OUTLINE

- Introduction
- Radio Environment
- Physical Layer Issues
- Channel Access Issues
- Network Issues
- Standards and Future Systems
- Summary
- References

CHANNEL ACCESS ISSUES

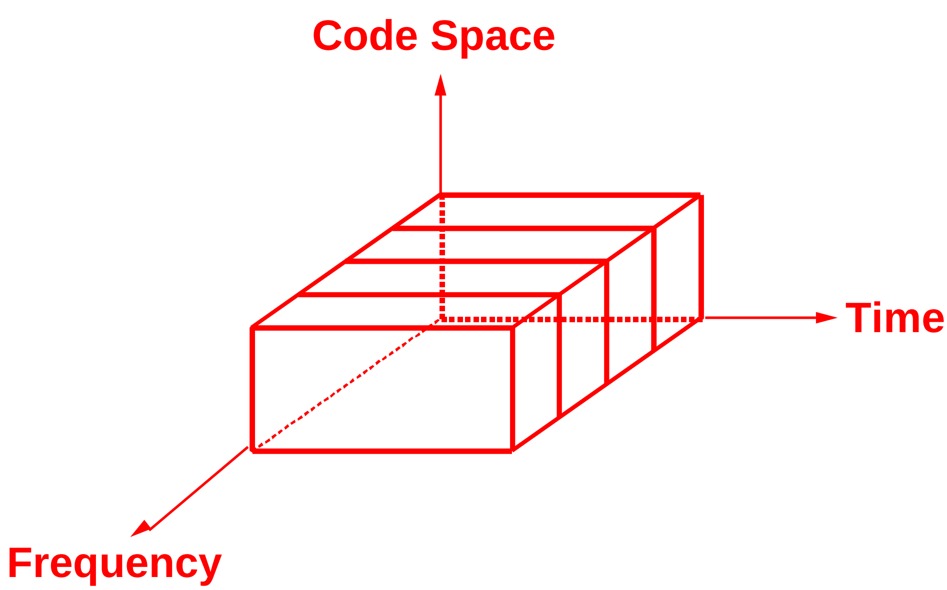
- Multiple Access
- Random Access
- Frequency Reuse

MULTIPLE ACCESS TECHNIQUES

- Frequency Division (FDMA)
- Time Division (TDMA)
- Code Division (CDMA)
- Hybrid Approaches

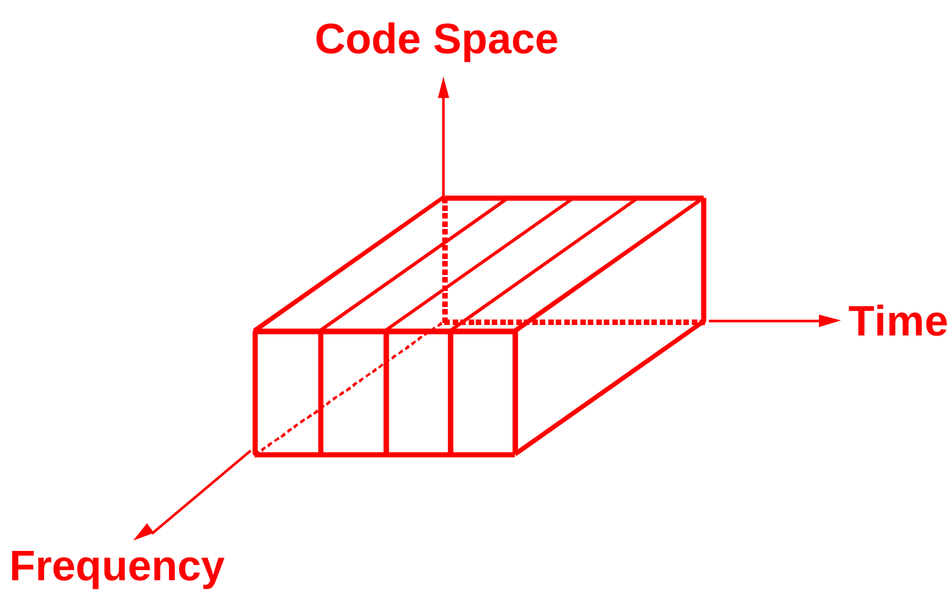
FDMA

The total system bandwidth is divided into channels which are allocated to the different users.



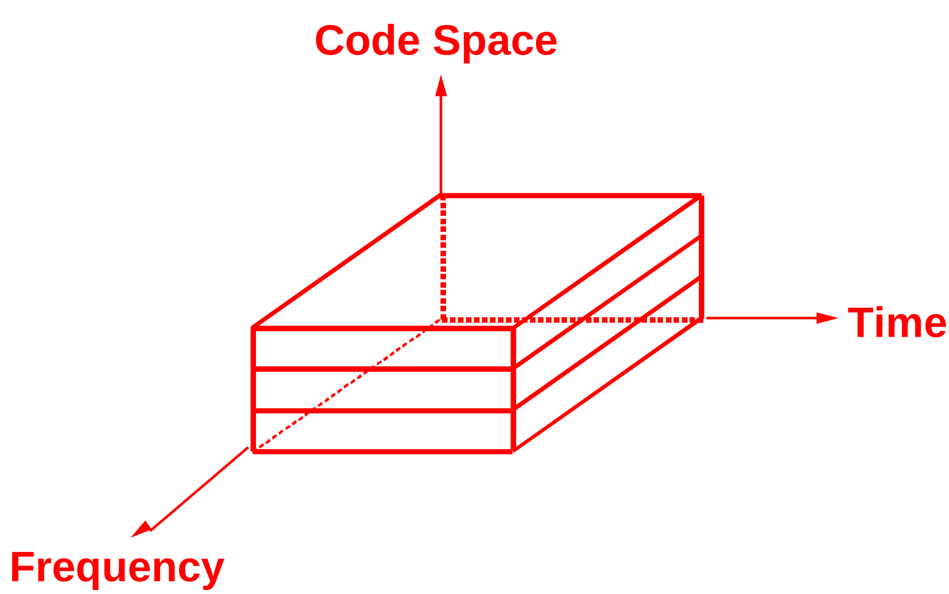
TDMA

Time is divided into slots which are allocated to the different users.



CDMA

Time and bandwidth are used simultaneously by different users, modulated by orthogonal or semi-orthogonal codes (e.g. spread spectrum).



IMPLICATIONS FOR HIGH-SPEED WIRELESS DATA

- Perform well with continuous stream traffic but inefficient for bursty traffic

- Complexity

  Frequency Division < Time Division < Code Division

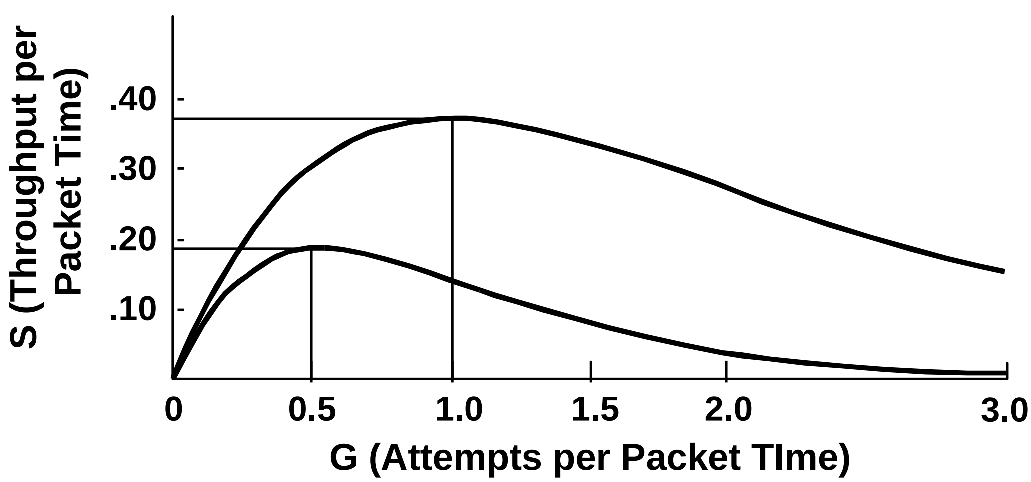
- Multiple Data Rates
  - multiple frequency bands
  - multiple timeslots
  - multiple codes

RANDOM ACCESS TECHNIQUES

- ALOHA
- Carrier-Sense Techniques
- Reservation Protocols
- Implication for High-Speed Wireless Data

ALOHA

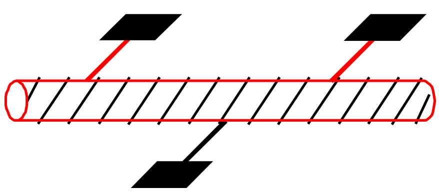
- Data is packetized.
- Retransmission is required when packets collide.
- Pure ALOHA
  - send packet whenever data is available
  - a collision occurs for any partial overlap of packets
- Slotted ALOHA
  - send packets during predefined timeslots
  - avoids partial overlap of packets



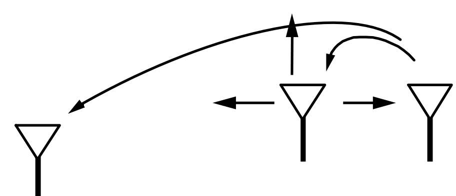
- Comments
  - inefficient for heavily loaded systems
  - capture effect improves efficiency
  - combining SS with ALOHA reduces collisions

CARRIER-SENSE TECHNIQUES

- Channel is sensed before transmission to determine if it is occupied.
- More efficient than ALOHA ⇒ fewer retransmissions
- Carrier sensing is often combined with collision detection in wired networks (e.g., Ethernet).
  ⇒ not possible in a radio environment



Wireless Network



Busy Tone

- Collision avoidance is used in current wireless LANs. (WaveLAN, IEEE802.11, Spectral Etiquette)

RESERVATION PROTOCOLS

- **Demand–Based Assignment**
  - a common reservation channel is used to assign bandwidth on demand
  - reservation channel requires extra bandwidth
  - very efficient if overhead traffic is a small percentage of the message traffic

- **Packet Reservation Multiple Access (PRMA)**
  - similar to reservation ALOHA
  - uses a slotted channel structure
  - all unreserved slots are open for contention
  - a successful transmission in an unreserved slot effectively reserves that slot for future transmissions

EXAMPLES

- ARDIS
  - slotted CSMA

- RAM Mobile Data
  - slotted CSMA

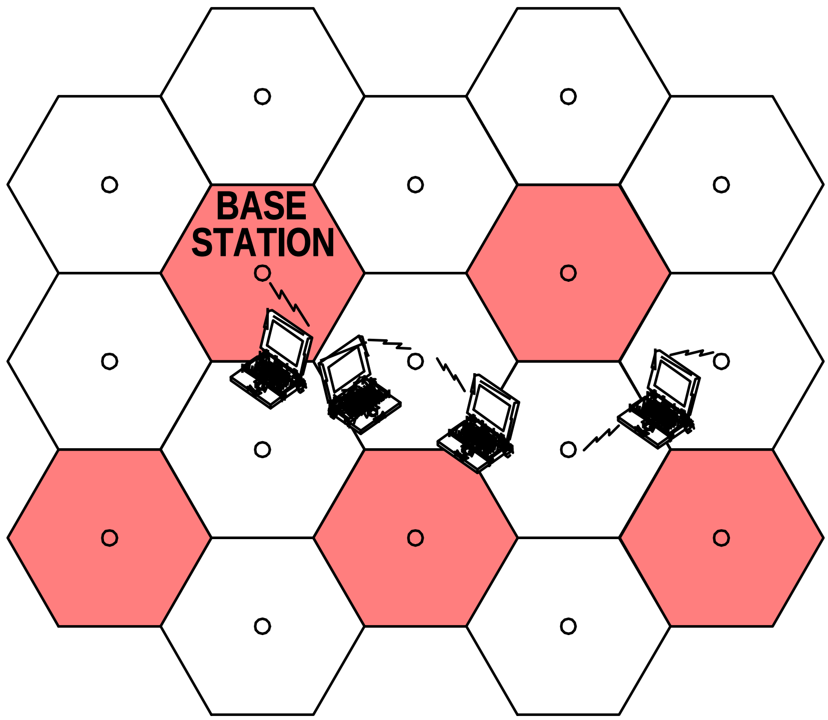
- CDPD
  - DSMA/CD - Digital Sense Multiple Access
  - collisions detected at receiver and transmitted back

- WaveLAN
  - CSMA/CA

IMPLICATIONS FOR HIGH SPEED WIRELESS DATA

- **Retransmissions are power and spectrally inefficient.**
- **ALOHA cannot satisfy high-speed data throughput requirements.**
- **Reservation protocols are also ineffective for short messaging.**
- **Delay constraints impose throughput limitations.**

FREQUENCY REUSE



- Frequencies (or time slots or codes) are reused at spatially-separated locations.
- Introduces interference ⇒ system capacity is interference-limited.
- Mainly designed for circuit-switched communications
- Base stations perform centralized control functions. (call setup, handoff, routing, etc.)

DESIGN CONSIDERATIONS

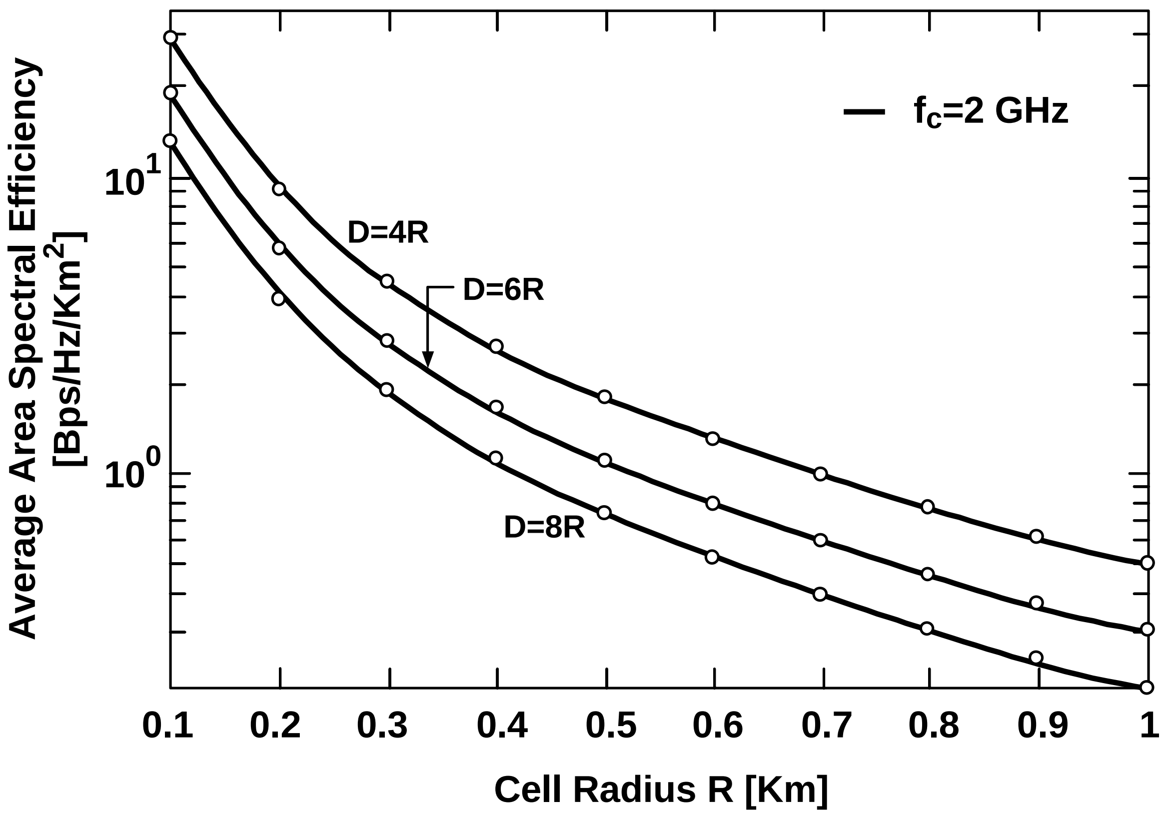
- Reuse Distance (D)
  - distance between cells using the same frequency, time slot, or code
  - smaller reuse distance packs more users into a given area, but also increases their co-channel interference

- Cell Radius
  - decreasing the cell size increases system capacity, but complicates the network functions of handoff and routing

- Area Spectral Efficiency, the total throughput per unit area, captures the cellular system design tradeoffs

$$A_e = \frac{K \cdot \bar{R}_b \, (S/I)}{(.25\, D^2 \pi)} \qquad \text{bps/Hz/km}^2$$

AREA SPECTRAL EFFICIENCY



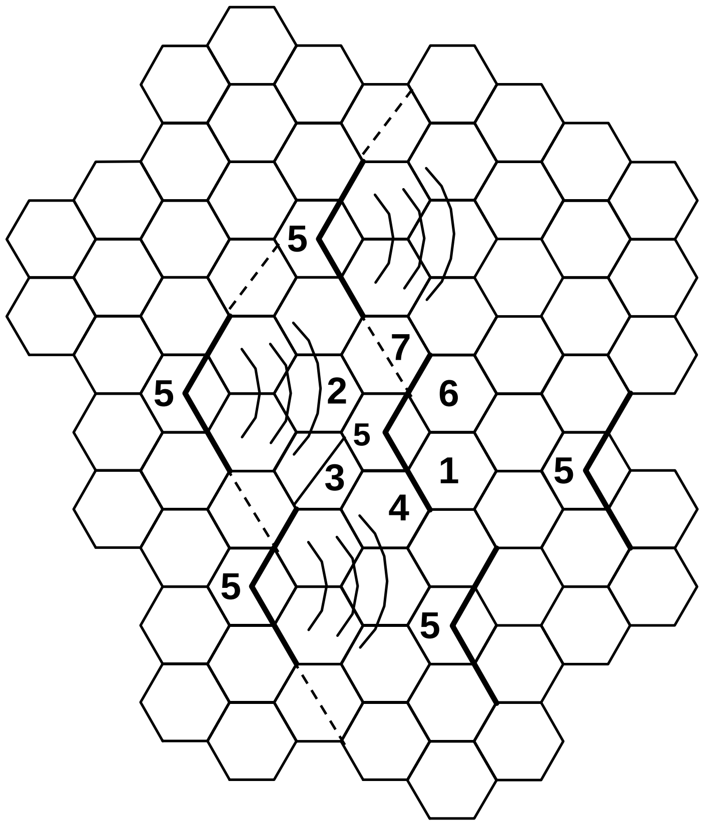
CHANNEL ASSIGNMENT

- **Fixed Channel Assignment (FCA)**
  - each cell is assigned a fixed number of channels
  - channels used for both handoff and new calls
- **Reservation Channels with FCA**
  - each cell reserves same channels for hand off calls
- **Channel Borrowing**
  - a cell may borrow free channels from neighboring cells
- **Dynamic Channel Assignment**

METHODS TO IMPROVE SPECTRUM UTILIZATION

- Interference Averaging (CDMA)
- Interference Reduction
  (power adaptation, sectorization)
- Interference Cancellation
  (smart antennas, multiuser detection)
- Interference Avoidance
  (dynamic resource allocation)

SECTORIZATION



- 120° sectoring reduces interference from co-channel cells.

- Out of the 6 co-channel cells in the first tier, only 2 of them interfere with the center cell.

- If omni-directional antennas were used at each base station, all 6 co-channel cells would interfere with the center cell.

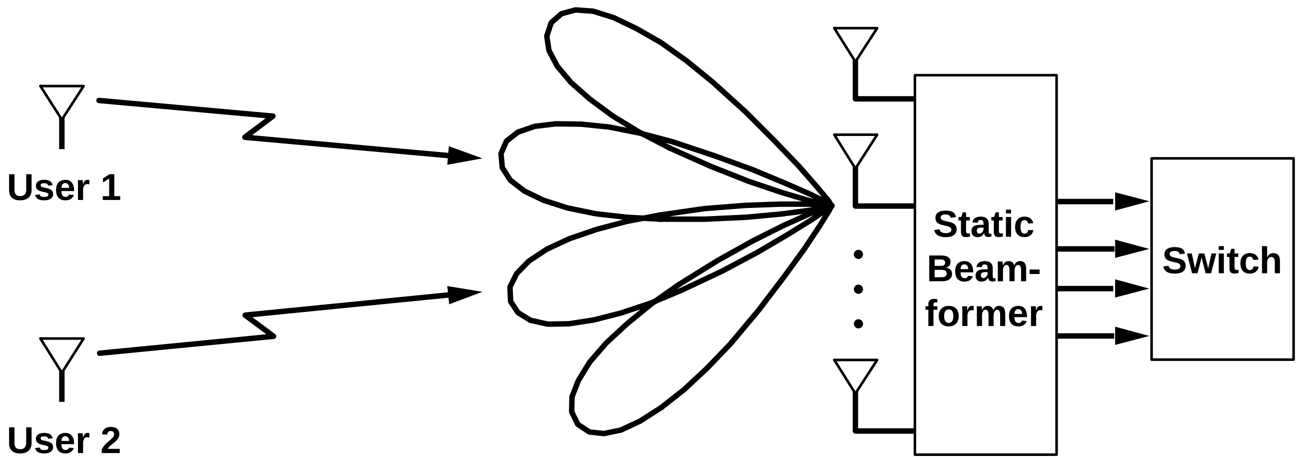
SMART ANTENNAS

- Multiple antenna elements at the receiver and/or the transmitter form an antenna array.

- Space-time processing of the received signal at the array reduces interference, and also compensates for flat-fading and delay spread.

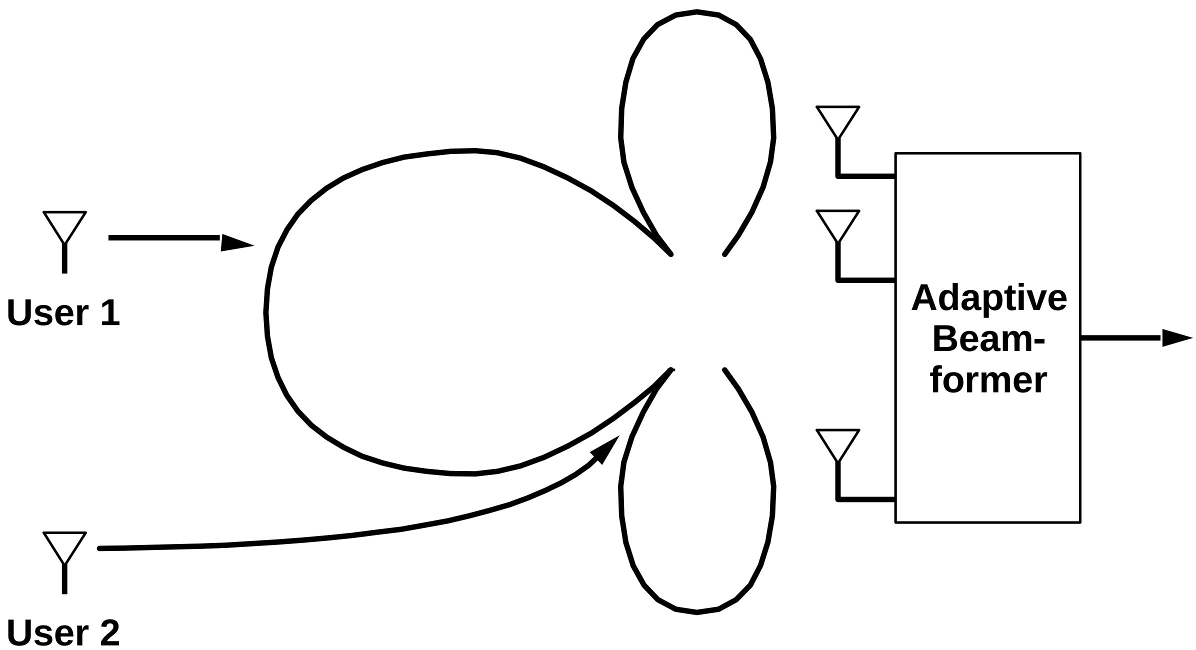
- Methods
  - switched beam
  - adaptive array

SWITCHED BEAMS



- Simple beamforming, is used followed by best beam selection
- An M-beam antenna reduces interference by roughly a factor of M.
- Diversity also reduces delay spread.
- Diversity gain can be obtained by combining beams

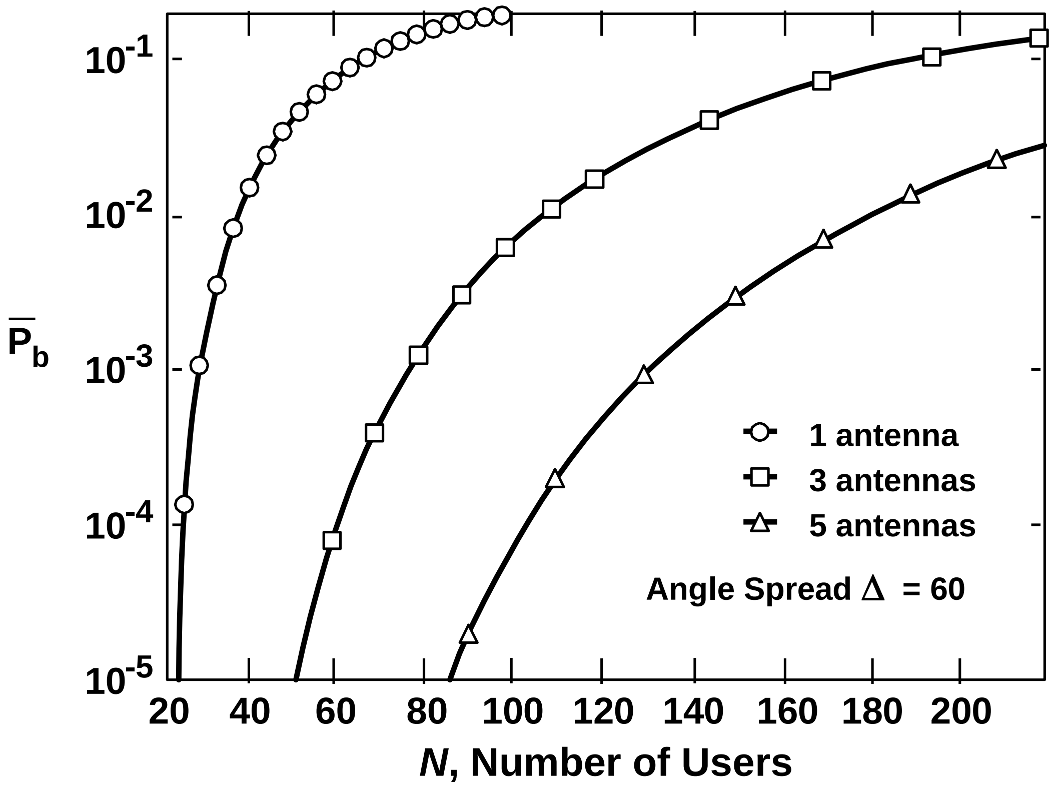
ADAPTIVE ARRAY



- Signals received by the multiple antennas are weighted and combined to maximize the signal-to-interference-plus-noise ratio.

- For M antenna elements, the array can cancel N<M interferers and achieve (M-N) fold diversity gain, when the delay spread is small.
  - signal processing is more complex in multipath
  - for large delay spreads, each multipath component must be treated as a separate signal

PERFORMANCE IMPROVEMENT



[A. F. Naguib and A. Paulraj, "Performance of Wireless CDMA with M-array Orthogonal Modulation and Cell-Site Antenna Arrays," *J. Sel. Areas Comm.,* Dec. 1996]

MULTIUSER DETECTION

- Goal: decode the interfering signals to remove them from the desired signal

- Interference cancellation
  - decode strongest signal first, and subtract it from the remaining signals
  - repeat the new cancellation process on the remaining signals
  - works best when signals are received at very different power levels

- Optimal multiuser detector (Verdu Algorithm)
  - cancels interference between users in parallel
  - complexity increases exponentially with the number of users

- Other techniques tradeoff performance and complexity
  - decorrelating detector
  - decision-feedback detector
  - multistage detector

$\Downarrow$

multiuser detection often requires knowledge of the channel parameters, which is difficult to obtain in a rapidly-changing environment

DYNAMIC CHANNEL ALLOCATION

- Generally, every channel (frequency, time slot,...) is available for use in every cell (subject to S/I constraint)
- Can adapt to local interference and traffic conditions
- Outperforms fixed assignment under light to moderate loading
- Can also adapt power, rate and base station assignment to further improve performance.
- Centralized versus distributed control
- Implications for high-speed packet data
  - can provide significant efficiency advantages
  - rapid measurements and reliable feedback channel required

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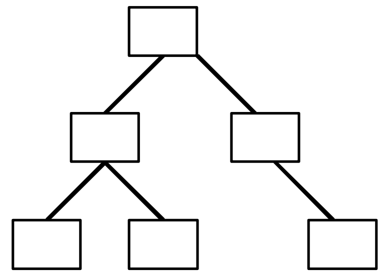
NETWORK ISSUES

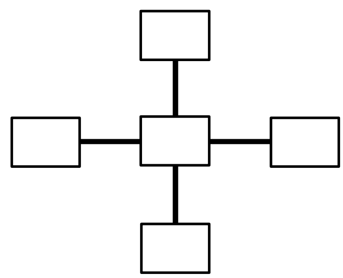
- Network Architectures
- Mobility Management
- Network Reliability
- Internetworking
- Security

NETWORK ARCHITECTURES

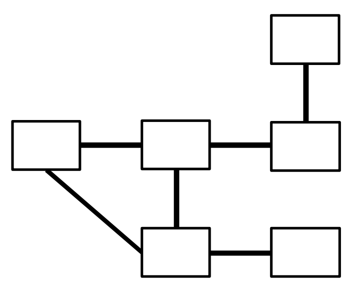
- Hierarchical/Tree



- Star



- Ad-Hoc



- **Implications for High-Speed Wireless Data**
  - single hop versus multiple hops
  - static versus dynamic topology
  - single points of failure

NETWORK CONTROL

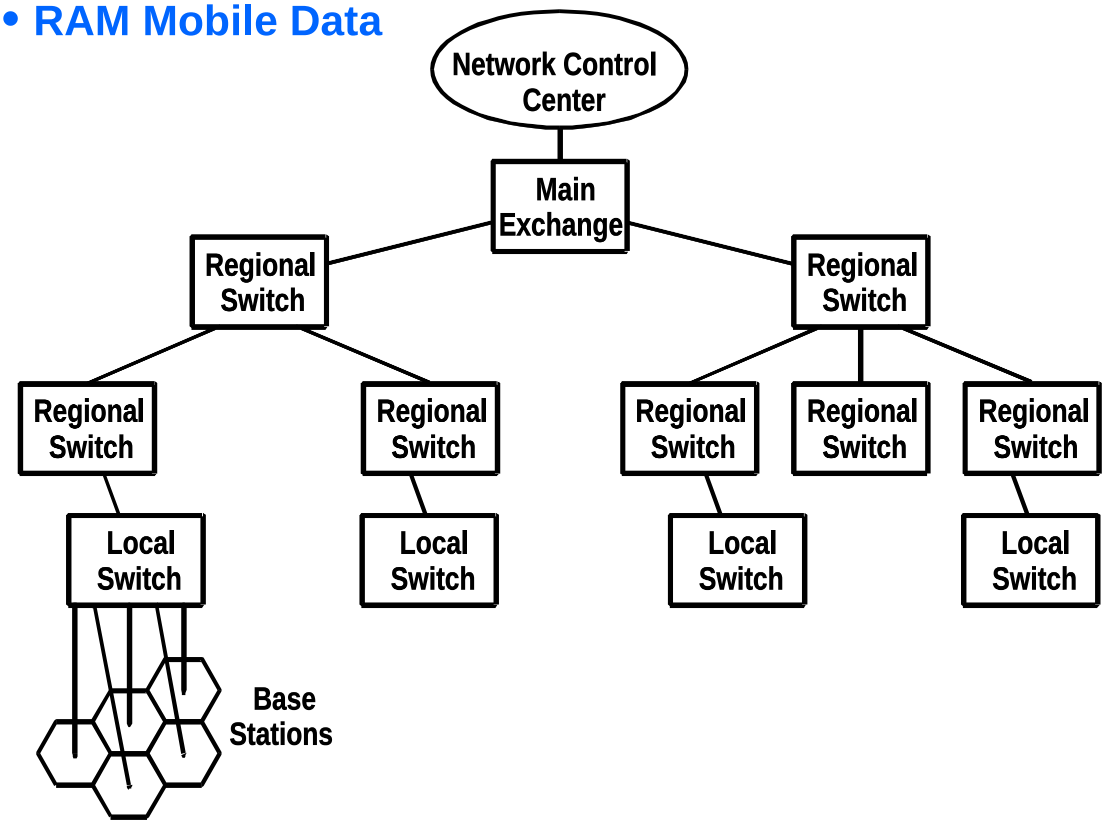
- Centralized
  - RAM Mobile Data
  - CDPD
  - Altair

- Distributed/Peer-to-Peer
  - WaveLAN

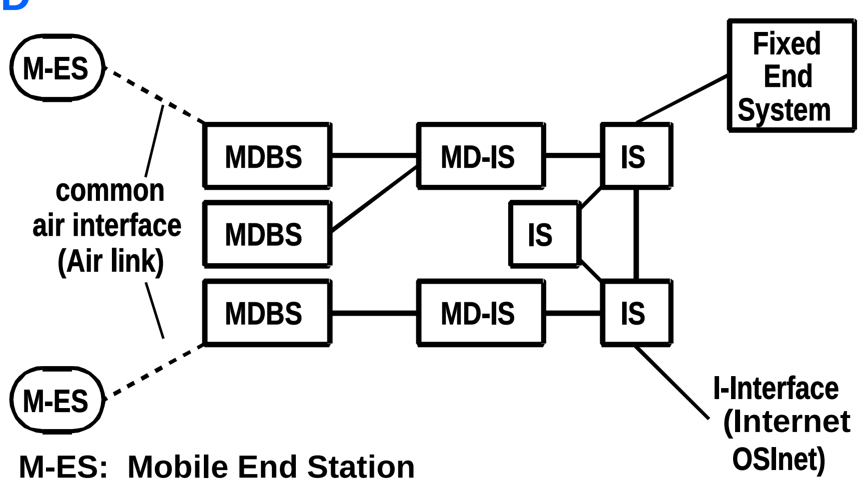
- Implications for High-Speed Wireless Data
  - less channel estimation required with centralized control $\Rightarrow$ increases efficiency of packet transmission
  - centralized control provides more efficient resource management with setup-time overhead
  - an extensive infrastructure is not required for distributed control

EXAMPLES

- RAM Mobile Data



- CDPD



M-ES: Mobile End Station
MDBS: Mobile Data Base Station
MD-IS: Intermediate Server for CDPD traffic

WIRELESS SOFTWARE AND MOBILITY PROTOCOLS

- IPv6 - Internet Engineering Task Force
- Wireless ATM - ATM Forum
- Windows CE - Microsoft
- Hand-Held Device Markup Language (HDML) - Unwired Planet
- GEOS Operating System - Geoworks

MOBILITY MANAGEMENT

- Location Management
  - identification and authentication
  - home and visitor location data bases (cellular)
  - discovery and registration (Mobile IP)

- Routing
  - fixed data bases (connection-oriented)
  - Mobile IP (connectionless)
  - tree (virtual connection)

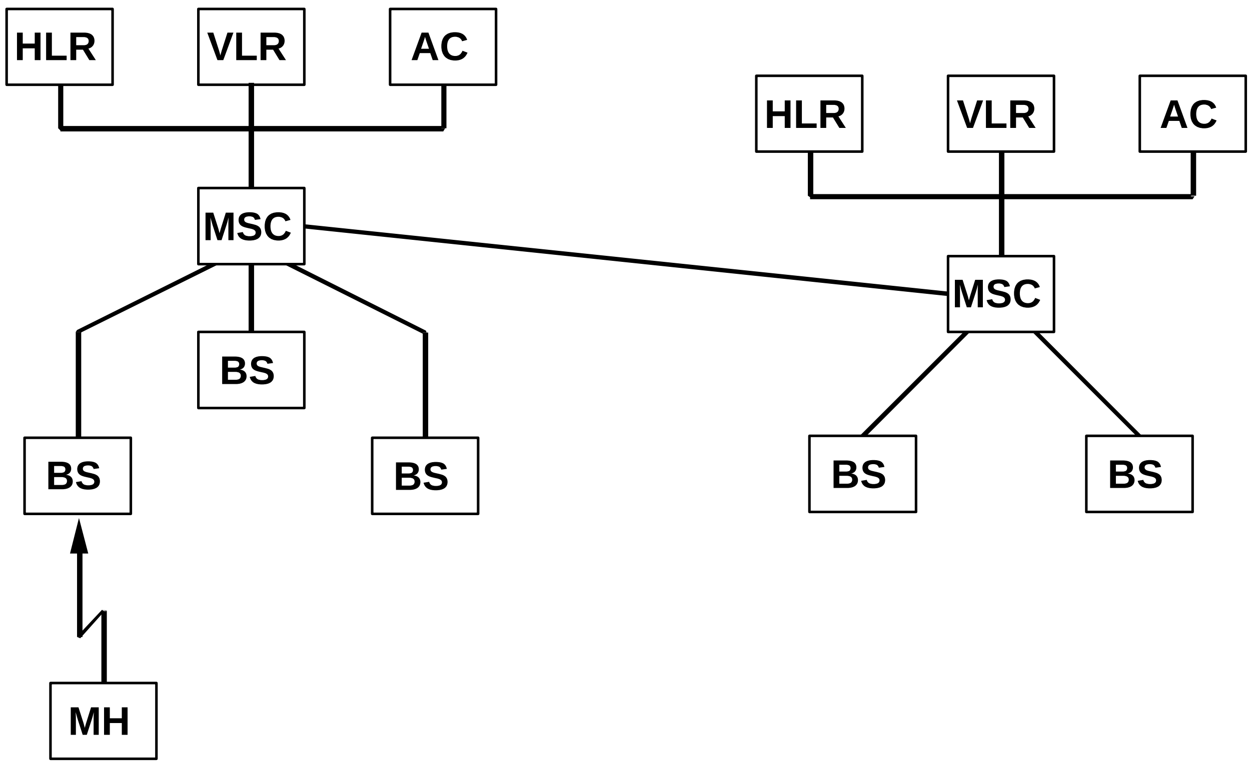
$\Downarrow$

overhead and delay impact throughput

suboptimal (triangle) routing $\Rightarrow$ delay inefficiency and higher congestion

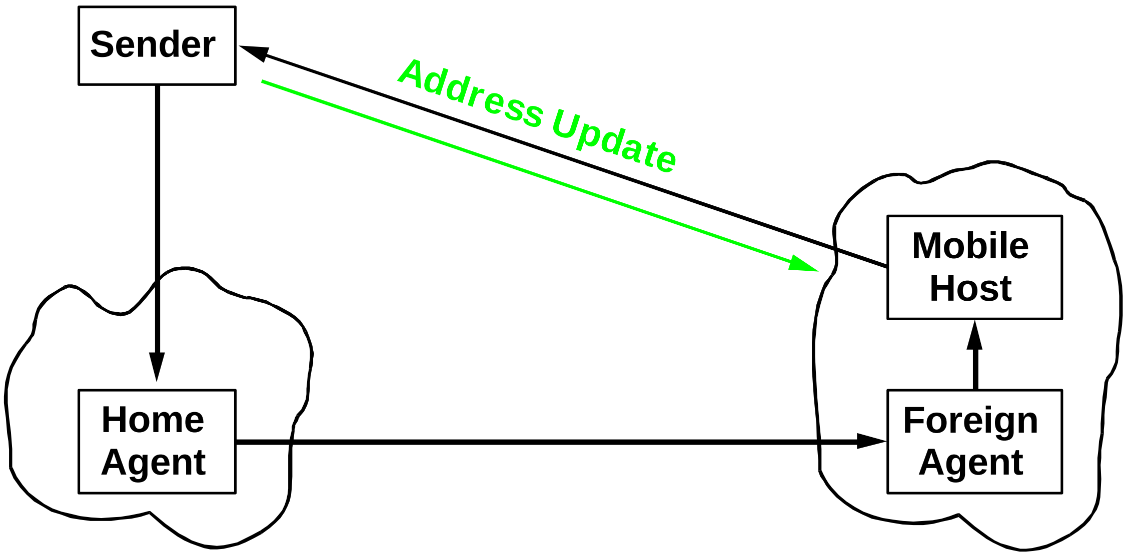
- Handoff
  - transmissions may be delayed or dropped $\Rightarrow$ impacts higher layer protocols
  - multi-homing $\Rightarrow$ inefficient use of resources

ROUTING IN CELLULAR SYSTEMS



- A roaming Mobile Host (MH) registers in the vehicle location register of the visiting network.
- The visiting MSC notifies the home MSC, which updates the HLR of the MH with its roaming information.
- Calls to the MH are routed from the home MSC to the visiting MSC.

MOBILE IP



- Communications takes place between a sender and a receiving Mobile Host (MH).
- Every MH has a home network and a corresponding home address.
- When the MH is roaming the home agent routes its packets to its care-of-address, either directly or through a foreign agent.
- The MH can send packets directly back to the sender, including its care-of-address (security issues).
- The latency of mobile IP is typically much less than a second.

NETWORK RELIABILITY

- End-to-End connection is composed of many wireless/wired hops.
  - widely varying data rates
  - high BERs on some/all hops
  - large, varying latencies
  - user mobility causes hop characteristics to vary

- Problem with reliability protocols like TCP.
  - wireless losses mistaken for congestion
  - bulk losses cause timeouts
  - large round-trip time variances and asymmetric channels

APPROACHES TO NETWORK RELIABILITY

- Local (link-layer) solutions
  - Forward error correction does not work well in fading
  - ARQ introduces large latency

- End-to-end solutions
  - Difficult to distinguish if packet loss due to congestion or link quality
  - Difficult to design for changing hop characteristics

$\Downarrow$

End-to-end performance guarantees are difficult to make

- Potential solutions
  - Hierarchical/layered coding of voice/video/images
  - Different Quality-of-Service classes
  - Application awareness
  - Local solution with end-to-end awareness

$\Downarrow$

Requires interaction between all layers

QUALITY OF SERVICE (QoS)

- Traffic dependent performance metrics required for type of data transmitted
  - bandwidth
  - latency
  - likelihood of packet (message) loss

- Categories
  - guaranteed
  - predictive
  - best effort

- Implications for high speed wireless data
  - QoS performance generally based on switched, fiber-optic, wired networks
  - wireless links have high P_b and high latency due to link layer retransmission and unpredictable link bandwidths
  - QoS guarantees and predictions are difficult to make for wireless networks $\Rightarrow$ it is not clear that the best effort is good enough for most applications

INTERNETWORKING

- TCP/IP
  - Compatible with existing wired networks
  - Works well over large range of wired subnet performance
  - TCP has problems operating over wireless links

- Wireless ATM
  - ATM is emerging standard for multimedia transmission over wired networks
  - ATM protocol based on links with 10^{-10} BER and Mbps/Gbps data rates
    - high overhead in packet structure
    - QOS guarantees
  - Not clear that ATM protocol can be modified for wireless links

SECURITY

- Network Security
  - end-to-end encryption
  - fraudulent access prevention
  - network monitoring prevention

- Link Security
  - message privacy
  - location privacy
  - anti-jam

- Hardware Security
  - fraudulent use prevention
  - user database security

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STANDARDS AND FUTURE SYSTEMS

- Wireless LANs
- High-Speed Digital Cellular
- International Mobile Telecommunications 2000 (IMT-2000)
- Wireless Local Loop
- Wireless "Cable"
  - Multichannel Multipoint Distribution Service (2.2 GHz)
  - Local Multipoint Distribution Service (28 GHz)

WIRELESS LANs

- “ANDREW” (Carnegie - Mellon)
- HIPERLAN 1 and 2
- National Information Infrastructure (NII)
- Wireless ATM

HIPERLAN TYPE 1

- European Wireless LAN Standard
- 5.15-5.3 GHz, 17.1-17.3 GHz
- 23 Mbps, 20 MHz Channel Spacing
- 50-meters Range
- Single Carrier
  - Equalization
  - GMSK

NII

- IEEE 802.11
- 5.15-5.35 GHz, 5.725-5.825 GHz
- 20 Mbps, 23.5294 MHz Channel Spacing
- OFDM
  - 48 subcarriers
  - 3/4-rate convolution coding
  - DQPSK
- Power Levels

5.15-5.25 GHz	50 mW
5.25-5.35 GHz	250 mW
5.725-5.825 GHz	1 W

- Broadband Radio Access Network (BRAN/HIPERLAN Type 2) in Europe

HIGH-SPEED DIGITAL CELLULAR

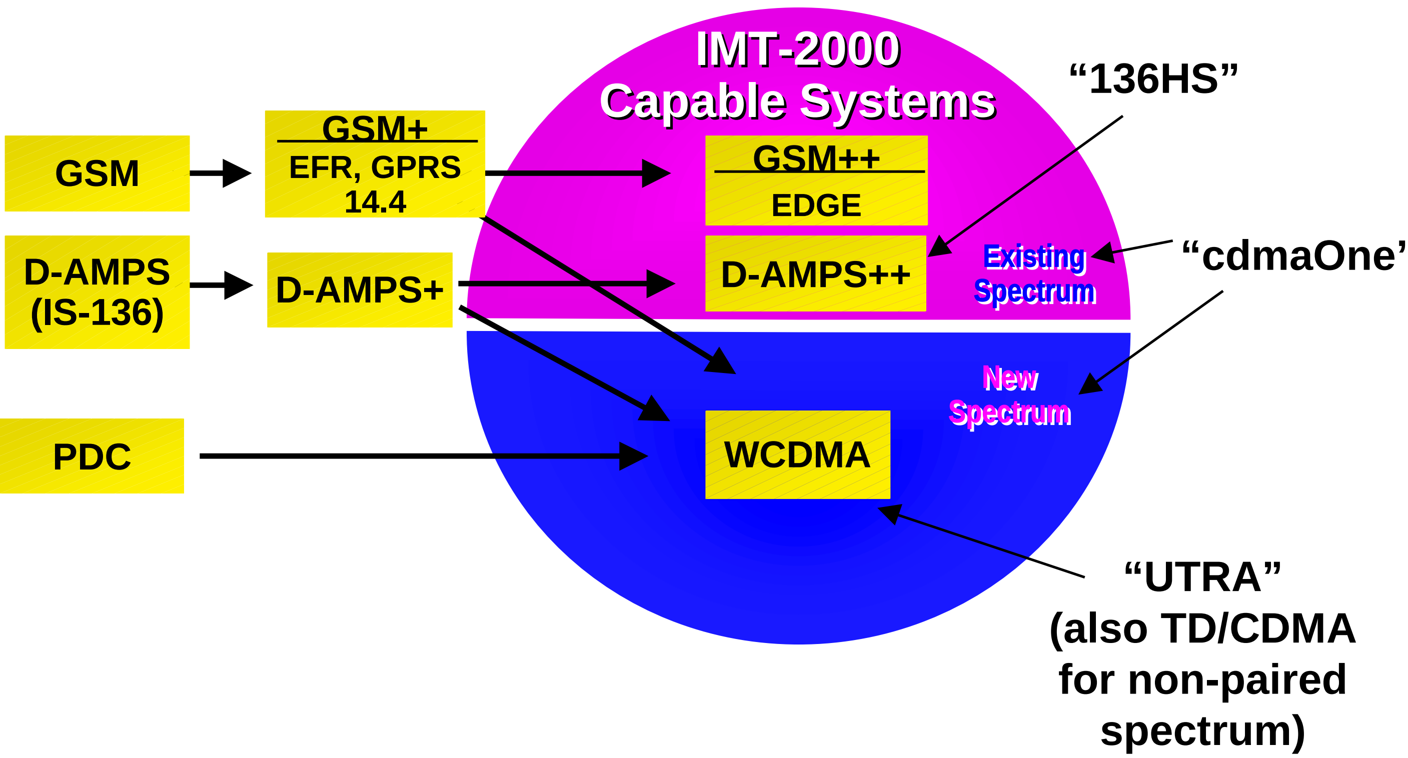
- North American Digital Cellular
  - CDMA (IS-95) enhancements
  - TDMA (IS-136) enhancements
  - IS-136+ ⇒ 32-64 kbps
  - IS-136HS ⇒ 384 kbps

- GSM
  - General Packet Radio System (GPRS)
  - Enhanced Data Rates for GSM Evolution (EDGE)

IMT-2000

- ITU Global Standards Effort ("Third Generation")
- Services
  - Voice, data, multimedia
  - Data rates 144k-384k-2M bps (vehicular-pedestrian-indoor)
  - Fixed wireless, satellite applications
- Wideband CDMA
- Wideband TDMA
- Enhanced Data Rates for GSM Evolution (EDGE)
- OFDM Approaches
  - Band Division Multiple Access (BDMA)
  - Telia OFDM
  - Advance Cellular Internet Service (ACIS)

EVOLUTION TO IMT-2000



IMT-2000 CANDIDATES

- US
  - Process: US TG 8/1; TR45, TR46, T1P1
  - cdmaOne (IS95 x 3)
  - IS136-based
  - IS136HS: IS136+ and EDGE

- Japan
  - Process: ARIB
  - W-CDMA
  - W-TDMA
    - OFDM,...

- Europe
  - Process: ETSI (UMTS; UTRA)
  - W-CDMA
  - W-TDMA
    - TDMA
    - TD/CDMA
    - OFDM

IMT-2000 SPECTRUM

- WRC ‘92
  - 50+ MHz x 2
  - 1900 and 2100 MHz

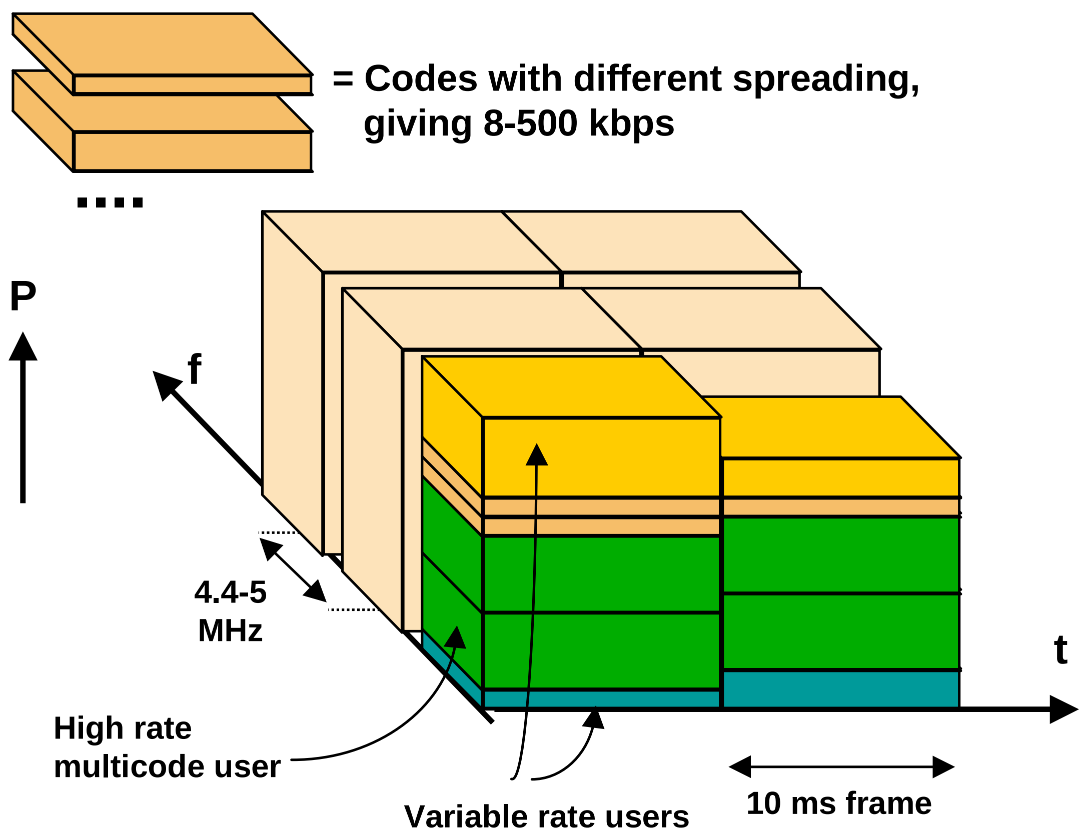
- Prospects
  - Europe - UMTS spectrum similar
  - Japan - yes
  - Asia - mixed but positive
  - US - 1900 spectrum allocated for PCS!

EDGE

- Evolution of GSM / GPRS
- ETSI standardization as GSM evolution chosen for data services for IS136HS
- Higher-level modulation (adaptive)
- 200 kHz carrier spacing
- Up to 384 kbps in 200 kHz

WIDEBAND CDMA

- The W-CDMA concept:
  - 4.096 Mcps Direct Sequence CDMA
  - Variable spreading and multicode operation
  - Coherent in both up-and downlink



W-CDMA
KEY TECHNICAL FEATURES

- High bit-rate services require wideband
- Flexibility for different services
- Optimized for packet data transfer
- Capacity and coverage gain from frequency diversity
- Built in support for
  - adaptive antenna arrays
  - multi-user detection
  - hierarchical cell structures
  - transmitter diversity
- Low infrastructure cost (many users/ transceiver)
- BS synchronization not required

W-CDMA EUROPE/JAPAN/US

		W-CDMA	IS-95
Basic chip rate		4.096 Mcps	1.228 Mcps
Carrier spacing		4.4-5 MHz	1.25 MHz
Inter-BS synchronization		Asynchronous	Synchronous
Frame length		10 ms	20 ms
Multi-rate/variable-rate		Multi-code + Orthog. Variable SF	DTX / Repetition
Coherent detect	U.L. D.L.	Pilot bits Pilot bits	Non-coherent Pilot code
Layer 1 control (pilot bits, TPC bits, etc)	U.L. D.L.	IQ / code multiplexed Time multiplexed	N/A TPC time multiplexed
Associated control		Time multiplexed (inband)	Time multiplexed (inband)
Soft Handover		Absolute thresholds	Relative thresholds
Interfrequency handover		Mobile Assisted (Slotted or Dual Receiver)	Not Mobile Assisted

cdmaOne: similar improvement but different chip rate

SUMMARY

- The desire for mobility coupled with the demand for Internet and multimedia services indicate a bright future for wireless data.
- Current products and services have unsatisfactory performance for high-speed wireless data applications.
- The inherent limitations of the radio channel can be significantly reduced using signal processing and architectural techniques, at the expense of cost and complexity.
- The network-level design must take into account the physical layer limitations of the wireless channel, as well as the impact of user mobility.