

Appendix **A**

First-Generation (1G) Analog

A.1 First-Generation (1G)

Although the advancement of technology (any technology) certainly involves quantum leaps forward from time to time, it is common for major progress also to occur as a result of incremental improvements. For mobile communications technology, advancement has come about in both ways—through occasional revolution and almost certain evolution. Therefore, although this book deals primarily with the technology of *Third-Generation* (3G) wireless networks, an understanding of earlier systems is important. This understanding provides the appropriate perspective from which to view 3G systems and helps us to understand how solutions for 3G systems have been developed. In other words, it is easier to understand where we are going if we understand where we have been. To help in this understanding, this chapter provides an overview of *First-Generation* (1G) systems.

Cellular communication, referred to as *1G*, is one of the most prolific voice communication platforms that has been deployed within the last two decades. Overall, cellular communication is the form of wireless communication that enables several key concepts to be employed, such as the following:

- Frequency reuse
- Mobility of the subscriber
- Handoffs

The cellular concept is employed in many different forms. Typically, when referencing cellular communication, it is usually associated with either the *Advanced Mobile Phone System* (AMPS) or *Total Access Communication Services* (TACS) technology. AMPS operates in the 800-MHz band for base-station receiving (821–849 MHz) and transmitting (869–894 MHz). For TACS, the frequency range is 890 to 915 MHz for base-station receiving and 935 to 960 MHz for base-station transmitting.

Many other technologies also fall within the category of cellular communication, and they involve the *Personal Communications Service* (PCS) bands, including both the domestic U.S. and international bands. In addition, the same concept is applied to several technology platforms that are used currently in the *Specialized Mobile Radio* (SMR) band (IS-136 and iDEN). However, cellular communication is really used by both the AMPS and TACS bands but is sometimes interchanged with the PCS and SMR bands

because of the similarities. However, AMPS and TACS systems are analog-based systems, not digital.

The concept of cellular radio was developed by AT&T at its Bell Laboratories to provide additional radio capacity for a geographic customer service area. The initial mobile systems from which cellular evolved were called *Mobile Telephone Systems* (MTSs). Later improvements to these systems occurred, and the systems were referred to as *Improved Mobile Telephone Systems* (IMTSs). One of the main problems with these systems was that a mobile call could not be transferred from one radio station to another without loss of communication. This problem was resolved by implementing the concepts of reusing the allocated frequencies of the system. Reusing the frequencies in cellular systems enables a market to offer higher radio traffic capacity. The increased radio traffic enables more users in a geographic service area than with the MTS or IMTS systems.

Cellular radio was a logical progression in the quest to provide additional radio capacity for a geographic area. The cellular system, as it is known today, has its primary roots in the MTS and the IMTS. Both MTS and IMTS are similar to cellular with the exception that no handoff takes place within these networks.

Cellular systems operate on the principle of frequency reuse. Frequency reuse in a cellular market enables a cellular operator to offer higher radio traffic capacity. The higher radio traffic capacity enables many more users in a geographic area to use radio communication than are available with an MTS or IMTS system.

The cellular systems in the United States are broken into *Metropolitan Statistical Areas* (MSAs) and *Rural Statistical Areas* (RSAs). Each MSA and RSA has two different cellular operations that offer service. The two cellular operations are referred to as *A-band* and *B-band systems*. The A-band system is the nonwireline system, and the B-band is the wireline system for the MSA or RSA.

A.2 1G Systems

Numerous mobile wireless systems have been deployed throughout the world. Each of the various 1G wireless systems has its own unique advantages and disadvantages depending on the spectrum available and the services envisioned for delivery. 1G mobility systems are defined as *analog systems* and typically are referred to as an *AMPS* or *TACS system*. It is important to note that analog systems use digital signaling in many aspects of their networks, including the air interface. However, the analog reference applies to the method that the information content is transported over; that is, no CODEC is involved.

Table A.1 represents the popular 1G wireless mobility service offerings that have been deployed. As mentioned previously, the two most prolific 1G systems deployed in the world are AMPS and TACS.

All the 1G systems shown in the table use a *Frequency-Division Multiple Access* (FDMA) scheme for radio system access. However, the specific channel bandwidth that each uses is slightly different, as is the typical spectrum allocations for each of the services. The channel bandwidths are as follows:

- *AMPS* is the cellular standard that was developed for use in North America. This type of system operates in the 800-MHz frequency band. AMPS systems also have been deployed in South America, Asia, and Russia.
- *Narrow-Band AMPS* (NAMPS) is a product that is used in parts of the United States, Latin America, and other parts of the world. NAMPS is a cellular

	AMPS	NAMPS	TACS	NMT450	NMT900	C450
Base Tx, MHz	869–894	869–894	935–960	463–468	935–960	461–466
Base Rx, MHz	824–849	824–849	890–915	453–458	890–915	451–456
Multiple access method	FDMA	FDMA	FDMA	FDMA	FDMA	FDMA
Modulation	FM	FM	FM	FM	FM	FM
Radio channel spacing	30 kHz	10 kHz	25 kHz	25 kHz	12.5 kHz	20 kHz (b) 10 kHz (m)
Number of channels	832	2496	1000	200	1999	222(b) 444(m)
CODEC	NA	NA	NA	NA	NA	NA
Spectrum allocation	50 MHz	50 MHz	50 MHz	10 MHz	50 MHz	10 MHz

TABLE A.1 1G Systems

standard that was developed as an interim platform between 1G and 2G systems and was developed by Motorola. Specifically, NAMPS is an analog radio system that is very similar to AMPS, with the exception that it uses 10-kHz-wide voice channels instead of the standard 30-kHz channels. The obvious advantage with this technology is the capability to deliver, under ideal conditions, three times more capacity than regular AMPS.

NAMPS is able to achieve this smaller bandwidth through changing the format and methodology for *Supervisory Audio Tone* (SAT) and control communications from the cell site to the subscriber unit. In particular, NAMPS uses a subcarrier method and a digital color code in place of SAT. These two methods make it possible to use less spectrum while communicating the same amount of or even more information at the same time and increasing the capacity of the system with the same spectrum.

However, this advantage in capacity, of course, requires a separate transmitter, either a *Power Amplifier* (PA) or a transceiver, for each NAMPS channel deployed. The control channel that is used for the cell site is the standard control channel (30 kHz) that is used by AMPS and other technology platforms employed for cellular communication. Additionally, the *Carrier-to-Interferer* (C/I) requirements owing to the narrower-bandwidth channels are different from those of a regular AMPS system, which has a direct impact on the capacity of the system.

- *TACS* is a cellular band that was derived from the AMPS technology. TACS systems operate in both the 800- and 900-MHz band. The first system of this kind was implemented in England. Later, these systems were installed in Europe, Hong Kong, Singapore, and the Middle East. A variation of this standard was implemented in Japan, called *JTACS*.
- *Nordic Mobile Telephone* (NMT) is the cellular standard that was developed by the Nordic countries of Sweden, Denmark, Finland, and Norway in 1981. This type of system was designed to operate in the 450- and 900-MHz frequency bands. These are noted as *NMT450* and *NMT900*. NMT systems also have been deployed throughout Europe, Asia, and Australia.

The basic service offering for 1G systems was and is voice communication. These systems have been extremely successful, and many of them are still in service offering 1G services only.

1G systems, however, suffer from a number of difficulties. Some of these difficulties were addressed by adding technology to the network, and some have required the implementation of 2G technology. The biggest problem that led to the introduction of 2G technology was the fact that 1G systems had limited system capacity. This became a serious issue as the popularity of mobile communications grew to a level that far exceeded anyone's expectations. Other problems included the fact that the technologies in question addressed only the air interface, and other interfaces in the network were not specified (at least not initially), which meant limited roaming, particularly between networks that were supplied by different vendors. The technologies did not initially include security mechanisms, which allowed for fraud. Finally, some limitation in the technologies led to the problem of "lost mobiles," where a subscriber is located at one *Mobile Switching Center* (MSC), and the network thinks that the subscriber is elsewhere.

Nevertheless, it is worth emphasizing the popularity of these technologies and the fact that, in some cases, they are the foundation on which 2G and 3G technologies have been built.

A.3 General 1G System Architecture

A generic 1G cellular system configuration is shown in Figure A.1. The configuration involves all the high-level system blocks of a cellular network. Many components consist of each of the blocks shown in Figure A.1.

Referring to Figure A.1, the mobile communicates with the cell site through the use of radio transmissions. The radio transmissions use a full-duplex configuration, which involves separate transmit and receive frequencies for the mobile and the cell sites. The cell site transmits on the frequency to which the mobile unit is tuned, whereas the mobile unit transmits on the radiofrequency to which the cell-site receiver is tuned.

The cell site acts as a conduit for the information transfer, converting the radio energy into another medium. The cell site sends and receives information from the mobile and the *Mobile Telephone System Office* (MTSO), also called the *Mobile Switching Office* (MSO). The MTSO is connected to the cell site either by leased T1/E1 lines or through a microwave system. The cellular system is made up of many cell sites that all interconnect back to the MTSO.

The MTSO processes the call and connects the cell-site radio link to the *Public Switched Telephone Network* (PSTN). The MTSO performs a variety of functions involved with call processing and is effectively the brains of the network. The MTSO maintains the individual subscriber records, the current status of subscribers, call routing information, and billing information, to mention a few items.

A.4 Typical MTSO Configuration

Figure A.2 is a generic MTSO configuration. The MTSO is the portion of the network that interfaces the radio world with the PSTN. Mature systems often have multiple MTSO locations, and each MTSO can have several cellular switches located within each building.

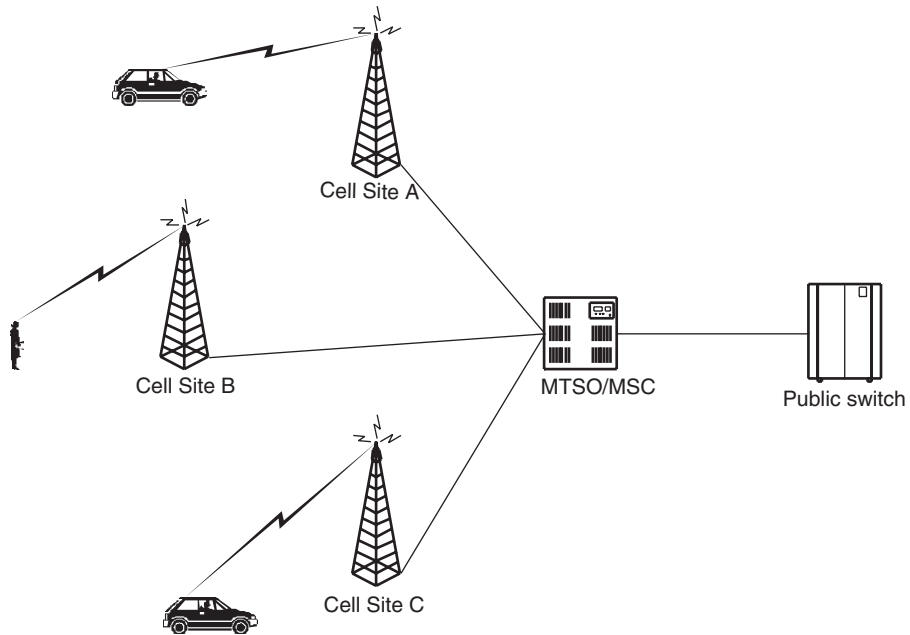


FIGURE A.1 General cellular system.

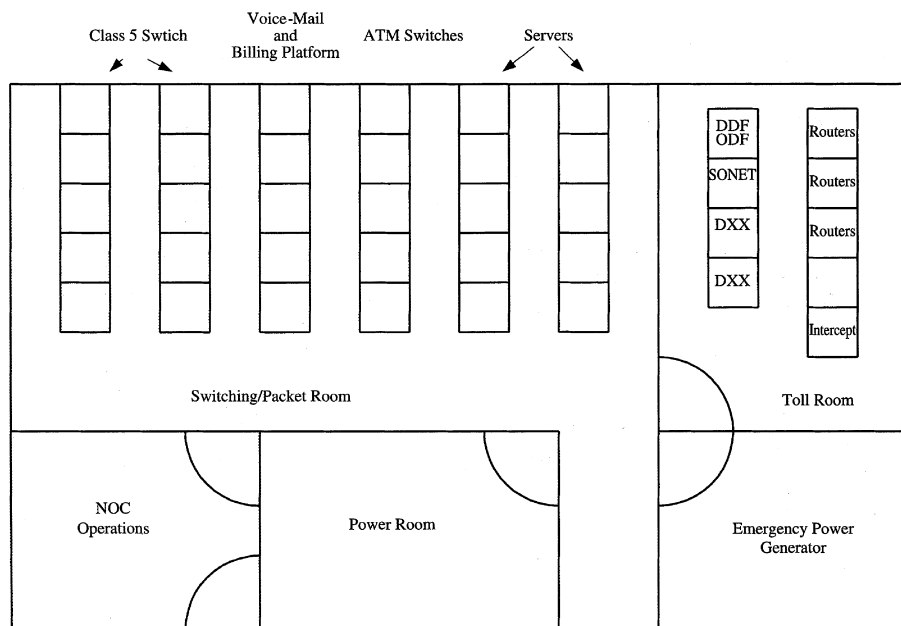


FIGURE A.2 General MTSO configuration.

A.5 1G BTS (Cell Site) Configuration

Figure A.3 is an example of a generic cell-site configuration that is a monopole site. The site has an equipment hut associated with it that houses the radio transmission equipment. The monopole, which is next to the equipment hut, supports the antennas used for the cell site at the very top of the monopole. The cable tray, which is between the equipment hut and the monopole, supports the coaxial cables that connect the antennas to the radio transmission equipment.

The radio transmission equipment used for a cellular base station, located in the equipment room, is shown in Figure A.4. The equipment room layout is a typical arrangement in a cell site. The cell-site radio equipment consists of a *Base-Site Controller* (BSC); a radio bay; and the amplifier, Tx bay. The cell-site radio equipment is connected to the *Antenna Interface Frame* (AIF) that provides the receiver and transmit filtering. The AIF then is connected to the antennas on the monopole via coaxial cables that are located next to the AIF bay.

With new versions of equipment the radio bay, Tx bay, and AIF along with the controller are located in one cabinet.

The cell site is also connected to the MTSO through the Telco bay. The Telco bay provides either T1/E1 leased lines or a microwave radio link connection. The power for the cell site is secured through the use of power bays and rectifiers that convert ac electricity to dc. Batteries are used in the cell site in the event of a power disruption to ensure that the site continues to operate until power is restored or the batteries are exhausted.

A.6 AMPS Call Setup Scenarios

Several general call scenarios can occur, and they pertain to all cellular systems. A few perturbations of the call scenarios are discussed here that are driven largely by fraud-prevention techniques employed by individual operators. Numerous algorithms are used throughout the call setup and processing scenarios that are not included in Figures A.5, A.6, and A.7. However, the call scenarios presented in these figures provide the fundamental building blocks for all call scenarios used in cellular.

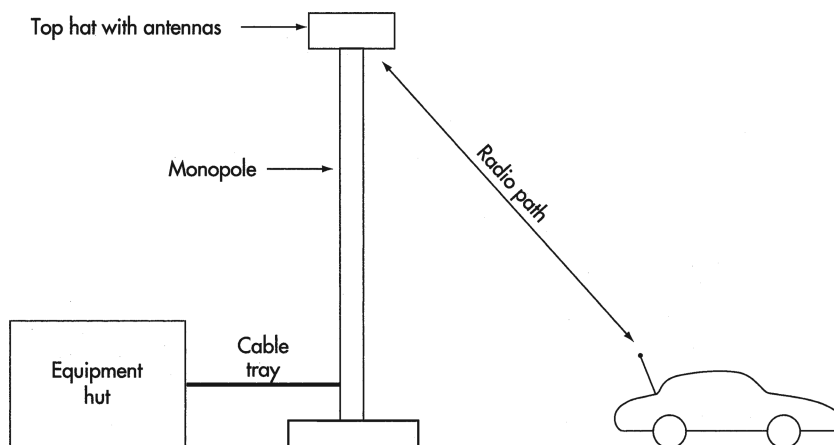


FIGURE A.3 General cell-site configuration.

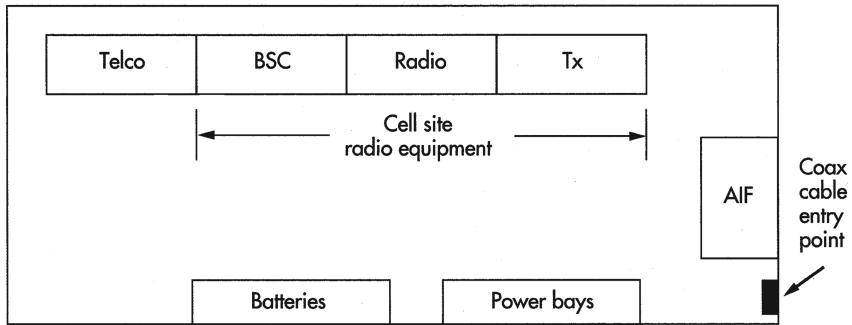


FIGURE A.4 Radio transmission equipment for a cellular base station.

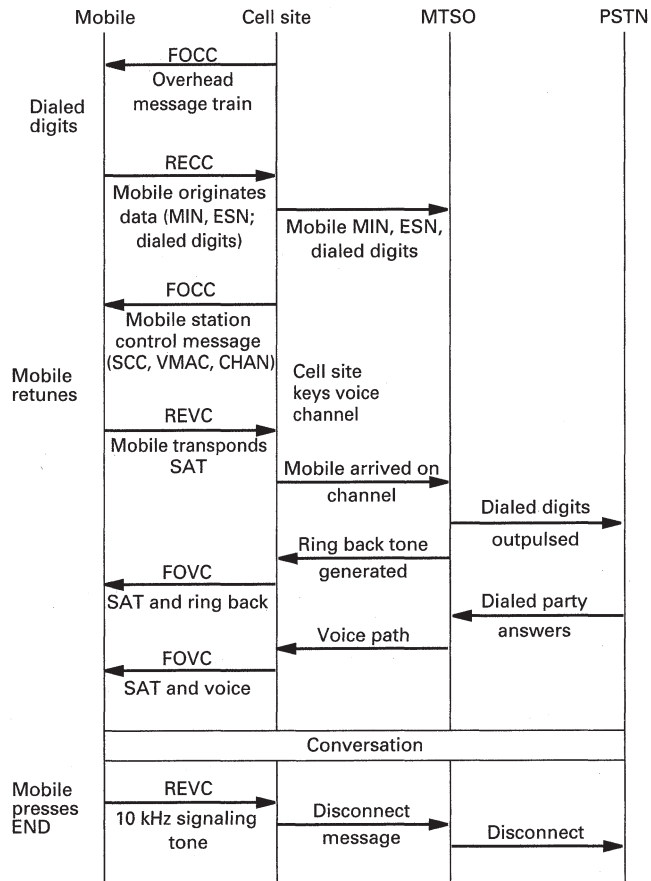


FIGURE A.5 Mobile-to-land call setup.

A.8

Appendix A

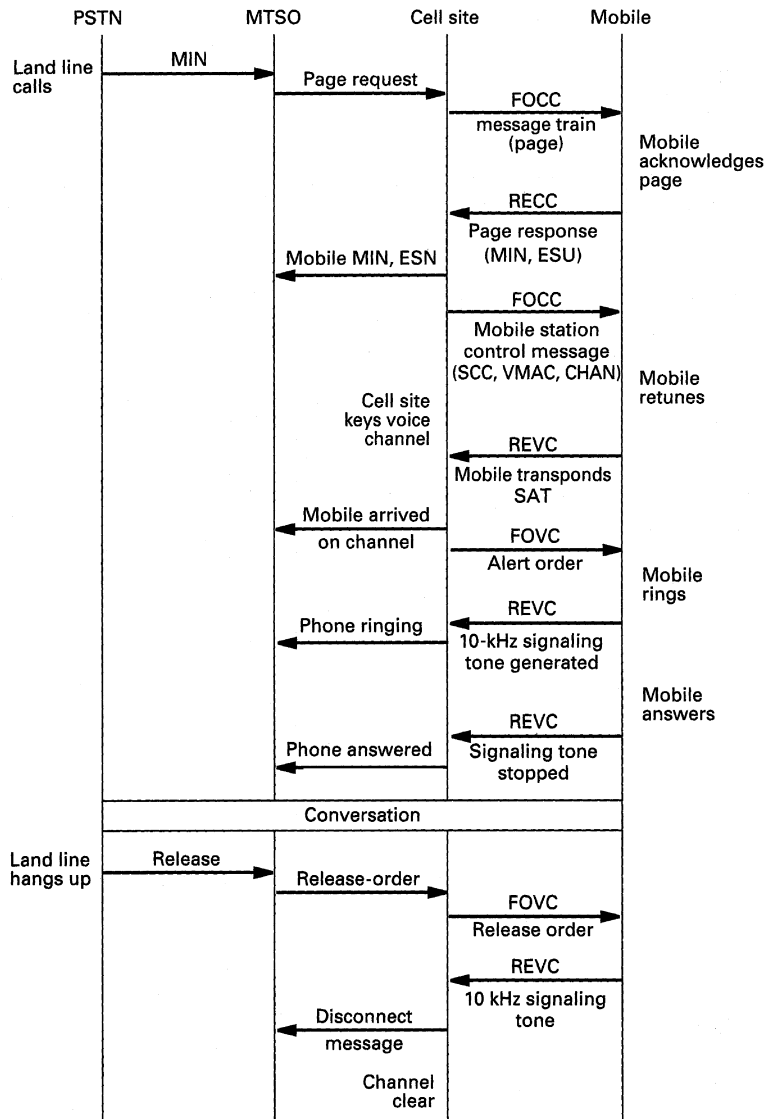


FIGURE A.6 Land-to-mobile call setup.

A.7 Handoff

The handoff concept is one of the fundamental principles of this technology. Handoffs enable cellular to operate at lower power levels and provide high capacity. The handoff scenario presented in Figure A.8 uses a simplified process. A multitude of algorithms are invoked for the generation and processing of a handoff request and an eventual

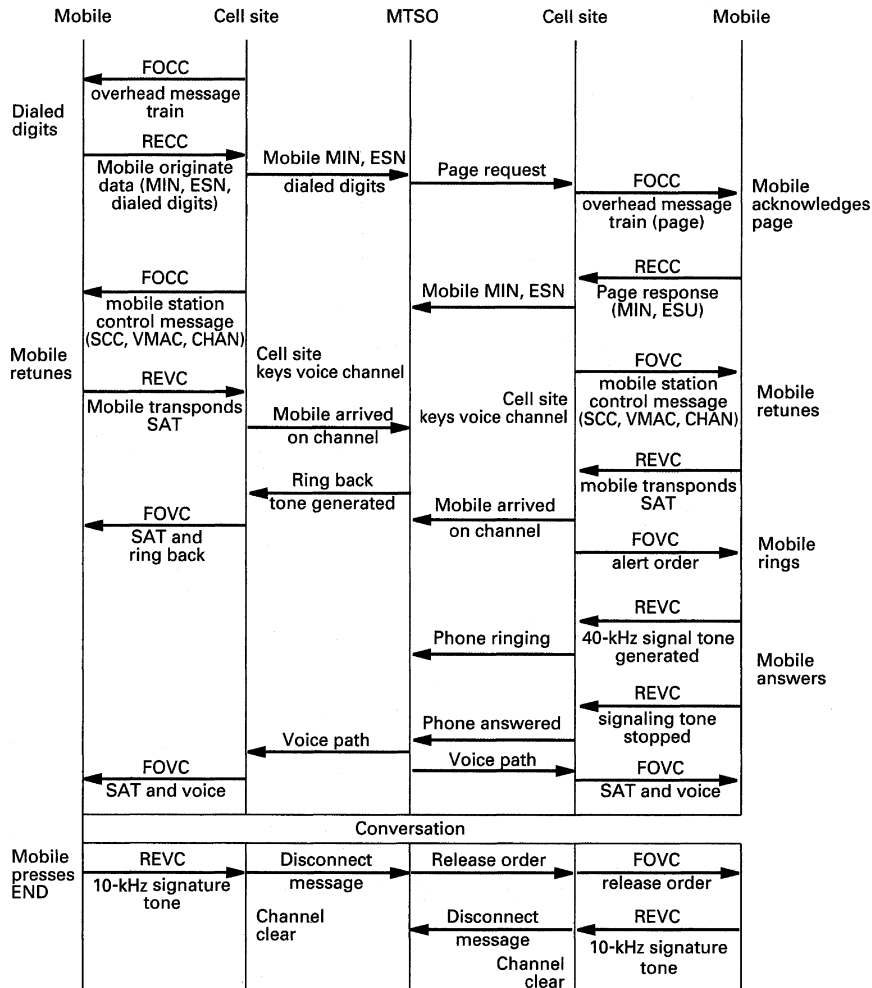


FIGURE A.7 Mobile-to-mobile call setup.

handoff order. The individual algorithms depend on the individual vendor for the network infrastructure and the software loads used.

Handing off from cell to cell is fundamentally the process of transferring the mobile unit that has a call in progress on a particular voice channel to another voice channel, all without interrupting the call. Handoffs can occur between adjacent cells or between sectors of the same cell site. The actual need for a handoff is determined by the quality of the *Radiofrequency* (RF) signal received from the mobile unit into the cell site.

As the mobile unit transverses the cellular network, it is handed off from one cell site to another cell site, ensuring that call quality is maintained for the duration of the conversation.

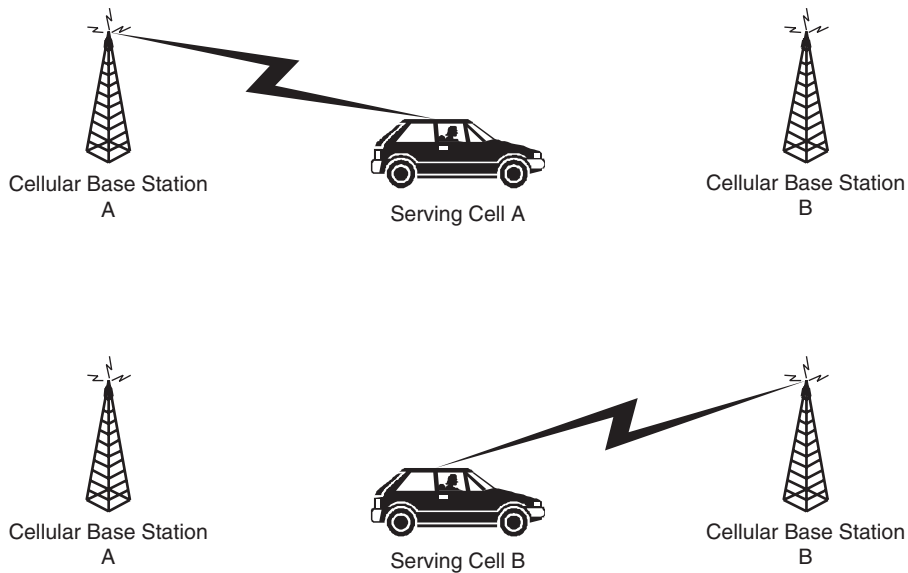


FIGURE A.8 Analog handoff.

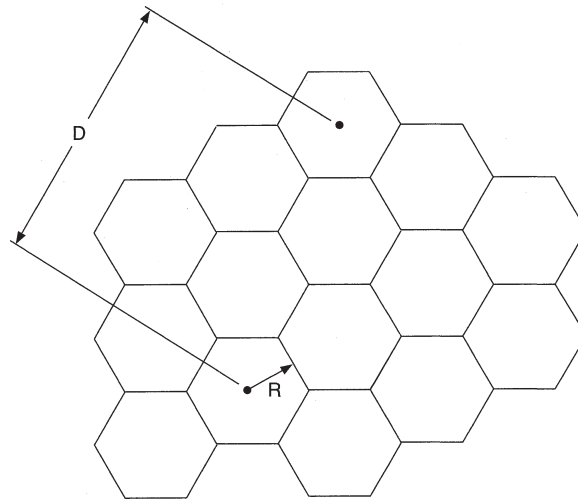
A.8 Frequency Reuse

The concept and implementation of frequency reuse were an essential element in the quest for cellular systems that had a higher capacity per geographic area than an MTS or IMTS system. *Frequency reuse* is the core concept defining a cellular system and involves reusing the same frequency in a system many times over. The ability to reuse the same radiofrequency many times in a system is the result of managing the C/I signal levels for an analog system. Typically, the minimum C/I level designed for a cellular analog system is 17 dB C/I .

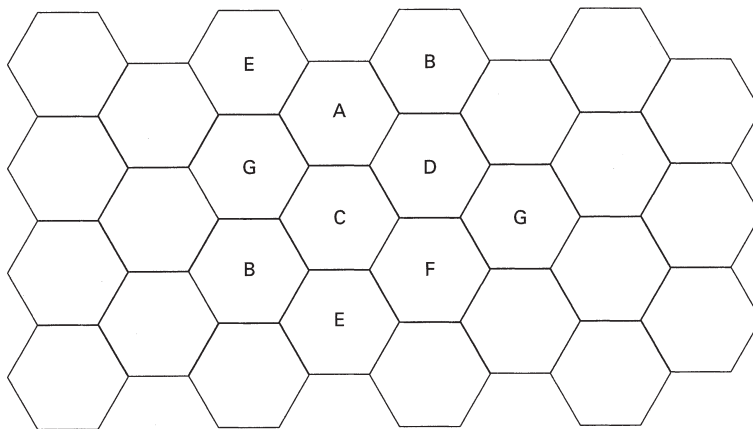
In order to improve the C/I ratio, the reusing channel should be as far away from the serving site as possible so as to reduce the interferer component of C/I . The distance between reusing base stations is defined by the D/R ratio, which is a parameter used to define the reuse factor for a wireless system. The D/R ratio, shown in Figure A.9, is the relationship between the reusing cell site and the radius of the serving cell sites. Table A.2 illustrates standard D/R ratios for different frequency-reuse patterns N .

As the D/R table implies, several frequency-reuse patterns are currently in use throughout the cellular industry. Each of the different frequency-reuse patterns has its advantages and disadvantages. The most common frequency-reuse pattern employed in cellular is the $N = 7$ pattern, which is shown in Figure A.10.

The frequency-reuse pattern ultimately defines the maximum amount of radios that can be assigned to an individual cell site. The $N = 7$ pattern can assign a maximum of 56 channels that are deployed using a three-sector design.

**FIGURE A.9** D/R ratio.

<i>D</i>	<i>N</i> (Reuse Pattern)
3.46R	4
4.6R	7
6R	12
7.55R	19

TABLE A.2 D/R Ratios**FIGURE A.10** $N = 7$ frequency-reuse pattern.

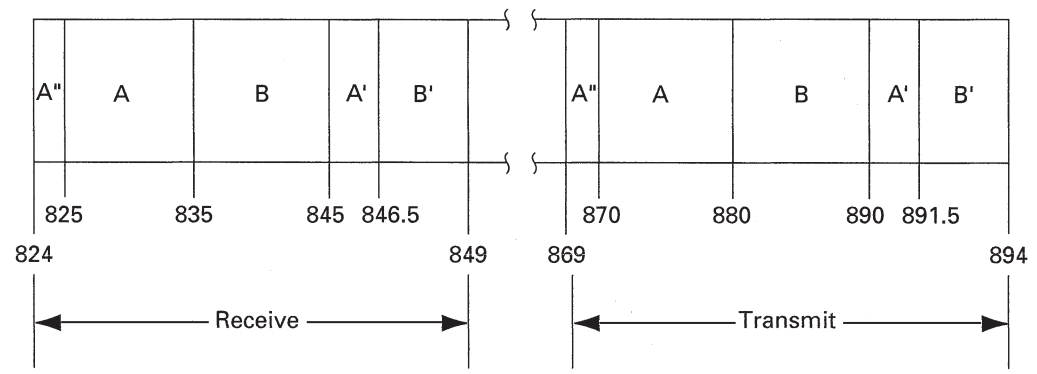


FIGURE A.11 AMPS spectrum.

A.9 Spectrum Allocation

Cellular systems have been allocated a designated frequency spectrum within which to operate. Both the A-band and B-band operators are allowed to use a total of 25 MHz of radio spectrum for their systems. The 25 MHz is divided into 12.5 MHz of transmit frequencies and 12.5 MHz of receive frequencies for each operator. The cellular spectrum is shown in Figure A.11.

The spectrum chart shown in Figure A.11 indicates the locations of the A-band and B-band cell-site transmit and receive frequencies. Currently, a total of 832 individual *Federal Communications Commission* (FCC) channels are available in the United States. The radio channels used in cellular are spaced at 30-kHz intervals, with the transmit frequency operating at 45 MHz above the receive frequency. Both A-band and B-band operators have available to them a total of 416 radio channels: 21 setup and 395 voice channels.

A.10 Channel Band Plan

A channel band plan is essential in any wireless system, especially one that reuses the spectrum at defined intervals. The channel band plan is a method of assigning channels, or fixed bandwidth, to a given amount of an RF spectrum that is then grouped in a local fashion.

An example of a channel band plan is shown in Table A.3. The channel band plan is for an AMPS (B-band) system using an $N = 7$ frequency-reuse pattern. The channels are all by definition 30 kHz in size. Therefore, if one were to count the individual channels listed in the chart, 12.5 MHz of spectrum would be accounted for. Since the cellular system is a duplexed system, 12.5 MHz is used for both transmit and receive, whereas the total spectrum used is 25 MHz per operator.

A.11 1G Systems

The introduction of 1G systems began the wireless revolution toward mobility being an accepted and expected method of communication. However, as implicated in the 1G discussions, the overwhelming demand for mobility services has resulted in the need to

Channel Group:	Wireline B-Band Channels									
	A1	B1	C1	D1	E1	F1	G1	A2	B2	C2
Control channel	334	335	336	337	338	339	340	341	324	343
	355	356	357	358	359	360	361	362	345	364
	376	377	378	379	380	381	382	383	366	385
	397	398	399	400	401	402	403	404	387	406
	418	419	420	421	422	423	424	425	408	427
	439	440	441	442	443	444	445	446	429	448
	460	461	462	463	464	465	466	467	450	469
	481	482	483	484	485	486	487	488	471	490
	502	503	504	505	506	507	508	509	492	511
	523	524	525	526	527	528	529	530	513	532
	544	545	546	547	548	549	550	551	534	553
	565	566	567	568	569	570	571	572	555	574
	586	587	588	589	590	591	592	593	576	595
	607	608	609	610	611	612	613	614	597	616
	628	629	630	631	632	633	634	635	618	637
	649	650	651	652	653	654	655	656	639	658
	717	718	719	720	721	722	723	724	725	726
	738	739	740	741	742	743	744	745	746	747
	759	760	761	762	763	764	765	766	767	768
	780	781	782	783	784	785	786	787	788	789
Channel Group:	Nonwireline A-Band Channels									
	A1	B1	C1	D1	E1	F1	G1	A2	B2	C2
Control channel	333	332	331	330	329	328	327	326	325	324
	312	311	310	309	308	307	306	305	304	303
	291	290	289	288	287	286	285	284	283	282
	270	269	268	267	266	265	264	263	262	261
	249	248	247	246	245	244	243	242	241	240
	228	227	226	225	224	223	222	221	220	219
	207	206	205	204	203	202	201	200	199	198
	186	185	184	183	182	181	180	179	178	177
	165	164	163	162	161	160	159	158	157	156
	144	143	142	141	140	139	138	137	136	135
	123	122	121	120	119	118	117	116	115	114
	102	101	100	99	98	97	96	95	94	93
	81	80	79	78	77	76	75	74	73	72
	60	59	58	57	56	55	54	53	52	51
	39	38	37	36	35	34	33	32	31	30
	18	17	16	15	14	13	12	11	10	9
	1020	1019	1018	1017	1016	1015	1014	1013	1012	1011
	999	998	997	996	995	994	993	992	991	716
	704	703	702	701	700	699	698	697	696	695
	683	682	681	680	679	678	677	676	675	674

TABLE A.3 Cellular A- and B-Band Channel Plans (Continued)

A.14 Appendix A

D2	Wireline B-Band Channels									
	E2	F2	G2	A3	B3	C3	D3	E3	F3	G3
344	345	346	347	348	349	350	351	352	353	354
365	366	367	368	369	370	371	372	373	374	375
386	387	388	389	390	391	392	393	394	395	396
407	408	409	410	411	412	413	414	415	416	417
428	429	430	431	432	433	434	435	436	437	438
449	450	451	452	453	454	455	456	457	458	459
470	471	472	473	474	475	476	477	478	479	480
491	492	493	494	495	496	497	498	499	500	501
512	513	514	515	516	517	518	519	520	521	522
533	534	535	536	537	538	539	540	541	542	543
554	555	556	557	558	559	560	561	562	563	564
575	576	577	578	579	580	581	582	583	584	585
596	597	598	599	600	601	602	603	604	605	606
617	618	619	620	621	622	623	624	625	626	627
638	639	640	641	642	643	644	645	646	647	648
659	660	661	662	663	664	665	666			
727	728	729	730	731	732	733	734	735	736	737
748	749	750	751	752	753	754	755	756	757	758
769	770	771	772	773	774	775	776	777	778	779
790	791	792	793	794	795	796	797	798	799	
D2	Nonwireline A-Band Channels									
	E2	F2	G2	A3	B3	C3	D3	E3	F3	G3
323	322	321	320	319	318	317	316	315	314	313
302	301	300	299	298	297	296	295	294	293	292
281	280	279	278	277	276	275	274	273	272	271
260	259	258	257	256	255	254	253	252	251	250
239	238	237	236	235	234	233	232	231	230	229
218	217	216	215	214	213	212	211	210	209	208
197	196	195	194	193	192	191	190	189	188	187
176	175	174	173	172	171	170	169	168	167	166
155	154	153	152	151	150	149	148	147	146	145
134	133	132	131	130	129	128	127	126	125	124
113	112	111	110	109	108	107	106	105	104	103
92	91	90	89	88	87	86	85	84	83	82
71	70	69	68	67	66	65	64	63	62	61
50	49	48	47	46	45	44	43	42	41	40
29	28	27	26	25	24	23	22	21	20	19
8	7	6	5	4	3	2	1			
								1023	1022	1021
1010	1009	1008	1007	1006	1005	1004	1003	1002	1001	1000
715	714	713	712	711	710	709	708	707	706	705
694	693	692	691	690	689	688	687	686	685	684
673	672	671	670	669	668	667				

TABLE A.3 Cellular A- and B-Band Channel Plans

improve the wireless system's overall capacity. A capacity increase is needed, but it needs to be provided in a more cost-effective manner of increasing capacity without introducing more cell sites into the system.

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