Introduction to Ad hoc Networks

CS-647: Advanced Topics in Wireless Networks

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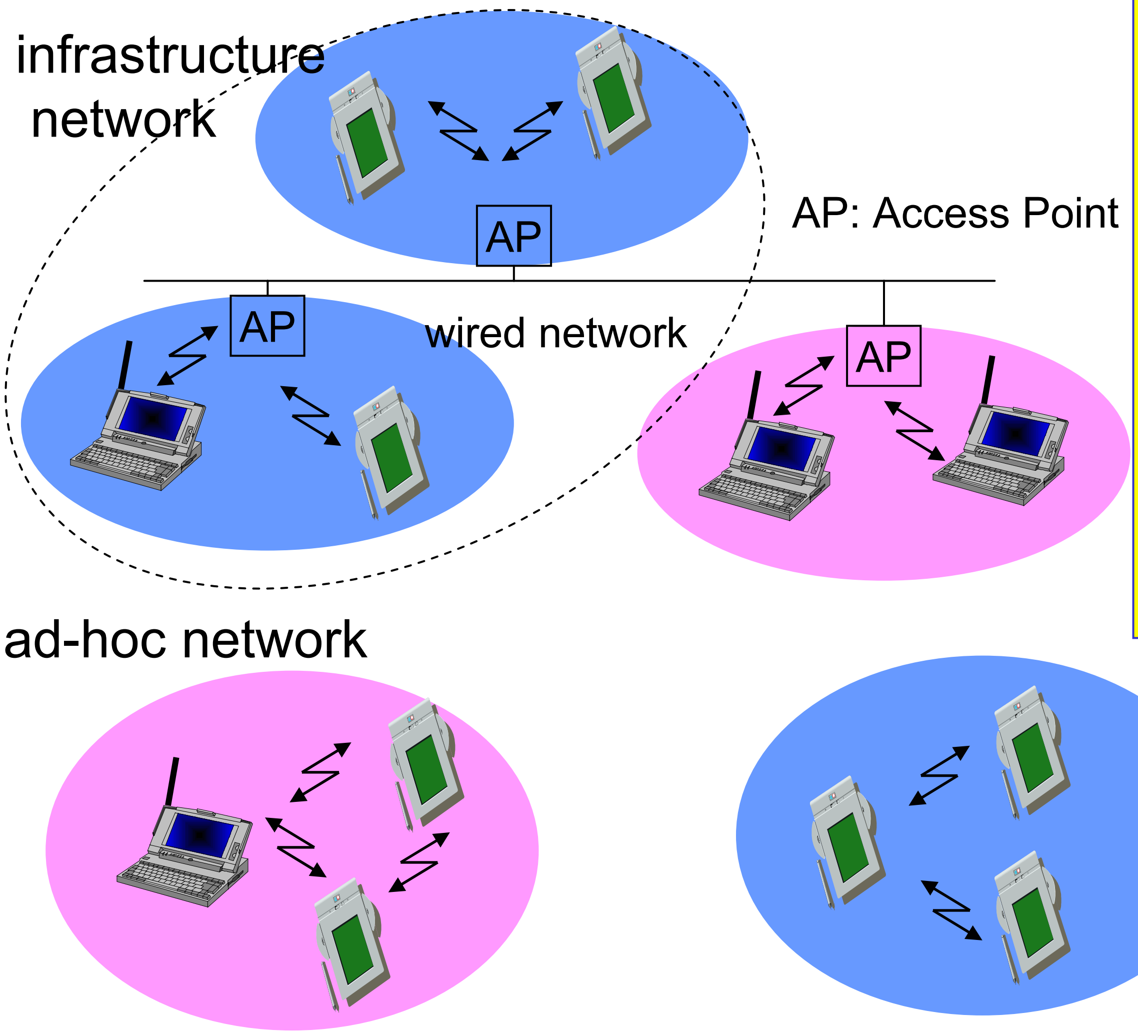
Outline

- What is an ad hoc network?
- Challenges facing ad hoc networks
- History of Ad hoc Networks
- General Concepts
- Introduction to IEEE 802.11
- Physical Layers of 802.11

Reading

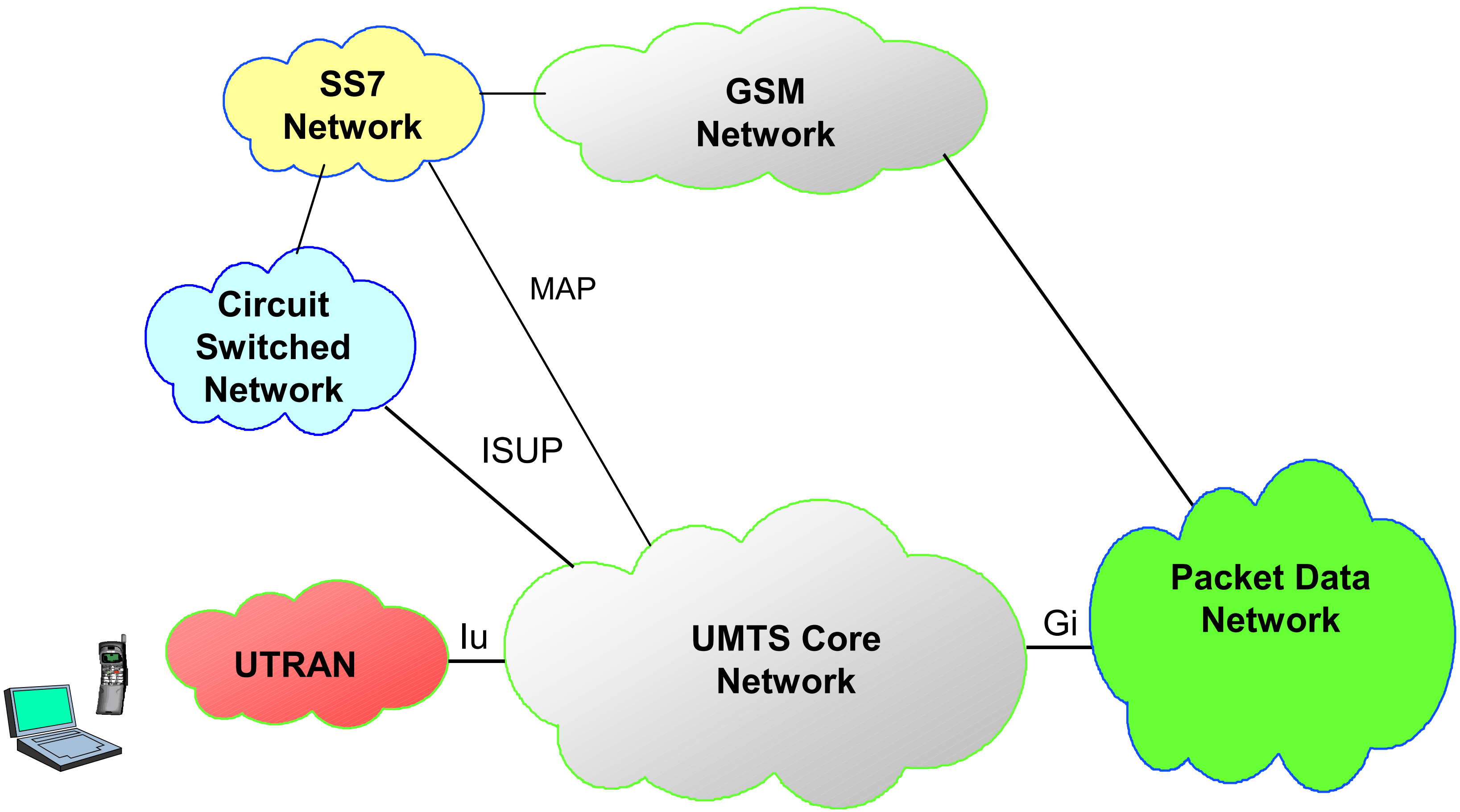
- C. K. Toh, Chapter 3, "Ad Hoc Wireless Networks", Prentice Hall, 2002
- D. P. Agrawal and Qing-An Zeng, Chapter 13, "Wireless & Mobile Systems", Thompson/Brooks Cole, 2003
- Refer one of the suggested textbooks

Types of Wireless Networks: infrastructure vs. ad-hoc networks



- **Infrastructure Networks**
  - Fixed, wired backbone
  - Mobile communicates directly with access points
  - Suitable for locations where access points can be placed
  - Cellular networks

Cellular Networks - UMTS (3G)

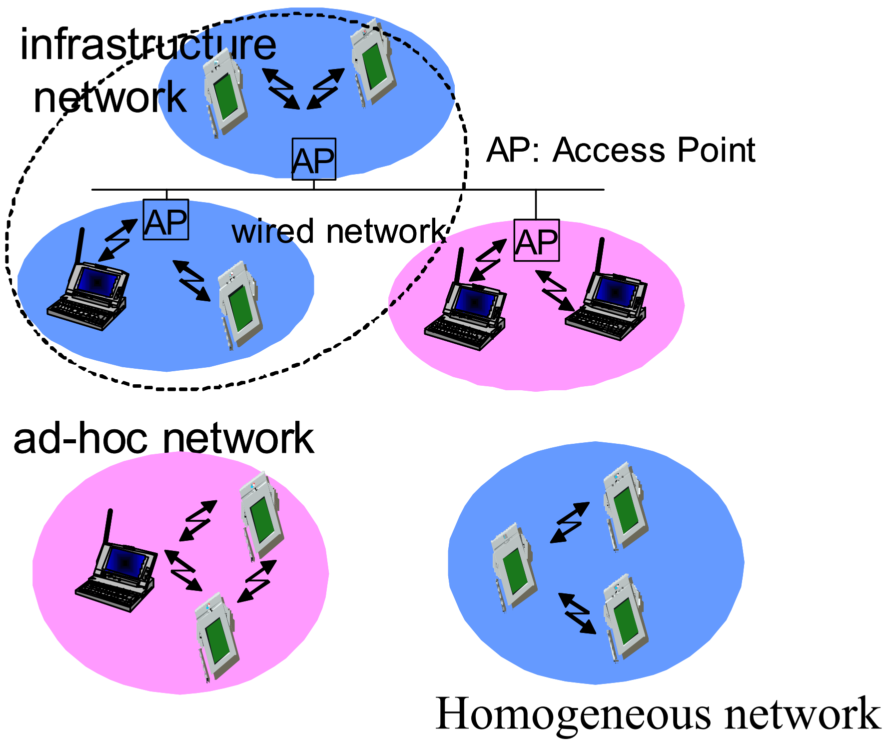


Why Ad Hoc Networks ?

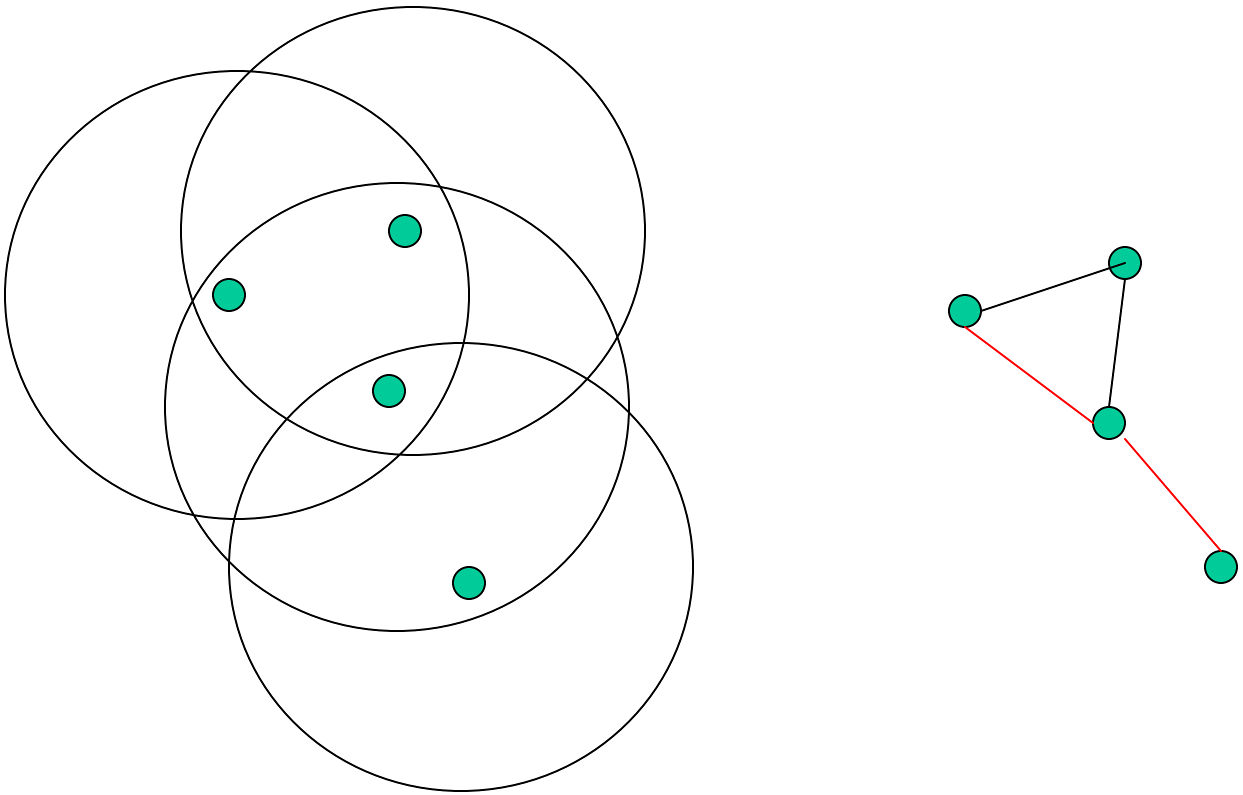
- Ease of deployment
- Speed of deployment
- Decreased dependence on infrastructure

What is an Ad hoc Network?

- 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
- Two topologies:
  - Heterogeneous (left)
    - Differences in capabilities
  - Homogeneous or fully symmetric (Right)
    - all nodes have identical capabilities and responsibilities

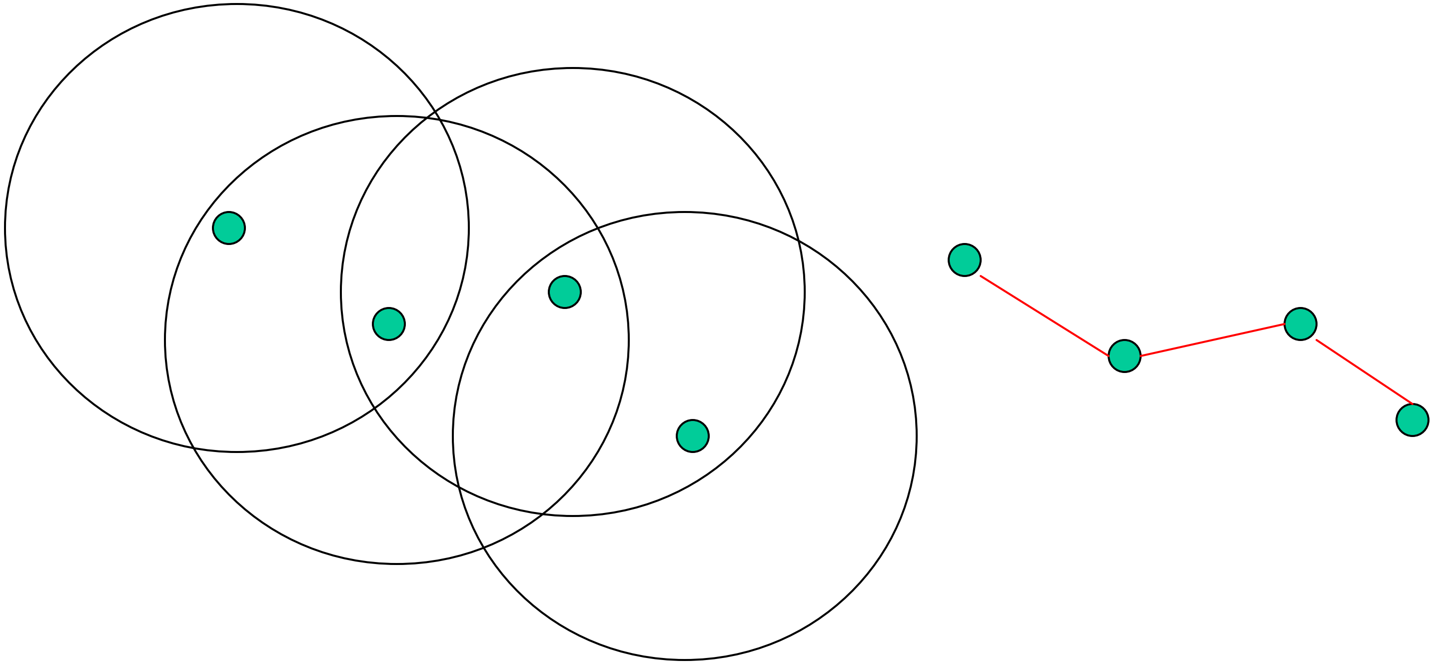


Mobile Ad Hoc Networks?



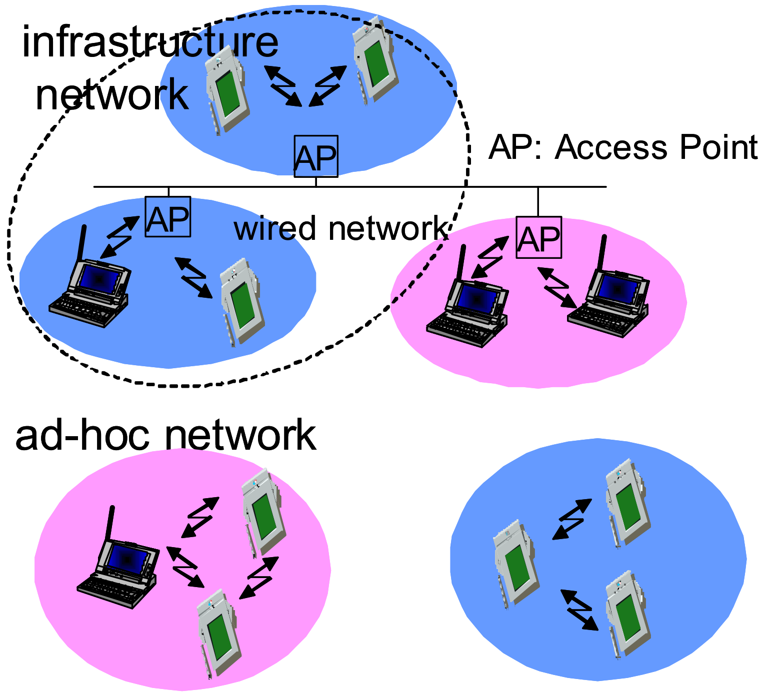
Mobile Ad Hoc Networks?

- Mobility causes route changes

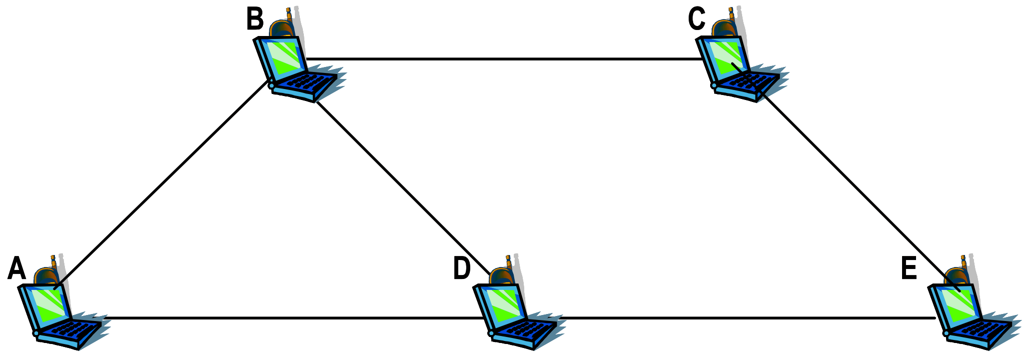


What is an Ad hoc Network?

- 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



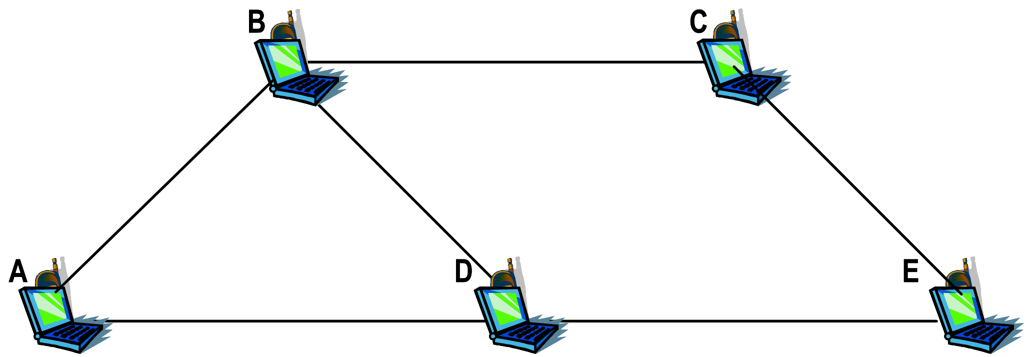
Ad Hoc Networks – Operating Principle



Example of an Ad Hoc Network

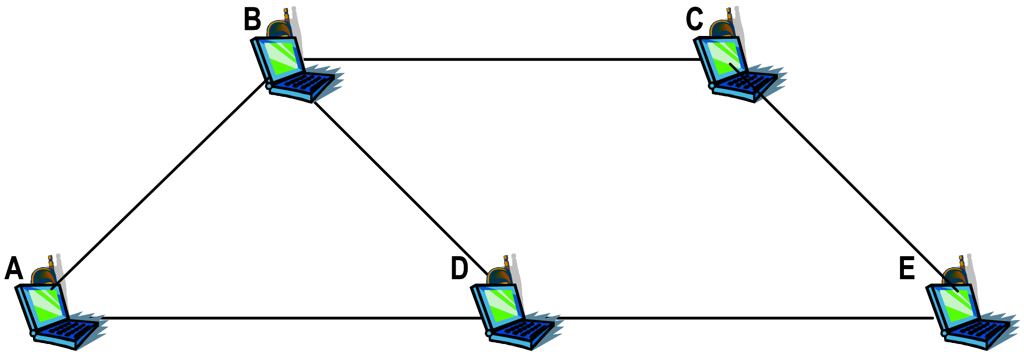
- Fig. depicts a peer-to-peer multihop ad hoc network
- Mobile node A communicates directly with B (single hop) when a channel is available
- If Channel is not available, then multi-hop communication is necessary e.g. A->D->B
- For multi-hop communication to work, the intermediate nodes should route 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



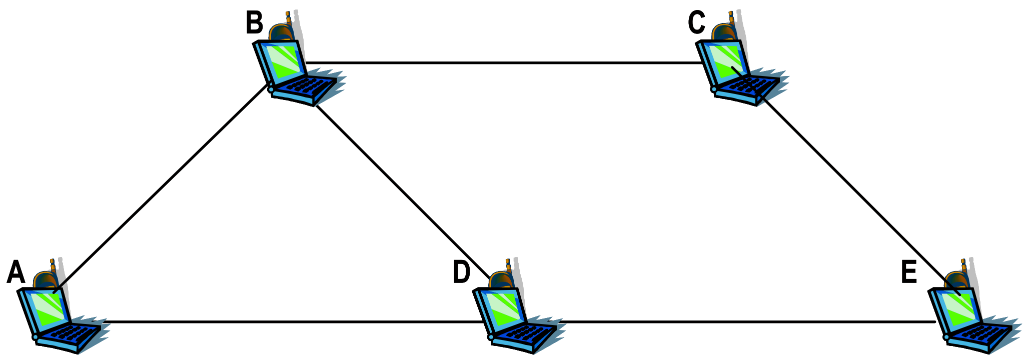
1. Ad hoc network begins with at least two nodes broadcasting their presence (beaconing) with their respective address information
2. They may also include their location info if GPS equipped
3. Beaconing messages are control messages. If node A is able to establish a direct communication with node B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

Bringing up an Ad hoc Network



4. 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



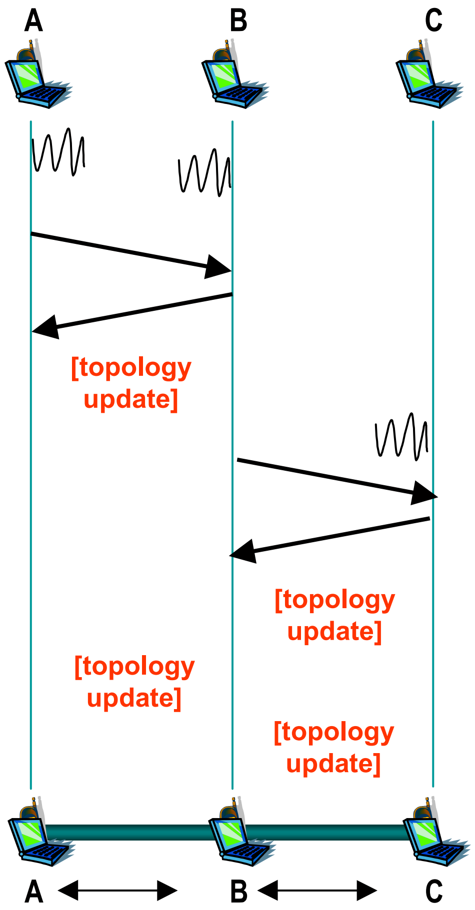
5. The distinct topology updates consisting of both address and the route updates are made in three nodes immediately.

5. In first scenario, all routes are direct i.e. A->B, B->C, and A->C (Lets assume bi-directional links)

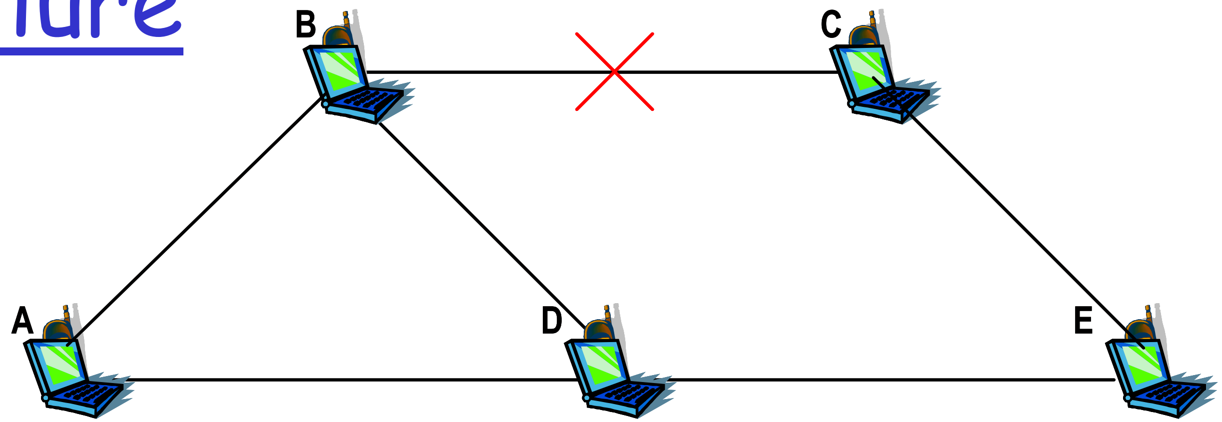
Bringing up an Ad hoc Network

- In the second scenario, the routes are updated

1. First between B & C,
2. then between B & A,
3. Then between B & C again confirming that A and C both can reach each other via B



Topology Update Due to a Link Failure



- 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

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- Challenges facing ad hoc networks
- History of Ad hoc Networks
- General Concepts
- Introduction to IEEE 802.11
- Physical Layers of 802.11

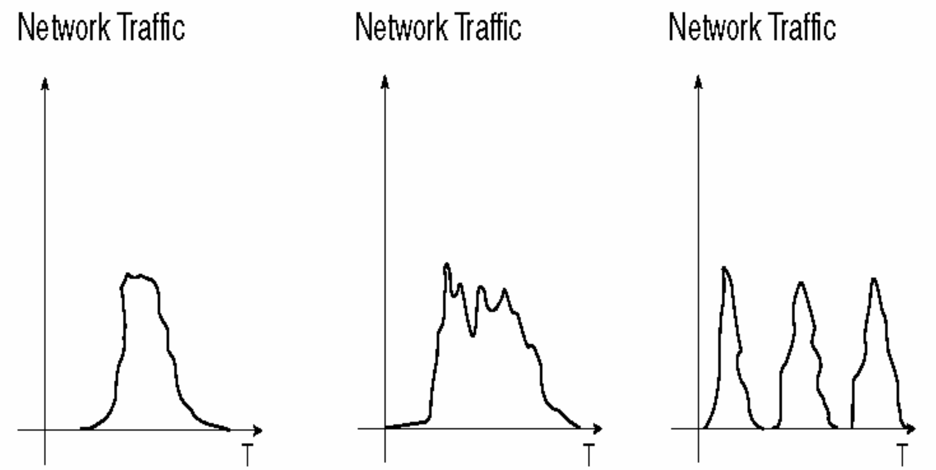
Traffic Characteristics

- Traffic characteristics may differ in different ad hoc networks
  - bit rate
  - timeliness constraints
  - reliability requirements
  - unicast / multicast / geocast
  - host-based addressing / content-based addressing / capability-based addressing

- May co-exist (and co-operate) with an infrastructure-based network

Traffic Profiles

- Three distinct types of traffic patterns observed in ad hoc networks
- Peer-to-peer between two entities (Fig. a) – Bursty
- Two or more devices in a group communication while moving as a group (correlated traffic) -> remote to remote communication
- Hybrid non-coherent communication among nodes -> uncorrelated traffic



Peer-to-peer communications; MHs communicating in paris.

Remote-to-remote communications; MHs migrating and communicating in groups.

Hybrid communications; MHs migrating without co-relation.

Challenges in Ad hoc Mobile Networks (1)

- Host is no longer an end system - can also be an acting intermediate system
- 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

Challenges in Ad hoc Mobile Networks (2)

- 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?

Problems Facing Routing in Ad hoc Networks

- 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

Problems facing channel access in Ad hoc Networks

- Distributed channel access, i.e. no fixed base station concept
- Very hard to avoid packet collisions
- Very hard to support QoS
- Early work on packet radio is based on CSMA

Problems of Mobility in Ad hoc

- Mobility affects signal transmission -> Affects communication
- Mobility affects channel access
- Mobility affects routing
  - Mobility-induced route changes
  - Mobility-induced packet losses
- Mobility affects multicasting
- Mobility affects applications

Mobility in Ad hoc Networks

- Mobility patterns may be different
  - people sitting at an airport lounge
  - New York taxi cabs
  - kids playing
  - military movements
  - personal area network

- Mobility characteristics
  - speed
  - predictability
    - direction of movement
    - pattern of movement
  - uniformity (or lack thereof) of mobility characteristics among different nodes

Problems of Power in Ad hoc

- Ad hoc devices come in many different forms
- Most of them battery powered
- Battery technology is not progressing as fast as memory or CPU technologies
- Wireless transmission, reception, retransmission, beaconing, consume power!
- Quest for power-efficient protocols
- Quest for better power management techniques

Research on Mobile Ad Hoc Networks

- Variations in capabilities & responsibilities
- Variations in traffic characteristics, mobility models, etc.
- Performance criteria (e.g., optimize throughput, reduce energy consumption)
- Increased research funding -> Significant research activity

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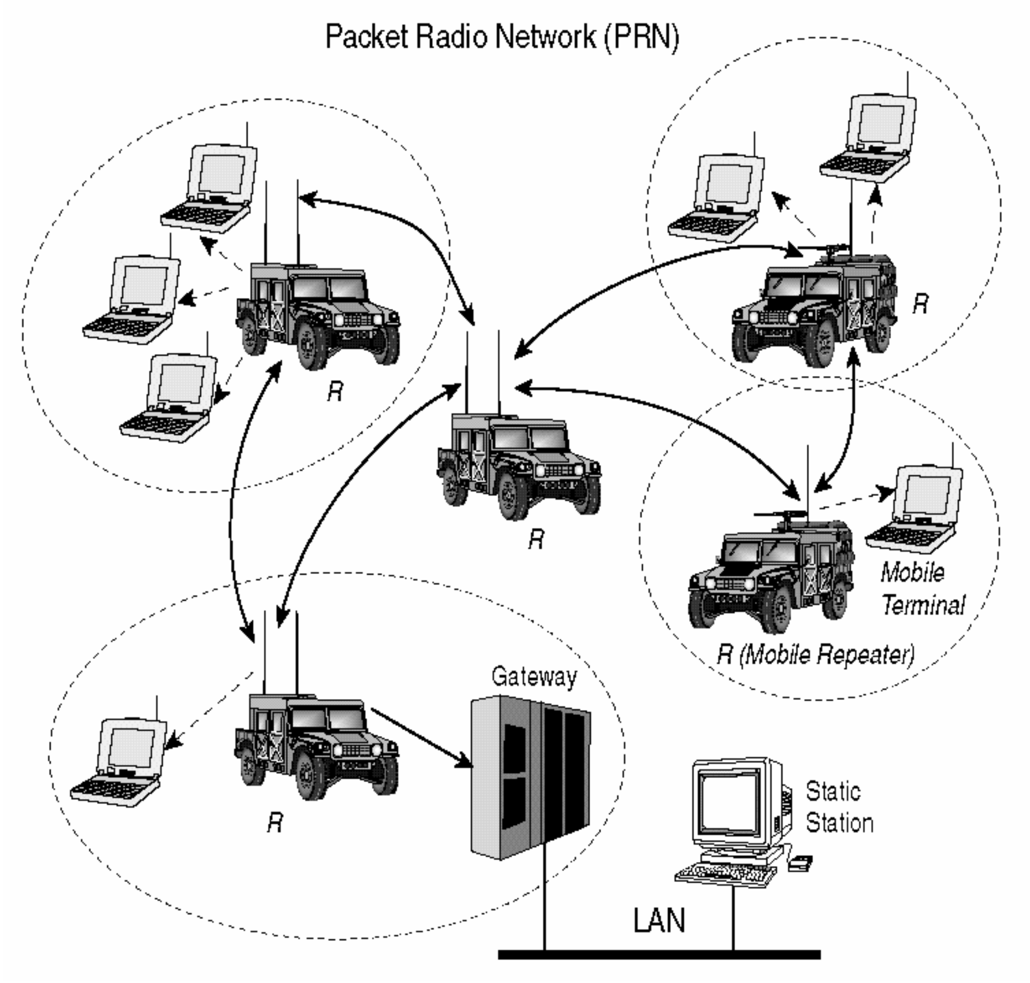
Packet Radio - First Ad hoc Network

- Packet switching was demonstrated by the ARPANet in the 1960
  - Key Advantage - Dynamic sharing of bandwidth among multiple users
- DARPA initiated a packet radio network (PRNet) research in 1972 recognizing packet switching
- PRNet was to provide an efficient means of sharing broadcast radio channel among many radios

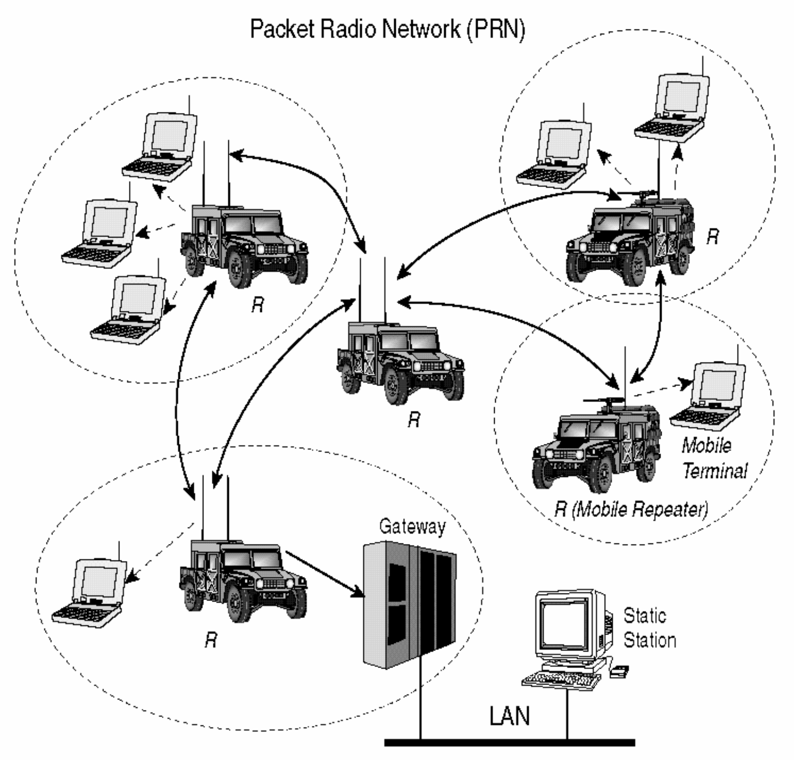
Architecture of PRNETs



The network architecture of PRNETs, which comprises mobile devices/terminals, packet radios, and repeaters. The static station is optional.

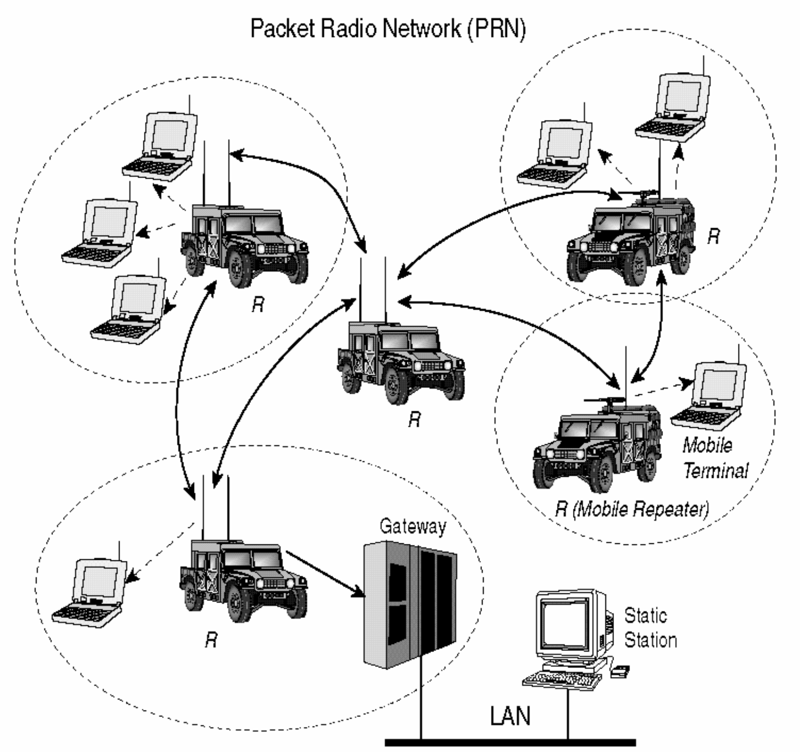
Early Packet Radio Networks - Characteristics

- Presence of mobile repeaters
- Mobile terminals
- Static station for routing
- Technology ahead of time
- Not entirely infrastructureless



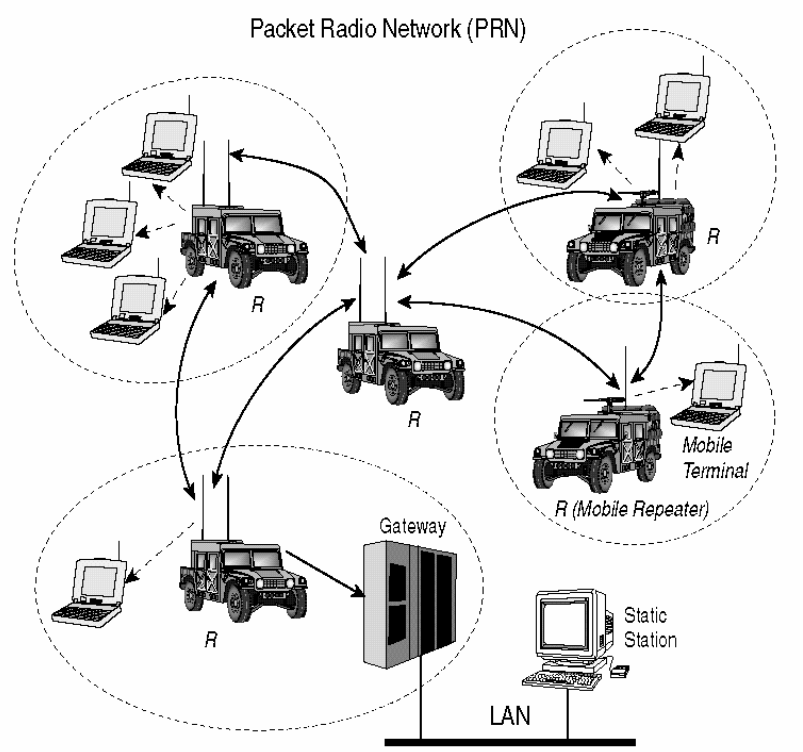
PRNet

- Mobile repeater relays packet from one repeater to other until the packet makes it to destination
- Bellman Ford (Distance-Vector) type of routing algorithm running in a static station
- Static station has complete topology
- Routing table broadcasted to each terminal
- Shortest delay path for every destination in the network available to every terminal

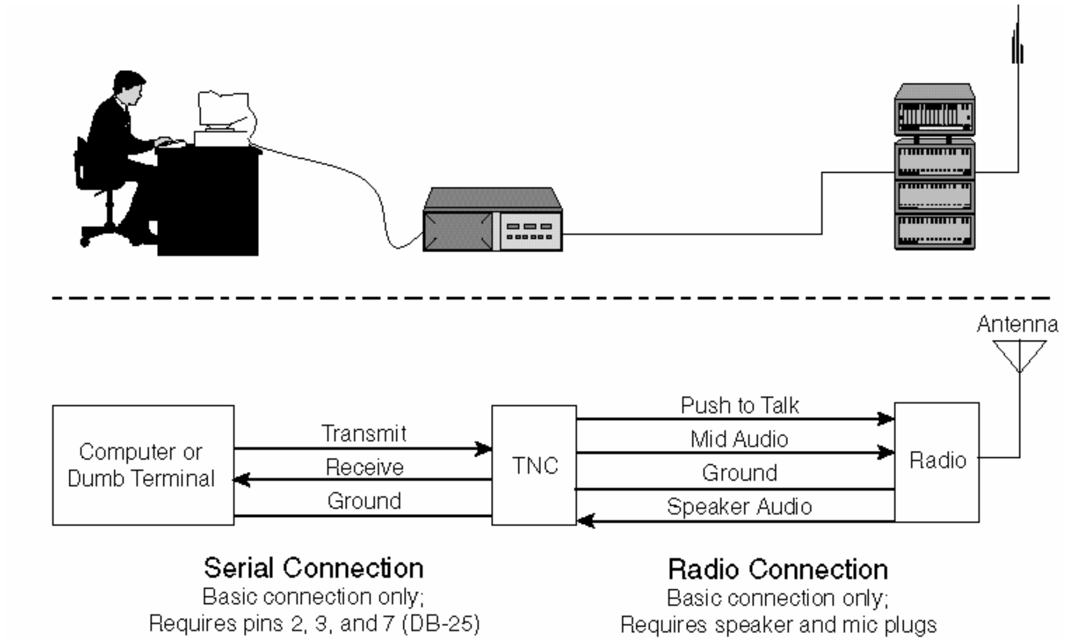


PRNet

- Periodic update for route changes
- ACK based flow control and recovery from errors
- CSMA based MAC
- Low mobility
- Low throughput (2 kbps per subscriber)



The interface of a data terminal to a packet radio



- The user computer interfaced to radio via terminal network controller (TNC)
- LSI based therefore bulky architecture
- TNC and Radio constitute packet radio that handles layer 1 to layer 3 functionalities
- Now a laptop integrates packet radio within itself due to VLSI

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General Concepts (1) - Duplexing Choices

- The duplexing mechanism refers to how the data transmission and the reception channels are multiplexed:
  - Can be multiplexed in different time slots
  - Can be multiplexed in different frequency bands
- Time Division Duplex (TDD) refers to multiplexing of transmission and reception in different time periods in the same frequency band
- Frequency Division Duplex (FDD) refers to using different frequency bands for uplink and downlink transmissions
- FDD - Its possible to send and receive data simultaneously
- TDD - Its not possible to send and receive data simultaneously

General Concepts (3) - Network Architecture

- Distributed Wireless Networks
  - Ad hoc networks fall in this category
  - Wireless nodes communicating with each other without any fixed infrastructure
  - Terminals have an RF or infrared interface
  - All data transmission and reception in the same frequency band (there is no special node to do the frequency translation)
  - All ad hoc networks operate in TDD mode
  - No centralized control for managing the network e.g. node failures etc.

General Concepts (4) - Network Architecture

- Centralized Wireless Networks
  - Cellular networks fall in this category
  - Also called last-hop networks
  - Wireless nodes communicating with each other using fixed infrastructure (Base Station)
  - Base station acts as an interface to the wire-line networks
  - Downlink transmission is broadcast – all nodes in the BS coverage can hear the transmission

General Concepts (5) - Network Architecture

- Centralized Wireless Networks
  - Uplink transmission is shared among nodes so its multiple access
  - Can operate in both the TDD or FDD mode
  - Centralized control for managing the network
  - BS provides flexibility in MAC design (admission control, scheduling, QoS provisioning etc.)

General Concepts (6) - Slotted Systems

- A wireless channel is said to be slotted if transmission attempts can take place at discrete instants in time
- A slot is the basic time unit – large enough to carry the smallest packet with overhead (header + guard band)
- A slotted system requires network wide synchronization – Base station facilitates it by acting as a time reference
- Synchronization is difficult in Ad hoc Networks

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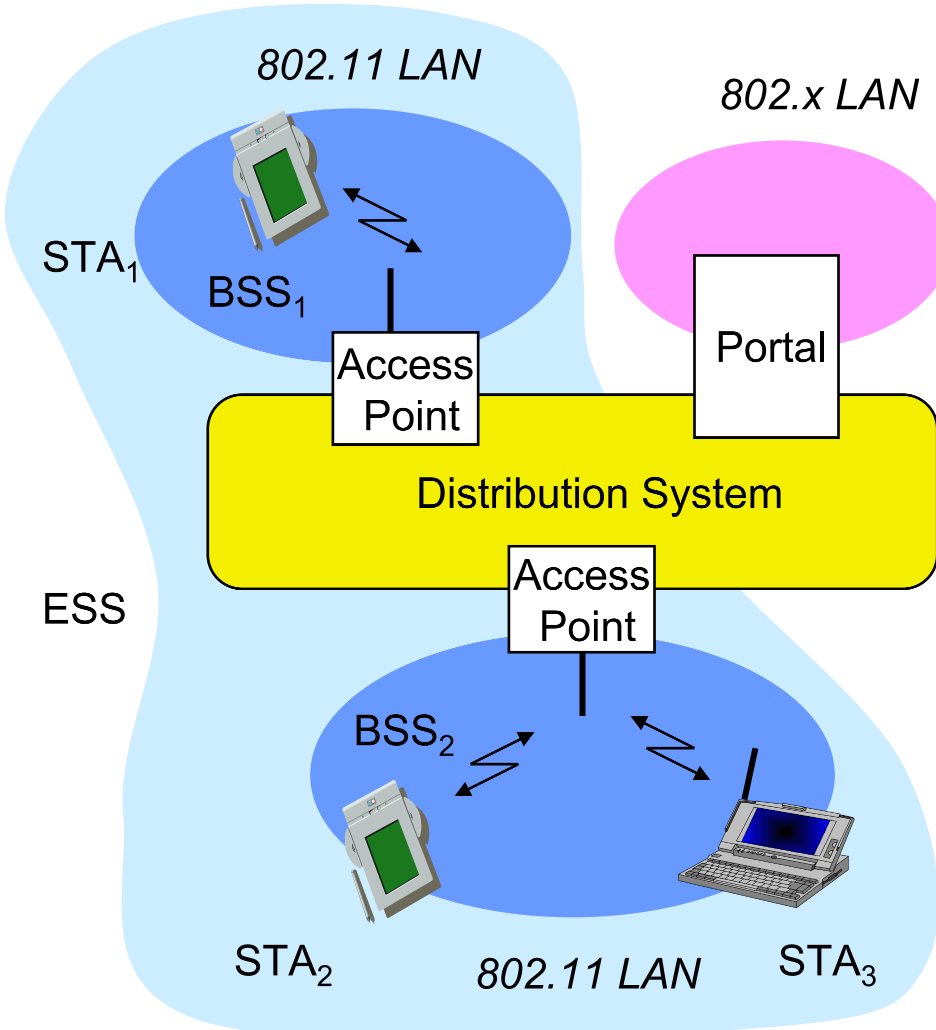
IEEE 802.11 - Introduction

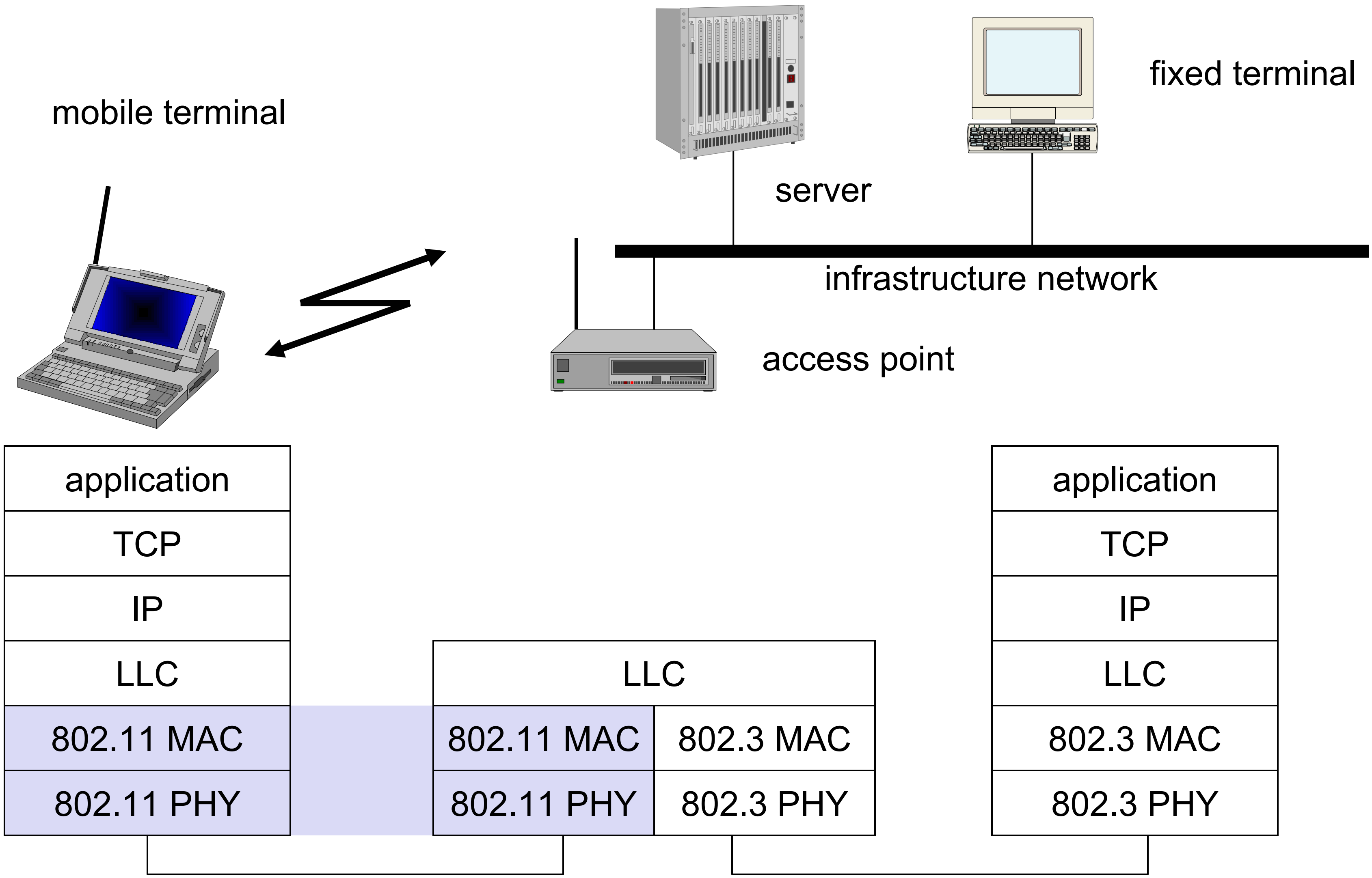
- Well known and adopted standard for wireless LANs
- Operates in the unlicensed 2.4 GHZ ISM (Industrial & Scientific & Medical) Band
- 802.11 MAC works with different physical layers (infra red as well as spread spectrum)
- Compatible with other 802.x standards, e.g. 802.3 (Ethernet), 802.5 (Token ring)
- Data rates 1 Mbps (mandatory), 2 Mbps (optional)
- Supports real time as well as non-real time applications
- Has features for power management to save battery

802.11 - Architecture of an infrastructure network



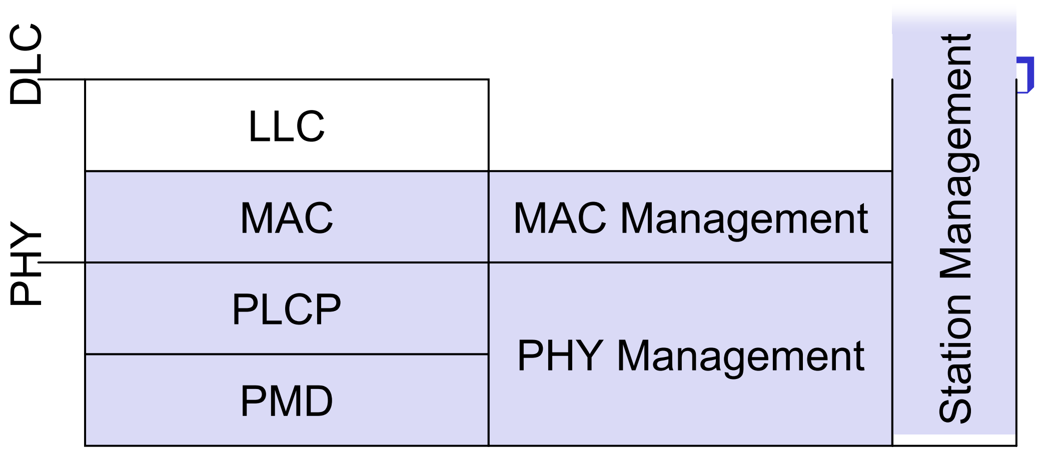
- Station (STA): terminal with access mechanisms to the wireless medium and radio contact to the access point
- Basic Service Set (BSS)
  - group of stations using the same radio frequency
- Access Point
  - station integrated into the wireless LAN and the distribution system
- Portal: bridge to other (wired) networks
- Distribution System
  - interconnection network to form one logical network (EES: Extended Service Set) based on several BSS

IEEE standard 802.11



802.11 - Layers and functions

- MAC
  - access mechanisms, fragmentation, encryption
- MAC Management
  - synchronization, roaming, MIB, power management
- PLCP Physical Layer Convergence Protocol
  - clear channel assessment signal (carrier sense)
- PMD Physical Medium Dependent
  - modulation, coding
- PHY Management
  - channel selection, MIB
- Station Management
  - coordination of all management functions



802.11 Physical Layers

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<tr><td colspan="6">Upper Layers</td></tr>
<tr><td colspan="6">Logical Link Control</td></tr>
<tr><td colspan="6">MAC Sublayer</td></tr>
<tr><td>802.11
Infrared</td><td>802.11
FHSS</td><td>802.11
DSSS</td><td>802.11a
OFDM</td><td>802.11b
HR-DSSS</td><td>802.11g
OFDM</td></tr>
</table>

802.11 Physical Layer

- Physical layer corresponds to OSI stack well
- Five different physical layers are proposed
- Data link layer split in two or more sublayers e.g. MAC and Logical link control sublayers
  - MAC allocates the channel
  - LLC hides differences between different physical layers to network layer

802.11 Physical Layer - History

- In 1997, only three physical layer technologies
  1. Infrared - Uses diffused light (not line of sight). Two speeds: 1 Mbps and 2 Mbps
  2. FHSS (Frequency Hopping Spread Spectrum) – Uses part of 2.4 GHz ISM band. Speed 1 – 2 Mbps
  3. DSSS (Direct Sequence Spread Spectrum) – Uses part of 2.4 GHz ISM band. Speed 1 – 2 Mbps
- In 1999, two new techniques were introduced to support higher data rates
  - OFDM (Orthogonal frequency division multiplexing). Speed 54 Mbps
  - HR – DSSS (High Rate Direct Sequence Spread Spectrum) – 11 Mbps
- In 2001, a second OFDM modulation in a different frequency band from the first one

IEEE 802.11a

- OFDM Based
- Can deliver up to 54 Mbps in the wider 5 GHz ISM band
- 52 Frequency bands (48 for data, 4 for synchronization)
- A form of spread spectrum yet different from CDMA and FHSS
- OFDM is compatible with the HiperLAN/2
- Good spectrum efficiency bits/Hz, and good immunity to multi-path fading

IEEE 802.11b

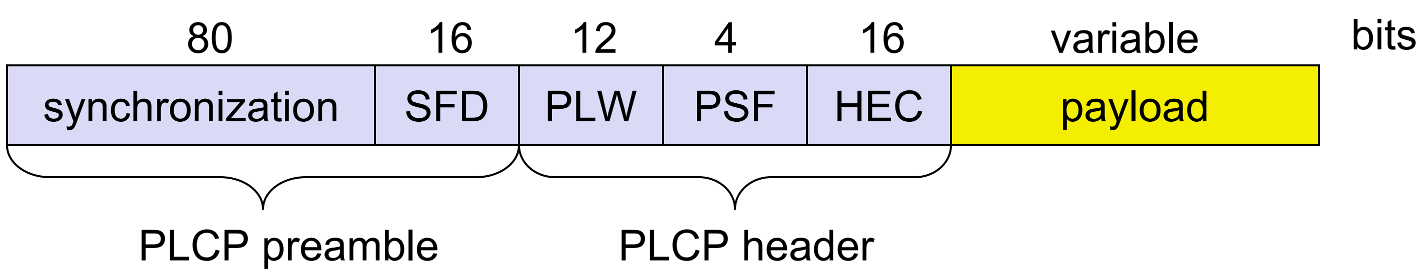
- HR-DSSS Based spread spectrum technique
- Achieves 11 Mbps in the 2.4 GHz band (Data rates are 1, 2, 5.5, 11 Mbps)
- Its not a follow up to 802.11a. It was approved earlier than 802.11a and came to market first
- Its slower than 802.11a but Its range is 7 times greater than 802.11 a

IEEE 802.11g

- Enhanced version of 802.11a
- Approved in Nov. 2001
- OFDM based but operates in 2.4 GHz band
- In theory can operate at 54 Mbps but lot slower in practice
- 802.11a, 802.11b and 802.11g are called high speed LANs (Broadband Wireless LANs)

FHSS PHY Packet Format

- Synchronization
  - synch with 010101... pattern
- SFD (Start Frame Delimiter)
  - 0000110010111101 start pattern
- PLW (PLCP_PDU Length Word)
  - length of payload incl. 32 bit CRC of payload, PLW < 4096
- PSF (PLCP Signaling Field)
  - data of payload (1 or 2 Mbit/s)
- HEC (Header Error Check)
  - CRC with $x^{16}+x^{12}+x^5+1$



DSSS PHY packet format

- Synchronization
  - synch., gain setting, energy detection, frequency offset compensation
- SFD (Start Frame Delimiter)
  - 1111001110100000
- Signal
  - data rate of the payload (0A: 1 Mbit/s DBPSK; 14: 2 Mbit/s DQPSK)
- Service
  - future use, 00: 802.11 compliant
- Length
  - length of the payload
- HEC (Header Error Check)
  - protection of signal, service and length, $x^{16}+x^{12}+x^5+1$