Wireless Communication Systems and Standards

Technical Issues in Wireless Communications

In the past:

- The adverse multipath, fading mobile channel

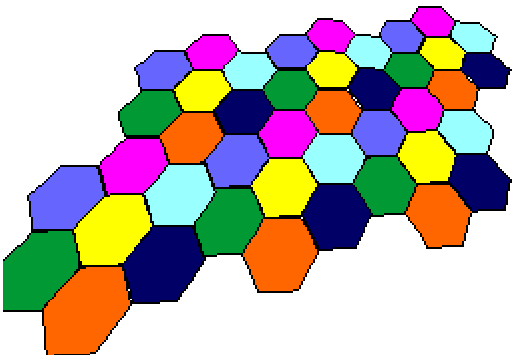
Nowadays:

- Spectral Bandwidth
  - Radio spectrum is a scarce resource
  - Bandwidth is being auctioned in U.S., NL, New Zealand, ..
- Energy
  - Battery weight dominates weight of handhelds
  - Talk-time of portable telephones is limited
  - Notebook computers operate only a few hours without external power supply
- Mobility
  - Complexity of network software:
    - handovers,
    - user location,
    - authentication and confidentiality,
    - tariffing
  - Speech and signalling may follow different paths

Cellular Radio

- Proposed in 1971 by Bell System
- FCC had asked for:
  - large subscriber capacity
  - efficient use of spectrum
  - nation-wide coverage
  - adaptability to traffic density
  - telephone service to vehicle and portable stations
  - telephony and special (voice) services (e.g. dispatch)
  - toll quality
  - affordability

The Cellular Solution for Frequency Reuse:



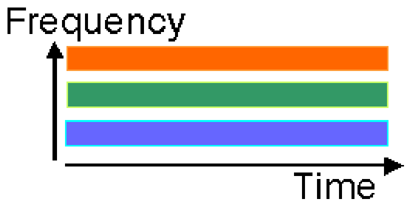
- Regular frequency reuse, hexagonal cell structure
- Handovers
- Low transmit antennas: reduce interference
- Optimize # users per cell, not bit/s/Hz

Radio Resource Management

1. Frequency reuse among cells
2. Multiple Access within cells:
   How to share radio resources among multiple users

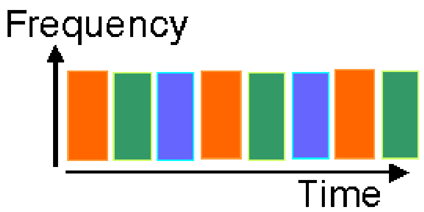
Frequency Division Multiple Access: FDMA

Every user has her own frequency channel



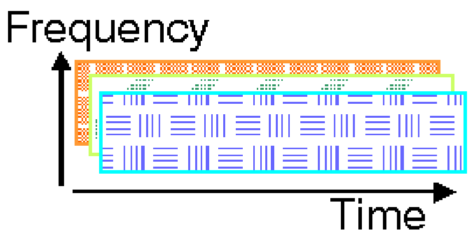
Time Division Multiple Access: TDMA

Users share the same bandwidth but transmit one after the other



Code Division Multiple Access: CDMA

User signals overlap in frequency and time. Orthogonality of waveforms is used to separate user signals



History of mobile Radio in Germany

Packet Radio

1992: Modacom X.25 packet

Cellular

1958: A-Net analog
1972: B-Net analog
1986: C-net analog
1991: D-net GSM
1994: PCN E1-Net DCS-1800

Private Mobile (Trunked) Radio

1974: private frequency division multiplexing
1991: Analog MPT
1995: TETRA: digital, European

Paging

1974: Eurosignal
1989: Cityruf
1990: Euromessage
1993: Ermes (European)

Cordless

1987: CT1, analog
1989: Telepoint, analog
1989: CT2, digital
1991: DECT

Satellite

1988: Inmarsat standard C
1996 Iridium low earth orbit

Broadband

2010: MBS mobile broadband system

Evolution of wireless networks

Generation	1	2	2.5	3
Cordless	CT1.......	CT2 DECT	*part of cellular service*	
Cellular	AMPS NMT	GSM D/E-AMPS ADC JDC	Cellular Based PCS	UMTS IMT- -2000 FPLMTS
Mobile Data		Mobitex CDPD	*part of cellular service*	

Personal Communication Services:

- Provision of speech and other services anywhere, anytime

Two contradictory visions of future systems

- Convergences of all services into universal PCS.
- In practice: deployment of many different new systems:
  - Optimization for specific application / service is more economic, spectrally more efficient, allows lower power consumption
  - Dual-mode, Multi-mode handsets

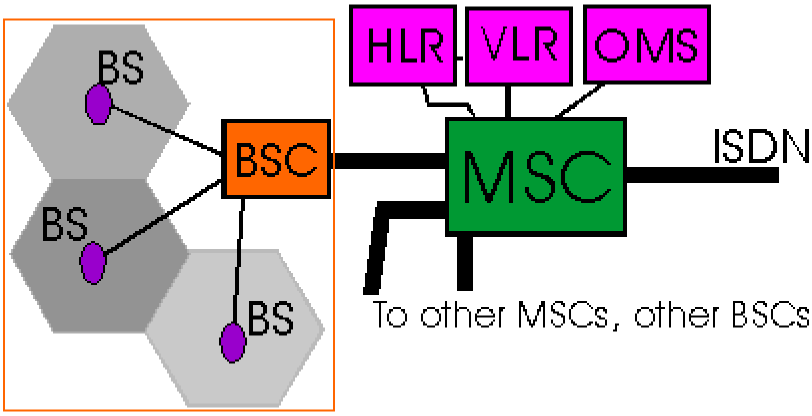
Network Features Supporting Mobility

- Terminal Mobility
  - As in first generation cellular networks
  - Requires location registration (not available in some CT2 systems)
  - Requires handover if mobility during a call is supported

- Personal Mobility
  - System follows the *user* rather than the *terminal*
  - Supported for instance in GSM system
  - Typically requires a smart-card or SIM card

- Personal UPT Number
  - Network continuously tracks the user, whether mobile, at home or in office.

Effect of Mobility on Network Functions



GSM network architecture

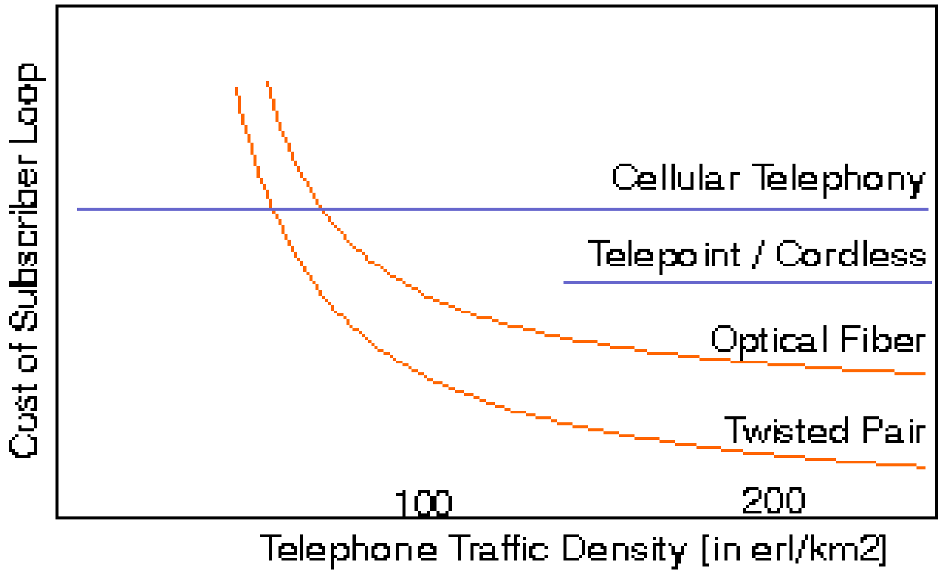
For an advanced cellular telephony networks, such as GSM,

- Amount of switching

is 6 times as much as in ISDN

- Amount of signalling
  is 15 times as much as in ISDN

“The Last Mile”



- 50 - 70 % of the investment of PSTN are in subscriber loops
- Developing countries: installing the “local loop” is most time consuming
- Radio telephony is cheaper than wireline in sparsely populated areas
- Continuously replacing networks and wires in office building is time consuming and expensive

Monthly Cellular Phone Bill

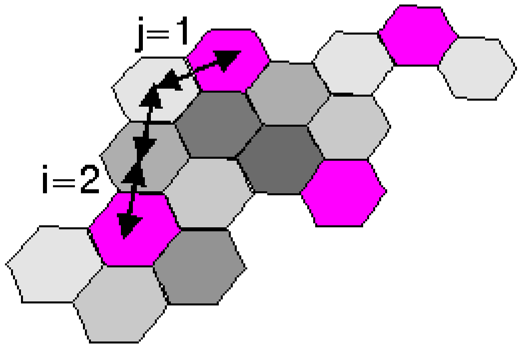
U.S. nationwide coverage, source CTIA

1987	97$
1988	98$
1989	90$
1990	82$
1991	73$
1992	68$
1993	63$

- Tariffs have dropped, due to competition
- New users have different calling pattern

1) call duration shorter
2) fewer calls

Frequency Reuse



- Frequency Reuse is the core concept of cellular mobile radio
- Users in different geographical areas (in different cells) may simultaneously use the same frequency channel
- Frequency reuse drastically increases user capacity and spectrum efficiency
- Frequency reuse causes mutual interference (trade off link quality versus subscriber capacity)

Cellular system planning is interference-limited, no longer noise-limited

- Cluster size $C = i^2 + ij + j^2 = 1, 3, 4, 7, 9, ...$
- Reuse distance = $\sqrt{(3C)}$
- Cellular telephony:

Choose C to ensure acceptable link quality at cell boundary

- Wireless data:

Choose C to optimize delay: $C = 1$ + robust retransmission

Cell Sizes Decrease with Growth of System

- Macro-cellular 1 - 30 km
- Micro-cellular 200 - 2000 m
- Pico-cellular 4 - 200 meter

The effect of decreasing cell size

- Increased user capacity
- Increased number of handovers per call
- Increased complexity in locating the subscriber
- Lower power consumption in mobile terminal:
  - Longer talk time,
  - Safer operation
- Different propagation environment, shorter delay spreads
- Different cell layout,
  - lower path loss exponent, more interference
  - cells follow street pattern
  - more difficult to predict and plan
  - more flexible, self-organizing system needed (cf. DECT vs. GSM)

Overview of Wireless Network Systems

International

- International Mobile Telecommunications

European

- Global System for Mobile Communications (GSM)
- Cordless Telephony CT1 and CT2
- Digital European Cordless Telephone (DECT)
- Paging Systems
- FM Broadcasting
- Digital Audio Broadcasting
- High Performance LAN (HIPERLAN)

US

- Analogue AMPS
- Digital AMPS (IS-54)
- Extended AMPS (Hughes)
- Cellular CDMA (IS-95)

Under Research

- Packet Reservation Multiple Access (Goodman et al. Rutgers)
- Infopad (Brodersen et al. Berkeley)

Groupe Speciale Mobile GSM

Global System for Mobile Communications

- Initiated by CEPT (Conf. Européenne des Postes et Télécommunications)
- Took lengthy CEPT/ETSI standardization and pan-european research
- History
  1978: 900 MHz band reserved in Europe
  1982: Standardization started
  1986: Decision to start implementation
  1994: PTT Telecom opened 1 network in NL
- GSM provides access to ISDN related services
- Designed as vehicular system but is being marketed as handheld
- Now also adopted in South Africa (rural fixed cellular), Singapore, Malaysia, India, Hong Kong, Australia, ... (South-East Asian MoU)
- May be successful also in US as PCS 1900
  (where IS54 TDMA and IS95 CDMA are competing and lagging in development of network/service features)
- DCS 1800 evolved from GSM
- GSM+ more services, better efficiency

GSM Technical Features

Multiple Access

- Frequency Division Multiple Access
  Carrier spacing 200 kHz
- Time Division Multiple Access
  8 users per carrier

Transmission

- channel bit rate 270 kbit/s
- channel bit rate per user 22.8 kbit/s, incl. ch. coding
- Gaussian Minimum Shift Keying (GMSK)
- 1.35 bit/s/Hz
- Channel equalization: 4 bit intervals
  - bit duration 3.7 μsec; maximum delay difference 16μsec
- Vehicle terminal: up to 8 watt
- Handheld: up to 2 watt

Max cell size: 30 km (limited by guard time interval)

Speech Coding

- Linear predictive coding and regular pulse excitation 13 kbit/s
- Half rate speech coding possible: 16 users per carrier

GSM Advanced Services

- Can support ISDN-type services
- Call redirect, automatic call-back
- Transparent G-3 fax mode
- Data Services standardized

GSM DATA SERVICES

- Voice codecs are not suitable for data
- Interworking functions needed in network
- Traffic Channel provides 22.8 kbit/s or 11.4 kbit/s

Transparent service

- Constant throughput, constant delay
- No Cyclic Redundancy Check (CRC); no error detection
- Depending on Forward Error Correction (FEC) used
  - 9.6, 4.8 or 2.4 kbit/s with full rate channel
  - 4.8 or 2.4 with half rate channel

Non-Transparent

- Transparent service + Radio Link Protocol
- Automatic Repeat Request (ARQ) using CRC
- BER $< 10^{-7}$

GSM Data Services (continued)

Short message service

- Packet based
- maximum length 160 bytes
- delays up to several seconds
- uses GSM signalling channels
- longer messages split into several packets
- sequence of reception not guaranteed

Packet data service

- Based on X-25 protocol for packet switching
- One virtual connection per GSM traffic channel
- Services to be extended
  Traffic and Transportation: floating car data

Fax

- Uses transparent data services
- Fax signalling is repeated for reliability
- Errors in document lines can occur

GSM Security Security Features

- Digital Encryption
- User Authentication
- Subscriber Identity module (SIM)
  - Smart-*SIM*-card: personal number, subscriber can use any GSM phone anywhere, but gets charged for calls made using his SIM
- “out of band” signalling

SIM-card

- Size: 25 by 15 mm
- The SIM enables:
  - authentication of subscriber to network
  - data confidentiality over the air interface (generate a cipher key)
  - access conditions for files required in GSM operation
- Authentication
  1) Network send a random number to the mobile (SIM)
  2) SIM returns a signed response
  3) Network checks signature
- User authentication key has 128 bits

DCS 1800

- 1710 - 1785 and 1805 - 1880 MHz
- DCS evolved from GSM
- DCS is better suited to serve densely populated areas
- 1800 MHz system has smaller range, smaller cells
- Dual-mode terminals with GSM 900
- Allows allocation of spectrum to "third and fourth GSM operators"

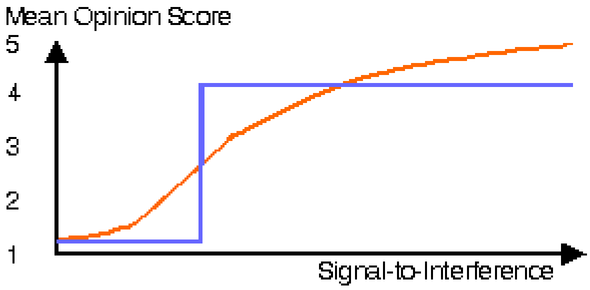
U.S. Cellular Telephone Systems

- Analogue AMPS
- Digital AMPS, IS-54 and E-AMPS
- Cellular CDMA, IS-95
- PCS
  - IS-54 based
  - IS-95 based
  - PCS 1900, GSM based
  - ....

AMPS American Mobile Phone System

- Analogue FM modulation
- RF bandwidth 30 kHz
- Operates at 800 MHz
- The same system throughout the US
- U.S., Canada, Hong Kong, New Zealand, Thailand

Advantages of Digital Transmission



Digital speech transmission reacts differently

to changing performance of the radio link

- Higher capacity:
  1) speech coding
  2) smaller protection ratios, denser reuse
  (NB: same reuse of IS-54 and analog AMPS in US)
- Security
  1) Privacy
  2) Protected against unauthorized use
- Additional services

But in US still competition over standards of digital system: TDMA versus CDMA

IS-54 (Digital AMPS)

- IS-54 is a digital version of AMPS
- Frequency Division Multiple Access
  Carrier spacing 30 kHz (same as AMPS)
- Time Division Multiple Access (3 users per carrier)
- Frequency planning is “compatible” with analogue AMPS
- Triples capacity of analogue AMPS
- Capacity increase has advantage to the operator:
  - But how to get subscribers to go digital?

Transmission aspects

- Channel bit rate 48.6 kbit/s
- Frame duration 40 ms, divided into six 6.67 ms slots
- Each slot: 324 bits, 260 user data
- Full rate and half rate speech:
  - Codebook excited linear predictive coding:
  - Vector Sum Excited Linear Prediction (VSELP)
  - Source rate 7.95 kbit/s, transmitted at 13 kbit/s
- Differential QPSK (not constant envelope: power penalty)
  $\pi/2$ shifted, root cosine rolloff filtering, rolloff factor 0.35
- 1.62 bit/s/Hz

Digital Speech Interpolation (DSI) :

- Used in Extended AMPS, TASI Satellites and PRMA
- Basic Principle:
  - Speech pauses are exploited to enhance user capacity.
  - Speech activity ≈ 0.4, 60% can be assigned to other users
- DSI in forward link: multiplexing
  DSI in reverse link: multiple access: collisions

Extended (E-)AMPS

- Designed by Hughes to improve IS-54
- Similar to IS-54, but
- E-AMPS uses DSI over frames of six slots; dynamically assigned to different users
  - No DSI: E-AMPS has 6 times capacity of AMPS
  - DSI on 1 RF carrier: 6 times analogue
  - 3 RF carriers: 7 times analogue
  - 8 RF carriers: 9 times analogue
  - 19 RF carriers: 11 time analogue
  - Many RF carriers: Law of large numbers:
    ultimately 6 / 0.4 = 15 times analogue AMPS
- Slow frequency hopping: mitigates effect of fading

CDMA Cellular Telephony

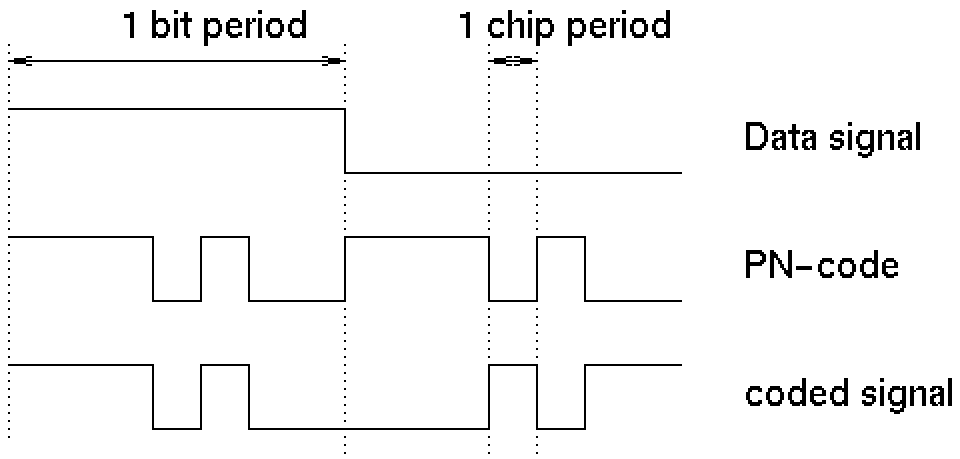


Figure: Basic Principle of Direct-Sequence CDMA

- IS-95 is a U.S. cellular standard based on CDMA transmission
- Multiple users simultaneously share the same (wide band) channel. Signals are separated through their code.
- Claim: 20 fold increase in capacity over analog cellular AMPS
- Speech coding at 9.6 kbit/s
- Initially research by Qualcomm, San Diego

Direct Sequence Signals

- DS-SS has small spectral density: low probability of intercept
- DS-SS offers anti-jamming
- CDMA offer multiple access
- DS-SS combats multipath self interference
- DS-SS can co-exist with other systems
- DS-SS offers frequency diversity; DS-SS does not need fade margins
- DS signal offer position location
- Exploits voice activity patterns
- Coding becomes very effective; required C/N is 7 dB
  - interference in Gaussian
  - fading is averaged
- Signal to noise ratio is approx.
  Number of users / Spread factor
- Near-far problems
- Power control is needed

IS 95 Transmission Standard

Forward link

- Chip rate 1.2288 Mchip/s = 128 times 9600 bit/sec
- Combines 64 Walsh-Hadamard and PN sequence
- Transmit bandwidth 1.25 MHz
- Convolutional coding with rate ½
- Pilot tone for synchronization

Reverse Link

- Graceful degradation when overloading the system
- Reverse link ciding rate 1/3
- Soft handoff

Cordless

- Functionality of cordless is much less than cellular

History

1) Illegal Imports
2) CT1
3) CT2 (marketed to home user)
4) DECT (marketed as wireless PBX)
5) Cordless functionality to be integrated into PCN / PCS

Cordless Telephone CT1

- Developed in response to illegally imported handhelds
- PSTN subscriber purchases its own home “base” station and handheld terminal
- Only coverage near its own base station

Cordless Telephone CT2

- Frequency Division Multiple Access
(“Each conversation has its own frequency”)
- Carrier Spacing 100 kHz
- Time Division Duplex, with 2 msec frame duration
- Channel rate 72 kbit/s
- Binary Frequency Shift Keying
- Speech coding: Adaptive Differential PCM at 32 kbit/s
- 0.72 bit/s/Hz
- Provides access to PSTN (telepoint, PTT Telecom: Kermit/ Greenpoint)
- Can not receive calls
but can be combined with paging service
- Can be used for fax
- Use with data modems: max 2400 bit/s

Digital European Cordless Telephone DECT

- Optimized for simple, low power, convenient handheld
- Also supports data services
  up to 1 Mbit/s per user (= one full carrier)
- Much interest in providing DECT over cable TV networks

Transmission aspects

- 10 TDMA carriers each carrying 12 voice channels
- Time Division Duplex TDD
- Frame duration 10 msec
- Slot length: 480 bit per slot
- 320 user bits per slot
- Channel bit rate 1.152 Mbit/s
- No equalization:
  - Operates with rms delay spread up to 90 nsec
- Speech coding: Adaptive Differential PCM 32 kbit/s
  - Low power consumption in handheld
  - High speech Quality
- Gaussian Minimum Shift Keying (GMSK)
- Distributed Dynamic Channel (and Slot) Allocation
- Synchronized base station operation

Future Systems

Telephony based

- UMTS
- IMT 2000

Wireless data & multimedia

- Hiperlan
- Mobile Broadband System MBS
- Digital Short Range Radio DSSR
- PRMA

  Proposed for PCS in US

  Concept adopted in Race
- The Wireless "Information Super Highway"

Broadcast

- Terrestrial DVB, DTTB, DAB
- Satellite

Universal Mobile Telecommunication Systems UMTS

- European activity (IMT 2000 is worldwide)
- 3^{rd} generation system
- combines advantages of all 2^{nd} generation systems
- 230 MHz at 2 Ghz

ACTS

- European Research & Development Program
- Follow-up on RACE
- Aimed at services, applications and demonstrators
- Deadline for proposals was March 1995 International Mobile Telecommunications

IMT-2000 (= FPLMTS)

- Initiative of ITU-Radio, Task Group 8/1
- WARC 92 indicated 1885-2025 and 2110-2200 MHz
  1980-2010 and 2170-2200 MHz for satellite
- Aim: unify diverse systems into universal system
  (One small user terminal usable world-wide)
  - Wide range of services
    (Voice and Non-voice / Multi-media, Incl. wideband (64 k.. 2 M bit/s))
  - Wide range of propagation environments (Indoor / Outdoor)
  - Wide range of user densities
- Performance comparable to fixed network
- Spectrum Efficient
- Open Architecture: Rapid introduction of new services and technology
  - Intelligent Network (IN) (e.g. Mobility Management)
- Modular Structure:
  - allows growth in size and complexity
  - Easy introduction of new services
- Supports radio links in tandem (e.g. use in aeroplanes)
- Connected to circuit-switched PSTN and packet-switched PSPDN
- Multi-vendor, multi-operator

Mobile Broadband System (MBS)

- Part of ACTS / RACE
- Bit rates of 2 Mbit/sec and more
- Compatible with ATM format

Cell Size

Large:	GSM	MBS
Small:	DCS 1800/DECT	Hiperlan
Bit Rate:	Low	High

Hiperlan

- A European standardization initiative
- Wireless **Hi**gh **Per**formance **L**ocal **A**rea **N**etwork
- 5.2 and 17.1 GHz
- 10 Mbit/s synchronous
  2 Mbit/s synchronous
- Maximum Terminal Speed 36 km/h
- Undetected PER 10^-8
- Range 50 meters
- No Handover
- Requires Gateway
- Not Necessarily Requires Base Stations:
  Also supports peer-to-peer
- Radio Modem should fit in PCMCIA slot of PC
- Supports time-bounded services (priority scheme)
- GMSK modulation (rather than OFDM)
  Reason: max power dissipation PCMCIA is 1 watt
  and OFDM requires power backoff
- Current R&D: how to interface with ATM

Wireless Local Area Networks

- Industrial Scientific Medical (ISM) bands (FCC part 15)
  U.S.: 900 MHz, 2.4 GHz, 5 GHz, ...
- Interference from microwave ovens, etc
- Secondary User: Devices must tolerate any interference, may not cause interference
- Band spreading at least factor 10
- low power, low spectral density
- No standards: market decides
- Stepping stone to de facto standards (?)
- Call for co-existence etiquette
- No control: band may become congested rapidly
- Some companies feel that poorly working ISM band products damage their reputation
- Frequency hopping may be better than Direct sequence

Wireless Infrared

- State-of-the-art: 50 Mbit/s at BER 10-9
- Eye safety requirements limit transmit power
- Diffuse transmission: reflection against ceiling
- Consortium of 100 companies defines standard
- First products: HP: 115 kbit/s interconnection between notebooks and GSM
- Modulated signal experiences multipath fading
- Receiver has inherent diversity: lens >> wavelength

Packet Reservation Multiple Access (PRMA)

- TDMA with slotted ALOHA reservation scheme
- Frame duration 16 msec (62.5 frames /sec)
- Source rate 32 kbit/s
- Channel bit rate 720 kbit/s; Bandwidth 720 kHz
- 20 slots per frame
- Wireless version of satellite telephony technology:
  - DSI Digital Speech Interpolation or
  - TASI Time Assigned Speech Interpolation
- One carrier supports 26 - 39 simultaneous calls
  Packet dropping rate ≈ 1%
- 576 bits / slot (includes 64 bit overhead)
- Strong research activity at Rutgers University (Winlab / Goodman)
- Voice and Data

Digital Short Range Communication DSRC

- Applications in Traffic and Transportation
  - electronic fee collection
  - automatic parking space assignments,
  - reservations for hotels, sports events, ...
  - automatic route guidance
- Experiments in DRIVE II Socrates
- Up to 100 kbit/s
- First standards end 1994 (CEN TC 278)
- Application-specific “cell” radius
- coverage 15 meters .. few hundred meters
- Infrared, 5.8 or 62 GHz
- Similar initiatives in US: ISM bands

Broadcast Systems

- AM / FM and PAL/ SECAM/ NTSC analogue TV
- Additions and upgrades
  - FM stereo
  - AM stereo
  - RDS / HSDS
  - Teletext
  - PAL plus

Digital systems

- DAB
- DTTB
- MMDS (wireless cable) (29 or 40 GHz)

- Long lifetime of broadcast standards
- Big Money/Mass Market (Entertainment / Consumer Electronics)

Analogue FM Broadcasting

- Vulnerable to interference and fading
- Requires large interference protection
  CCIR advice: more than 36 dB
  In practice: FM capture ratio 10 dB
- Stereo information is added to audio signal
  - 19 kHz pilot tone
  - DSB modulated at 38 kHz (2 x 19 kHz)
- Stereo signal more vulnerable to noise and interference
- Bandwidth per transmitter 200 to 400 MHz
- Bandwidth for national coverage 0.7 + 2.1 *M* MHz for *M* programmes
- 88 - 108 MHz band typically allows 6 or 7 national programs
- frequency planning more involved in adjacent channel interference than telephony systems
- Transmit powers:
  5 .. 10 watt for highway coverage of a few miles, directional antennas

  30 .. 100 watt for community station

  10 .. 100 kwatt for large area coverage
- Constant Envelope: Class C nonlinear amplifiers

FM subcarrier systems

- Subcarrier data can be added (eg at 57 kHz)
- ARI: autofahrer information
- Radio Data System provides approx. 1200bit/s data, e.g.
  - Program / format type
  - Other transmitters
  - Traffic information (300 bit/s)
- RDS requires small reduction (1 dB) of loudness
- High Speed Data System (HSDS) by Seiko/ ACTTIVE
  - Micro-electronic chips allow installation in watch or other devices
  - Higher data speed than RDS:
  - Paging,
  - Info: traffic, weather, financial, sport
  - Portland and Seattle (20.000 subscribers each pay 80-100$ for watch + 10$ per month)
  - To cover 80% of US by end 1996
  - Introduced in NL and F in 1995

Digital Audio Broadcasting (DAB)

- Standardized and developed in Eureka DAB EU-147 project, since 1988
- To be introduced in 1997 in Europe,
- Tests are operational since 1994
- Convenience (no need to know the station's 'wavelength')
- More programmes, efficient use of spectrum
- 'static-free' reception and improved mobile reception
- CD quality
- New (data) services
  - listener can set voice / music power ratio and dynamic range of audio material
  - programme / format information
  - song texts
  - traffic information
  - conditional access (subscriber radio)
  - 'radiotext'

DAB Transmission Aspects

- Lower transmit power
- Bit synchronized transmitters
- Single frequency networks
- Orthogonal Frequency Division Multiplexing
  - OFDM = Multi Subcarrier Modulation
  - offers frequency diversity
  - eliminates effect of ‘local’ fades
  - 15 to 20 programmes per carrier
- MUSICAM at 192 kbit/s: Mask pattern adapted Universal subband Integrated Coding and Multiplexing
  exploits psycho-acoustic masking:
  Strong tone masks nearby weak tones
  inaudible details are not transmitted
- Transmit bandwidth >> coherence bandwidth
- Problem: how to offer local radio coverage

IRIDIUM

- Satellite system that covers areas without cellular coverage
- Global wireless, handheld system
- Based on 66 low earth orbit satellites
- Telephone, G3 fax and data up to 2400 bit/s
- Complementary to terrestrial
- Dual-mode operation with terrestrial cellular, satellites reach remote rural areas
- voice services similar to GSM
- satellite power 1.2 kW
- 48 beams per satellite

U.C. Berkeley Infopad System

- Wireless multimedia computing and communications
- To be operated in ISM bands
- Research focus is on reducing power consumption
  Supply voltages 1.1 .. 1.5 Volt
- Downlink 1 .. 2 Mbit/s video
  CDMA continuous wave transmission
  Spread factor 64
- Uplink pen / voice commands random access
  4 kbit/s digitized pen data; 64 kbit/s voice μ-law speech
- Base station controls several cells
  Each cell has a simple TIC (Thing In the Ceiling)
- Each terminal has a **PAD server** in the network
  - manages access to terminal
  - shares communication resources amoung applications
  - control transmit powers, tracks location
- Cell Server
  - Controls power level among terminals
  - Negotiates handovers