that are deployed in a particular region.
- Distinct properties of wireless sensor networks:
  - Mobility of nodes are not needed in all cases in wireless sensor networks.
  - The size of the network is much larger than that in a typical ad hoc wireless network.
  - The density of nodes in a sensor network varies with the domain of application.
  - The power constraints in sensor networks are much more stringent than those in ad hoc wireless networks.

Wireless Sensor Networks

- Distinct properties of wireless sensor networks:
  - The power source can be classified into three categories:
    - Replenishable power resource
    - Non- Replenishable power source
    - Regenerative power source
  - Data/information fusion aims at processing the sensed data at the intermediate nodes and relaying the outcome to the monitor node.
  - The communication traffic pattern varies with the domain of applications.

Hybrid Wireless Networks

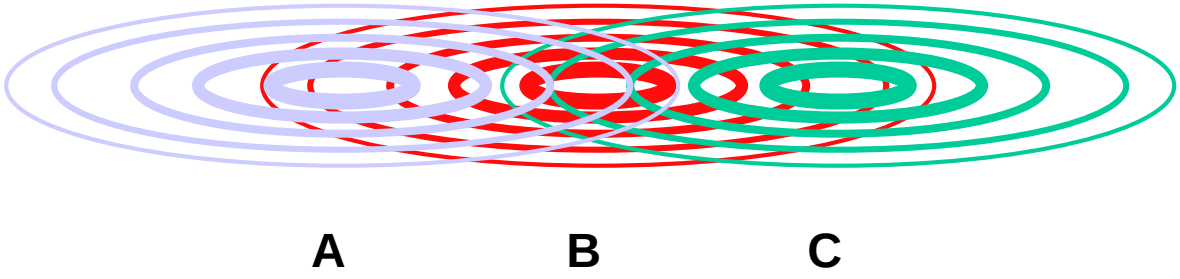
- Hybrid Wireless Networks
  - Multi-hop cellular networks (MCNs) allows the transmission through the base stations or multi-hop of mobile nodes.
  - Integrated cellular ad hoc relay (iCAR) is a system that combines conventional cellular technology with Ad hoc Relay Station (ARS) technology. In this system cellular stations will relay or reroute calls from the congested cell to an adjacent one that is not congested.
- Advantages
  - Higher capacity than cellular networks
  - Increased flexibility and reliability in routing
  - Better coverage and connectivity

Issues in Ad hoc Wireless Networks Medium access scheme

- **Distributed operation -** fully distributed involving minimum control overhead
- **Synchronization** is required in TDMA-based systems.
- **Hidden terminals** are nodes hidden from a sender - Can significantly reduce the throughput of a MAC protocol
- **Exposed terminals** are exposed nodes preventing a sender from sending - To improve the efficiency of the MAC protocol, the exposed nodes should be allowed to transmit in a controlled fashion without causing collision to the on-going data transfer
- **Throughput and access delay**
  - To minimize the occurrence of collision, maximize channel utilization, and minimize control overhead

Exposed Terminal Problem

- Exposed terminals
  - B sends to A, C wants to send to another terminal (not A or B)
  - C senses carrier, finds medium in use and has to wait
  - A is outside the radio range of C, therefore waiting is not necessary
  - C is “exposed” to B



Issues in Ad hoc Wireless Networks Medium access scheme

- **Fairness** Equal share or weighted share of the bandwidth to all
- competing nodes
- **Real-time traffic support** is required for voice, video, and real-time data.
- **Resource reservation** Such as BW, buffer space, and processing power
- **Ability to measure resource availability**
- **Capability for power control** to reduce the energy consumption.
- **Adaptive rate control** refers to the variation in the data bit rate.
- **Use of directional antennas** for increased spectrum reuse, reduced interference, and reduced power consumption.

Issues in Ad hoc Wireless Networks Routing - Challenges

- Mobility - frequent path break, packet collision, and difficulty in resource reservation
- Bandwidth constraint - BW is shared by every node
- Error-prone and shared channel: high bit error rate
- Location-dependent contention
  - depends on the number of nodes
  - Needs to distribute the network load uniformly across the network
- Other resource constraints such as computing power, battery power, buffer storage

Issues in Ad hoc Wireless Networks Routing – Major Requirements

- Minimum route acquisition delay
- Quick route reconfiguration to handle path breaks
- Loop-free routing
- Distributed routing approach
- Minimum control overhead
- Scalability
- Provisioning of QoS - supporting differentiated classes of services
- Support for time-sensitive traffic: hard real-time and soft real-time traffic
- Security and privacy

Issues in Ad hoc Wireless Networks Multicast Routing

- Provisioning of multiple links among the nodes in an ad hoc network results in a mesh-shaped structure
- The mesh-shaped multicast routing structure works well in a high-mobility environment.
- The issues in multicast routing protocols are:
  - **Robustness**: It must be able to recover and reconfigure quickly from link breaks
  - **Efficiency**: It should make a minimum number of transmissions to deliver a packet to all the group members
  - Minimal **control overhead**.
  - **Quality of service** support.
  - **Efficient group management** needs to be performed with minimal exchange of control messages.
  - **Scalability**: It should be able to scale for a large network.
  - **Security** is important.

Issues in Ad hoc Wireless Networks Transport Layer Protocols

- The objectives of the transport layer protocols include:
  - Setting up and maintaining end-to-end connections
  - Reliable end-to-end delivery of data packets
  - Flow control
  - Congestion control
- Connectionless transport layer protocol (UDP) - unaware of high contention, increases the load in the network
- Major performance degradation: Frequent path breaks, presence of old routing information, high channel error rate, and frequent network partitions

Issues in Ad hoc Wireless Networks
QoS Provisioning

- QoS often requires negotiation between the host and the network, resource reservation schemes, priority scheduling and call admission control
- QoS in Ad hoc wireless networks can be on a per flow, per link, or per node
- Qos Parameters: different applications have different requirements
  - Multimedia: bandwidth and delay are the key parameters
  - Military: BW, delay, security and reliability
  - Emergency search –and-rescue: availability is the key parameter, multiple link disjoint paths
  - WSN: battery life, minimum energy consumption

Issues in Ad hoc Wireless Networks
QoS Provisioning

- QoS-aware routing:
  - To have the routing use QoS parameters for finding a path
  - The parameters are network through put, packet delivery ratio, reliability, delay, delay jitter, packet lost rate, bit error rate, and path loss
- QoS framework:
  - A framework for QoS is a complete system that attempts to provide the promised service
  - The QoS modules such as routing protocol, signaling protocol, and resource management should react promptly according to changes in the network state

Issues in Ad hoc Wireless Networks Self-Organization

- An important property that an ad hoc wireless network should exhibit is organizing and maintaining the network by itself
- Ad hoc wireless networks should be able to perform self-organization quickly and efficiently
- Self-Organization is required in ad hoc wireless networks:
  - Neighbor discovery
  - Topology organization
  - Topology reorganization

Issues in Ad hoc Wireless Networks Security

- The attack against ad hoc wireless networks are classified into two types: passive and active attacks
  - Passive attack: malicious nodes to observe the nature of activities and to obtain information in the network without disrupting the operation
  - Active attack: disrupt the operation of the network
    - Internal attack: nodes belong to the same network
    - External attack: nodes outside the network

Issues in Ad hoc Wireless Networks Security

- Major Security Threats
  - Denial of service: either consume the network BW or overloading the system
  - Resource consumption
    - Energy depletion: deplete the battery power of critical nodes by directing unnecessary traffic through nodes
    - Buffer overflow: filling unwanted data, routing table attack (filling nonexistent destinations)
  - Host impersonation: A compromised node can act as another node and respond control packets to create wrong route entries and terminate the traffic
  - Information disclosure: a compromised node can act as an informer
  - Interference: jam wireless communication by creating a wide-spectrum noise

Issues in Ad hoc Wireless Networks Addressing and Service Discovery

- Essential because of absence of a centralized coordinator
  - An address that is globally unique is required for a node to participate communication
    - Auto-configuration of address is required to allocate nonduplicate address to the nodes
    - In networks frequent partitioning and merging of network components require duplicate address detection mechanisms
  - Nodes in the network should be able to locate services that other nodes provide
- Energy Management
  - Transmission power management: The radio frequency (RF) hardware design should ensure minimum power consumption.
  - Battery energy management is aimed at extending the battery life.
  - Processor power management: The CPU can be put into different power saving modes.

Issues in Ad hoc Wireless Networks Energy Management

- Energy Management
  - Transmission power management: The radio frequency (RF) hardware design should ensure minimum power consumption.
  - Battery energy management is aimed at extending the battery life.
  - Processor power management: The CPU can be put into different power saving modes.
  - Devices power management: Intelligent device management can reduce power consumption of a mobile node
    - can be done by OS by selectively powering down interface devices that are not used or by putting devices into different powersaving modes

Issues in Ad hoc Wireless Networks Scalability

- Scalability is expected in ad hoc wireless networks
- The latency of path-finding involved with an on-demand routing protocol in a large ad hoc wireless network may be unacceptably high
- A hierarchical topology-based system and addressing may be more suitable for large ad hoc wireless networks

Issues in Ad hoc Wireless Networks Deployment Considerations

- The deployment of a commercial ad hoc wireless network has the following benefits
  - Low cost of deployment
  - Incremental deployment
  - Short deployment time
  - Re-configurability
- Scenario of deployment
    - Military deployment
      - Data-centric (e.g. WSN)
      - User-centric (soldiers or vehicles carrying with wireless communication devices)
    - Emergency operations deployment
    - Commercial wide-area deployment
    - Home network deployment

Issues in Ad hoc Wireless Networks Deployment Considerations

- Required longevity of network: regenerative power source can be deployed when the connectivity is required for a longer duration of time
- Area of coverage
- Service availability: redundant nodes can be deployed to avoid nodes failure
- Operational integration with other infrastructure can be considered for improve the performance or gathering additional information, or for providing better QoS
- Choice of protocols at different layers of the protocol stack should be taken into consideration

Ad Hoc Wireless in Internet

- Similar to wireless internet, the ad hoc wireless internet extends the service of the Internet to the end user over an ad hoc wireless network
- Gateways
  - Gateway nodes are the entry points to the wired Internet and generally owned and operated by a service provider.
  - Perform the following tasks: keeping track of the end users, band-width fairness, address, and location discovery
- Address mobility: such as Mobile IP
- Routing: major problem in ad hoc wireless Internet – specific protocols are needed

Ad Hoc Wireless in Internet

- Transport layer protocol
  - Split approaches that use traditional wired TCP for the wired part and a specialized transport layer protocol for the ad hoc wireless network part.
- Load balancing
  - Load balancing techniques are essential to distribute the load so as to avoid the situation where the gateway nodes become bottleneck nodes.
- Pricing/billing
  - It is important to introduce pricing/billing strategies for the ad hoc wireless Internet.
- Provisioning of security
  - It is essential to include security mechanisms in the ad hoc wireless Internet.
- QoS support
  - Voice over IP (VoIP) and multimedia applications require the QoS support.

Issues of Ad hoc Wireless Internet

- Service, address, and location discovery
  - **Service discovery** refers to the activity of discovering or identifying the party which provides a particular service or resource.
  - **Address discovery** refers to the services such as address resolution protocol (ARP) or domain name service (DNS).
  - **Location discovery** refers to different activities such as detecting the location of a particular mobile node.

Summary of Challenges in Ad hoc Mobile Networks

- Changing the network topology over time
- Potentially frequent network partitions
- Every node can be mobile
- Limited power capacity
- Limited wireless bandwidth
- Presence of varying channel quality

Summary of Challenges in Ad hoc Mobile Networks

- No centralized entity – distributed
- How to support routing?
- How to support channel access?
- How to deal with mobility?
- How to conserve power?
- How to use bandwidth efficiently?

Summary of Challenges in Ad hoc Mobile Networks

Routing

- Routers are now moving
- Link changes are happening quite often
  - Packet losses due to transmission errors
- Event updates are sent often – a lot of control traffic
- Routing table may not be able to, converge
- Routing loop may exist
- Current wired routing uses shortest path metric
  - May not work for ad hoc networks

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