Wireless Communications

Chapter 1

Introduction to Wireless Communication Systems

Guglielmo Marconi

- **古列爾莫·馬可尼**（1874年4月25日－1937年7月20日）
- 義大利波隆那出生
- 義大利工程師，專門從事無線電設備的研製和改進；
- 1909年諾貝爾物理學獎得主

- 1895年 馬可尼發明散屑器，並且送出一個越過葛里封別館附近一座小山的信號。
- 1896年 二十一歲的馬可尼，在義大利郵政局拒絕他的發明後，和母親前往英國。
- 1896年6月27日 實用性無線電報的第一次公開試驗在英國舉行。

- 1896年9月2日 馬可尼送出越過英國索爾斯伯利平原三公里的信號。
- 1897年 5月 馬可尼送出橫越布里斯托海峽14.5公里遠的信號。
- 1897年7月 馬可尼在位義大利海軍進行試驗的期間，送出一個海對地的無線電信號。馬可尼的“無線電報公司”成立。
- 1899年 馬可尼送出橫越英吉利海峽的信號。
- 1900年 馬可尼為調頻 (tuning) 研究工作帶來重大發展。
- 1901年 12月12日 從英國波爾滬(Poldhu, Cornwall) 傳送出摩斯電碼“S”，並且在加拿大的紐芬蘭(Signal Hill in St John‘s, Newfoundland)接收到，使用152.4 公尺(500 ft) kite-supported antenna。

Transatlantic Transmissions

- 他採用水平指向性天線(horizontal directional aerial)，對增加長途發報的範圍非常重要。
- 1909年 馬可尼和德國物理學家布朗(Carl Ferdinand Braun)共同獲得諾貝爾物理獎。“in recognition of their contributions to the development of wireless telegraphy”
- 1912年 4月14、15日 永不沈沒”的鐵達尼號，在首航中撞上冰山。船上馬可尼公司的發報員利用無線電機求救，附近收到信號的一艘的船隻前來救援，使得七百餘人倖免於難。
- 1919年 馬可尼代表義大利參加巴黎和會。
- 1926年 數家短波電台開播。
- 1937年 7月20日 馬可尼去世，享年63歲

- In 1897, Guglielmo Marconi first demonstrated radio's ability to provide continuous contact with ships sailing the English channel.
- Particularly during the past ten years, the mobile radio communications industry has grown by orders of magnitude.
- Digital and RF circuit fabrication improvements, VLSI and other miniaturization technologies make portable radio equipment smaller, cheaper, and more reliable.
- Digital switching techniques also have facilitated the deployment of radio communication networks.

1.1 Evolution of Mobile Radio Communications

- Bell Laboratories developed the cellular concept in the 1960s and 1970s.
- With the development of highly reliable, miniature, solid-state radio frequency hardware in the 1970s, the wireless communications era was born.

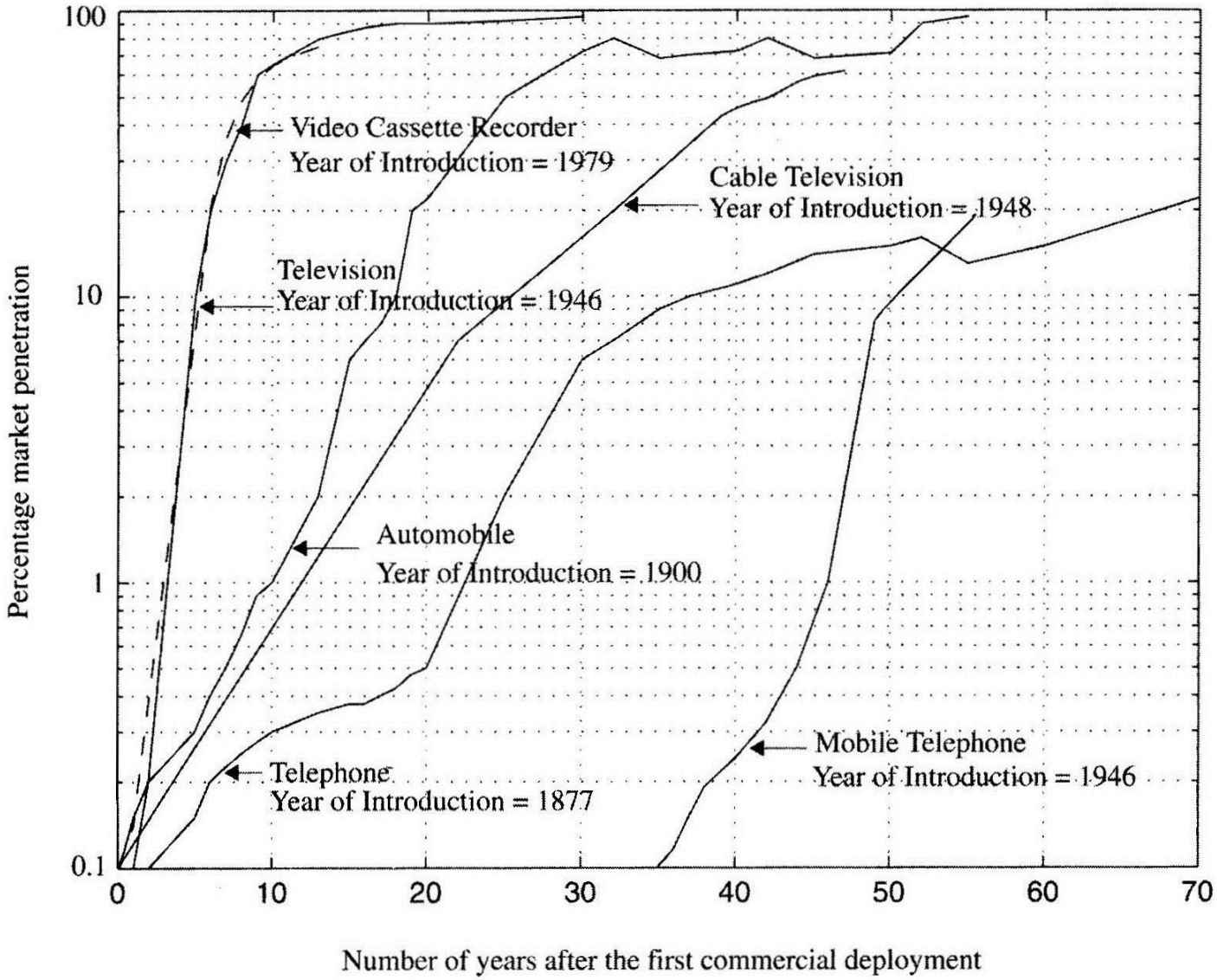


Figure 1.1 The growth of mobile telephony as compared with other popular inventions of the 20th century.

- Figure 1.1 illustrates how mobile telephony has penetrated our daily lives compared with other popular inventions of the 20*th* century.
- The number of worldwide cellular telephone users grew from 25,000 in 1984 to about 25 million in 1993, and since then customer growth rates are well in excess of 50% per year.
- 630 million in 2001 $\longrightarrow$ 60 % of world's population in 2009.

1.2 Mobile Radiotelephony in the U.S.

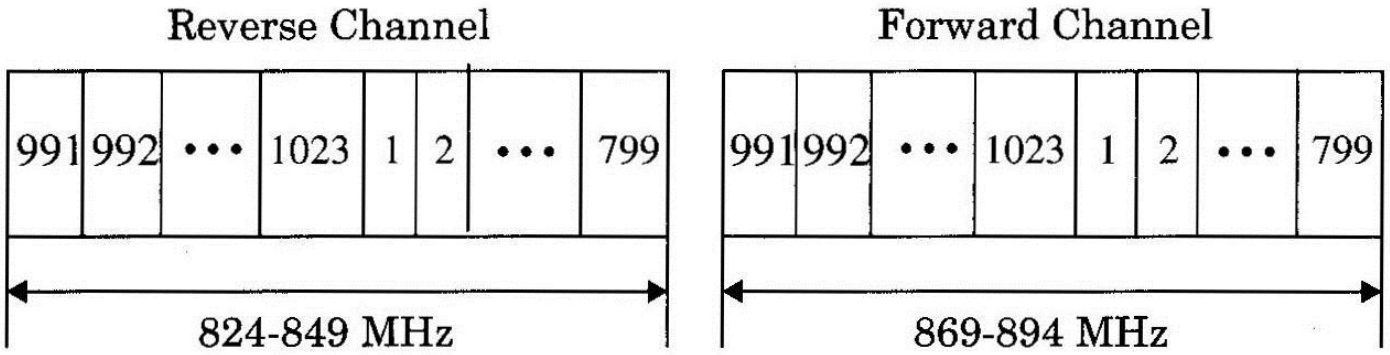
- In 1946, the first public mobile telephone service was introduced in twenty-five major American cities.
- Each system used a single, high-powered transmitter and large tower to cover distances of over 50 km.
- The early FM push-to-talk telephone systems of the late 1940s used 120 kHz of RF bandwidth in a half-duplex mode.
- The actual telephone-grade speech occupies only 3kHz of baseband spectrum.

- Because of the difficulty in mass-producing tight RF filters and low-noise, front-end receiver amplifiers.
- In 1950, channel bandwidth of voice transmissions was cut to 30kHz.
- There was only a factor of four increase in spectrum efficiency due to technology advances from WWII to the mid 1960s.

- In 1950s and 1960s, automatic channel trunking was introduced and implemented under the label IMTS (Improved Mobile Telephone Service).
- IMTS – The Bell Mobile Phone service for the New York City by 1976
  - ✓a market of 10,000,000 people
  - ✓12 channel could serve only 543 paying customers
  - ✓a waiting list of 3,700 people
  - ✓service was poor

- During the 1950s and 1960s, AT&T Bell Lab. and other telecommunications companies developed the theory and techniques of cellular radiotelephony.
- The basic idea of cellular system is similar to that used by the FCC when it allocates television stations or radio stations.
- AT&T proposed the concept of a cellular mobile system to FCC in 1968, although the implementing technology was not available until the late of 1970s.

- In 1983, the FCC finally allocated 666 duplex channels for the U.S. Advanced Mobile Phone System (AMPS)
  - ✓ 40 MHz of spectrum in the 800 MHz band
  - ✓ each channel has a one-way bandwidth of 30 kHz
  - ✓ 60 kHz for each duplex channel
- Each city (called a market) was only allowed to have two cellular radio system providers – a duopoly.



	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.

- Cellular radio systems rely on judicious frequency reuse plans and FDMA to maximize capacity.
- In late 1991, the first US Digital Cellular (USDC) system hardware was installed in major U.S. cities.
- The USDC standard (IS-54 and later IS-136) could support three users in the same 30 kHz bandwidth with digital channels.

- Speech coding technology will increase the capacity to six users per channel in the same 30 kHz bandwidth.
- A cellular system based on code division multiple access (CDMA) was developed by Qualcomm, Inc. and standardized by the Telecommunications Industry Association (TIA) as an Interim Standard (IS-95).
- In the early 1990s, a new specialize mobile radio service (SMR) was developed to compete with U.S. cellular radio carriers.

- Motorola replace MIRS (Motorola's integrated radio system) with the integrated digital enhanced network (iDen).
- Personal Communication Service (PCS) licenses in the 1800/1900 MHz band were auctioned by the U.S. Government to wireless providers in early 1995.
- PCS licenses have spawned new wireless services that complement, as well as compete with, cellular and SMR.

1.3 Mobile Radio Systems Around the World

- The world's most common paging standard is the Post Office Code Standard Advisory Group (POCSAG).
- POCSAG was developed by British Post office in the late 1970s.
- The CT2 and Digital European Cordless Telephone (DECT) standards developed in Europe are the two most popular cordless telephone standards throughout Europe and Asia.

- In the U.S., the PACS standard, developed by Bellcore and Motorola, is likely to be used inside office buildings as a wireless voice and data telephone system or radio local loop.
- The Personal Handyphone System (PHS) standard supports indoor and local loop applications in Japan.

- The world's first cellular system was implemented by the Nippon Telephone and Telegraph company (NTT) in Japan in 1979, using 600 FM duplex channels (25 kHz for each one-way link) in the 800 kHz band.
- In Europe, the European Total Access Cellular System (ETACS) was deployed in 1985 and is virtually identical to the U.S. AMPS system.

- The Pan European digital cellular standard GSM (Global Systems for Mobiles) was first deployed in 1990 in a new 900 MHz band which all of Europe dedicated for cellular telephone service.
- In Japan, the Pacific Digital Cellular (PDC) standard provides digital cellular coverage using a system similar to North America's USDC.

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	π/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	π/4-DQPSK	300 kHz
MIRS	SMR/PCS	1994	TDMA	Several	16-QAM	25 kHz
iDen	SMR/PCS	1995	TDMA	Several	16-QAM	25 kHz

Table 1.2 Major Mobile Radio Standards in Europe

Standard	Type	Year of Introduction	Multiple Access	Frequency Band	Modula-tion	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

Table 1.3 Major Mobile Radio Standards in Japan

Standard	Type	Year of Introduction	Multiple Access	Frequency Band	Modulation	Channel Bandwidth
JTACS	Cellular	1988	FDMA	860-925 MHz	FM	25 kHz
PDC	Cellular	1993	TDMA	810-1501 MHz	π/4-DQPSK	25 kHz
NTT	Cellular	1979	FDMA	400/800 MHz	FM	25 kHz
NTACS	Cellular	1993	FDMA	843-925 MHz	FM	12.5 kHz
NTT	Paging	1979	FDMA	280 MHz	FSK	12.5 kHz
NEC	Paging	1979	FDMA	Several	FSK	10 kHz
PHS	Cordless	1993	TDMA	1895-1907 MHz	π/4-DQPSK	300 kHz

1.4 Examples of Wireless Communication Systems

mobile – historically, mean any radio terminal that could be moved during operation.
Recently, mean a radio terminal that is attached to a high speed mobile platform.

portable – a radio terminal that can be hand-held and used by someone at walking speed.

subscriber – a mobile or portable user.

subscriber unit – a user's communication device.

users or mobiles – the collective group of users.

- The mobiles communicate to fixed base stations which are connected to a commercial power source and a fixed backbone network.
- Mobile radio transmission systems may be classified as simplex, half-duplex or full-duplex.
- Frequency division duplexing (FDD) – by providing two simultaneous but separate channels.

- A duplexer is used inside the subscriber unit to enable the same antenna to be used for simultaneous transmission and reception.

forward channel – the channel used to covey traffic to the mobile user from a base station.

reverse channel – the channel used to carry traffic from the mobile user to a base station.

time division duplexing (TDD) – by providing adjacent time slots on a single radio channel.

TDD is only possible with digital transmission formats and digital modulation, and is very sensitive to timing.

1.4.1 Paging Systems

- Paging systems are designed to provide reliable communication to subscribers wherever they are.
- This necessitates large transmitter power and low data rates for maximum coverage from each base station.

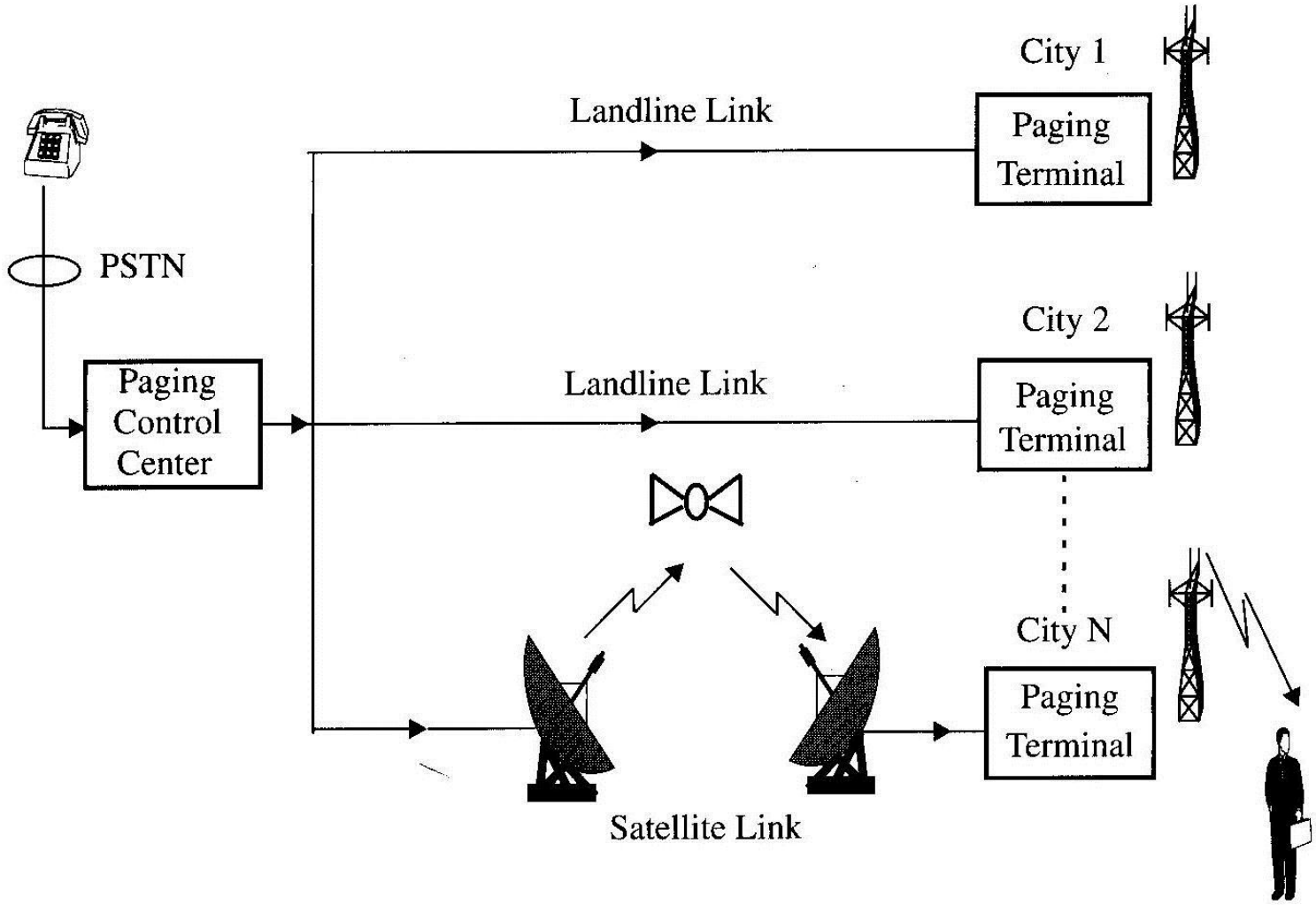


Figure 1.3 A wide area paging system. The paging control center dispatches pages received from the PSTN throughout several cities at the same time.

1.4.2 Cordless Telephone Systems

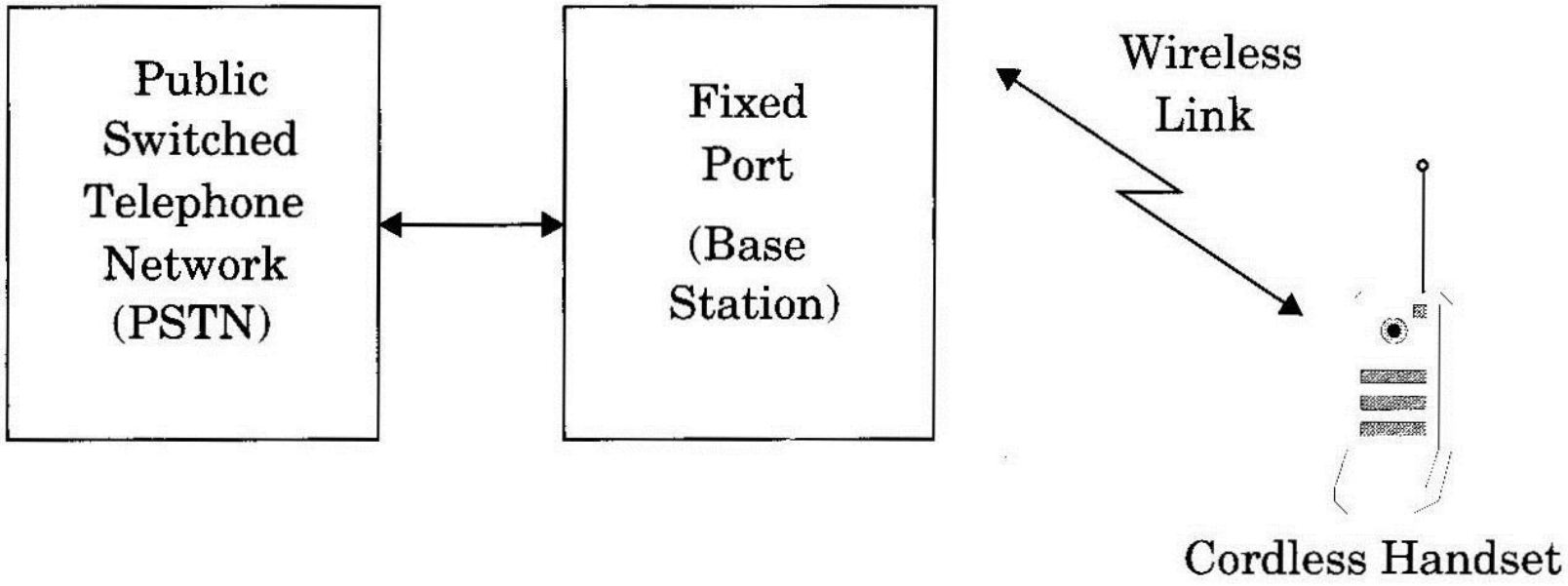


Figure 1.4 A cordless telephone system.

1.4.3 Cellular Telephone Systems

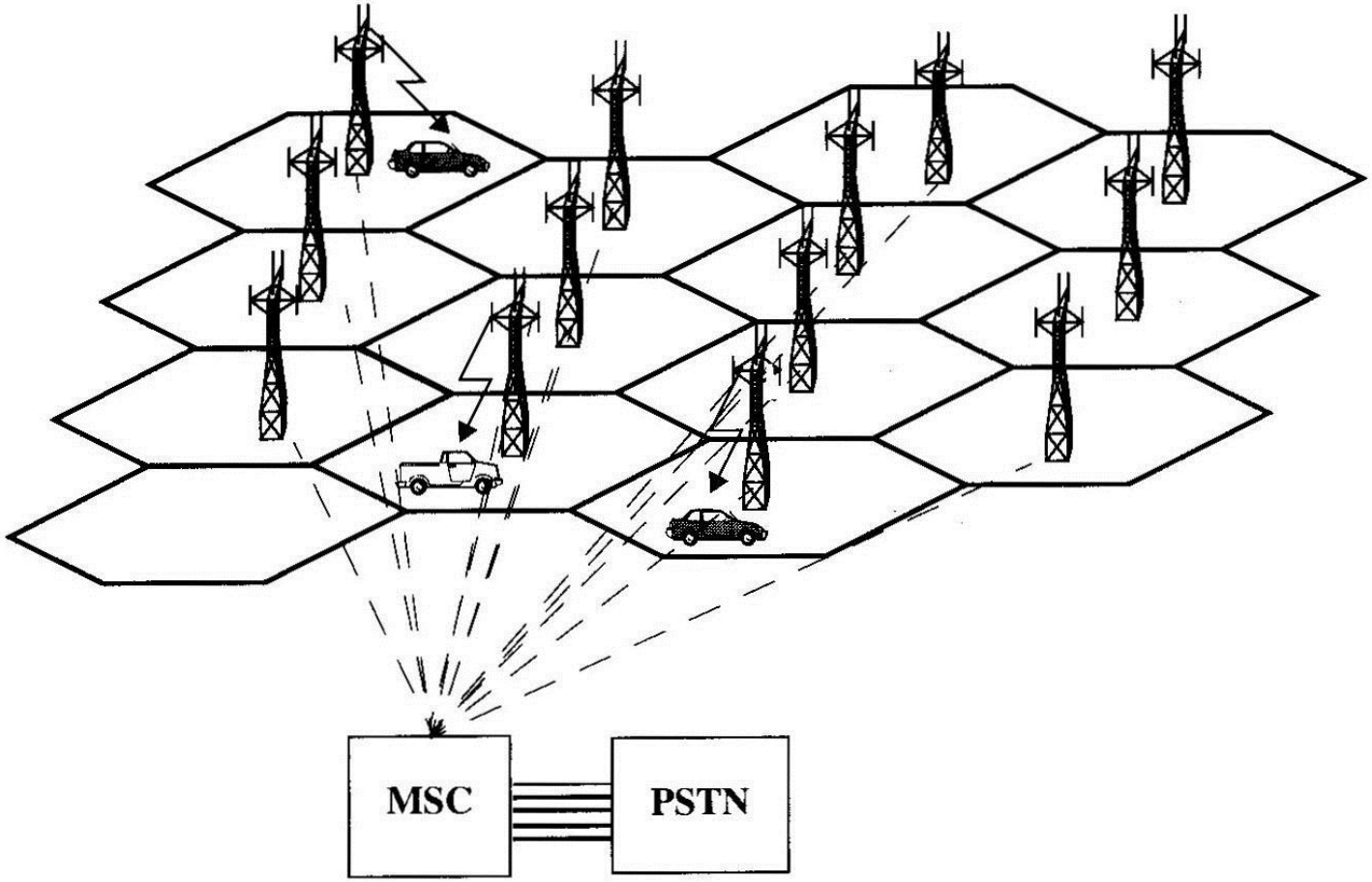


Figure 1.5 A cellular system. The towers represent base stations which provide radio access between mobile users and the mobile switching center (MSC).

- cell
- handoff
- mobile stations, base stations, mobile switching center (MSC), mobile telephone switching office (MTSO).
- A typical MSC handles 100,000 cellular subscribers and 5,000 simultaneous conversations at a time, and accommodates all billing and system maitenance functions, as well.

- Forward voice channels (FVC), reverse voice channels (RVC), forward control channels (FCC), reverse control channels (RCC).

1.4.3.1 How a Cellular Telephone Call is Made

- Mobile identification number (MIN) – the subcriber's telephone number.
- Electronic serial number
- Station class mark – indicates what the maximum transmitter power level is for the particular user.

MSC		Receives call from PSTN. Sends the requested MIN to all base stations.			Verifies that the mobile has a valid MIN, ESN pair.	Requests BS to move mobile to unused voice channel pair.		Connects the mobile with the calling party on the PSTN.
Base Station	FCC		Transmits page (MIN) for specified user.				Transmits data message for mobile to move to specific voice channel.	
	RCC			Receives MIN, ESN, Station Class Mark and passes to MSC.				
	FVC							Begin voice transmission.
	RVC							Begin voice reception.
Mobile	FCC		Receives page and matches the MIN with its own MIN.				Receives data messages to move to specified voice channel.	
	RCC			Acknowledges receipt of MIN and sends ESN and Station Class Mark.				
	FVC							Begin voice reception.
	RVC							Begin voice transmission.

time →

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.

1.4.4 Comparison of Common Wireless Communication Systems

Table 1.5 Comparison of Mobile Communication Systems—Mobile Station

Service	Coverage Range	Required Infra-structure	Complexity	Hardware Cost	Carrier Frequency	Functionality
TV Remote Control	Low	Low	Low	Low	Infrared	Transmitter
Garage Door Opener	Low	Low	Low	Low	< 100 MHz	Transmitter
Paging System	High	High	Low	Low	< 1 GHz	Receiver
Cordless Phone	Low	Low	Moderate	Low	< 1 GHz	Transceiver
Cellular Phone	High	High	High	Moderate	< 2 GHz	Transceiver

Table 1.6 Comparison of Mobile Communication Systems—Base Station

Service	Coverage Range	Required Infra-structure	Complexity	Hardware Cost	Carrier Frequency	Functionality
TV Remote Control	Low	Low	Low	Low	Infrared	Receiver
Garage Door Opener	Low	Low	Low	Low	< 100 MHz	Receiver
Paging System	High	High	High	High	< 1 GHz	Transmitter
Cordless Phone	Low	Low	Low	Moderate	< 1 GHz	Transceiver
Cellular Phone	High	High	High	High	< 2 GHz	Transceiver