Introduction

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Contents

- History and Background
- Evolution and Future Generation
- Current Wireless Systems

Is there a future for wireless?

Some history

- Ancient Systems: Smoke Signals, Carrier Pigeons, …
- Radio invented in the 1880s by Marconi
- Many sophisticated military radio systems were developed during and after WW2
- Cellular has enjoyed exponential growth since 1988, with almost 1 billion users worldwide today
  - Triggered by the recent wireless revolution
  - Fast growth rate
  - 3G (voice+data) supports many applications
- Many spectacular failures recently
  - 1G Wireless LANs/Iridium/Metricom

Need of Wireless Networks

- Internet and laptop use exploding
- 2G/3G wireless LANs growing rapidly
- Low rate data demand is high
- Military and security needs require wireless
- Emerging interdisciplinary applications

Background

- # wireless (mobile) phone subscribers now exceeds # wired phone subscribers!
- computer nets: laptops, palmtops, PDAs, Internet-enabled phone promise anytime untethered Internet access
- two important (but different) challenges
  - communication over wireless link
  - handling mobile user who changes point of attachment to network

Wireless Link Characteristics

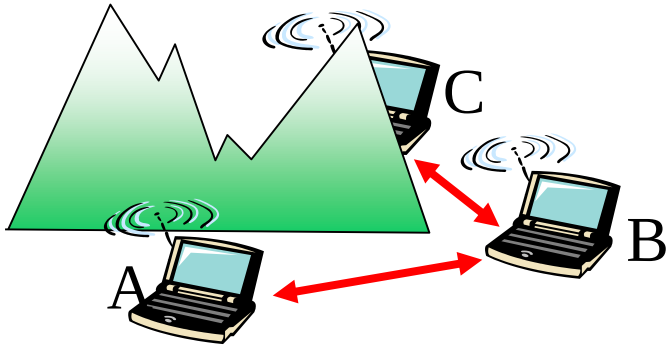
Differences from wired link ….

- decreased signal strength: radio signal attenuates as it propagates through matter (path loss)
- interference from other sources: standardized wireless network frequencies (e.g., 2.4 GHz) shared by other devices (e.g., phone); devices (motors) interfere as well
- multipath propagation: radio signal reflects off objects ground, arriving ad destination at slightly different times

…. make communication across (even a point to point) wireless link much more "difficult"

Wireless network characteristics

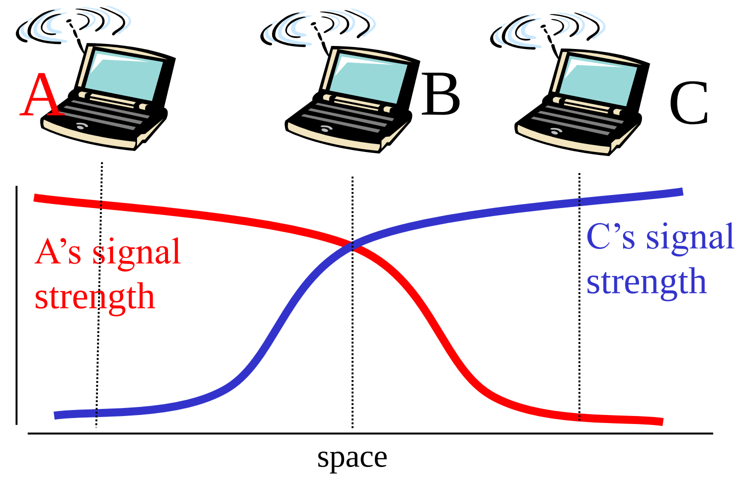
Multiple wireless senders and receivers create additional problems (beyond multiple access):



Hidden terminal problem

- B, A hear each other
- B, C hear each other
- A, C can not hear each other

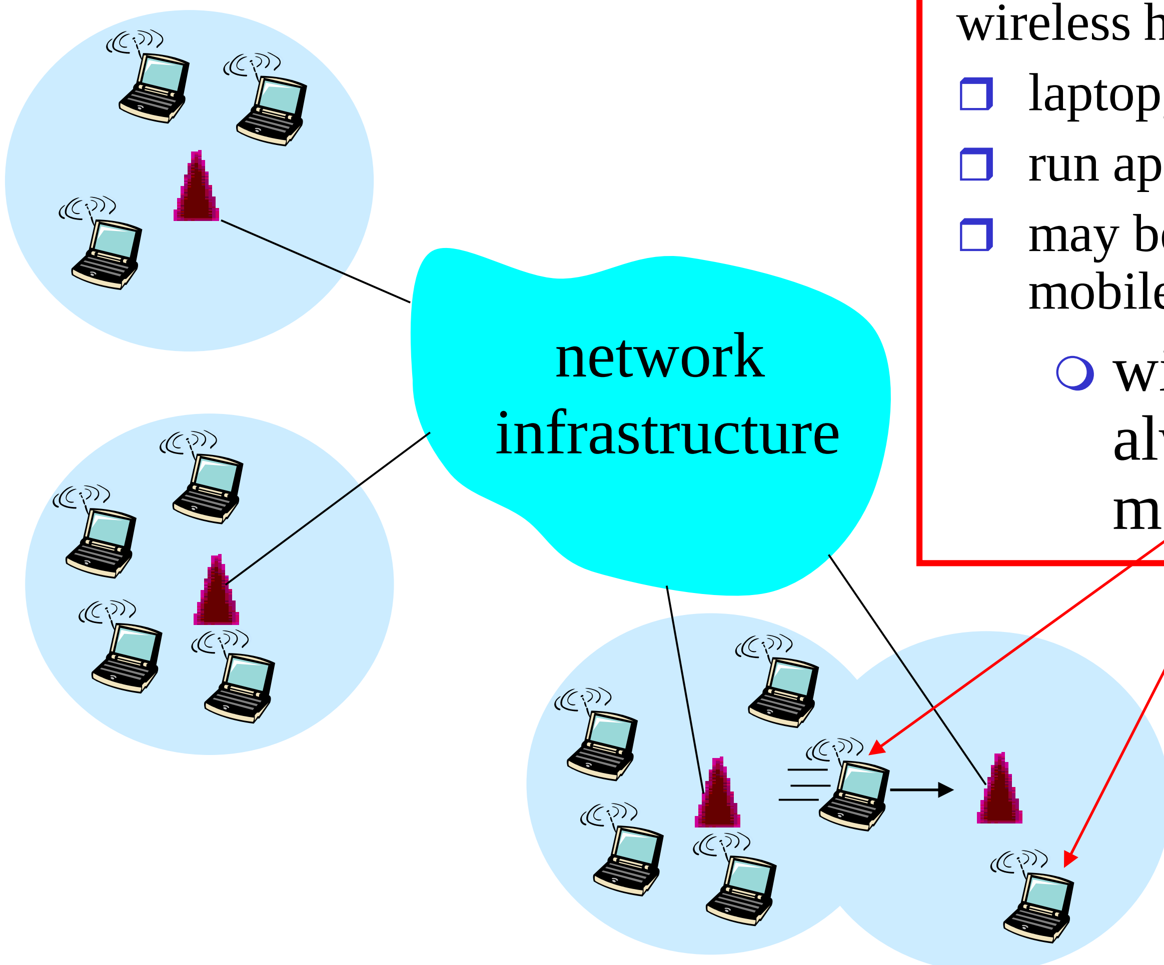
means A, C unaware of their interference at B



Signal fading:

- B, A hear each other
- B, C hear each other
- A, C can not hear each other interferring at B

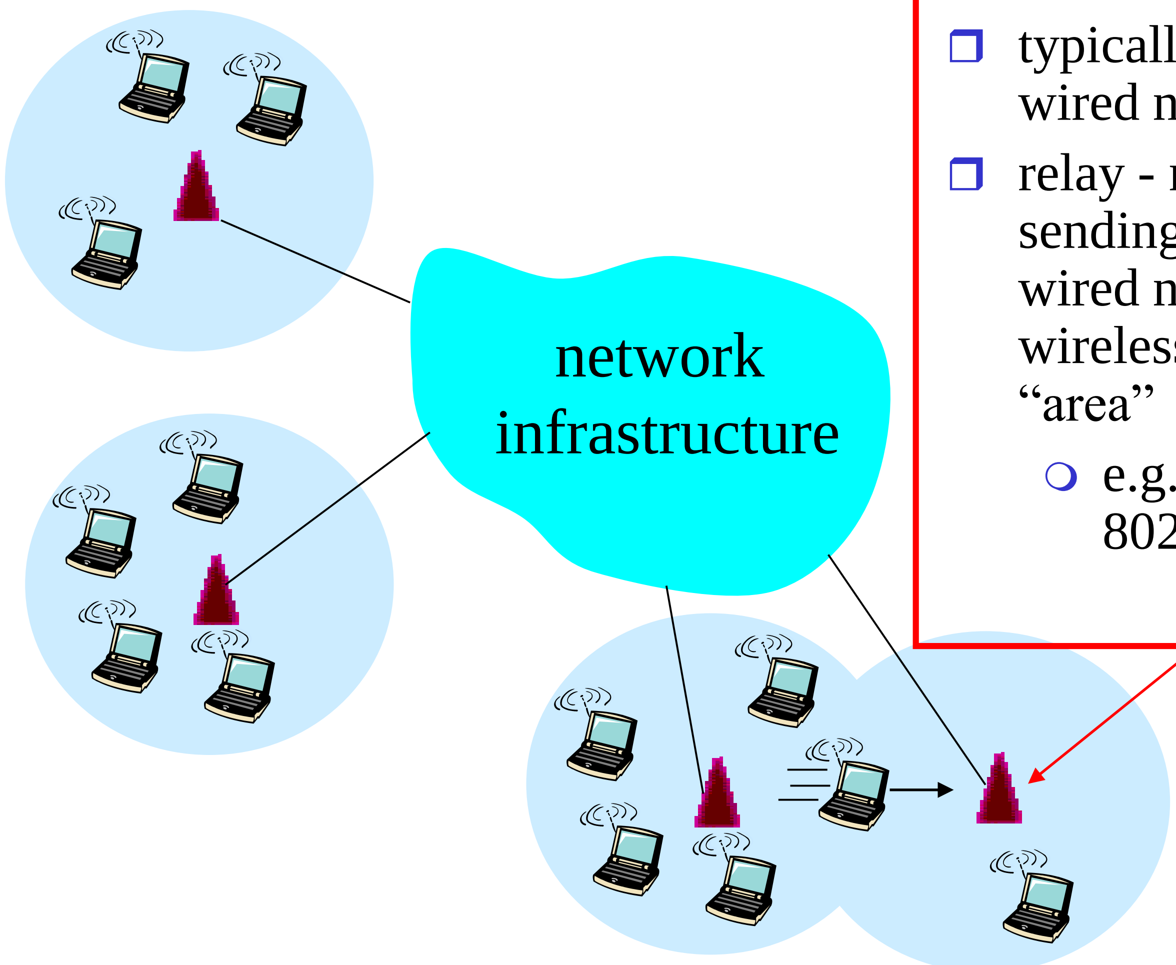
Elements of a wireless network



wireless hosts

- laptop, PDA, IP phone
- run applications
- may be stationary (non-mobile) or mobile
  - wireless does *not* always mean mobility

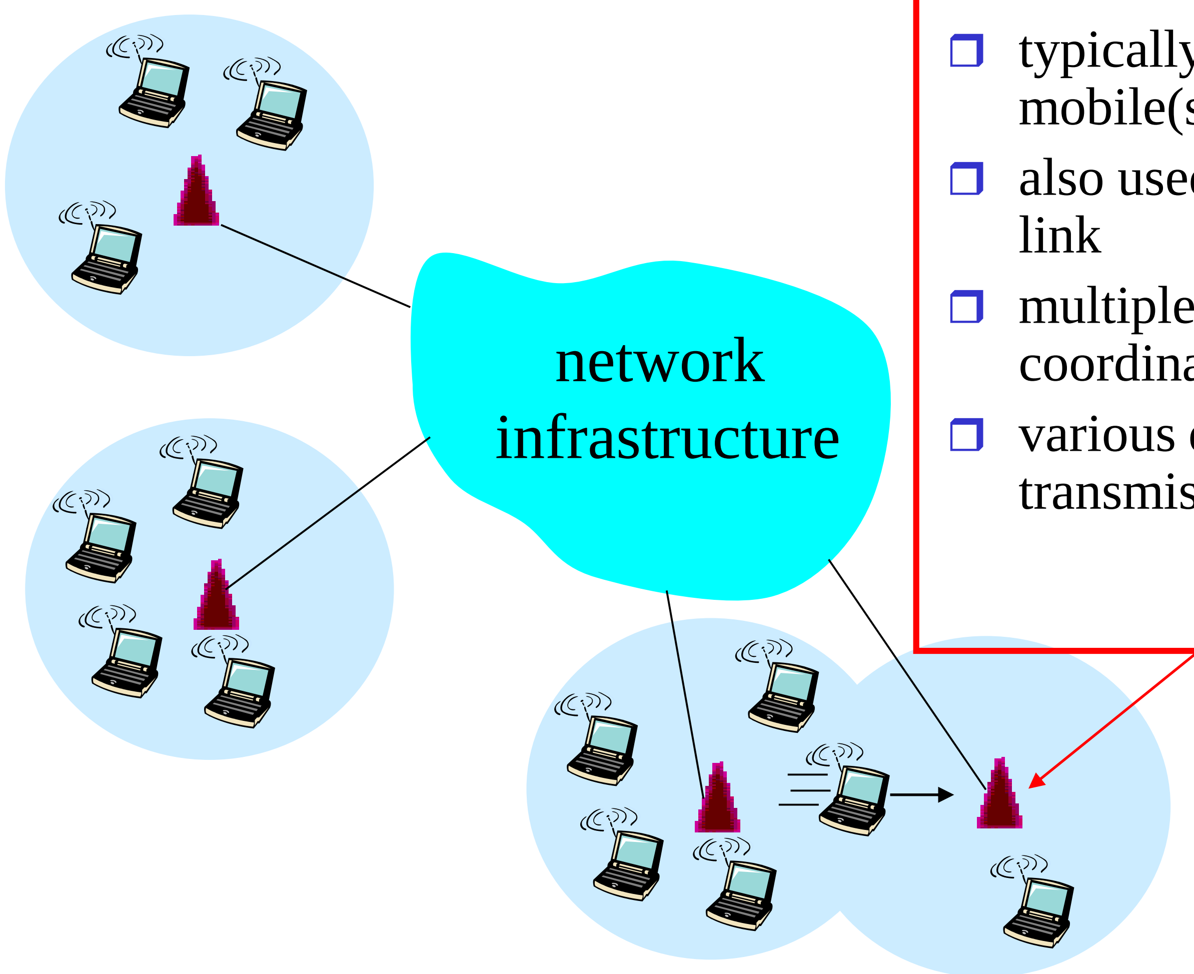
Elements of a wireless network



base station

- typically connected to wired network
- relay - responsible for sending packets between wired network and wireless host(s) in its “area”
    - e.g., cell towers 802.11 access points

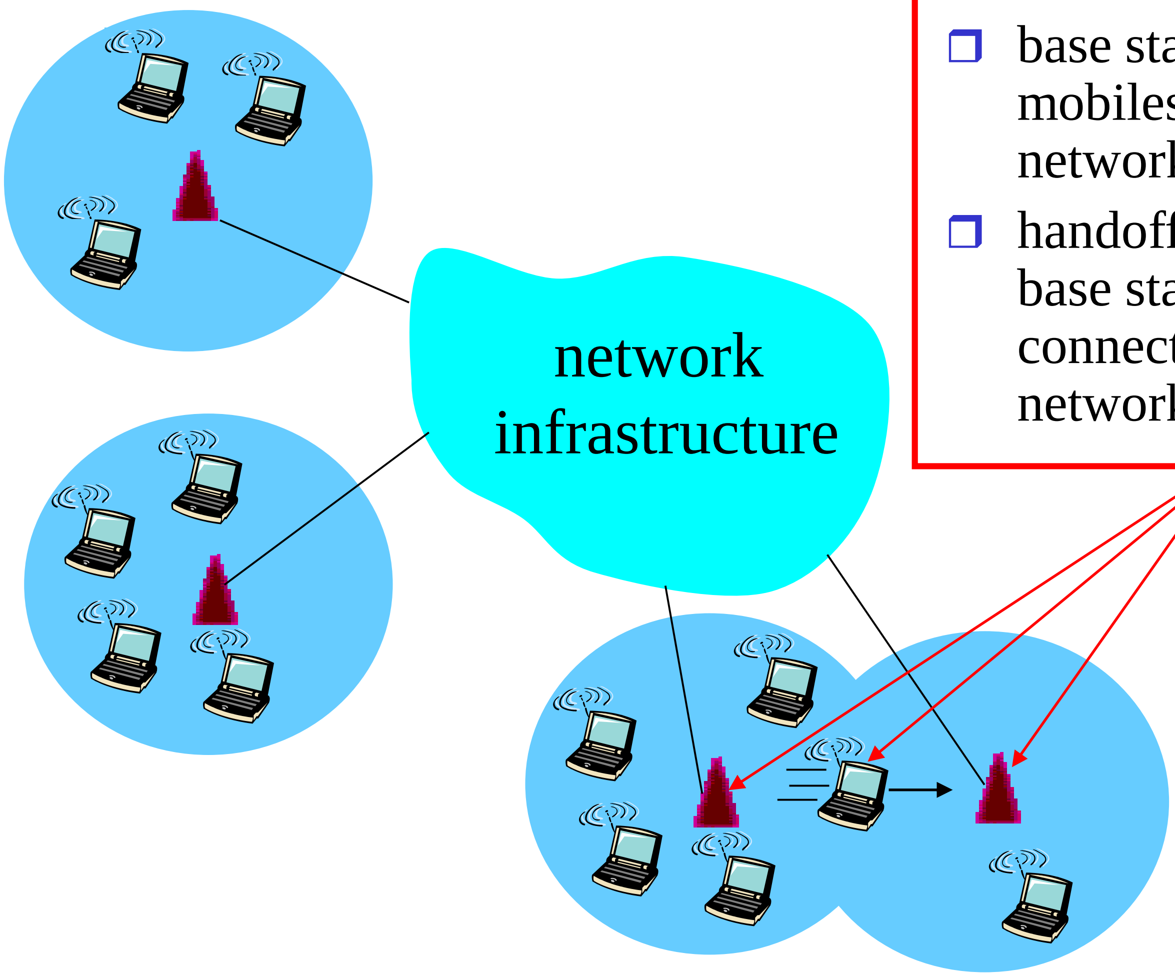
Elements of a wireless network



wireless link

- typically used to connect mobile(s) to base station
- also used as backbone link
- multiple access protocol coordinates link access
- various data rates, transmission distance

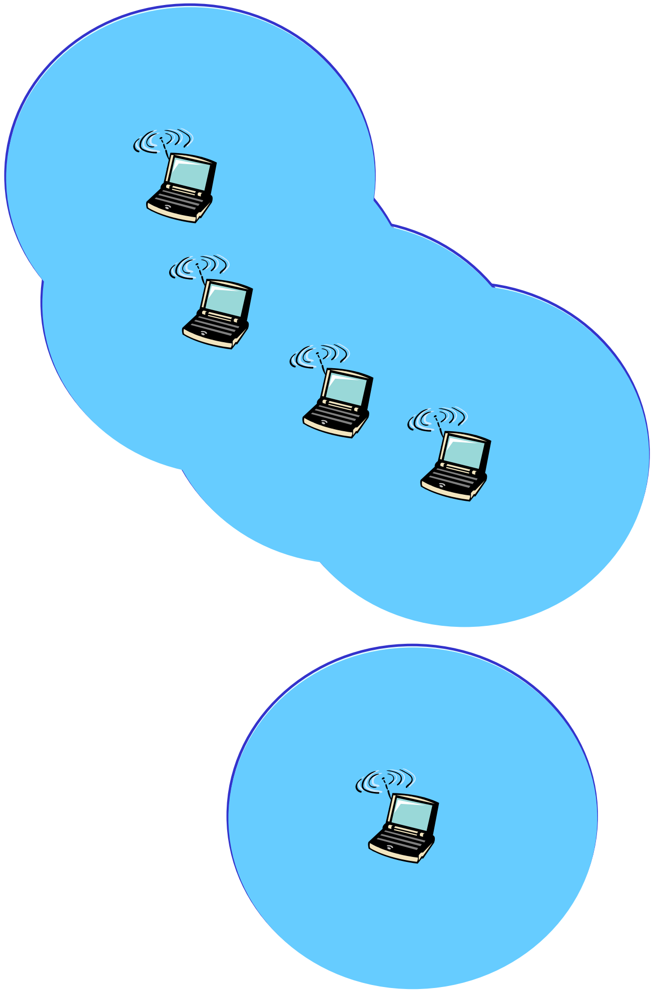
Elements of a wireless network



infrastructure mode

- base station connects mobiles into wired network
- handoff: mobile changes base station providing connection into wired network

Elements of a wireless network

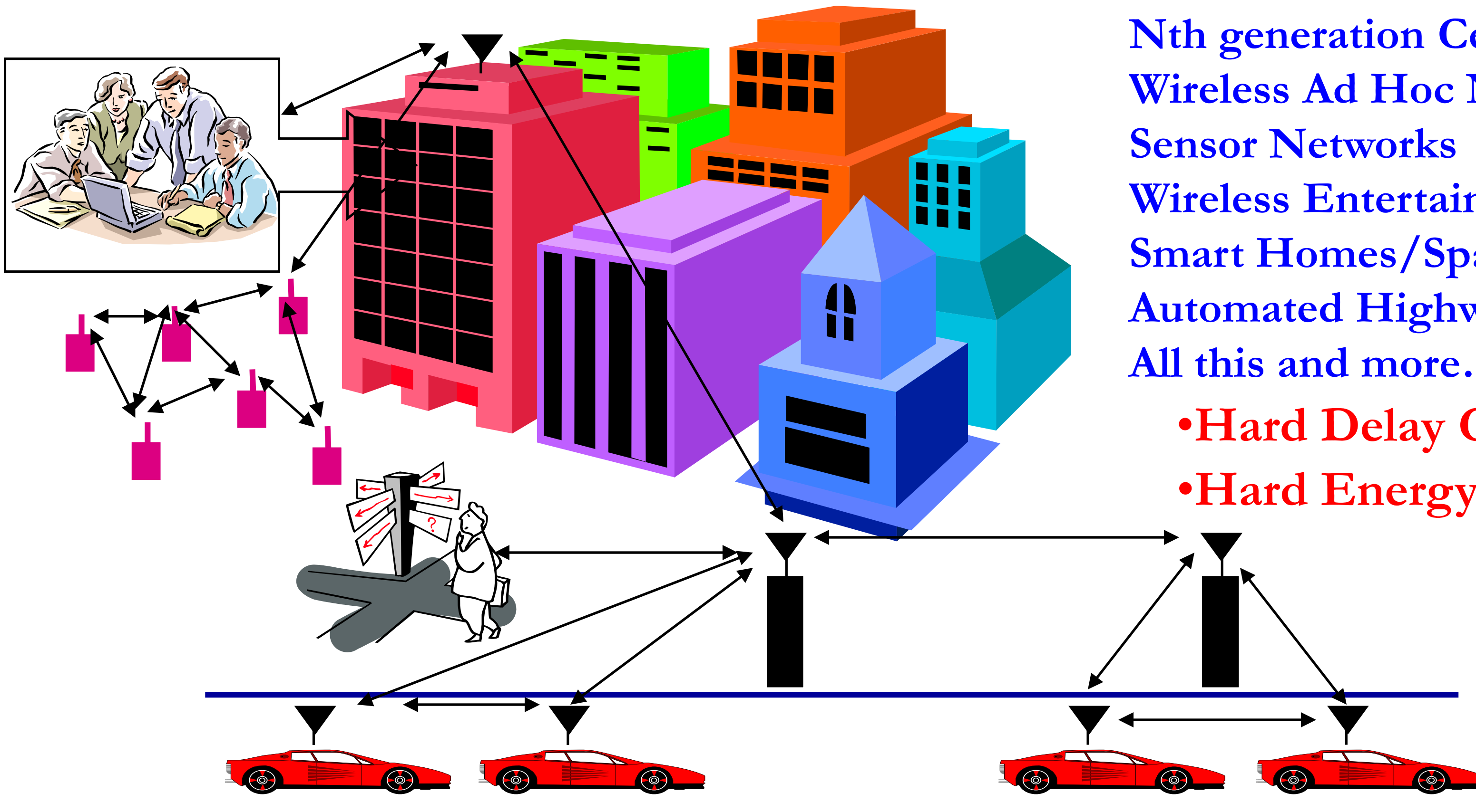


Ad hoc mode

- no base stations
- nodes can only transmit to other nodes within link coverage
- nodes organize themselves into a network: route among themselves

Future Wireless Networks

Ubiquitous Communication Among People and Devices



Wireless Internet access
Nth generation Cellular
Wireless Ad Hoc Networks
Sensor Networks
Wireless Entertainment
Smart Homes/Spaces
Automated Highways
All this and more…

- Hard Delay Constraints
- Hard Energy Constraints

Design Challenges

- Wireless channels are a difficult and capacity-limited broadcast communications medium
- Traffic patterns, user locations, and network conditions are constantly changing
- Applications are heterogeneous with hard constraints that must be met by the network
- Energy and delay constraints change design principles across all layers of the protocol stack

Wireless Media

- Physical layers used in wireless networks
  - have neither absolute nor readily observable boundaries outside which stations are unable to receive frames
  - are unprotected from outside signals
  - communicate over a medium significantly less reliable than the cable of a wired network
  - have dynamic topologies
  - lack full connectivity and therefore the assumption normally made that every station can hear every other station in a LAN is invalid (i.e., STAs may be "hidden" from each other)
  - have time varying and asymmetric propagation properties

Limitations of the mobile environment

- Limitations of the Wireless Network
  - limited communication bandwidth
  - frequent disconnections
  - heterogeneity of fragmented networks

- Limitations Imposed by Mobility
  - route breakages
  - lack of mobility awareness by system/applications

- Limitations of the Mobile Device
  - short battery lifetime
  - limited capacities

Wireless v/s Wired networks

- Regulations of frequencies
  - Limited availability, coordination is required
  - useful frequencies are almost all occupied
- Bandwidth and delays
  - Low transmission rates
    - few Kbps to some Mbps.
  - Higher delays
    - several hundred milliseconds
  - Higher loss rates
    - susceptible to interference, e.g., engines, lightning
- Always shared medium
  - Lower security, simpler active attacking
  - radio interface accessible for everyone
  - Fake base stations can attract calls from mobile phones
  - secure access mechanisms important

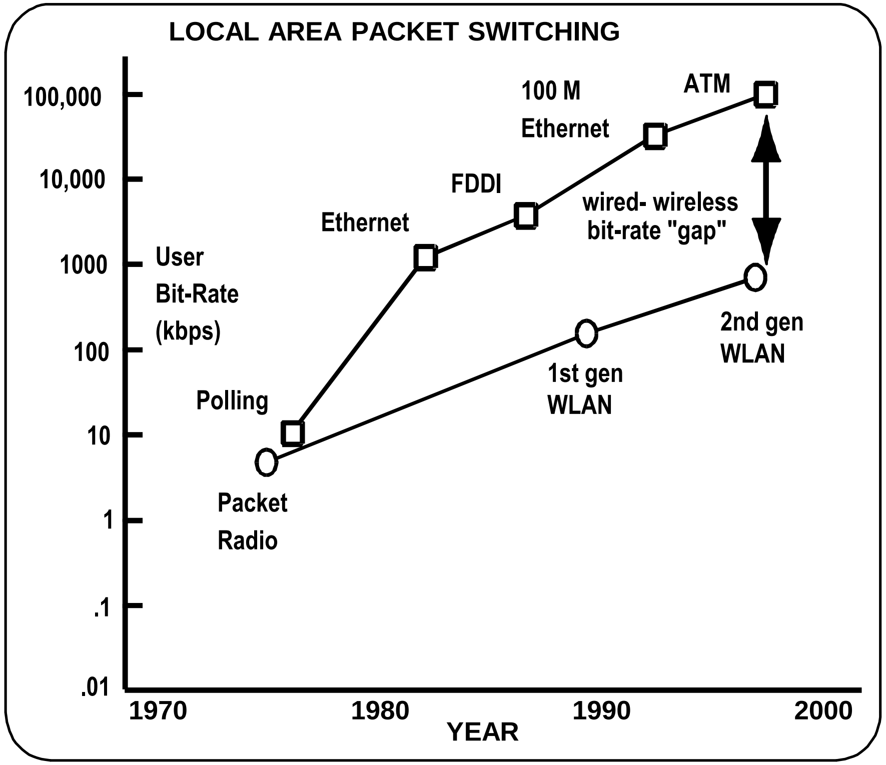
Multimedia Requirements

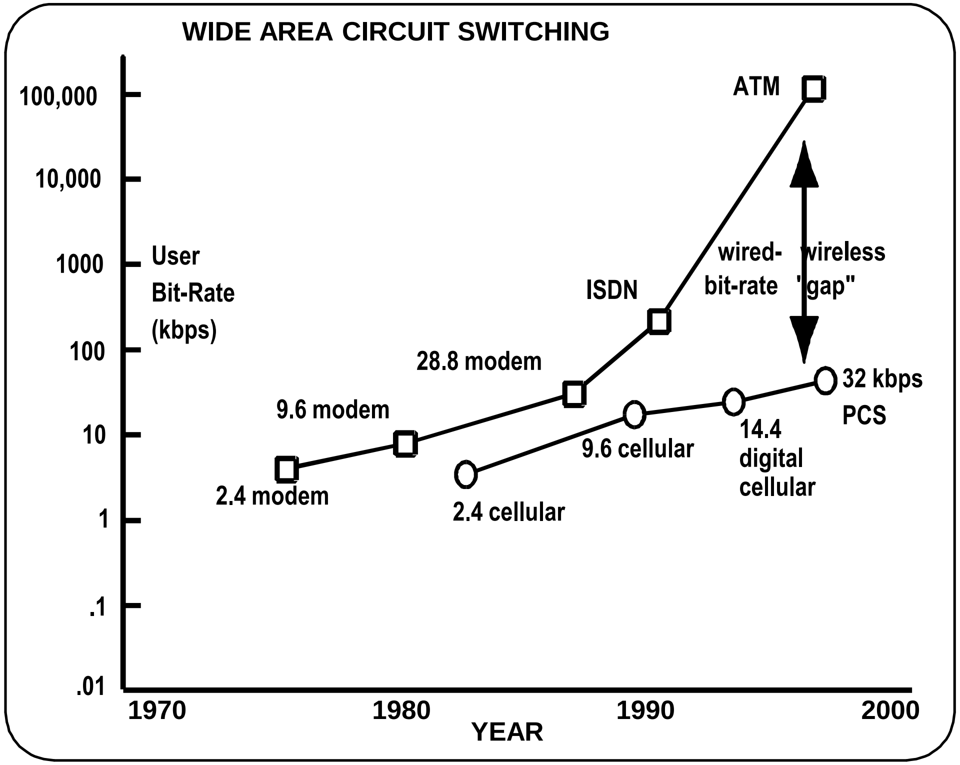
	Voice	Data	Video
Delay	<100ms	-	<100ms
Packet Loss	<1%	0	<1%
BER	10^{-3}	10^{-6}	10^{-6}
Data Rate	8-32 Kbps	1-100 Mbps	1-20 Mbps
Traffic	Continuous	Bursty	Continuous

One-size-fits-all protocols and design do not work well

Wired networks use this approach

Wireless Performance Gap

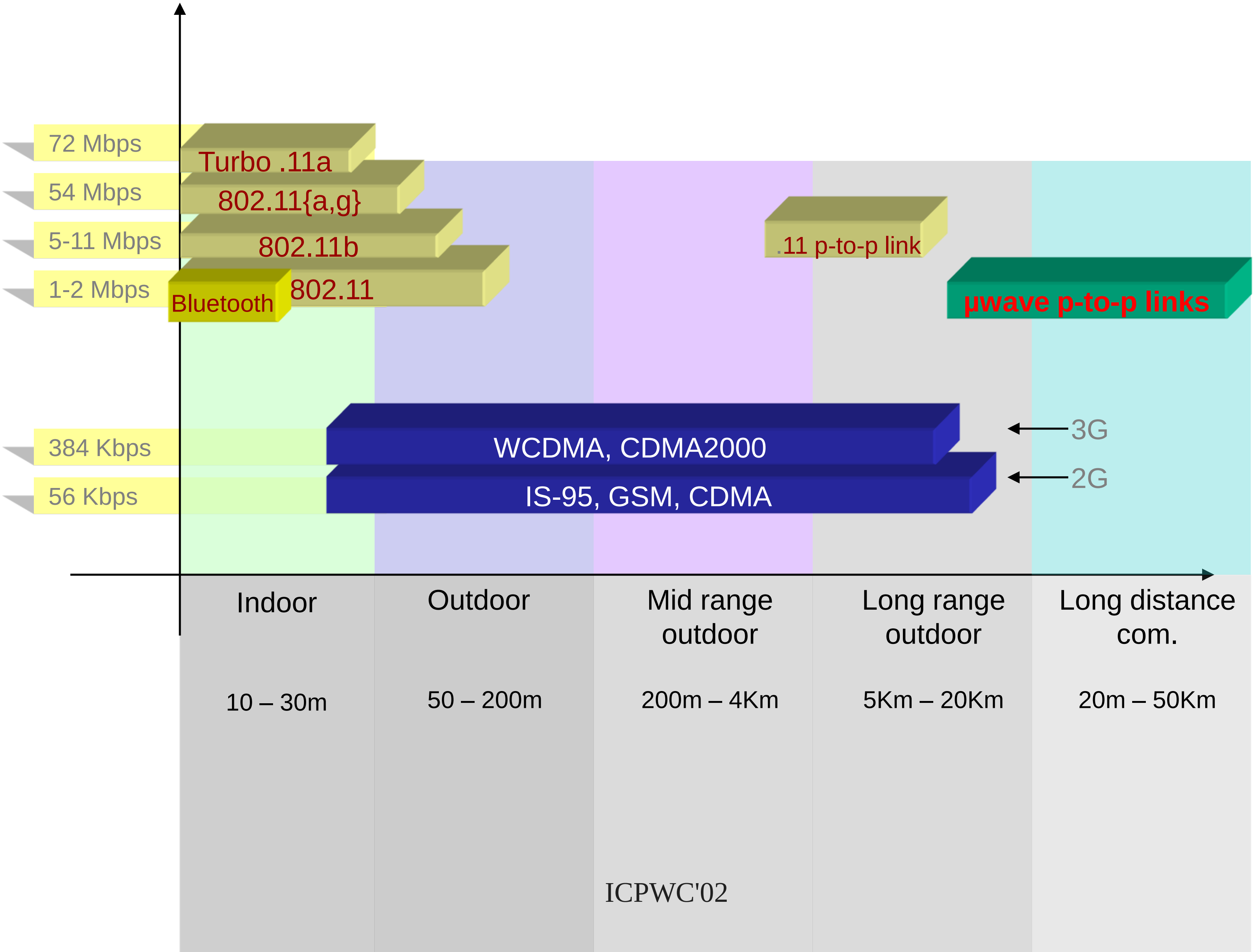




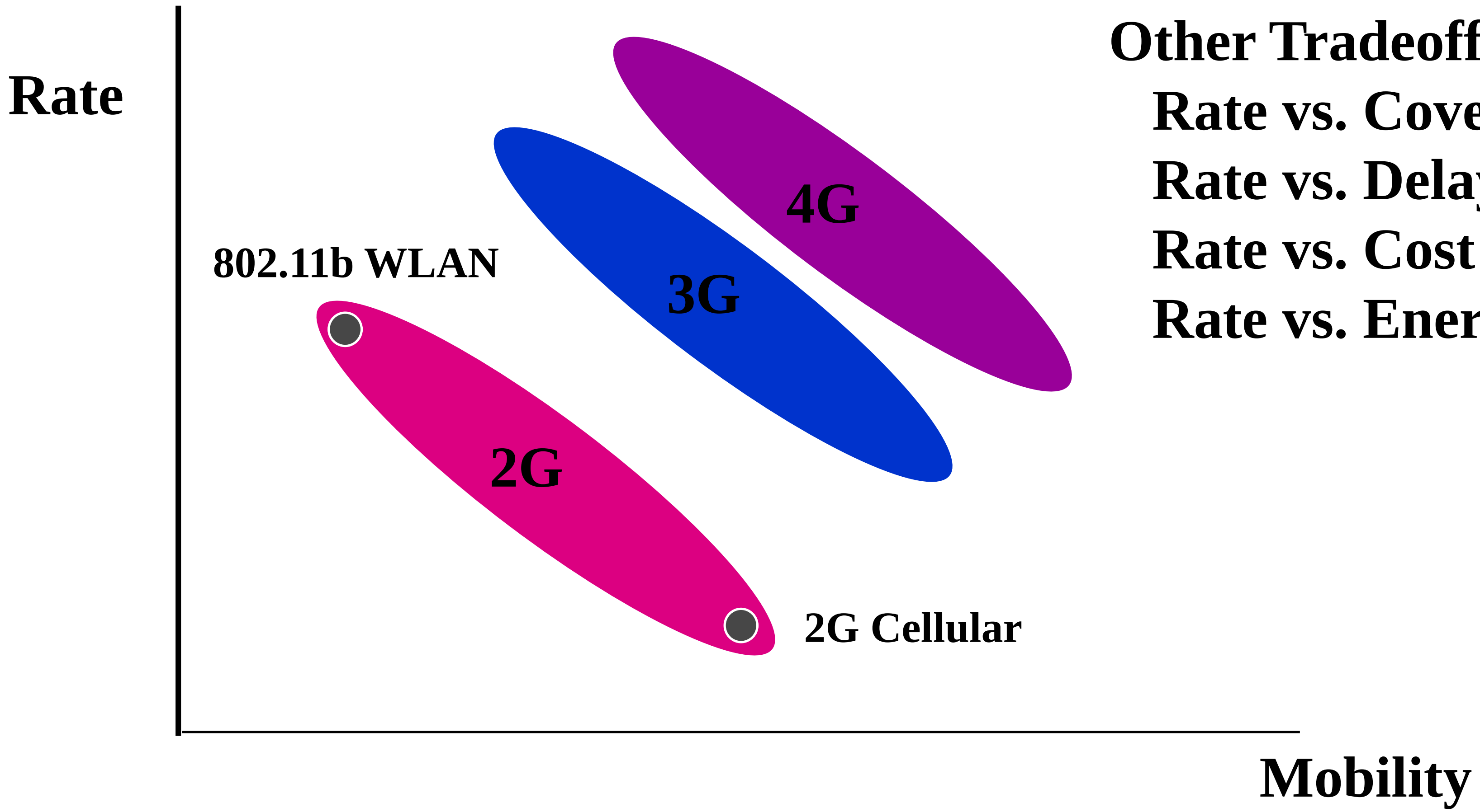
Evolution of Current Systems

- Wireless systems today
  - 2/3-G Cellular: ~30-300 Kbps
  - WLANs: ~10-100 Mbps
- Technology Enhancements
  - Hardware: Better batteries. Better circuits/processors
  - Link: Antennas, modulation, coding, adaptivity, DSP, BW
  - Network: Dynamic resource allocation, Mobility support
  - Application: Soft and adaptive QoS

Wireless Technology Landscape



Future Generations



Other Tradeoffs:

- Rate vs. Coverage
- Rate vs. Delay
- Rate vs. Cost
- Rate vs. Energy

Fundamental Design Breakthroughs Needed

Crosslayer Design

- Hardware
- Link
- Access
- Network
- Application

Delay Constraints
Rate Constraints
Energy Constraints

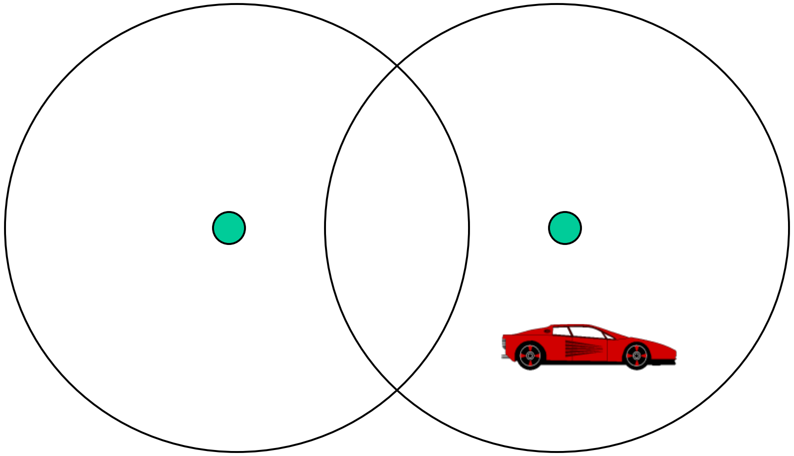
Adapt across design layers
Reduce uncertainty through scheduling
Provide robustness via diversity

Current Wireless Systems

- Cellular Systems
- Wireless LANs
- Satellite Systems
- Paging Systems
- Bluetooth
- Self-Organized/Emerging Systems
  - Mobile Ad-Hoc Networks (MANETs)
  - Wireless Sensor Networks (WSNs)
  - Internet of Things (IoT): RFID

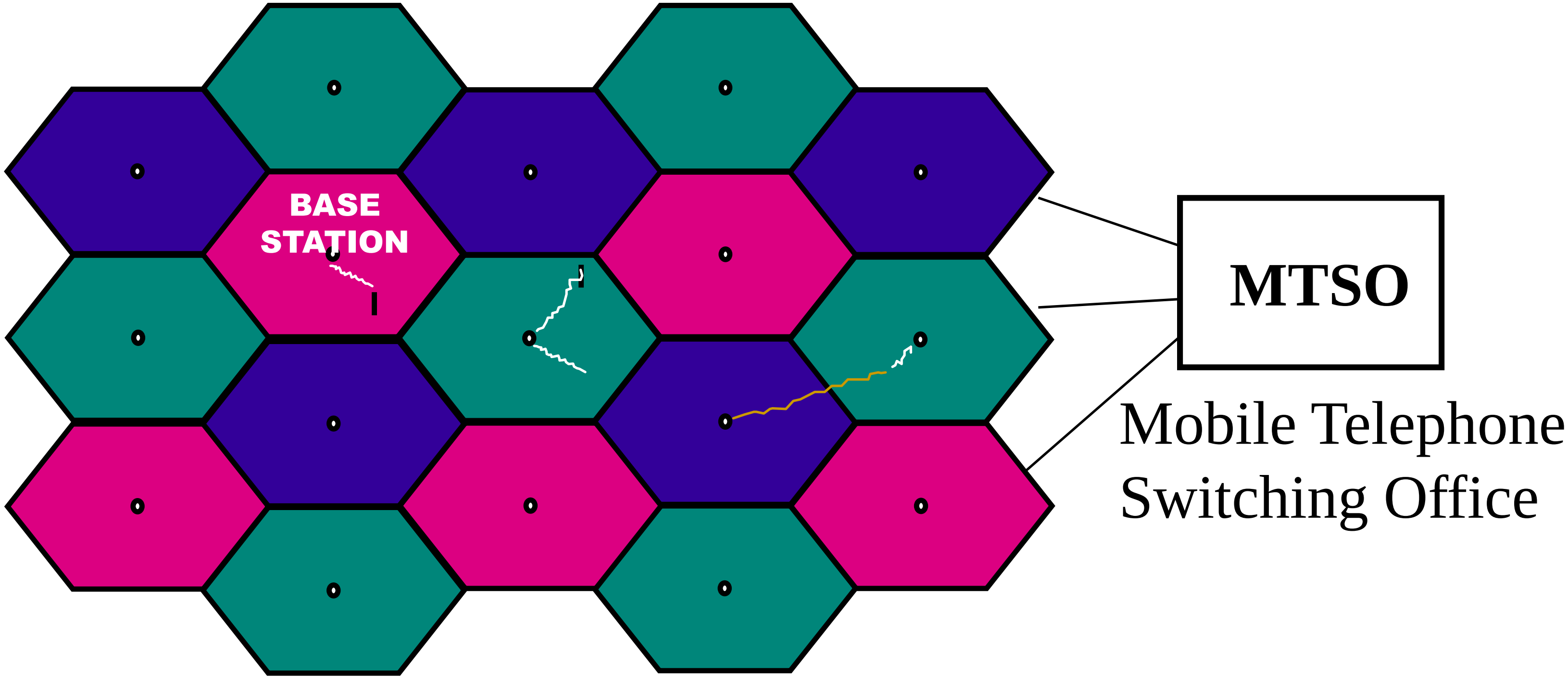
Cellular Wireless

- Single hop wireless connectivity to the wired world
  – Space divided into cells, and hosts assigned to a cell
  – A base station is responsible for communicating with hosts/nodes in its cell
  – Mobile hosts can change cells while communicating
  – Hand-off occurs when a mobile host starts communicating via a new base station

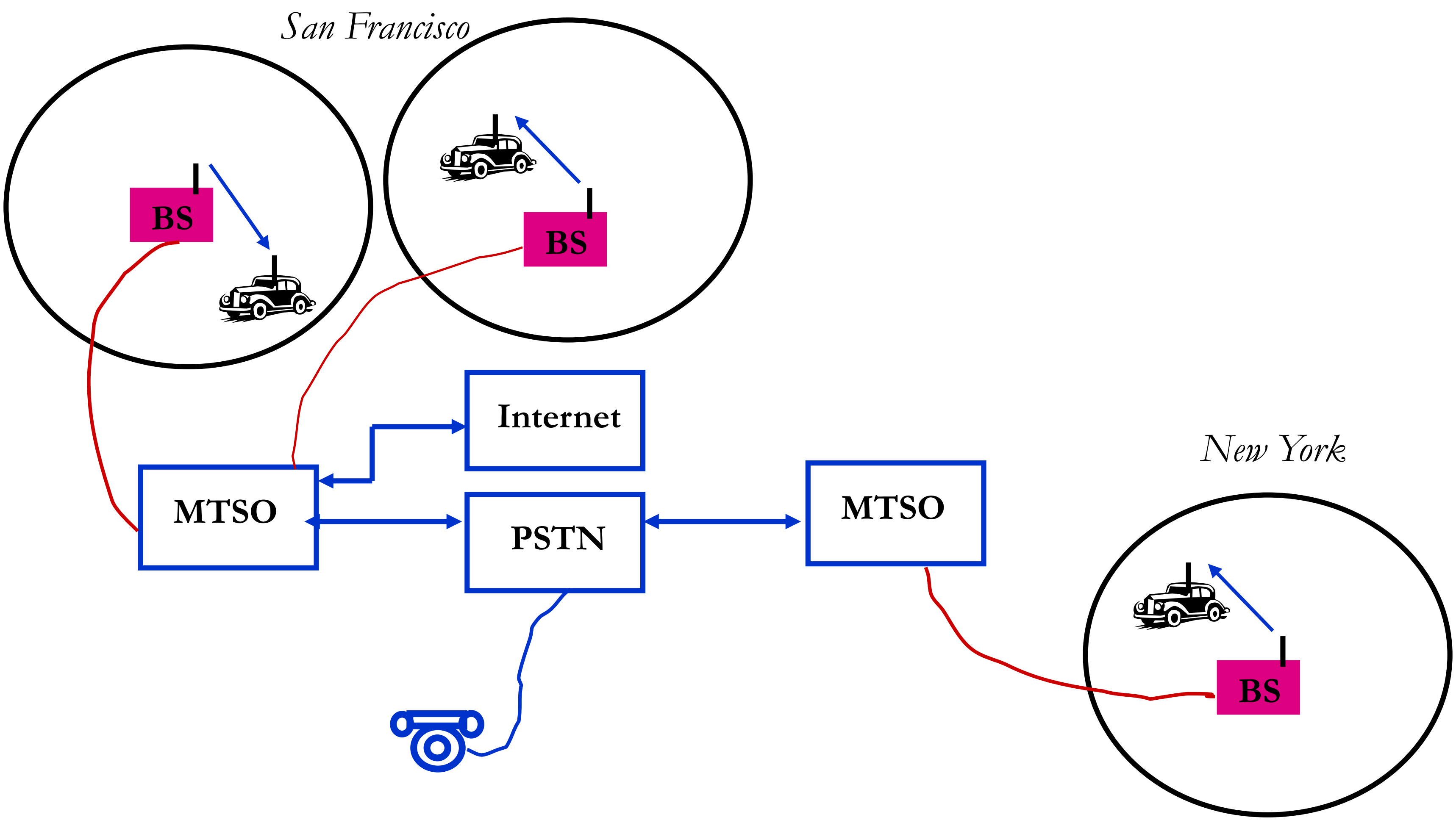


Cellular Systems: Reuse channels to maximize capacity

- Geographic region divided into cells
- Frequencies/timeslots/codes reused at spatially-separated locations.
- Co-channel interference between same color cells.
- Base stations/MTSOs coordinate handoff and control functions
- Shrinking cell size increases capacity, as well as networking burden



Cellular Phone Networks



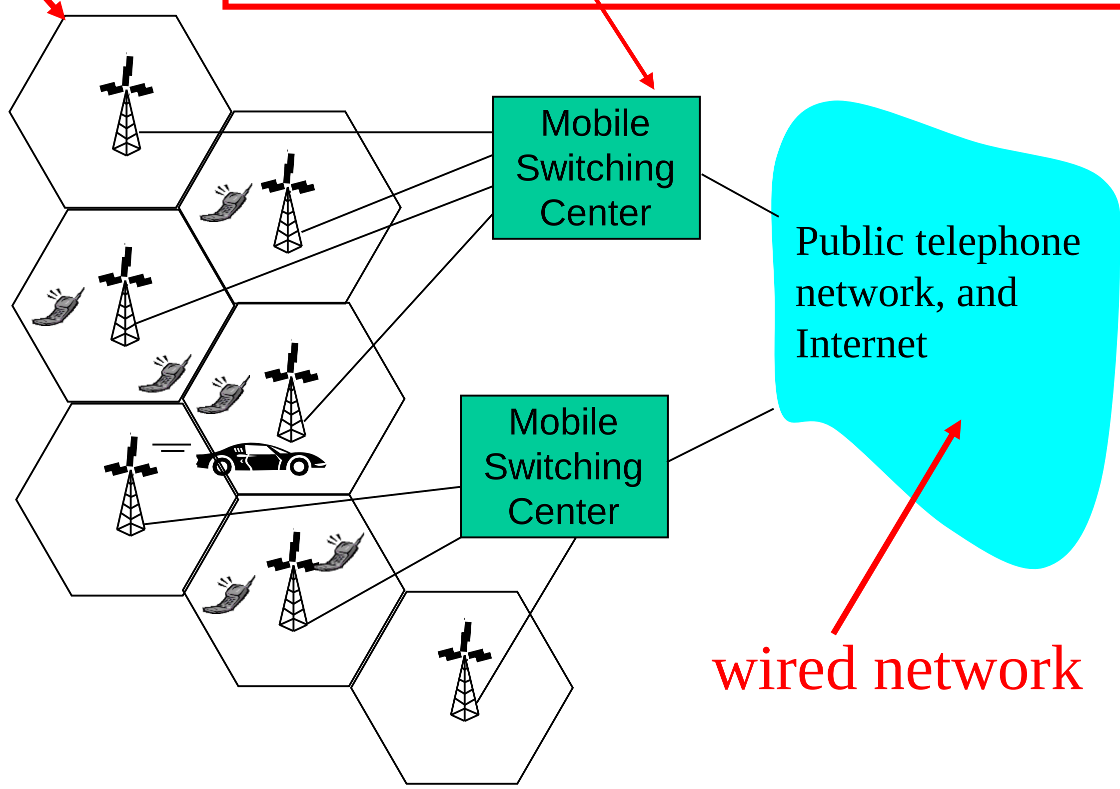
Components of cellular network architecture

cell

- covers geographical region
- *base station* (BS) analogous to 802.11 AP
- *mobile users* attach to network through BS
- *air-interface:* physical and link layer protocol between mobile and BS

MSC

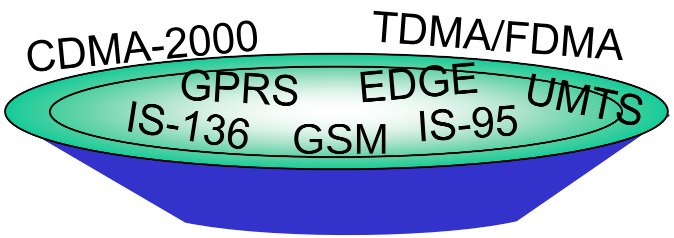
- connects cells to wide area net
- manages call setup (more later!)
- handles mobility (more later!)



Cellular standards: brief survey

2G systems: voice channels

- IS-136 TDMA: combined FDMA/TDMA (north america)
- GSM (global system for mobile communications): combined FDMA/TDMA
  - most widely deployed
- IS-95 CDMA: code division multiple access



Cellular standards: brief survey

2.5 G systems: voice and data channels

- for those who can't wait for 3G service: 2G extensions
- general packet radio service (GPRS)
  - evolved from GSM
  - data sent on multiple channels (if available)
- enhanced data rates for global evolution (EDGE)
  - also evolved from GSM, using enhanced modulation
  - Date rates up to 384K
- CDMA-2000 (phase 1)
  - data rates up to 144K
  - evolved from IS-95

Cellular standards: brief survey

3G systems: voice/data

- Universal Mobile Telecommunications Service (UMTS)
  - GSM next step, but using CDMA
- CDMA-2000

..... more (and more interesting) cellular topics due to mobility (stay tuned for details)

Evolution of cellular networks

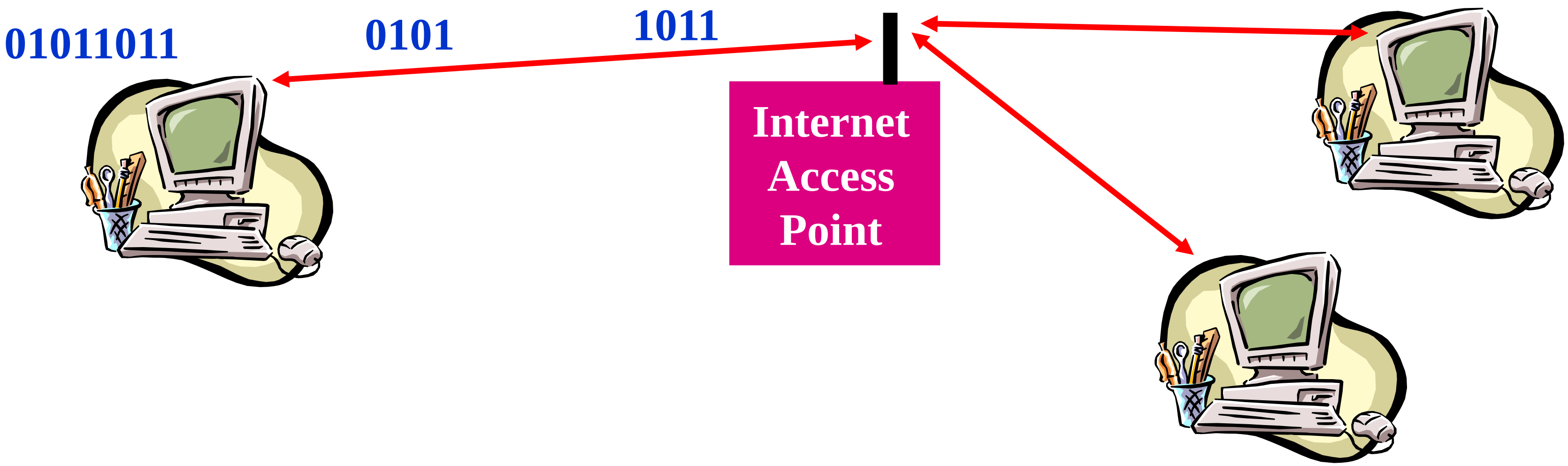
- First-generation: Analog cellular systems (450-900 MHz)
  - Frequency shift keying; FDMA for spectrum sharing
  - NMT (Europe), AMPS (US)
- Second-generation: Digital cellular systems (900, 1800 MHz)
  - TDMA/CDMA for spectrum sharing; Circuit switching
  - GSM (Europe), IS-136 (US), PDC (Japan)
  - <9.6kbps data rates
- 2.5G: Packet switching extensions
  - Digital: GSM to GPRS; Analog: AMPS to CDPD
  - <115kbps data rates
- 3G: Full-fledged data services
  - High speed, data and Internet services
  - IMT-2000, UMTS
  - <2Mbps data rates

3G Cellular Design:
Voice and Data

- Data is bursty, whereas voice is continuous
  - Typically require different access and routing strategies
- 3G “widens the data pipe”:
  - 384 Kbps.
  - Standard based on wideband CDMA
  - Packet-based switching for both voice and data
- 3G cellular struggling in Europe and Asia
- Evolution of existing systems (2.5G,2.6798G):
  - GSM+EDGE
  - IS-95(CDMA)+HDR
  - 100 Kbps may be enough
- What is beyond 3G?

The trillion dollar question

Wireless Local Area Networks (WLANs)



- WLANs connect “local” computers (100m range)
- Breaks data into packets
- Channel access is shared (random access)
- Backbone Internet provides best-effort service
  - Poor performance in some apps (e.g. video)

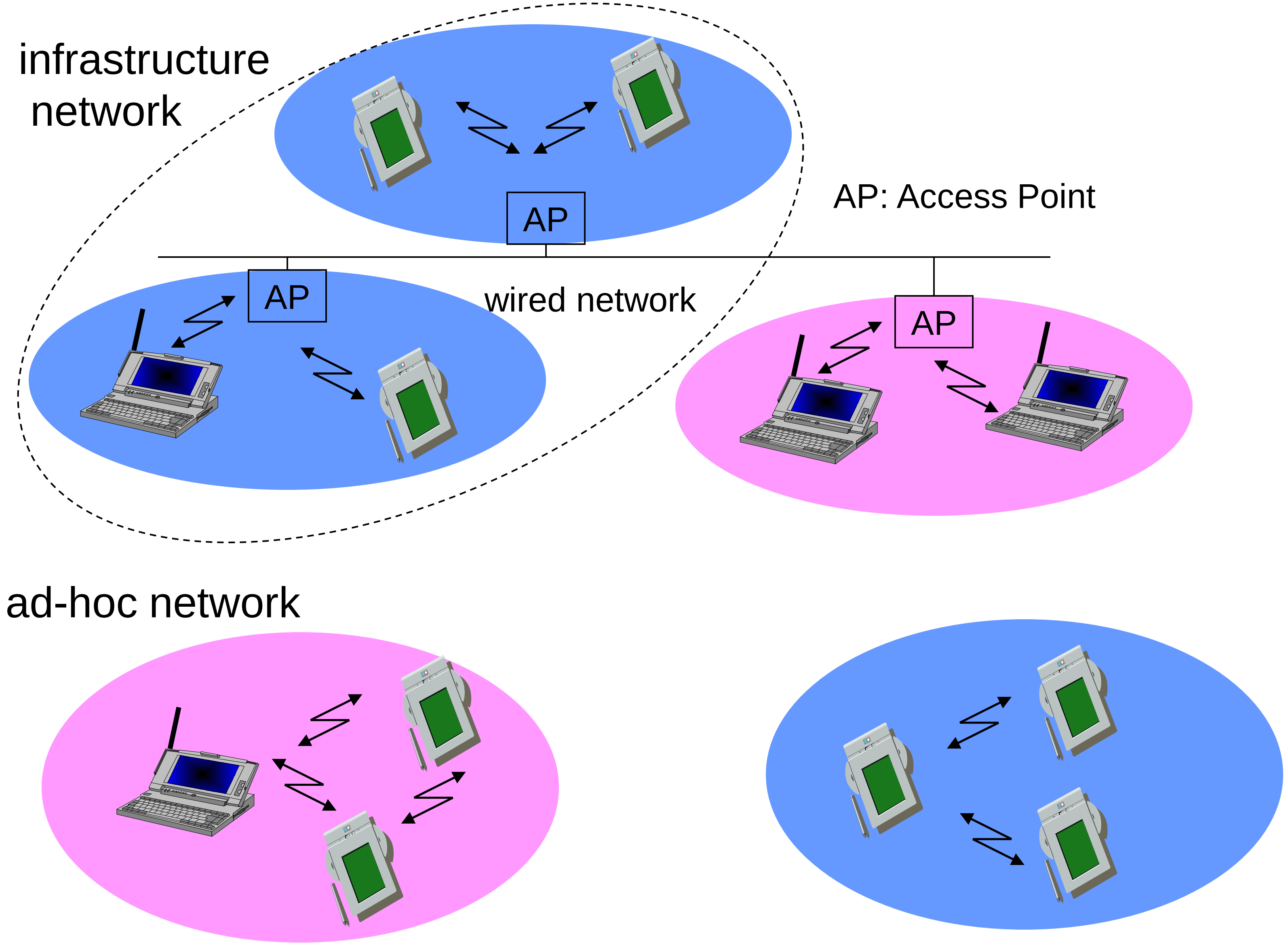
Wireless LANs

- Infrared (IrDA) or radio links (Wavelan)
- Advantages
  - very flexible within the reception area
  - Ad-hoc networks possible
  - (almost) no wiring difficulties
- Disadvantages
  - low bandwidth compared to wired networks
  - many proprietary solutions
    - Bluetooth, HiperLAN and IEEE 802.11

Wireless LANs vs. Wired LANs

- Destination address does not equal destination location
- The media impact the design
  - wireless LANs intended to cover reasonable geographic distances must be built from basic coverage blocks
- Impact of handling mobile (and portable) stations
  - Propagation effects
  - Mobility management
  - Power management

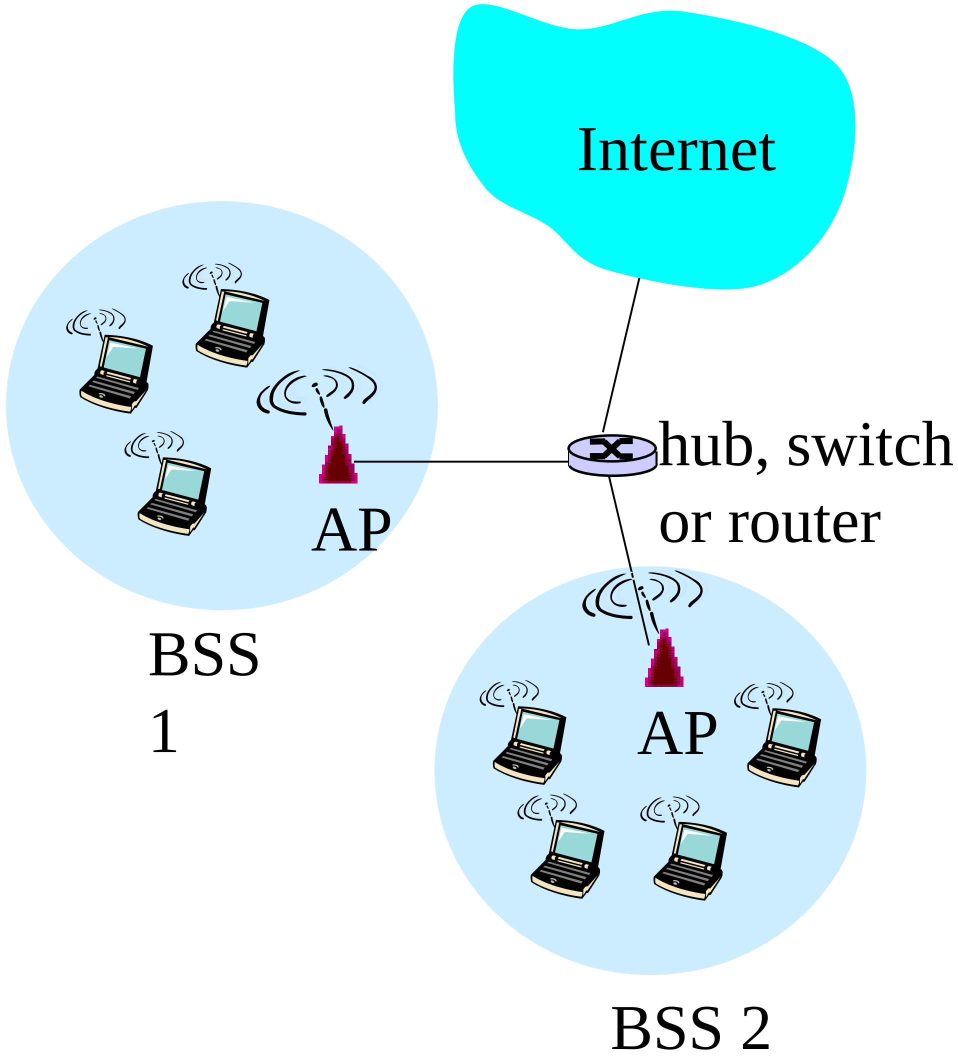
Infrastructure vs. Ad hoc WLANs



Wireless LAN Standards

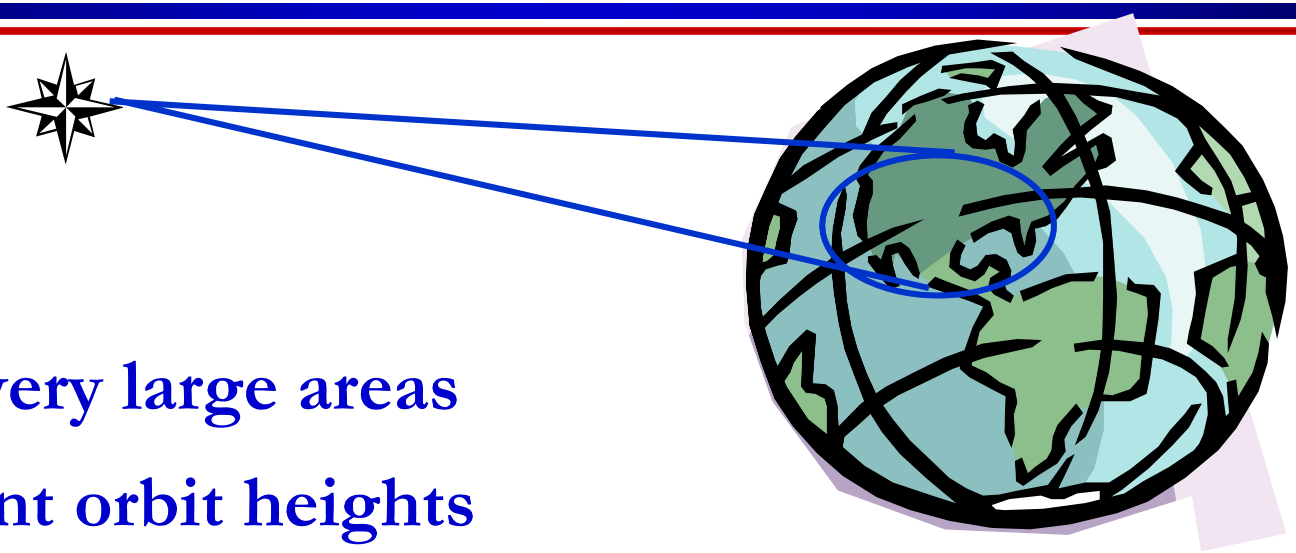
- 802.11b (Current Generation)
  - Standard for 2.4GHz ISM band (80 MHz)
  - Frequency hopped spread spectrum
  - 1.6-10 Mbps, 500 ft range
- 802.11a (Emerging Generation)
  - Standard for 5GHz NII band (300 MHz)
  - OFDM with time division
  - 20-70 Mbps, variable range
  - Similar to HiperLAN in Europe
- 802.11g (New Standard)
  - Standard in 2.4 GHz and 5 GHz bands
  - OFDM
  - Speeds up to 54 Mbps

802.11 LAN architecture



- wireless host communicates with base station
  - base station = access point (AP)
- Basic Service Set (BSS) (aka "cell") in infrastructure mode contains:
  - wireless hosts
  - access point (AP): base station
  - ad hoc mode: hosts only

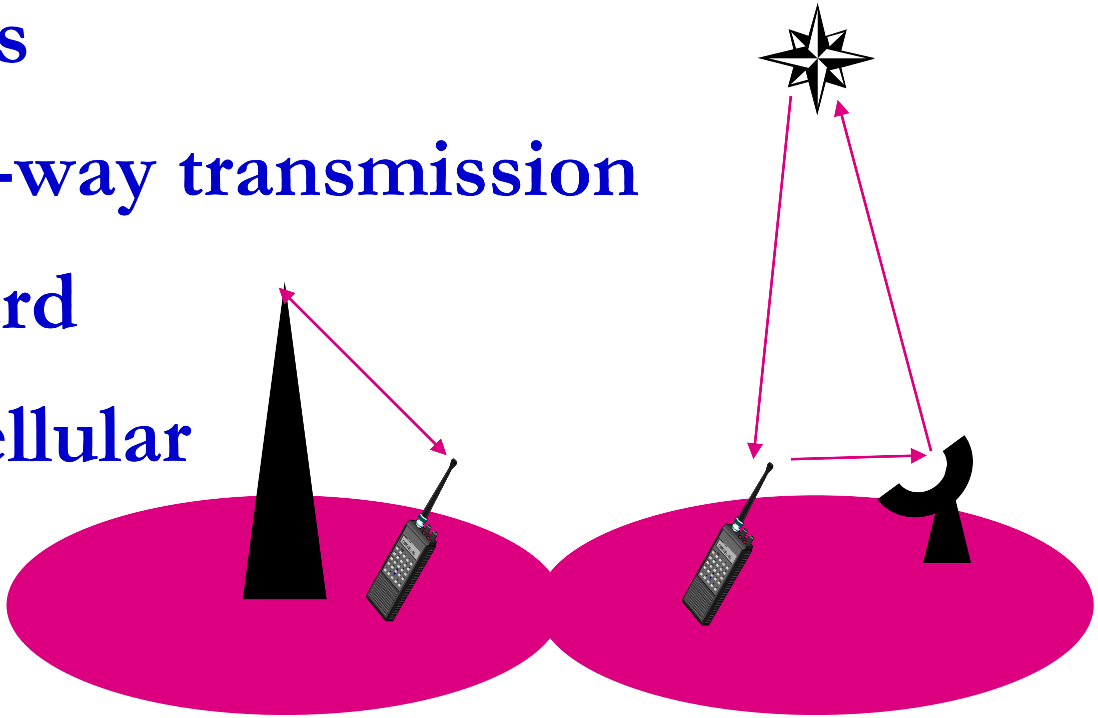
Satellite Systems



- Cover very large areas
- Different orbit heights
  - GEOs (39000 Km) versus LEOs (2000 Km)
- Optimized for one-way transmission
  - Radio (XM, DAB) and movie (SatTV) broadcasting
- Most two-way systems struggling or bankrupt
  - Expensive alternative to terrestrial system
  - A few ambitious systems on the horizon

Paging Systems

- Broad coverage for short messaging
- Message broadcast from all base stations
- Simple terminals
- Optimized for 1-way transmission
- Answer-back hard
- Overtaken by cellular



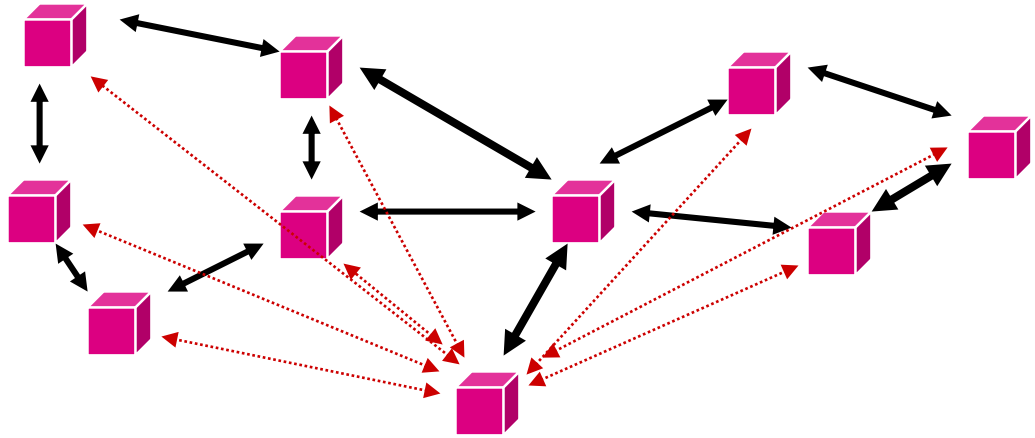
Bluetooth

- Cable replacement RF technology (low cost)
- Short range (10m, extendable to 100m)
- 2.4 GHz band (crowded)
- 1 Data (700 Kbps) and 3 voice channels
- Widely supported by telecommunications, PC, and consumer electronics companies
- Few applications beyond cable replacement

Emerging Systems

- Ad hoc wireless networks
- Sensor networks
- Distributed control networks

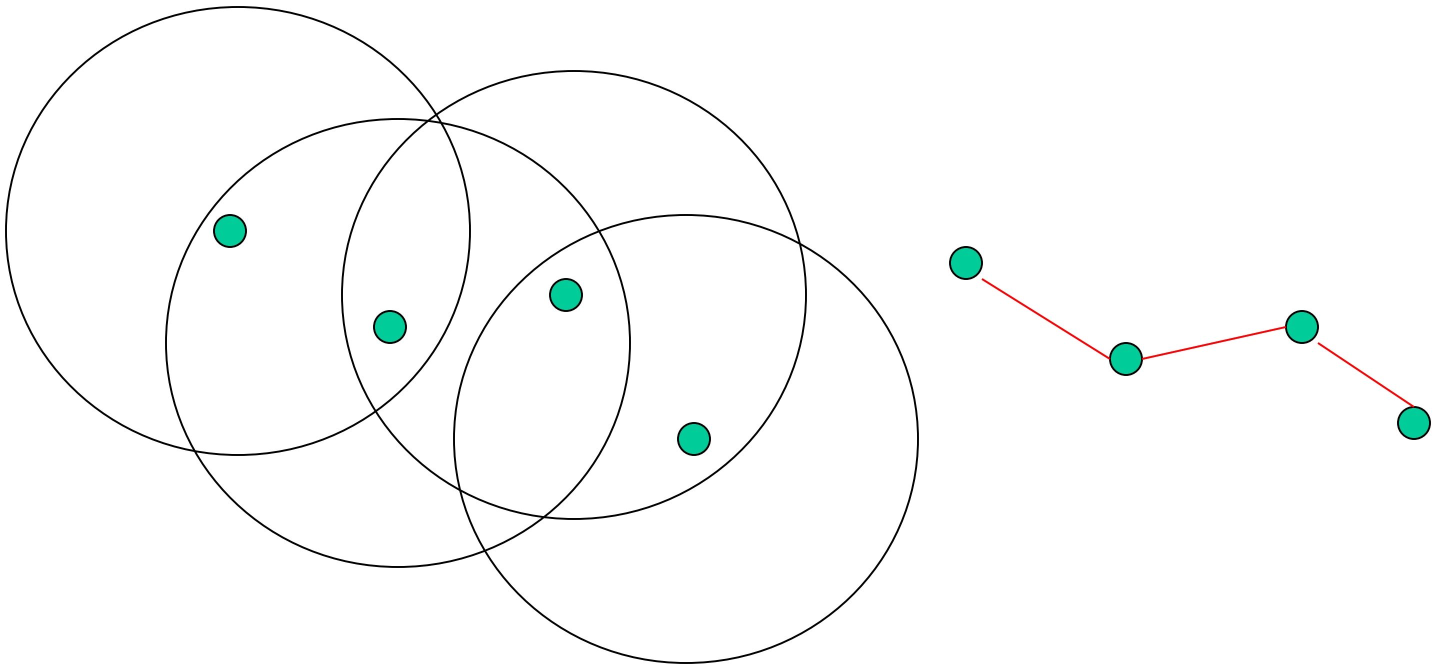
Ad-Hoc Networks



- Peer-to-peer communications
- No backbone infrastructure
- Routing can be multihop
- Topology is dynamic
- Fully connected with different link SINRs

Multi-Hop Wireless

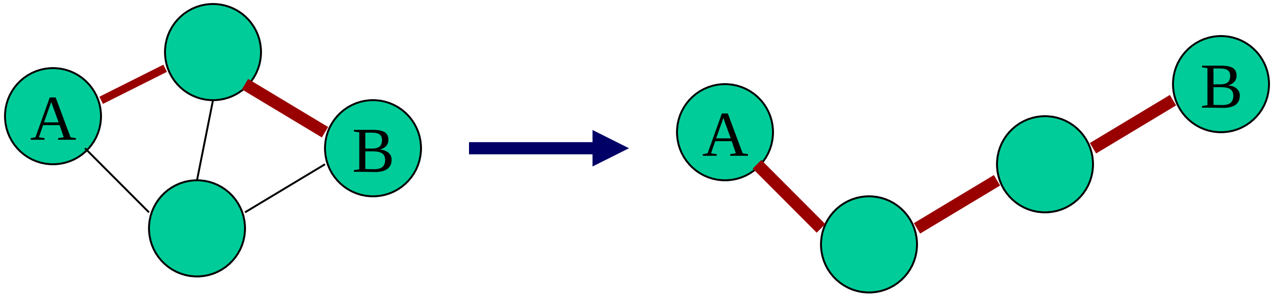
- May need to traverse multiple links to reach destination



- Mobility causes route changes

Mobile Ad Hoc Networks (MANET)

- Do not need backbone infrastructure support
- Host movement frequent
- Topology change frequent



- Multi-hop wireless links
- Data must be routed via intermediate nodes

Applications of MANETS

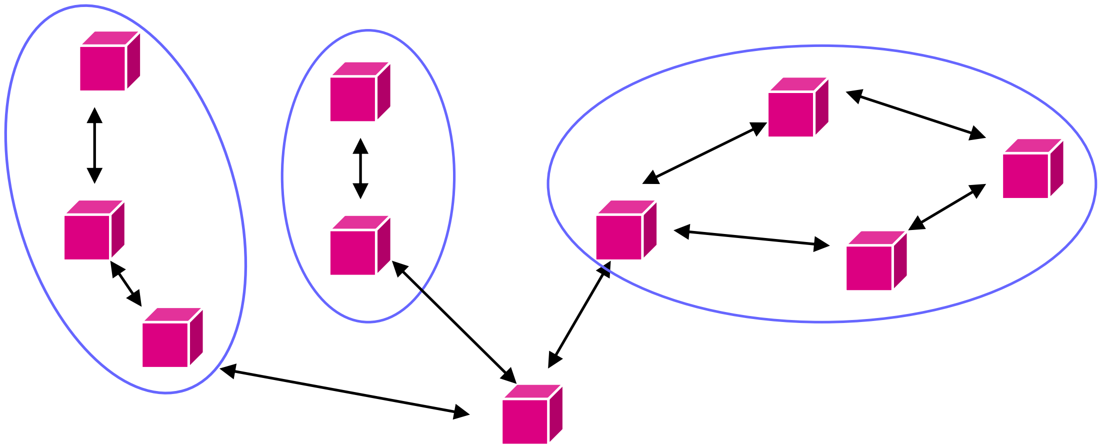
- Military - soldiers at Kargil, tanks, planes
- Disaster Management – Orissa, Gujarat
- Emergency operations – search-and-rescue, police and firefighters
- Sensor networks
- Taxicabs and other closed communities
- airports, sports stadiums etc. where two or more people meet and want to exchange documents
- Presently MANET applications use 802.11 hardware
- Personal area networks - Bluetooth

Design Issues

- Ad-hoc networks provide a flexible network infrastructure for many emerging applications
- The capacity of such networks is generally unknown
- Transmission, access, and routing strategies for ad-hoc networks are generally ad-hoc
- Cross-layer design critical and very challenging
- Energy constraints impose interesting design tradeoffs for communication and networking

Sensor Networks

Energy is the driving constraint

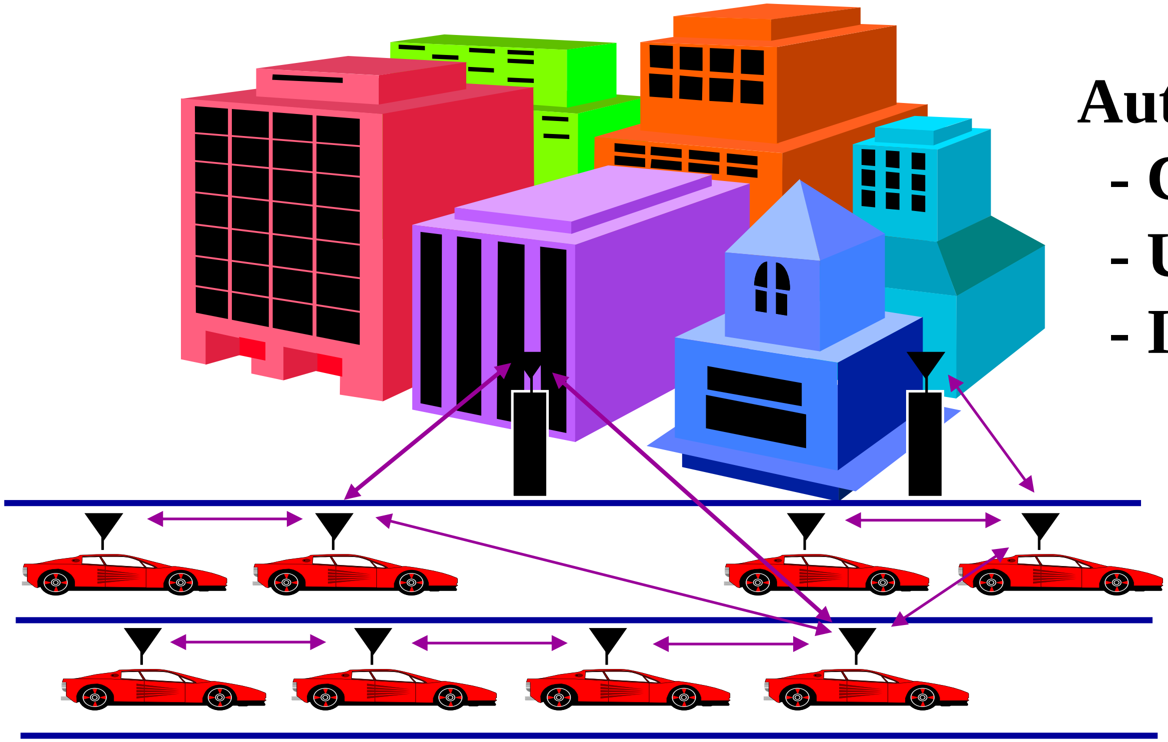


- Nodes powered by non-rechargeable batteries
- Data flows to centralized location
- Low per-node rates but up to 100,000 nodes
- Data highly correlated in time and space
- Nodes can cooperate in transmission, reception, compression, and signal processing

Energy-Constrained Nodes

- Each node can only send a finite number of bits
  - Transmit energy minimized by maximizing bit time
  - Circuit energy consumption increases with bit time
  - Introduces a delay versus energy tradeoff for each bit
- Short-range networks must consider transmit, circuit, and processing energy
  - Sophisticated techniques not necessarily energy-efficient
  - Sleep modes save energy but complicate networking
- Changes everything about the network design:
  - Bit allocation must be optimized across all protocols
  - Delay vs. throughput vs. node/network lifetime tradeoffs
  - Optimization of node cooperation

Distributed Control over Wireless Links



Automated Vehicles
- Cars
- UAVs
- Insect flyers

- Packet loss and/or delays impacts controller performance
- Controller design should be robust to network faults
- Joint application and communication network design

Joint Design Challenges

- There is no methodology to incorporate random delays or packet losses into control system designs
- The best rate/delay trade-off for a communication system in distributed control cannot be determined
- Current autonomous vehicle platoon controllers are not string stable with *any* communication delay

Can we make distributed control robust to the network?

Yes, by a radical redesign of the controller and the network

Spectrum Regulation

- Spectral Allocation in US controlled by FCC (commercial) or OSM (defense)
- FCC auctions spectral blocks for set applications
- Some spectrum set aside for universal use
- Worldwide spectrum controlled by ITU-R

Regulation can stunt innovation, cause economic disasters, and delay system rollout

Standards

- Interacting systems require standardization
- Companies want their systems adopted as standard
  - Alternatively try for de-facto standards
- Standards determined by TIA/CTIA in US
  - IEEE standards often adopted
- Worldwide standards determined by ITU-T
  - In Europe, ETSI is equivalent of IEEE

Standards process fraught with inefficiencies and conflicts of interest

Main Points

- The wireless vision encompasses many exciting systems and applications
- Technical challenges transcend across all layers of the system design
- Wireless systems today have limited performance and interoperability
- Standards and spectral allocation heavily impact the evolution of wireless technology