

# **Cellular Wireless Networks**

## **Principles of Cellular Networks**

- Underlying technology for mobile phones, personal communication systems, wireless networking etc.
- Developed for mobile radio telephone
  - Replace high power transmitter/receiver systems
    - Typical support for 25 channels over 80km
  - Use lower power, shorter range, more transmitters

## **Cellular Network Organization**

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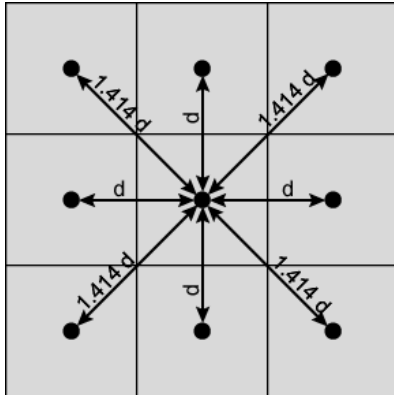
- Multiple low power transmitters
  - 100W or less
- Area divided into cells
  - Each with own antenna
  - Each with own range of frequencies
  - Served by base station
    - Transmitter, receiver, control unit
  - Adjacent cells on different frequencies to avoid crosstalk

## **Shape of Cells**

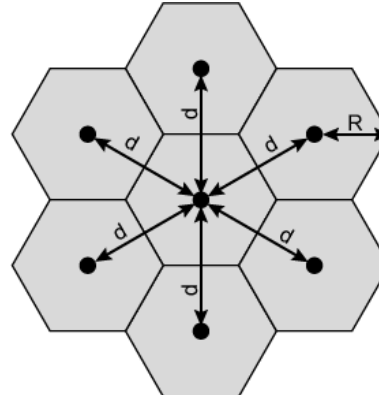
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- Square
  - Width  $d$  cell has four neighbors at distance  $d$  and four at distance  $\sqrt{2}d$
  - Better if all adjacent antennas equidistant
    - Simplifies choosing and switching to new antenna
- Hexagon
  - Provides equidistant antennas
  - Radius defined as radius of circum-circle
    - Distance from center to vertex equals length of side
  - Distance between centers of cells radius  $R$  is  $\sqrt{3}R$
  - Not always precise hexagons
    - Topographical limitations
    - Local signal propagation conditions
    - Location of antennas

## Cellular Geometries



(a) Square pattern



(b) Hexagonal pattern

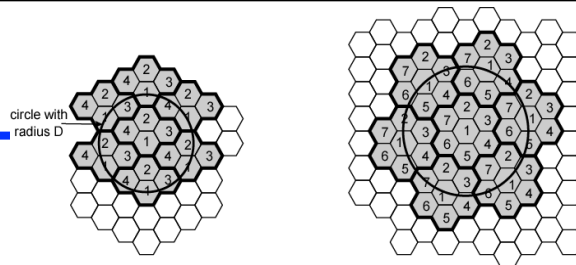
## Frequency Reuse

- Power of base transceiver controlled
  - Allow communications within cell on given frequency
  - Limit escaping power to adjacent cells
  - Allow re-use of frequencies in nearby cells
  - Use same frequency for multiple conversations
  - 10 – 50 frequencies per cell
- *E.g.*
  - $N$  is the number of cells in a pattern, all using same number of frequencies
  - $K$  total number of frequencies used in systems
  - Each cell can use  $K/N$  frequencies
  - Advanced Mobile Phone Service (AMPS)  $K=395$ ,  $N=7$  giving 57 frequencies per cell on average

# Characterizing Frequency Reuse

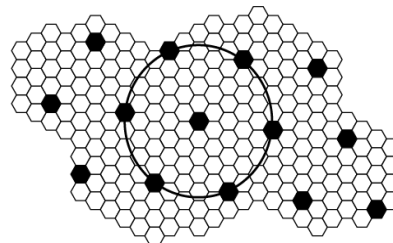
- D = minimum distance between centers of cells that use the same band of frequencies (called co-channels)
- R = radius of a cell
- d = distance between centers of adjacent cells ( $d = \sqrt{3} R$ )
- N = number of cells in repetitious pattern
  - Reuse factor
  - Each cell in pattern uses unique band of frequencies
- Hexagonal cell pattern, following values of N possible
  - $N = I^2 + J^2 + (I \times J)$ ,  $I, J = 0, 1, 2, 3, \dots$
- Possible values of N are 1, 3, 4, 7, 9, 12, 13, 16, 19, 21, ...
- $D/R = \sqrt{3N}$
- $D/d = \sqrt{N}$

# Frequency Reuse Patterns



(a) Frequency reuse pattern for N = 4

(b) Frequency reuse pattern for N = 7

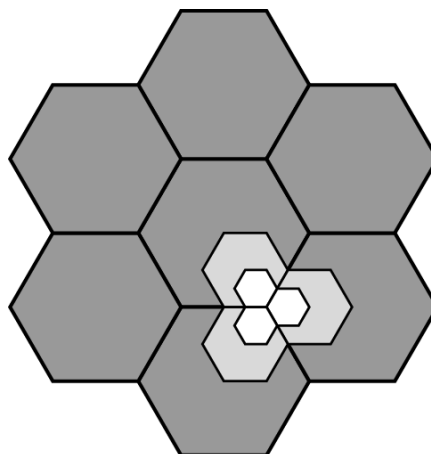


(c) Black cells indicate a frequency reuse for N = 19

## **Increasing Capacity (1)**

- Add new channels
  - Not all channels used to start with
- Frequency borrowing
  - Taken from adjacent cells by congested cells
  - Or assign frequencies dynamically
- Cell splitting
  - Non-uniform distribution of topography and traffic
  - Smaller cells in high use areas
    - Original cells 6.5 – 13 km
    - 1.5 km limit in general
    - More frequent handoff
    - More base stations

## **Cell Splitting**



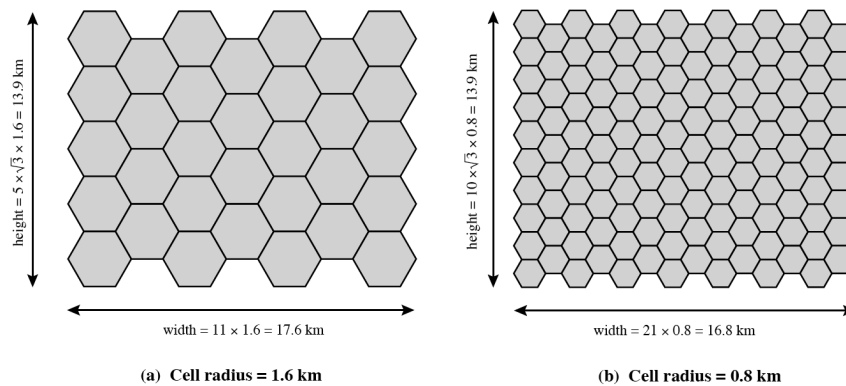
## Increasing Capacity (2)

- Cell Sectoring
  - Cell divided into wedge shaped sectors
  - 3 – 6 sectors per cell
  - Each with own channel set
    - Subsets of cell's channels
  - Directional antennas
- Microcells
  - Move antennas from tops of hills and large buildings to tops of small buildings and sides of large buildings
    - Even lamp posts
  - Form microcells
  - Reduced power
  - Good for city streets, along roads and inside large buildings

## Frequency Reuse Example

Assume: 32 cells, cell radius = 1.6 km, frequency bandwidth supports 336 channels, reuse factor  $N=7$ .

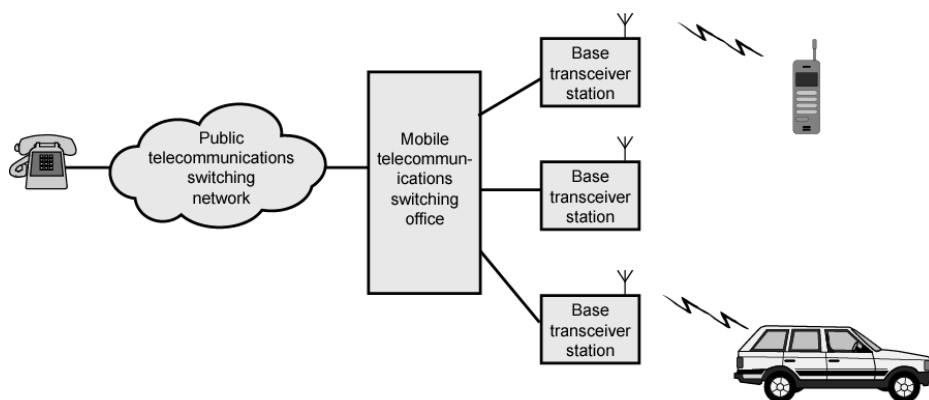
How many channels per cell? What is total # of concurrent calls?



## Operation of Cellular Systems

- Base station (BS) at center of each cell
  - Antenna, controller, transceivers
- Controller handles call process
  - Number of mobile units may in use at a time
- BS connected to Mobile Telecommunications Switching Office (MTSO)
  - One MTSO serves multiple BS
  - MTSO to BS link by wire or wireless
- MTSO:
  - Connects calls between mobile units and from mobile to fixed telecommunications network
  - Assigns voice channel
  - Performs handoffs
  - Monitors calls (billing)
- Fully automated

## Overview of Cellular System



## **Channels**

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- Control channels
  - Setting up and maintaining calls
  - Establish relationship between mobile unit and nearest BS
- Traffic channels
  - Carry voice and data

## **Typical Call in Single MTSO Area (1)**

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- Mobile unit initialization
  - Scan and select strongest set up control channel
  - Automatically selected BS antenna of cell
    - Usually but not always nearest (propagation anomalies)
  - Handshake to identify user and register location
  - Scan repeated to allow for movement
    - Change of cell
  - Mobile unit monitors for pages (see below)



## **Typical Call in Single MTSO Area (2)**

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- Mobile originated call
  - Check if set up channel is free
    - Monitor forward channel (from BS) and wait for idle
  - Send number on pre-selected channel
- Paging
  - MTSO attempts to connect to mobile unit
  - Paging message sent to BSs depending on called mobile number
  - Paging signal transmitted on set up channel

## **Typical Call in Single MTSO Area (3)**

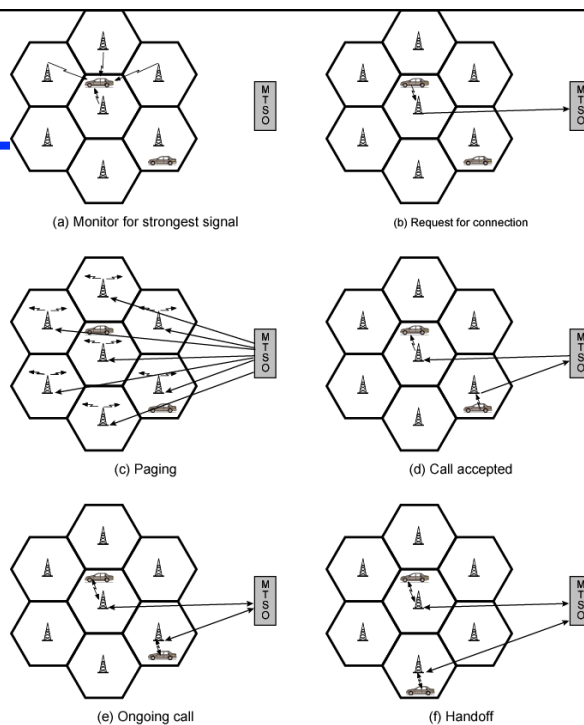
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- Call accepted
  - Mobile unit recognizes number on set up channel
  - Responds to BS which sends response to MTSO
  - MTSO sets up circuit between calling and called BSs
  - MTSO selects available traffic channel within cells and notifies BSs
  - BSs notify mobile unit of channel

## Typical Call in Single MTSO Area (4)

- Ongoing call
  - Voice/data exchanged through respective BSs and MTSO
- Handoff
  - Mobile unit moves out of range of cell into range of another cell
  - Traffic channel changes to one assigned to new BS
    - Without interruption of service to user

## Call Stages



## **Other Functions**

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- Call blocking
  - During mobile-initiated call stage, if all traffic channels busy, mobile tries again
  - After number of fails, busy tone returned
- Call termination
  - User hangs up
  - MTSO informed
  - Traffic channels at two BSs released

## **Other Functions**

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- Call drop
  - BS cannot maintain required signal strength
  - Traffic channel dropped and MTSO informed
- Calls to/from fixed and remote mobile subscriber
  - MTSO connects to PSTN
  - MTSO can connect mobile user and fixed subscriber via PSTN
  - MTSO can connect to remote MTSO via PSTN or via dedicated lines
  - Can connect mobile user in its area and remote mobile user

## **Mobile Radio Propagation Effects**

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- Signal strength
  - Strength of signal between BS and mobile unit strong enough to maintain signal quality at the receiver
  - Not strong enough to create too much co-channel interference
  - Noise varies
    - Automobile ignition noise greater in city than in suburbs
    - Other signal sources vary
    - Signal strength varies as function of distance from BS
    - Signal strength varies dynamically as mobile unit moves
- Fading
  - Even if signal strength in effective range, signal propagation effects may disrupt the signal

## **Design Factors**

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- Propagation effects
  - Dynamic
  - Hard to predict
- Maximum transmit power level at BS and mobile units
- Typical height of mobile unit antenna
- Available height of the BS antenna
- These factors determine size of individual cell
- Model based on empirical data
- Apply model to given environment to develop guidelines for cell size

## Fading

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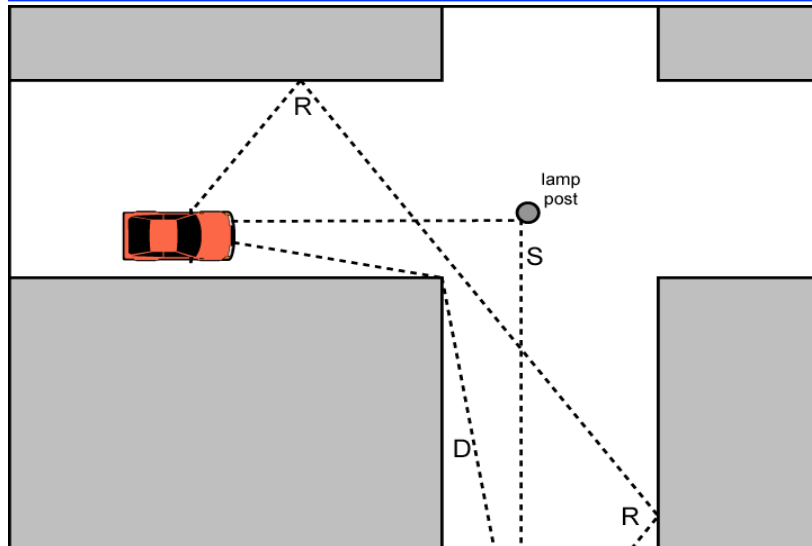
- Time variation of received signal
- Caused by changes in transmission path(s)
  - E.g. atmospheric conditions (rain)
  - Movement of (mobile unit) antenna

## Multipath Propagation

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- Reflection
  - Surface large relative to wavelength of signal
  - May have phase shift from original
  - May cancel out original or increase it
- Diffraction
  - Edge of impenetrable body that is large relative to wavelength
  - May receive signal even if no **line of sight** (LOS) to transmitter
- Scattering
  - Obstacle size on order of wavelength
    - Lamp posts etc.
- If LOS, diffracted and scattered signals not significant
  - Reflected signals may be
- If no LOS, diffraction and scattering are primary means of reception

## Reflection, Diffraction, Scattering



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Page 27

Sequence 14

## Effects of Multipath Propagation

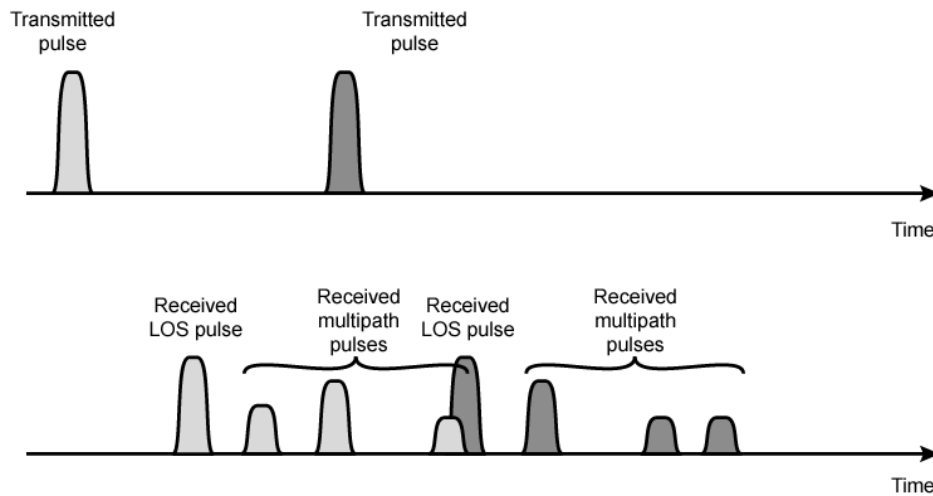
- Signals may cancel out due to phase differences
- Inter-symbol Interference (ISI)
  - Sending narrow pulse at given frequency between fixed antenna and mobile unit
  - Channel may deliver multiple copies at different times
  - Delayed pulses act as noise making recovery of bit information difficult
  - Timing changes as mobile unit moves
    - Harder to design signal processing to filter out multipath effects

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Page 28

Sequence 14

## Two Pulses in Time-Variant Multipath



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Page 29

Sequence 14

## Types of Fading

- Fast fading
  - Rapid changes in strength over distances about half wavelength
    - 900MHz wavelength is 0.33m
    - 20-30dB
- Slow fading
  - Slower changes due to user passing different height buildings, gaps in buildings etc.
  - Over longer distances than fast fading
- Flat fading
  - Nonselective
  - Affects all frequencies in same proportion
- Selective fading
  - Different frequency components affected differently

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Page 30

Sequence 14

## **Error Compensation Mechanisms (1)**

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- Forward error correction
  - Applicable in digital transmission applications
  - Typically, ratio of total bits sent to data bits between 2 and 3
  - Big overhead
    - Capacity one-half or one-third
    - Reflects difficulty of mobile wireless environment

## **Error Compensation Mechanisms (2)**

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- Adaptive equalization
  - Applied to transmissions that carry analog or digital information
  - Used to combat inter-symbol interference
  - Gathering the dispersed symbol energy back together into its original time interval
  - Techniques include so-called lumped analog circuits and sophisticated digital signal processing algorithms



## **Error Compensation Mechanisms (3)**

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- Diversity
  - Based on fact that individual channels experience independent fading events
  - Provide multiple logical channels between transmitter and receiver
  - Send part of signal over each channel
  - Does not eliminate errors
  - Reduce error rate
  - Equalization, forward error correction then cope with reduced error rate
  - May involve physical transmission path
    - Space diversity
    - Multiple nearby antennas receive message or collocated multiple directional antennas
  - More commonly, diversity refers to frequency or time diversity

## **Frequency Diversity**

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- Signal is spread out over a larger frequency bandwidth or carried on multiple frequency carriers
- E.g. spread spectrum

## **First Generation Analog**

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- Original cellular telephone networks
- Analog traffic channels
- Early 1980s in North America
- Advanced Mobile Phone Service (AMPS)
  - AT&T
- Also common in South America, Australia, and China

## **Spectral Allocation In North America**

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- Two 25-MHz bands are allocated to AMPS
  - One from BS to mobile unit (869–894 MHz)
  - Other from mobile to base station (824–849 MHz)
- Bands is split in two to encourage competition
  - In each market two operators can be accommodated
- Operator is allocated only 12.5 MHz in each direction
- Channels spaced 30 kHz apart
  - Total of 416 channels per operator
- Twenty-one channels allocated for control
- 395 to carry calls
- Control channels are 10 kbps data channels
- Conversation channels carry analog using frequency modulation
- Control information also sent on conversation channels in bursts as data
- Number of channels inadequate for most major markets
- For AMPS, frequency reuse is exploited

## Operation

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- AMPS-capable phone has numeric assignment module (NAM) in read-only memory
  - NAM contains number of phone
    - Assigned by service provider
  - Serial number of phone
    - Assigned by the manufacturer
  - When phone turned on, transmits serial number and phone number to MTSO
  - MTSO has database of mobile units reported stolen
    - Uses serial number to lock out stolen units
  - MTSO uses phone number for billing
  - If phone is used in remote city, service is still billed to user's local service provider

## Call Sequence

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1. Subscriber initiates call by keying in number and presses send
2. MTSO validates telephone number and checks user authorized to place call
  - Some service providers require a PIN to counter theft
3. MTSO issues message to user's phone indicating traffic channels to use
4. MTSO sends ringing signal to called party
  - All operations, 2 through 4, occur within 10 s of initiating call
5. When called party answers, MTSO establishes circuit and initiates billing information
6. When one party hangs up MTSO releases circuit, frees radio channels, and completes billing information

## **AMPS Control Channels**

- 21 full-duplex 30-kHz control channels
  - Transmit digital data using FSK
  - Data are transmitted in frames
- Control information can be transmitted over voice channel during conversation
  - Mobile unit or the base station inserts burst of data
    - Turn off voice FM transmission for about 100 ms
    - Replacing it with an FSK-encoded message
  - Used to exchange urgent messages
    - Change power level
    - Handoff

## **Second Generation (CDMA)**

- Higher quality signals
- Higher data rates
- Support of digital services
- Greater capacity
- Digital traffic channels
  - Support digital data
  - Voice traffic digitized
  - User traffic (data or digitized voice) converted to analog signal for transmission
- Encryption
  - Simple to encrypt digital traffic
- Error detection and correction
  - (See chapter 6)
  - Very clear voice reception
- Channel access
  - Channel dynamically shared by users via Time division multiple access (TDMA) or code division multiple access (CDMA)

## **Code Division Multiple Access**

- Each cell allocated frequency bandwidth
  - Split in two
    - Half for reverse, half for forward
    - Direct-sequence spread spectrum (DSSS)

## **Code Division Multiple Access Advantages**

- Frequency diversity
  - Frequency-dependent transmission impairments (noise bursts, selective fading) have less effect
- Multipath resistance
  - DSSS overcomes multipath fading by frequency diversity
  - Also, chipping codes used only exhibit low cross correlation and low autocorrelation
  - Version of signal delayed more than one chip interval does not interfere with the dominant signal as much
    - chips per second (number of bits per second)
- Privacy
  - From spread spectrum
- Graceful degradation
  - With FDMA or TDMA, fixed number of users can access system simultaneously
  - With CDMA, as more users access the system simultaneously, noise level and hence error rate increases
  - Gradually system degrades

## **Code Division Multiple Access**

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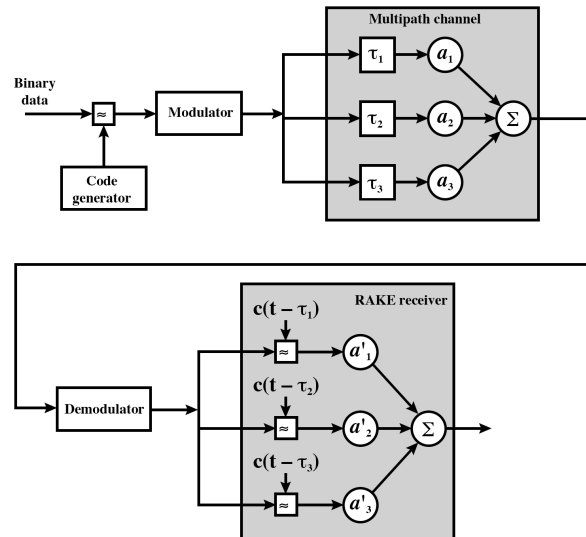
- Self-jamming
  - Unless all mobile users are perfectly synchronized, arriving transmissions from multiple users will not be perfectly aligned on chip boundaries
  - Spreading sequences of different users not orthogonal
  - Some cross correlation
  - Distinct from either TDMA or FDMA
    - In which, for reasonable time or frequency guardbands, respectively, received signals are orthogonal or nearly so
- Near-far problem
  - Signals closer to receiver are received with less attenuation than signals farther away
  - Given lack of complete orthogonality, transmissions from more remote mobile units may be more difficult to recover

## **RAKE Receiver**

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- If multiple versions of signal arrive more than one chip interval apart, receiver can recover signal by correlating chip sequence with dominant incoming signal
  - Remaining signals treated as noise
- Better performance if receiver attempts to recover signals from multiple paths and combine them, with suitable delays
- Original binary signal is spread by XOR operation with chipping code
- Spread sequence modulated for transmission over wireless channel
- Multipath effects generate multiple copies of signal
  - Each with a different amount of time delay ( $\tau_1$ ,  $\tau_2$ , etc.)
  - Each with a different attenuation factors ( $a_1$ ,  $a_2$ , etc.)
  - Receiver demodulates combined signal
  - Demodulated chip stream fed into multiple correlators, each delayed by different amount
  - Signals combined using weighting factors estimated from the channel

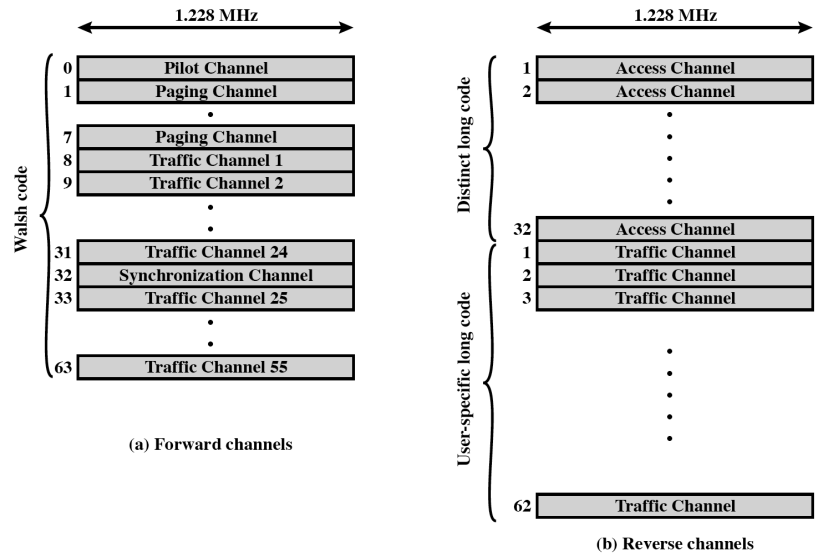
## Principle of RAKE Receiver



## IS-95

- Second generation CDMA scheme
- Primarily deployed in North America
- Transmission structures different on forward and reverse links

## IS-95 Channel Structure



## IS-95 Forward Link (1)

- Up to 64 logical CDMA channels each occupying the same 1228-kHz bandwidth
- Four types of channels:
  - Pilot (channel 0)
    - Continuous signal on a single channel
    - Allows mobile unit to acquire timing information
    - Provides phase reference for demodulation process
    - Provides signal strength comparison for handoff determination
    - Consists of all zeros
  - Synchronization (channel 32)
    - 1200-bps channel used by mobile station to obtain identification information about the cellular system
    - System time, long code state, protocol revision, etc.



## **IS-95 Forward Link (2)**

- Paging (channels 1 to 7)
  - Contain messages for one or more mobile stations
- Traffic (channels 8 to 31 and 33 to 63)
  - 55 traffic channels
  - Original specification supported data rates of up to 9600 bps
  - Revision added rates up to 14,400 bps
- All channels use same bandwidth
  - Chipping code distinguishes among channels
  - Chipping codes are the 64 orthogonal 64-bit codes derived from  $64 \times 64$  Walsh matrix

## **Forward Link Processing**

- Voice traffic encoded at 8550 bps
- Additional bits added for error detection
  - Rate now 9600 bps
- Full capacity not used when user not speaking
- Quiet period data rate as low as 1200 bps
- 2400 bps rate used to transmit transients in background noise
- 4800 bps rate to mix digitized speech and signaling data
- Data transmitted in 20 ms blocks
- Forward error correction
  - Convolutional encoder with rate  $\frac{1}{2}$
  - Doubling effective data rate to 19.2 kbps
  - For lower data rates encoder output bits (called code symbols) replicated to yield 19.2-kbps
- Data interleaved in blocks to reduce effects of errors by spreading them

## Scrambling

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- After interleaver, data scrambled
- Privacy mask
- Prevent sending of repetitive patterns
  - Reduces probability of users sending at peak power at same time
- Scrambling done by long code
  - Pseudorandom number generated from 42-bit-long shift register
  - Shift register initialized with user's electronic serial number
  - Output of long code generator is at a rate of 1.2288 Mbps
    - 64 times 19.2 kbps
    - One bit in 64 selected (by the decimator function)
    - Resulting stream XORed with output of block interleaver

## Power Control

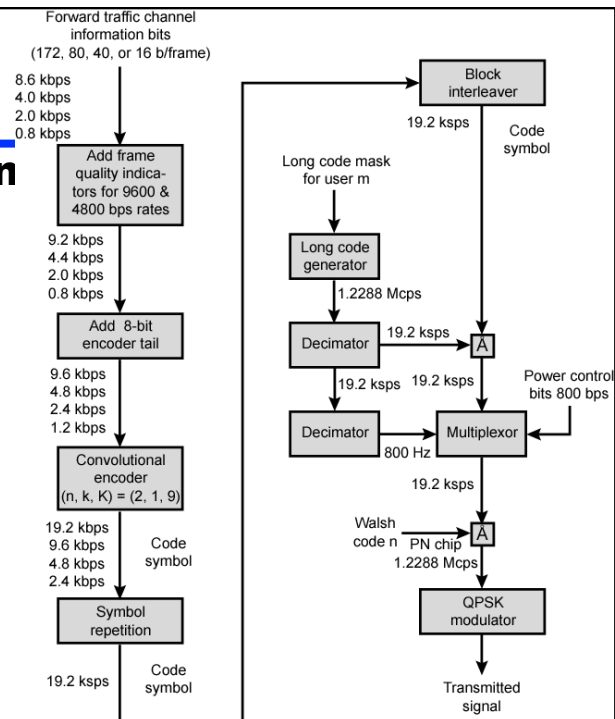
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- Next step inserts power control information in traffic channel
  - To control the power output of antenna
  - Robs traffic channel of bits at rate of 800 bps by stealing code bits
  - 800-bps channel carries information directing mobile unit to change output level
  - Power control stream multiplexed into 19.2 kbps
    - Replace some code bits, using long code generator to encode bits

# DSSS

- **D**irect-**S**equence **S**pread **S**pectrum
- Spreads 19.2 kbps to 1.2288 Mbps
- Using one row of Walsh matrix
  - Assigned to mobile station during call setup
  - If 0 presented to XOR, 64 bits of assigned row sent
  - If 1 presented, bitwise XOR of row sent
- Final bit rate 1.2288 Mbps
- Bit stream modulated onto carrier using QPSK
  - Data split into I and Q (in-phase and quadrature) channels
  - Data in each channel XORed with unique short code
    - Pseudorandom numbers from 15-bit-long shift register

# Forward Link Transmission



## Reverse Link

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- Up to 94 logical CDMA channels
  - Each occupying same 1228-kHz bandwidth
  - Supports up to 32 access channels and 62 traffic channels
- Traffic channels mobile unique
  - Each station has unique long code mask based on serial number
    - 42-bit number,  $2^{42} - 1$  different masks
    - Access channel used by mobile to initiate call, respond to paging channel message, and for location update

## Reverse Link Processing and Spreading

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- First steps same as forward channel
  - Convolutional encoder rate 1/3
  - Tripling effective data rate to max. 28.8 kbps
  - Data block interleaved
- Spreading using Walsh matrix
  - Use and purpose different from forward channel
  - Data from block interleaver grouped in units of 6 bits
  - Each 6-bit unit serves as index to select row of matrix ( $2^6 = 64$ )
  - Row is substituted for input
  - Data rate expanded by factor of 64/6 to 307.2 kbps
  - Done to improve reception at BS
  - Because possible codings orthogonal, block coding enhances decision-making algorithm at receiver
  - Also computationally efficient
  - Walsh modulation form of block error-correcting code
  - $(n, k) = (64, 6)$  and  $d_{\min} = 32$
  - In fact, all distances 32

## **Data Burst Randomizer**

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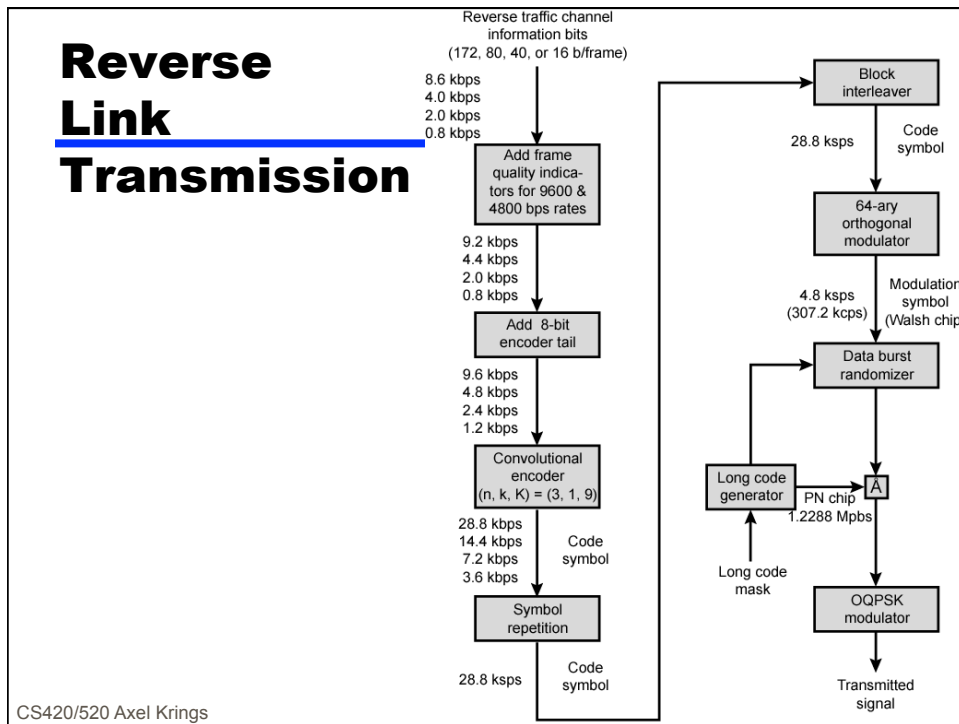
- Reduce interference from other mobile stations
- Using long code mask to smooth data out over 20 ms frame

## **DSSS**

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- Long code unique to mobile XORed with output of randomizer
- 1.2288-Mbps final data stream
- Modulated using orthogonal QPSK modulation scheme
- Differs from forward channel in use of delay element in modulator to produce orthogonality
  - Forward channel, spreading codes orthogonal
    - Coming from Walsh matrix
  - Reverse channel orthogonality of spreading codes not guaranteed

# Reverse Link Transmission



## Third Generation Systems

- Objective to provide fairly high-speed wireless communications to support multimedia, data, and video in addition to voice
- ITU's International Mobile Telecommunications for the year 2000 (IMT-2000) initiative defined ITU's view of third-generation capabilities as:
  - Voice quality comparable to PSTN
  - 144 kbps available to users in vehicles over large areas
  - 384 kbps available to pedestrians over small areas
  - Support for 2.048 Mbps for office use
  - Symmetrical and asymmetrical data rates
  - Support for packet-switched and circuit-switched services
  - Adaptive interface to Internet
  - More efficient use of available spectrum
  - Support for variety of mobile equipment
  - Flexibility to allow introduction of new services and technologies

## **Driving Forces**

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- Trend toward universal personal telecommunications
  - Ability of person to identify himself and use any communication system in globally, in terms of single account
- Universal communications access
  - Using one's terminal in a wide variety of environments to connect to information services
  - e.g. portable terminal that will work in office, street, and planes equally well
- GSM cellular telephony with subscriber identity module, is step towards goals
- Personal communications services (PCSs) and personal communication networks (PCNs) also form objectives for third-generation wireless
- Technology is digital using time division multiple access or code-division multiple access
- PCS handsets low power, small and light

## **Alternative Interfaces (1)**

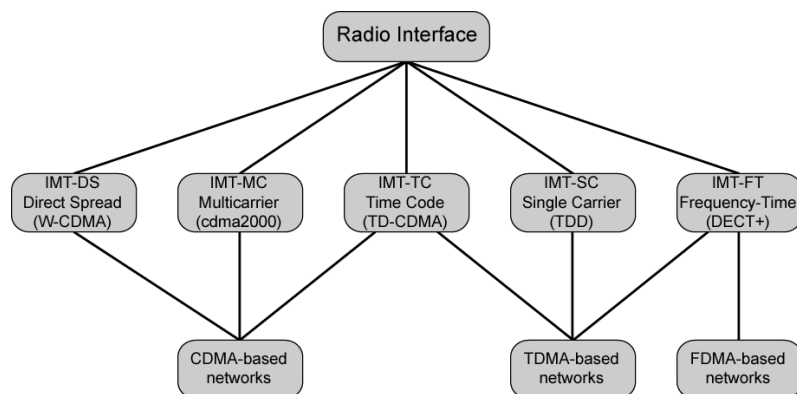
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- IMT-2000 specification covers set of radio interfaces for optimized performance in different radio environments
- Five alternatives to enable smooth evolution from existing systems
- Alternatives reflect evolution from second generation
- Two specifications grow out of work at European Telecommunications Standards Institute (ETSI)
  - Develop a UMTS (universal mobile telecommunications system) as Europe's 3G wireless standard
  - Includes two standards
    - Wideband CDMA, or W-CDMA
      - Fully exploits CDMA technology
      - Provides high data rates with efficient use of bandwidth
    - IMT-TC, or TD-CDMA
      - Combination of W-CDMA and TDMA technology
      - Intended to provide upgrade path for TDMA-based GSM systems

## Alternative Interfaces (2)

- CDMA2000
  - North American origin
  - Similar to, but incompatible with, W-CDMA
    - W-DCMA = Wideband Code Division Multiple Access
      - In part because standards use different chip rates
      - Also, cdma2000 uses multicarrier, not used with W-CDMA
- IMT-SC designed for TDMA-only networks
- IMT-FC can be used by both TDMA and FDMA carriers
  - To provide some 3G services
  - Outgrowth of Digital European Cordless Telecommunications (DECT) standard

## IMT-2000 Terrestrial Radio Interfaces





source: wikipedia

Overview of 3G/IMT-2000 standards<sup>[4]</sup>

ITU IMT-2000	common name(s)	bandwidth of data	pre-4G	duplex	channel	description	geographical areas
TDMA Single-Carrier (IMT-SC)	EDGE (UWT-136)	EDGE Evolution	none	FDD	TDMA	evolutionary upgrade to GSM/GPRS <sup>[nb 1]</sup>	worldwide, except Japan and South Korea
CDMA Multi-Carrier (IMT-MC)	CDMA2000	EV-DO	UMB <sup>[nb 2]</sup>		CDMA	family of revolutionary standards.	Americas, Asia, some others
CDMA Direct Spread (IMT-DS)	UMTS <sup>[nb 3]</sup>	W-CDMA <sup>[nb 4]</sup>	HSPA	LTE			worldwide
CDMA TDD (IMT-TC)		TD-CDMA <sup>[nb 5]</sup>					
FDMA/TDMA (IMT-FT)	DECT	none	TDD	FDMA/TDMA	short-range; standard for cordless phones	Europe, USA	
IP-OFDMA		WiMAX (IEEE 802.16)		OFDMA		worldwide	

1. <sup>^</sup> Can also be used as an upgrade to PDC or D-AMPS.
2. <sup>^</sup> development halted in favour of LTE.<sup>[9]</sup>
3. <sup>^</sup> also known as FOMA<sup>[6]</sup>; UMTS is the common name for a standard that encompasses multiple air interfaces.
4. <sup>^</sup> also known as UTRA-FDD; W-CDMA is sometimes used as a synonym for UMTS, ignoring the other air interface options.<sup>[6]</sup>
5. <sup>^</sup> also known as UTRA-TDD 3.84 Mcps high chip rate (HCR)
6. <sup>^</sup> also known as UTRA-TDD 1.28 Mcps low chip rate (LCR)

While EDGE fulfills the 3G specifications, most GSM/UMTS phones report EDGE ("2.75G") and UMTS ("3G") network availability as separate functionality.

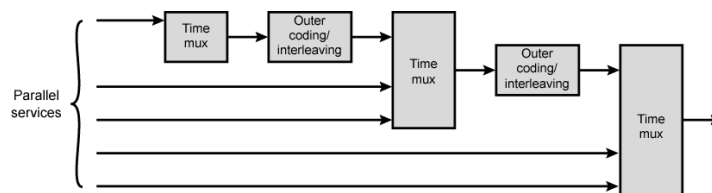
## CDMA Design Considerations – Bandwidth and Chip Rate

- Dominant technology for 3G systems is CDMA
  - Three different CDMA schemes have been adopted
  - Share some common design issues
- Bandwidth
  - Limit channel usage to 5 MHz
  - Higher bandwidth improves the receiver's ability to resolve multipath
  - But available spectrum is limited by competing needs
  - 5 MHz reasonable upper limit on what can be allocated for 3G
  - 5 MHz is enough for data rates of 144 and 384 kHz
- Chip rate
  - Given bandwidth, chip rate depends on desired data rate, need for error control, and bandwidth limitations
  - Chip rate of 3 Mcps or more reasonable

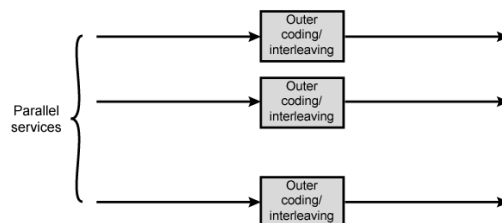
## CDMA Design Considerations – Multirate

- Provision of multiple fixed-data-rate logical channels to a given user
- Different data rates provided on different logical channels
- Traffic on each logical channel can be switched independently through wireless fixed networks to different destinations
- Flexibly support multiple simultaneous applications from user
- Efficiently use available capacity by only providing the capacity required for each service
- Achieved with TDMA scheme within single CDMA channel
  - Different number of slots per frame assigned for different data rates
  - Subchannels at a given data rate protected by error correction and interleaving techniques
- Alternative: use multiple CDMA codes
  - Separate coding and interleaving
  - Map them to separate CDMA channels

## Time and Code Multiplexing



(a) Time multiplexing



(b) Code multiplexing

## **Summary**

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- principles of wireless cellular networks
- operation of wireless cellular networks
- first-generation analog
- second-generation CDMA
- third-generation systems