Mobile Radio Systems
(Wireless Communications)

Klaus Witrisal
witrisal@tugraz.at
Signal Processing and Speech Communication Lab,
TU Graz

Lecture 1 – WS2015/16 (6 October 2016)

Key Topics of this Lecture

- **Physical layer** (radio air-interface)
- Including mobile propagation **channel**
- Basic **system design** considerations

- understand the impact of the **multipath radio channel** on (different types of) wireless communications signals
- and how to **design radio air-interfaces** to overcome these

Outline – Lecture 1

- Course outline
- Course material; text books
- Administrative issues
- Introduction
  - "Enabling technologies"
- Fundamental concepts
  - System design fundamentals

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Course outline (1)

- Introduction (L1)
  - Key features; design challenges; **enabling technologies**
  - A glance on the history of wireless
- Cellular Concept and Multiple Access (L1-2)
  - **System design fundamentals**
  - Cellular concept
  - Multiple Access Schemes
  - Handoffs
  - Co-channel interference

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Course outline (2)

- The Mobile Radio Channel (L3-5)
  - Path loss and shadowing
  - **Multipath propagation** and narrowband **fading**
  - Wideband channel models and parameters
  - System classifications
- **Narrowband** systems (L6-8)
  - Performance under flat fading
  - Principle of **diversity** and MIMO systems
  - Diversity gain; Alamouti scheme
  - GSM

Course outline (3)

- **Wideband** and Spread Spectrum Systems (L9-11)
  - Inter-symbol-interference and equalization
  - Principle of multicarrier modulation (OFDM)
  - Spread spectrum, Rake reception, and CDMA
  - WLAN (IEEE 802.11a,b,g)
- Ultra-Wideband Systems (L12-13)
  - Definitions, signals, and features
  - Impulse radio systems and receiver choices

Course Material; Text Books

- A. F. Molisch: *Wireless Communications*, Wiley, 2nd ed., 2011 (Lehrbuchsammlung!)
- T. S. Rappaport: *Wireless Communications – Principles and Practice*, 2nd ed., 2002, Prentice Hall
- J. R. Barry, E. A. Lee, D. G. Messerschmitt: *Digital Communication*, 3rd ed., 2004, Kluwer
- J. G. Proakis and M. Salehi: *Communication Systems Engineering*, 2nd ed., 2002, Pearson
- J. G. Proakis: *Digital Communications*, 4th ed., 2000, McGraw Hill
- J. D. Parsons: *The Mobile Radio Propagation Channel*, 2nd ed., 2000, Wiley
- A. Paulraj, R. Nabar, and D. Gore: *Introduction to Space-Time Wireless Communications*, 2003, Cambridge
- S. Verdu: *Multiuser Detection*, 1999, Cambridge

Administrative Issues (1)

- 12/13 lectures of 1:45 hrs.
  - Schedule on TUG online
  - Wednesday 10:15 – 12:00, i5
- Course web-site: www.spsc.tugraz.at/courses
- Master’s Thesis / Master Projects:
  - **Topics on web site**
  - **Email for an appointment: witrisal@tugraz.at**
- Adv. Signal Processing SE in SS 2016
  - Tentative topic: 5G networks (mmWave; massive MIMO; ultra-dense; D2D)

Administrative Issues (2)

- Exam
  - **oral exam** (two questions)
  - Email for an appointment
  - Proposed dates in Feb/March

Ch. 1 – Introduction

- A glance on the history of wireless
- Key features; design challenges; **enabling technologies**

- Based on text book by T. S. Rappaport: *Wireless Communications*
- Figures taken from this book

Wireless Communications Systems

- Mobile Radio Communications
  - Marconi 1897
  - Radio communication to movable devices
  - Not connected to phone network (PSTN)
- Mobile Radio Telephony
  - Connected to PSTN
  - 1946 in US
  - Fast growth? Yes/no? Why?

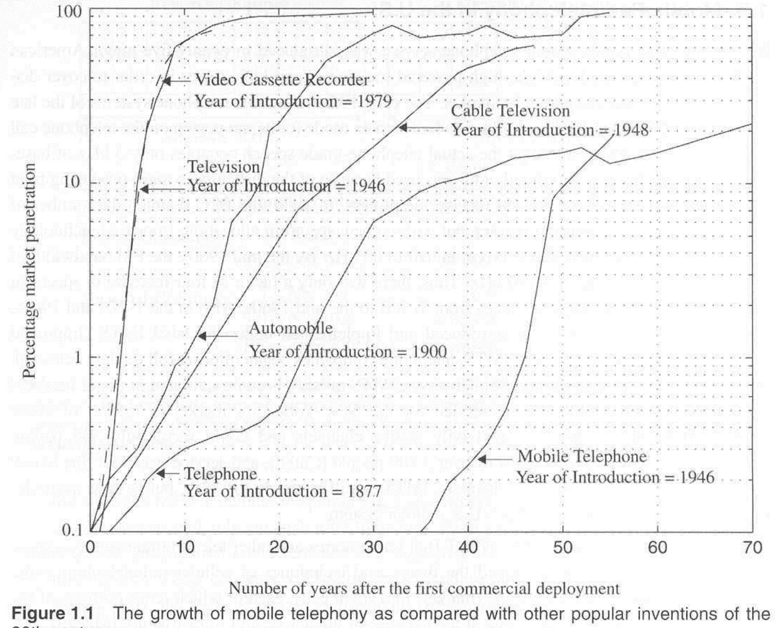
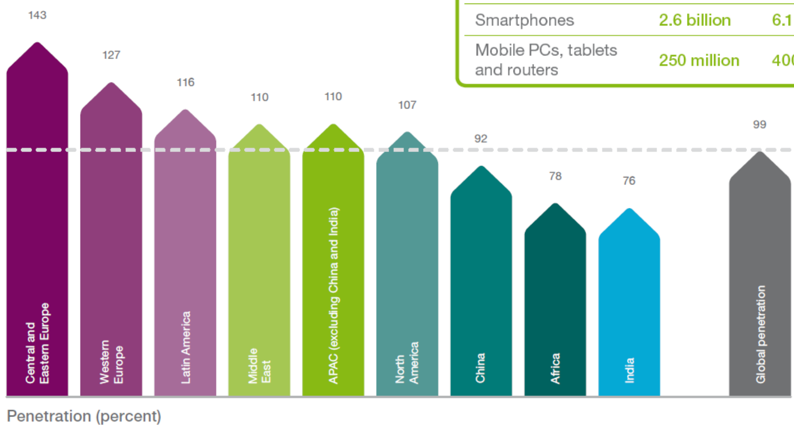


Figure 1.1 The growth of mobile telephony as compared with other popular inventions of the 20th century.

Current situation

Subscriptions	2014	2020
Total mobile	7.1 billion	9.2 billion
Mobile broadband	2.9 billion	7.7 billion
Smartphones	2.6 billion	6.1 billion
Mobile PCs, tablets and routers	250 million	400 million



[source: June 2015 Ericsson Mobility Report]

Historic facts

- after WW2: 1 TRX station per city; half duplex; 120 kHz RF bandwidth
- till 60s: reduction of bandwidth to 30 kHz
- 50s/60s: full duplex; auto dial.

Very small capacity!

  - **an example:** New York City; 1976: 12 channels available; 543 customers served; (3700 customers on waiting list)

Enabling technologies

- **Cellular concept**
  - Developed by Bell Labs in 60s/70s (published 1979 by McDonald)
  - Break coverage area into small **cells**
  - **Reuse** frequencies
  - → Higher system capacity but at higher **complexity**
- Miniaturization (feasible in late 70s)
  - Advances in **digital** and **RF** (radio frequency) large scale integrated circuits
  - To automatically establish calls (active and passive); hand-offs; etc.

A Cellular System

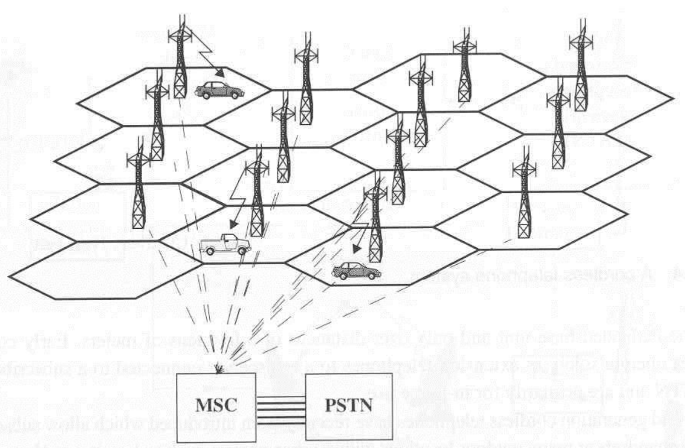


Figure 1.5 A cellular system. The towers represent base stations which provide radio access between mobile users and the mobile switching center (MSC).

Cellular Systems

- Basic elements
  - Mobile Switching Center (MSC)
    - Connected to PSTN
  - Base Stations
  - Mobile Stations
- Common air interface
  - 4 different channels:
    - FCC, RCC, FVC, RVC (forward/reverse; control/voice channels)

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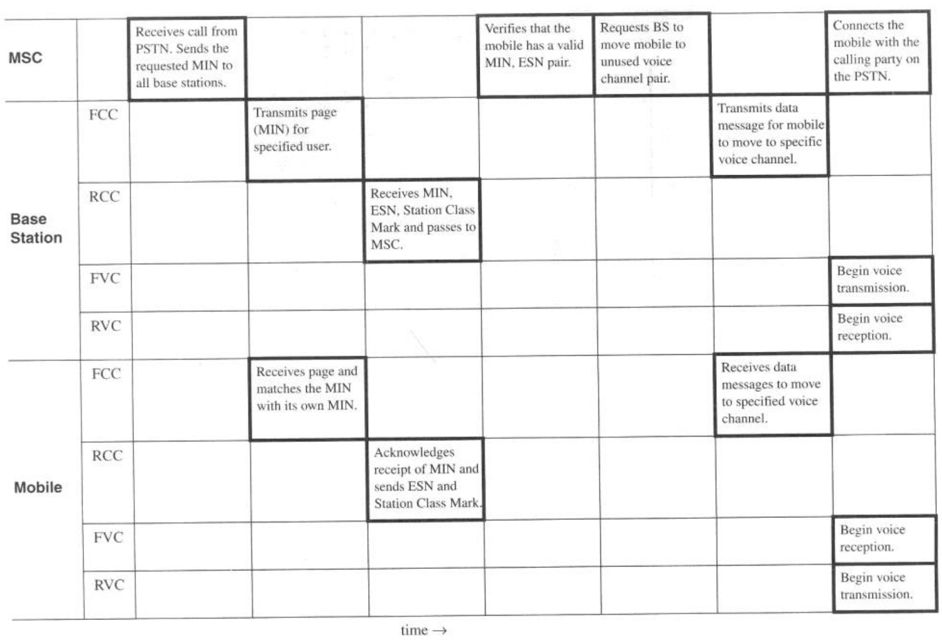


Figure 1.6 Timing diagram illustrating how a call to a mobile user initiated by a landline subscriber is established.

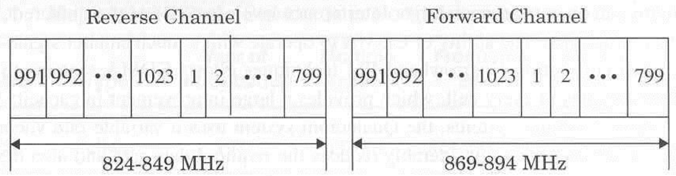
MSC			Receives call initiation request from base station and verifies that the mobile has a valid MIN, ESN pair.	Instructs FCC of originating base station to move mobile to a pair of voice channels.		Connects the mobile with the called party on the PSTN.	
Base Station	FCC				Page for called mobile, instructing the mobile to move to voice channel.		
	RCC	Receives call initiation request and MIN, ESN, Station Class Mark.					
	FVC						Begin voice transmission.
	RVC						Begin voice reception.
Mobile	FCC				Receives page and matches the MIN with its own MIN. Receives instruction to move to voice channel.		
	RCC	Sends a call initiation request along with subscribe MIN and number of called party.					
	FVC						Begin voice reception.
	RVC						Begin voice transmission.

time →

Figure 1.7 Timing diagram illustrating how a call initiated by a mobile is established.

1st Generation

- **Analog FM radio**
- Digital data only for **control information**
- Frequency-division multiple access **(FDMA)**
  (25 – 30 kHz per channel/direction)
- Frequency division duplex **(FDD)**
- Examples:
  - AMPS (US, 83); NTT (Japan, 79); NMT (1st European, 81)
  - Various **incompatible** systems



	Channel Number	Center Frequency (MHz)
Reverse Channel	$1 \le N \le 799$	$0.030N + 825.0$
	$991 \le N \le 1023$	$0.030(N - 1023) + 825.0$
Forward Channel	$1 \le N \le 799$	$0.030N + 870.0$
	$991 \le N \le 1023$	$0.030(N - 1023) + 870.0$

(Channels 800–990 are unused)

Figure 1.2 Frequency spectrum allocation for the U.S. cellular radio service. Identically labeled channels in the two bands form a forward and reverse channel pair used for duplex communication between the base station and mobile. Note that the forward and reverse channels in each pair are separated by 45 MHz.

2nd Generation

- Digital transmission of voice
- Time-Division Multiple Access (TDMA)
  - More than one channel per RF carrier
- Higher spectral efficiency through
  - Digital modulation / TDMA / TDD
  - Speech coding
- Examples:
  - GSM ('90); IS-54 (later IS-136) (US, '91); Qualcomm CDMA ('95)

TDMA

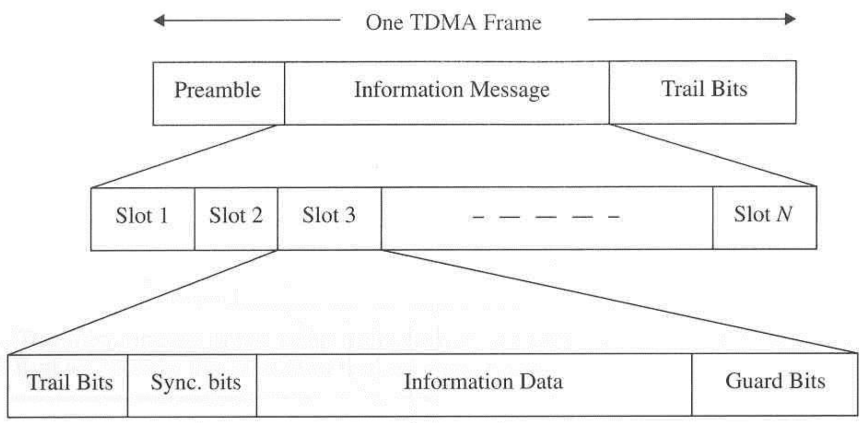


Figure 9.4 TDMA frame structure. The frame is cyclically repeated over time.

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Table 1.2 Major Mobile Radio Standards in Europe

Standard	Type	Year of Introduction	Multiple Access	Frequency Band	Modulation	Channel Bandwidth
ETACS	Cellular	1985	FDMA	900 MHz	FM	25 kHz
NMT-450	Cellular	1981	FDMA	450-470 MHz	FM	25 kHz
NMT-900	Cellular	1986	FDMA	890-960 MHz	FM	12.5 kHz
GSM	Cellular /PCS	1990	TDMA	890-960 MHz	GMSK	200 kHz
C-450	Cellular	1985	FDMA	450-465 MHz	FM	20 kHz/ 10 kHz
ERMES	Paging	1993	FDMA	Several	4-FSK	25 kHz
CT2	Cordless	1989	FDMA	864-868 MHz	GFSK	100 kHz
DECT	Cordless	1993	TDMA	1880-1900 MHz	GFSK	1.728 MHz
DCS-1800	Cordless /PCS	1993	TDMA	1710-1880 MHz	GMSK	200 kHz

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Table 1.1 Major Mobile Radio Standards in North America

Standard	Type	Year of Introduction	Multiple Access	Frequency Band	Modulation	Channel Bandwidth
AMPS	Cellular	1983	FDMA	824-894 MHz	FM	30 kHz
NAMPS	Cellular	1992	FDMA	824-894 MHz	FM	10 kHz
USDC	Cellular	1991	TDMA	824-894 MHz	$\pi/4$-DQPSK	30 kHz
CDPD	Cellular	1993	FH/ Packet	824-894 MHz	GMSK	30 kHz
IS-95	Cellular/ PCS	1993	CDMA	824-894 MHz 1.8-2.0 GHz	QPSK/ BPSK	1.25 MHz
GSC	Paging	1970s	Simplex	Several	FSK	12.5 kHz
POCSAG	Paging	1970s	Simplex	Several	FSK	12.5 kHz
FLEX	Paging	1993	Simplex	Several	4-FSK	15 kHz
DCS-1900 (GSM)	PCS	1994	TDMA	1.85-1.99 GHz	GMSK	200 kHz
PACS	Cordless/ PCS	1994	TDMA/ FDMA	1.85-1.99 GHz	$\pi/4$-DQPSK	300 kHz
MIRS	SMR/PCS	1994	TDMA	Several	16-QAM	25 kHz
iDen	SMR/PCS	1995	TDMA	Several	16-QAM	25 kHz

Current Technologies

- 3rd Generation (3G): e.g. UMTS
  - CDMA; packet oriented data transmission
  - Developed for voice and data
    - High mobility; hundred(s) kBit/s
- Indoor wireless networking
  - WLAN (Wireless LAN)
    - IEEE802.11a, b (WiFi), g (OFDM; CDMA)
    - Low mobility; MBit/s

Current Technologies (cont'd)

- LTE (Long Term Evolution)
  - Evolution of GSM (2G) and UMTS (3G)
  - First truly global standard (also evolution to USA/Japanese CDMA standards)
  - Based on those network technologies; simplifications; unified "all-IP" network; lower latencies
  - Incompatible air interface (E-UTRA)
    - OFDMA, MIMO
    - Flexible bandwidth (1.4 to 20 MHz channels)
    - Data rates up to 300 Mbit/s (DL) / 75 Mbit/s (UL)

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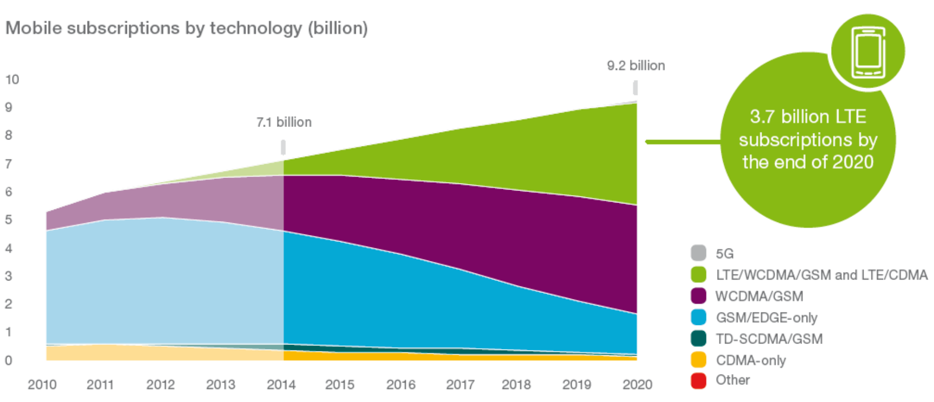
Current market shares



[source: June 2015 Ericsson Mobility Report]

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Future Trends

- The Internet of Things
  - Communication, identification, localization
- Sensor networks
- Cognitive radio
  - Sensing and using free (white) spaces
- Cooperative radio
  - Relaying of wireless links

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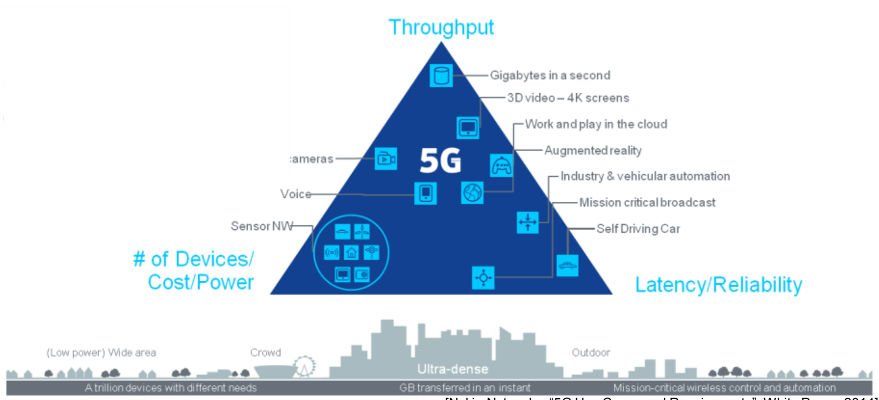
5G Networks:

- *higher capacity, lower latency, ultra-dense deployment*
- **5G technologies:** mm-wave; massive MIMO; small cells; D2D

Diversity of services, use cases and (extreme) requirements



[Nokia Networks, "5G Use Cases and Requirements", White Paper, 2014]

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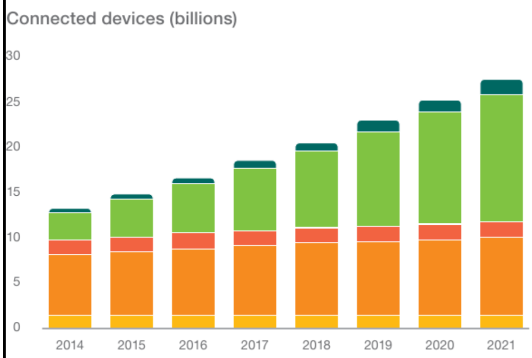
Connected devices



	15 billion	28 billion	CAGR 2015–2021
Cellular IoT	0.4	1.5	27%
Non-cellular IoT	4.2	14.2	22%
PC/laptop/tablet	1.7	1.8	1%
Mobile phones	7.1	8.6	3%
Fixed phones	1.3	1.4	0%
	2015	2021	

[source: 2016 Ericsson Mobility Report]

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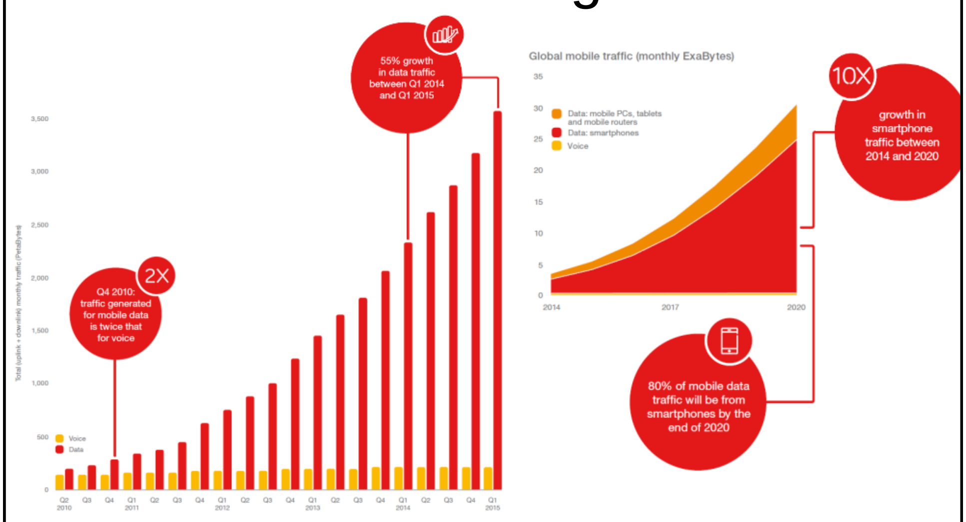
Mobile traffic growth



[source: June 2015 Ericsson Mobility Report]

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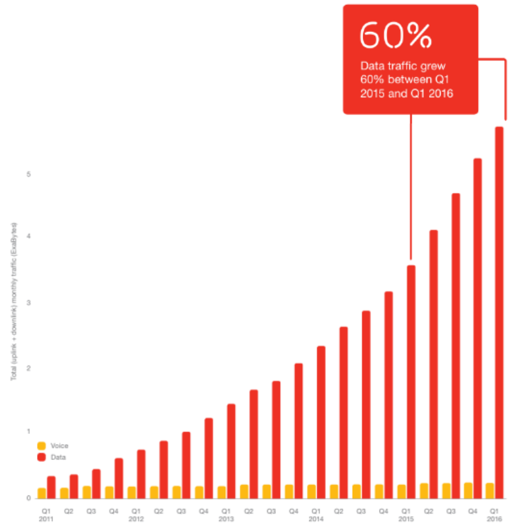
Mobile traffic growth



[source: 2016 Ericsson Mobility Report]

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Design challenges

- Radio spectrum is limited
- Increasing data rate is not trivial
  - Radio channel is a randomly time-variant linear filter
  - Link budgets get tighter

→ **trade-off:** distance (mobility) – data rate

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Ch. 2 – Cellular Concept and Multiple Access

- Cellular concept – frequency reuse
- System Design Fundamentals
  - Placement of base stations
  - Frequency planning
  - System capacity
- Handoff strategies
- Interference and system capacity

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Frequency reuse

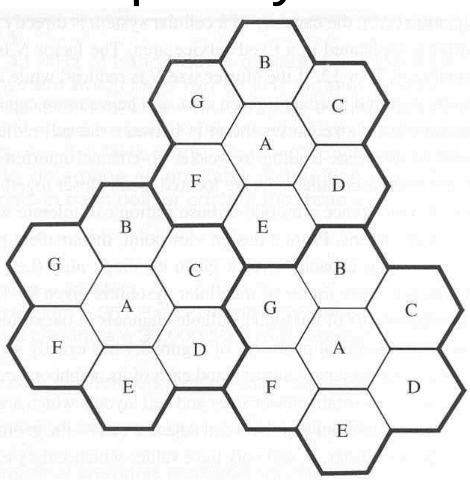


Figure 3.1 Illustration of the cellular frequency reuse concept. Cells with the same letter use the same set of frequencies. A cell cluster is outlined in bold and replicated over the coverage area. In this example, the cluster size, *N*, is equal to seven, and the frequency reuse factor is 1/7 since each cell contains one-seventh of the total number of available channels.

Frequency reuse (cont'd)

$$N = i^2 + ij + j^2$$

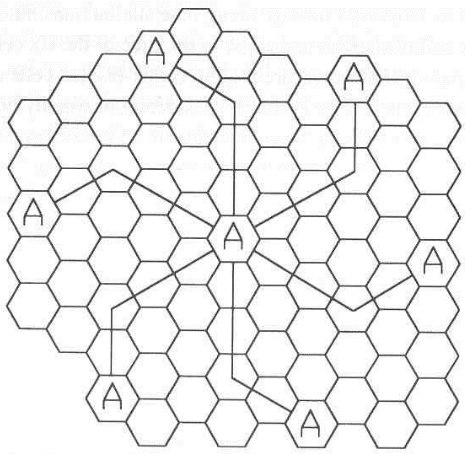


Figure 3.2 Method of locating co-channel cells in a cellular system. In this example, $N = 19$ (i.e., $i = 3$, $j = 2$). (Adapted from [Oet83] © IEEE.)

Design example

Example 3.1

If a total of 33 MHz of bandwidth is allocated to a particular FDD cellular telephone system which uses two 25 kHz simplex channels to provide full duplex voice and control channels, compute the number of channels available per cell if a system uses (a) four-cell reuse, (b) seven-cell reuse, and (c) 12-cell reuse. If 1 MHz of the allocated spectrum is dedicated to control channels, determine an equitable distribution of control channels and voice channels in each cell for each of the three systems.

Channel assignment (frequency planning)

- Fixed
- Dynamic – assigned by MSC
  - E.g. borrowing from neighboring cells

Handoff (handover)

- Mobile moves into different cell

→MSC hands over call
  - Different BS; new channel
- 1G: **Locator receiver** in BS
  - monitors RSS of users in adjacent cells
- 2G: (mobile assisted handoff - MAHO)
  - Mobile monitors RSS from neighboring BS
  - Reports back to MSC

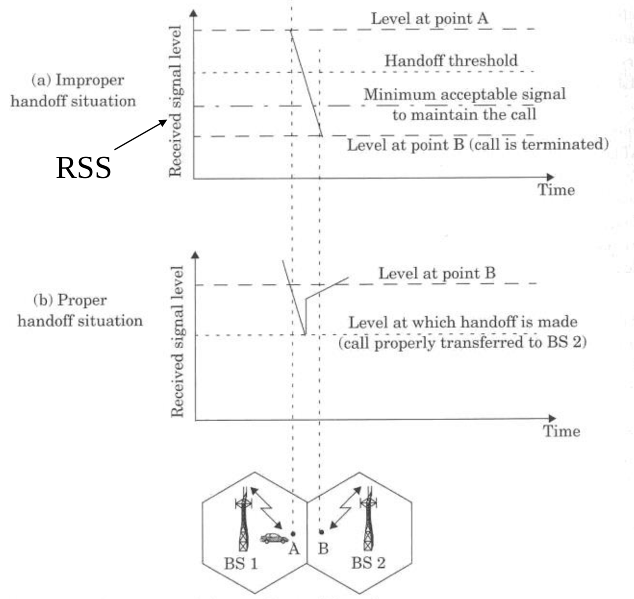


Figure 3.3 Illustration of a handoff scenario at cell boundary.

Handoff (cont’d)

- Hard handoff
  - assign **different RF channel**
  - in **TDMA and analog** systems
- Soft handoff
  - different BS takes over using **same RF ch.**
    - MSC can **instantaneously** select strongest RF signal
  - with **CDMA** systems having $N = 1$

Handoff (cont'd)

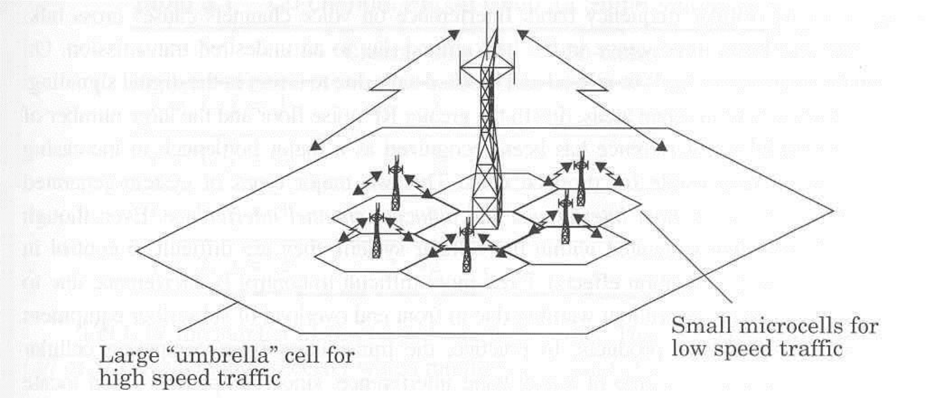


Figure 3.4 The umbrella cell approach.

Interference and system capacity

- Interference is **major limiting factor**!
- Sources
  - Other users in same cell
  - Users in neighboring cells
  - BS using same frequencies (co-channel IF)
  - Unintended electromagnetic radiation
- **Can't** be solved by increasing TX power
  - Frequency planning; power control

Approxim. of S/I

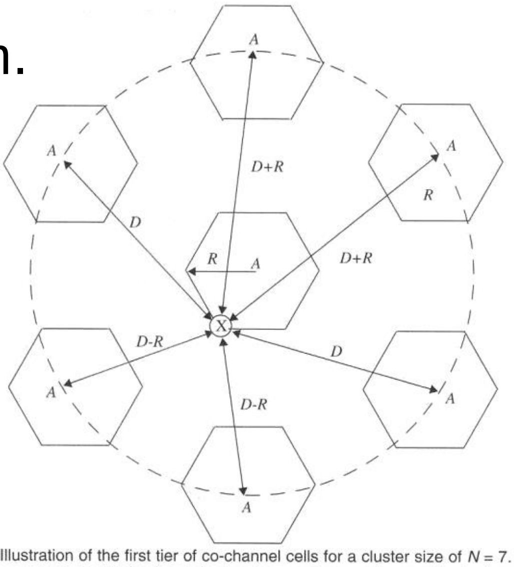


Figure 3.5 Illustration of the first tier of co-channel cells for a cluster size of $N = 7$. An approximation of the exact geometry is shown here, whereas the exact geometry is given in [Lee86]. When the mobile is at the cell boundary (point X), it experiences worst case co-channel interference on the forward channel. The marked distances between the mobile and different co-channel cells are based on approximations made for easy analysis.

Design Example (2) - CCI

Example 3.2

If a signal-to-interference ratio of 15 dB is required for satisfactory forward channel performance of a cellular system, what is the frequency reuse factor and cluster size that should be used for maximum capacity if the path loss exponent is (a) $n = 4$, (b) $n = 3$? Assume that there are six co-channel cells in the first tier, and all of them are at the same distance from the mobile. Use suitable approximations.

Improving coverage and capacity

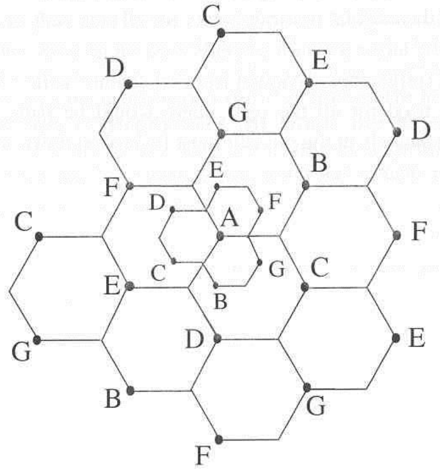


Figure 3.8 Illustration of cell splitting.

Sectoring (1)

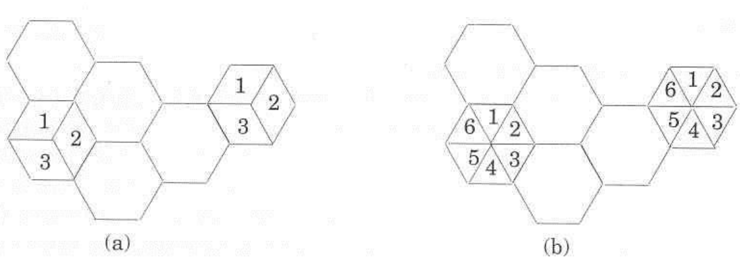


Figure 3.10 (a) 120° sectoring; (b) 60° sectoring.

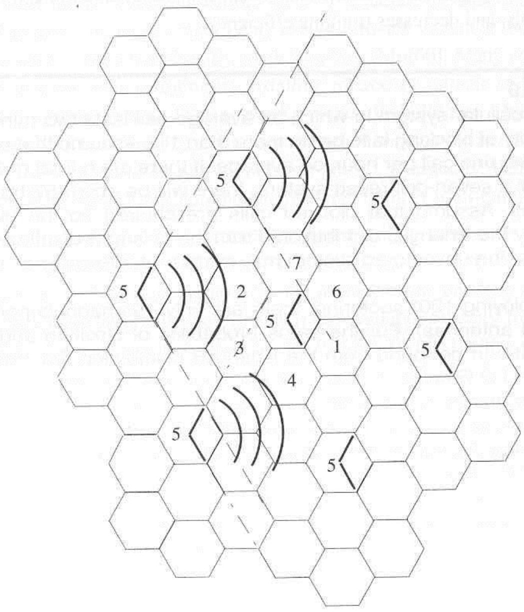


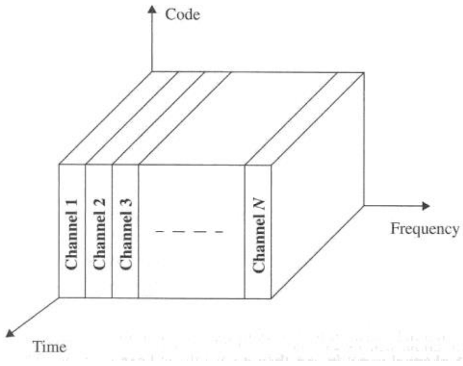
Figure 3.11 Illustration of how 120° sectoring reduces interference from co-channel cells. Out of the 6 co-channel cells in the first tier, only two of them interfere with the center cell. If omnidirectional antennas were used at each base station, all six co-channel cells would interfere with the center cell.

Multiple Access Schemes

- Many users must share radio spectrum
- Three basic principles
  - Frequency
  - Time
  - Code (SNR)
- Best choice is trade-off; influenced by
  - System specifications
  - Technology restrictions

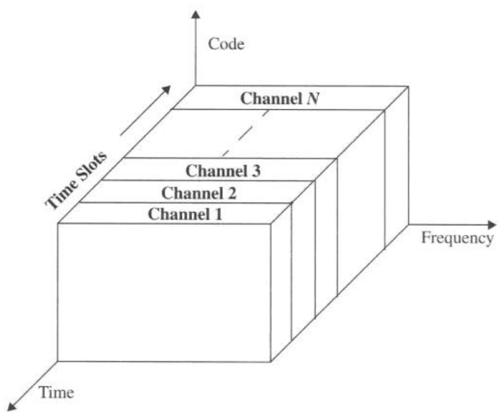
Frequency Division Multiple Access (FDMA)

- Advantages
  - Suitable for analog
  - Less overhead for synchronization
  - Less ISI since narrowband
- Disadvantages
  - Expensive RF (duplexers, filters)
  - One RF channel per user
  - Nonlinear effects at BS antenna



Time Division Multiple Access (TDMA)

- Advantages
  - Multiple users per RF carrier
  - No continuous transm.
    - No duplexers
    - Simpler handoff
  - Higher flexibility
- Disadvantages
  - Equalization needed
  - More synchronization overhead
  - Guard times



Code Division Multiple Access (CDMA)

- Spread spectrum
- Advantages
  - Soft capacity limit
  - Soft handoff
  - Fading reduced
  - Multipath resolvable (Rake receiver)
- Disadvantages
  - Self jamming
  - Near-far problem

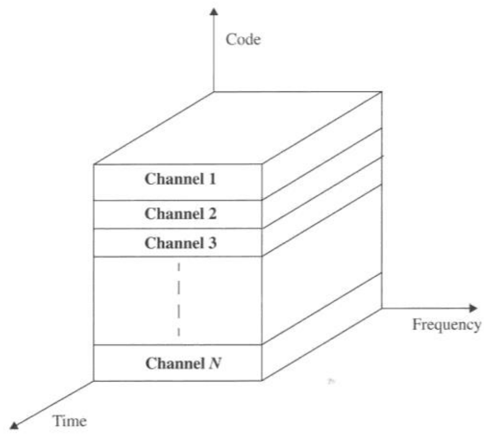


Table 9.1 Multiple Access Techniques Used in Different Wireless Communication Systems

Cellular System	Multiple Access Technique
Advanced Mobile Phone System (AMPS)	FDMA/FDD
Global System for Mobile (GSM)	TDMA/FDD
US Digital Cellular (USDC)	TDMA/FDD
Pacific Digital Cellular (PDC)	TDMA/FDD
CT2 (Cordless Telephone)	FDMA/TDD
Digital European Cordless Telephone (DECT)	FDMA/TDD
US Narrowband Spread Spectrum (IS-95)	CDMA/FDD
W-CDMA (3GPP)	CDMA/FDD CDMA/TDD
cdma2000 (3GPP2)	CDMA/FDD CDMA/TDD