Cellular Wireless Networks

- Chapter 14

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

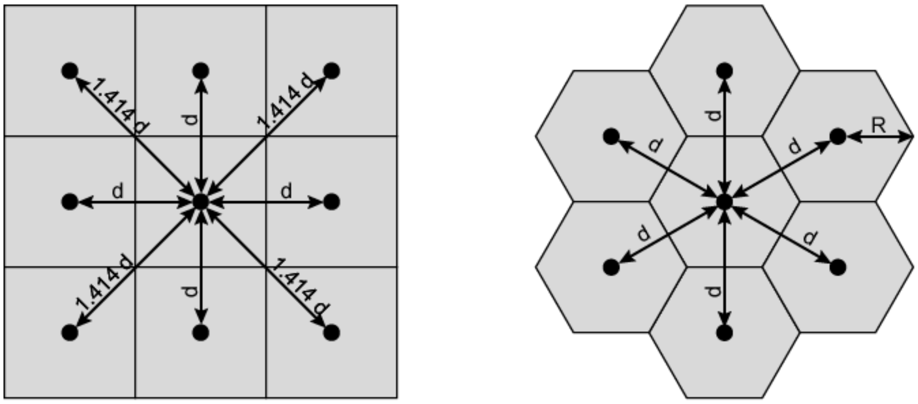
Cellular Network Organization

- 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

- 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

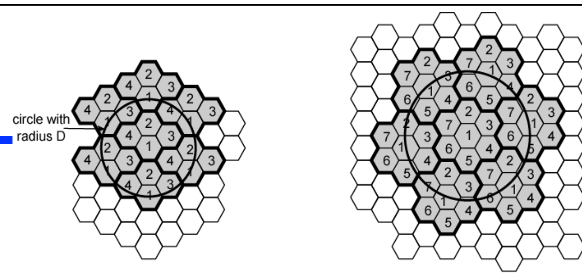
- Power of base transceiver controlled
  - Allow communications within cell on given frequency
  - Limit escaping power to adjacent cells
  - Allow re-use of frequencies in nearby cells
  - Use same frequency for multiple conversations
  - 10 – 50 frequencies per cell
- *E.g.*
  - N is the number of 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

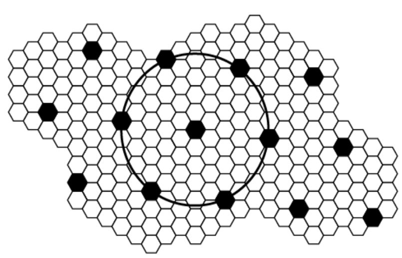
- D = minimum distance between centers of cells that use the same band of frequencies (called co-channels)
- R = radius of a cell
- d = distance between centers of adjacent cells ($d = \sqrt{3} R$)
- N = number of cells in repetitious pattern
  — Reuse factor
  — Each cell in pattern uses unique band of frequencies
- Hexagonal cell pattern, following values of N possible
  — $N = I^2 + J^2 + (I \times J)$, $I, J = 0, 1, 2, 3, \ldots$
- 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

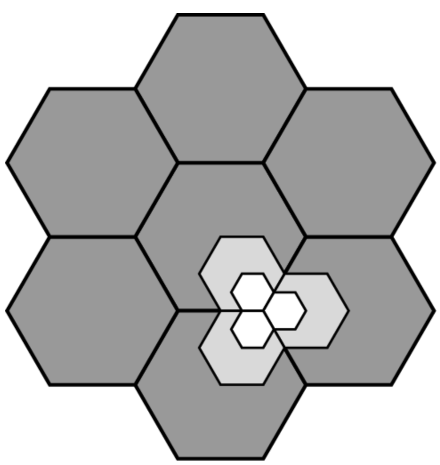


(c) Black cells indicate a frequency reuse for N = 19

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

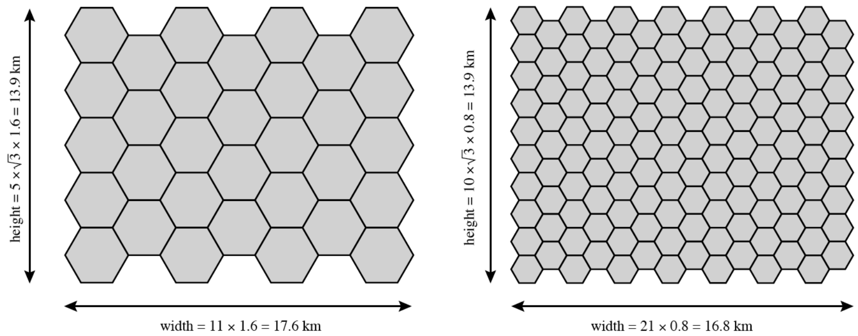


Increasing Capacity (2)

- 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?

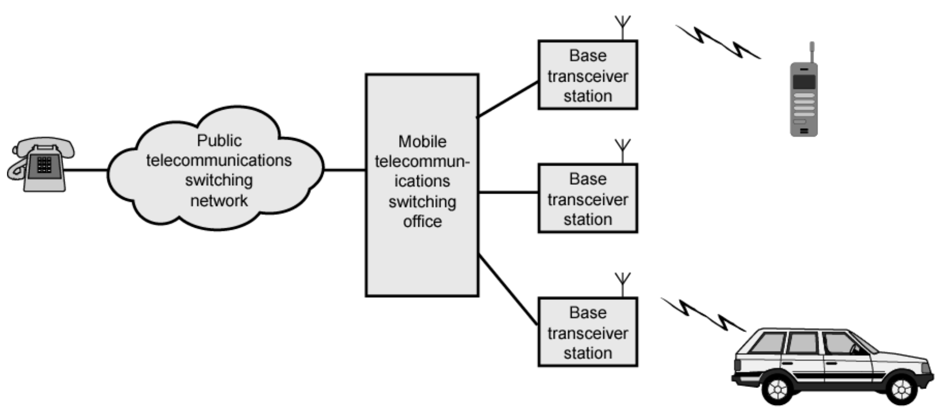


(a) Cell radius = 1.6 km (b) Cell radius = 0.8 km

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

- 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)

- 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)

- 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

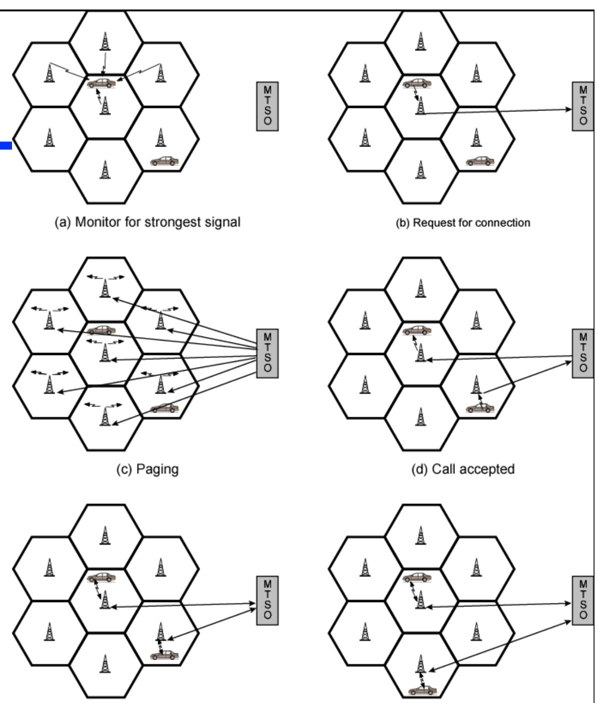
Typical Call in Single MTSO Area (3)

- 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



(a) Monitor for strongest signal (b) Request for connection (c) Paging (d) Call accepted (e) Ongoing call (f) Handoff

Other Functions

- 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

- 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

- 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

- 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

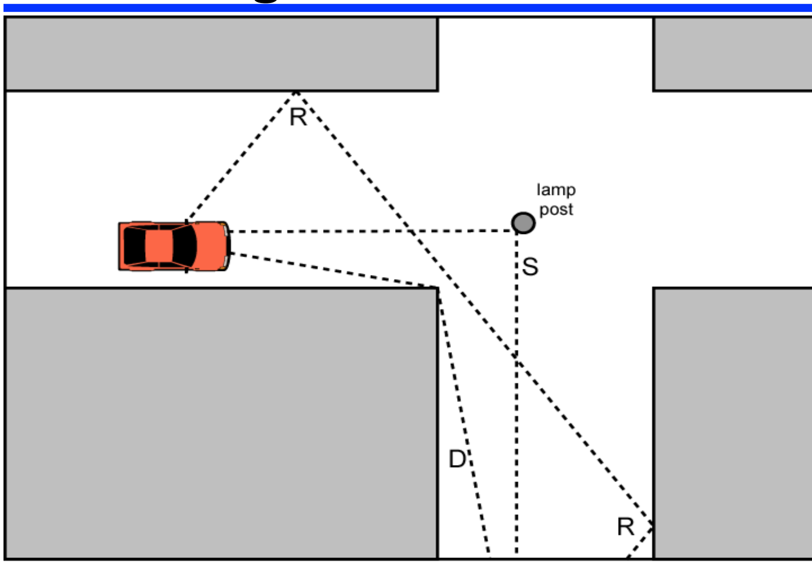
Fading

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

Multipath Propagation

- 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

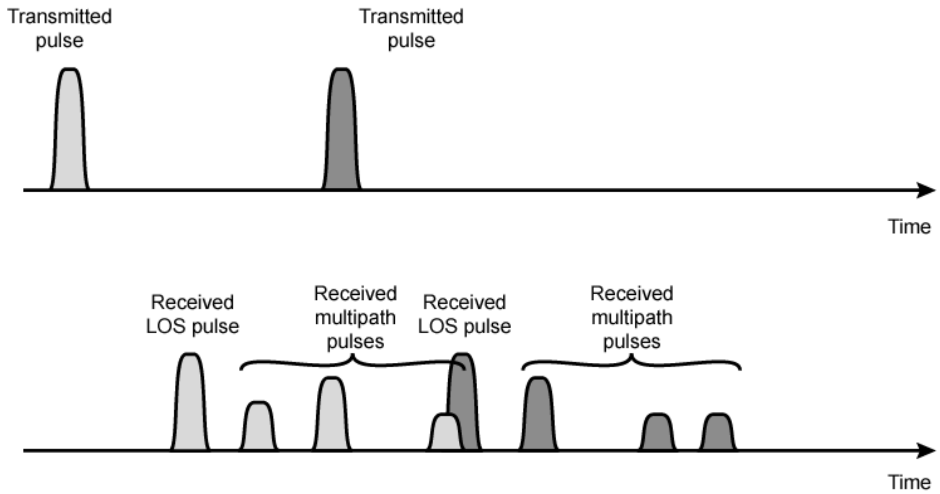
Reflection, Diffraction, Scattering



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

Two Pulses in Time-Variant Multipath



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

Error Compensation Mechanisms (1)

- 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)

- 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)

- 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

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

First Generation Analog

- 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

- 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

- 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

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

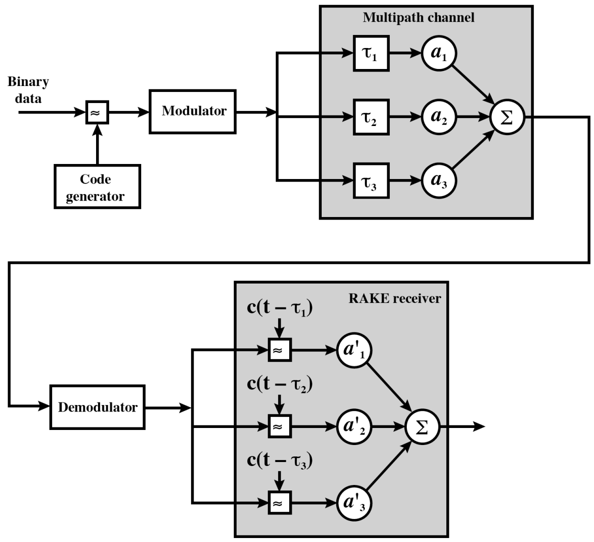
Code Division Multiple Access

- 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

- 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 (a1, a2, 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

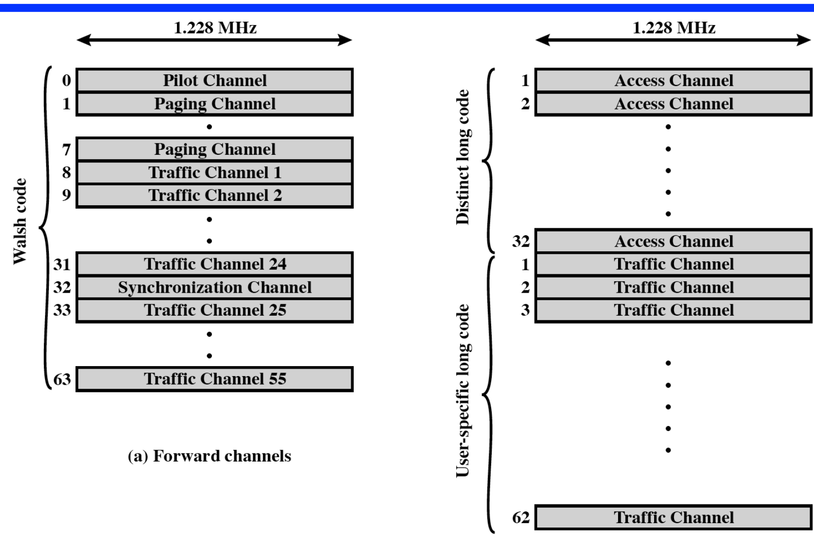
Principle of RAKE Receiver



IS-95

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

IS-95 Channel Structure



(a) Forward channels

(b) Reverse channels

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 × 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 ½
  - 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

- 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

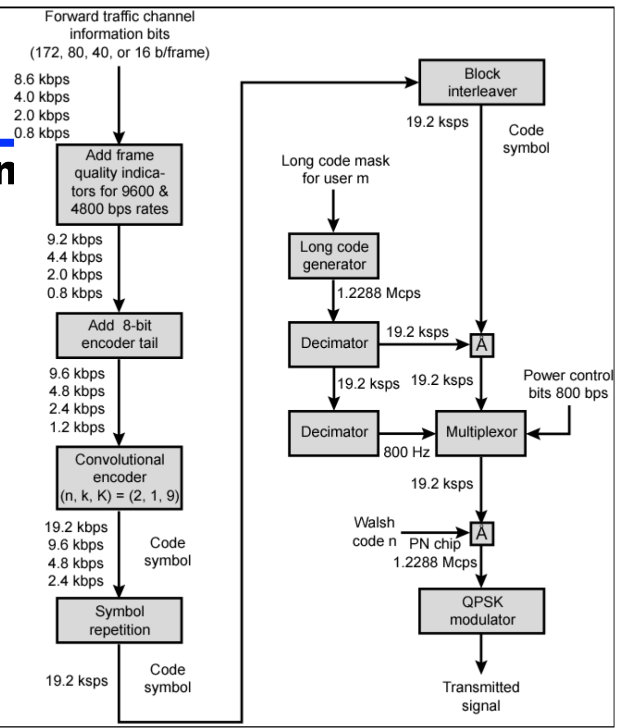
Power Control

- 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

- 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

- 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

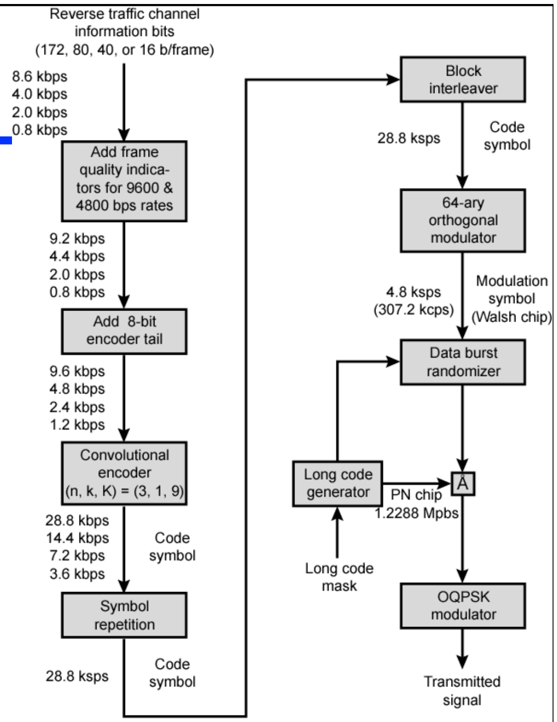
Data Burst Randomizer

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

DSSS

- 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

- 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

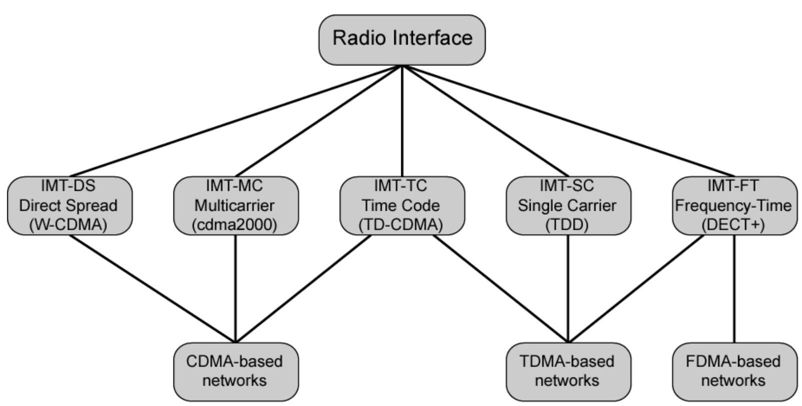
Alternative Interfaces (1)

- 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[4]

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[nb 1]	worldwide, except Japan and South Korea
CDMA Multi-Carrier (IMT-MC)	CDMA2000		EV-DO	UMB[nb 2]		CDMA	evolutionary upgrade to cdmaOne (IS-95)	Americas, Asia, some others
CDMA Direct Spread (IMT-DS)	UMTS[nb 3]	W-CDMA[nb 4]	HSPA	LTE			family of revolutionary standards.	worldwide
CDMA TDD (IMT-TC)		TD-CDMA[nb 5]			TDD			Europe
		TD-SCDMA[nb 6]						China
FDMA/TDMA (IMT-FT)	DECT		*none*			FDMA/TDMA	short-range; standard for cordless phones	Europe, USA
IP-OFDMA			WiMAX (IEEE 802.16)			OFDMA		worldwide

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

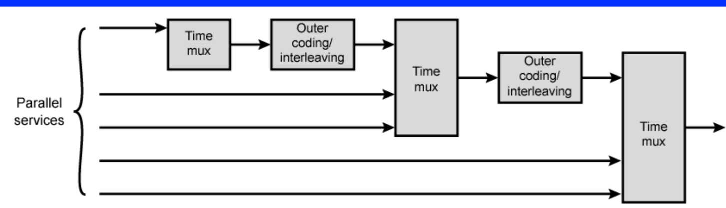
CDMA Design Considerations – Bandwidth and Chip Rate

- 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

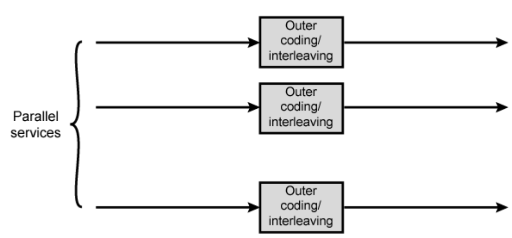
CDMA Design Considerations – Multirate

- 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

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