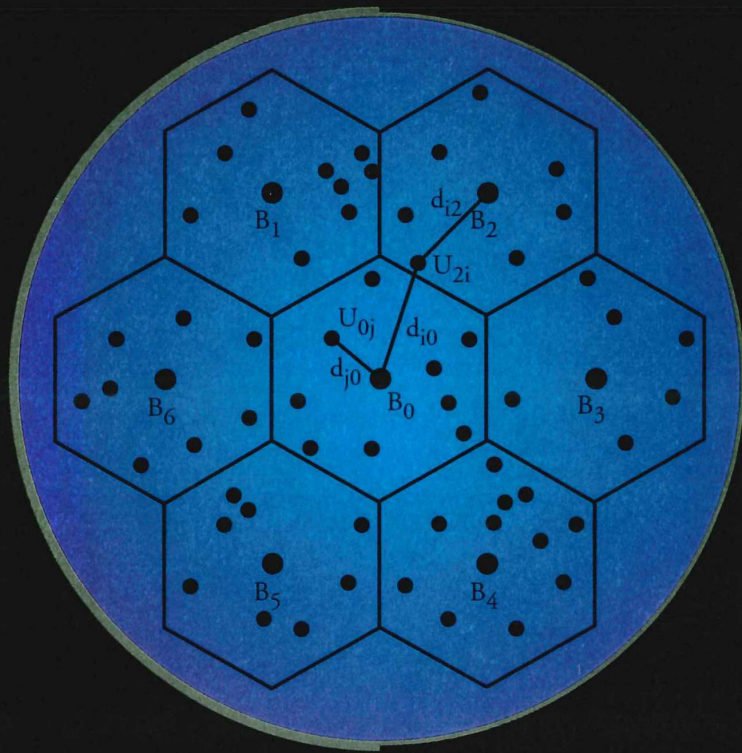


WIRELESS

communications

Principles  Practice



 Theodore S. Rappaport

Wireless Communications

Principles and Practice

Theodore S. Rappaport

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square centered around A, (a) without the use of microcells, (b) with the use of microcells as shown in Figure 2.9, and (c) if all the original base stations are replaced by microcells. Assume cells on the edge of the square to be contained within the square.

Solution to Example 2.8

(a) without the use of microcells:

A cell radius of 1 km implies that the sides of the larger hexagons are also 1 km in length. To cover the 3 km by 3 km square centered around base station A, we need to cover 1.5 km (1.5 times the hexagon radius) towards the right, left, top, and bottom of base station A. This is shown in Figure 2.9. From Figure 2.9 we see that this area contains 5 base stations. Since each base station has 60 channels, the total number of channels without cell splitting is equal to $5 \times 60 = 300$ channels.

(b) with the use of the microcells as shown in Figure 2.9:

In Figure 2.9, the base station A is surrounded by 6 microcells. Therefore, the total number of base stations in the square area under study is equal to $5 + 6 = 11$. Since each base station has 60 channels, the total number of channels will be equal to $11 \times 60 = 660$ channels. This is a 2.2 times increase in capacity when compared to case (a).

(c) if all the base stations are replaced by microcells:

From Figure 2.9, we see that there are a total of $5 + 12 = 17$ base stations in the square region under study. Since each base station has 60 channels, the total number of channels will be equal to $17 \times 60 = 1020$ channels. This is a 3.4 times increase in capacity when compared to case (a).

Theoretically, if all cells were microcells having half the radius of the original cell, the capacity increase would approach 4.

2.7.2 Sectoring

As shown in section 2.7.1, cell splitting achieves capacity improvement by essentially rescaling the system. By decreasing the cell radius R and keeping the co-channel reuse ratio D/R unchanged, cell splitting increases the number of channels per unit area. However, another way to increase capacity is to keep the cell radius unchanged and seek methods to decrease the D/R ratio. In this approach, capacity improvement is achieved by reducing the number of cells in a cluster and thus increasing the frequency reuse. However, in order to do this, it is necessary to reduce the relative interference without decreasing the transmit power.

The co-channel interference in a cellular system may be decreased by replacing a single omni-directional antenna at the base station by several directional antennas, each radiating within a specified sector. By using directional antennas, a given cell will receive interference and transmit with only a fraction

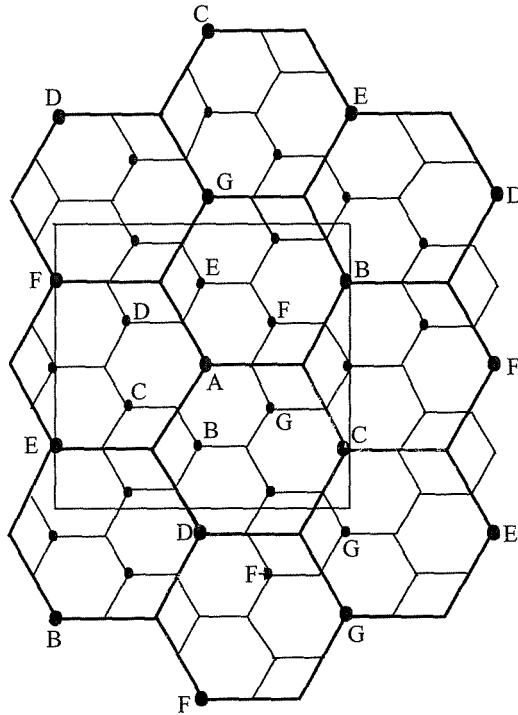


Figure 2.9

Illustration of cell splitting within a 3 km by 3 km square centered around base station A.

of the available co-channel cells. The technique for decreasing co-channel interference and thus increasing system capacity by using directional antennas is called *sectoring*. The factor by which the co-channel interference is reduced depends on the amount of sectoring used. A cell is normally partitioned into three 120° sectors or six 60° sectors as shown in Figure 2.10(a) and (b).

When sectoring is employed, the channels used in a particular cell are broken down into sectorized groups and are used only within a particular sector, as illustrated in Figure 2.10(a) and (b). Assuming 7-cell reuse, for the case of 120° sectors, the number of interferers in the first tier is reduced from 6 to 2. This is because only 2 of the 6 co-channel cells receive interference with a particular sectorized channel group. Referring to Figure 2.11, consider the interference experienced by a mobile located in the right-most sector in the center cell labeled "5". There are 3 co-channel cell sectors labeled "5" to the right of the center cell, and 3 to the left of the center cell. Out of these 6 co-channel cells, only 2 cells have sectors with antenna patterns which radiate into the center cell, and hence a mobile in the center cell will experience interference on the forward link from only these two sectors. The resulting S/I for this case can be found using equa-

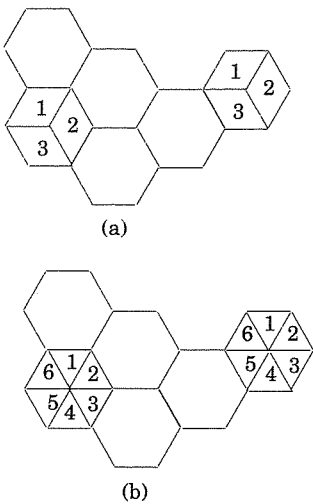


Figure 2.10
(a) 120° sectoring.
(b) 60° sectoring.

tion (2.8) to be 24.2 dB, which is a significant improvement over the omni-directional case in Section 2.5, where the worst case S/I was shown to be 17 dB. In practical systems, further improvement in S/I is achieved by downtilting the sector antennas such that the radiation pattern in the vertical (elevation) plane has a notch at the nearest co-channel cell distance.

The improvement in S/I implies that with 120° sectoring, the minimum required S/I of 18 dB can be easily achieved with 7-cell reuse, as compared to 12-cell reuse for the worst possible situation in the unsectored case (see Section 2.5.1). Thus, sectoring reduces interference, which amounts to an increase in capacity by a factor of 12/7, or 1.714. In practice, the reduction in interference offered by sectoring enable planners to reduce the cluster size N , and provides an additional degree of freedom in assigning channels. The penalty for improved S/I and the resulting capacity improvement is an increased number of antennas at each base station, and a decrease in trunking efficiency due to channel sectoring at the base station. Since sectoring reduces the coverage area of a particular group of channels, the number of handoffs increases, as well. Fortunately, many modern base stations support sectorization and allow mobiles to be handed off from sector to sector within the same cell without intervention from the MSC, so the handoff problem is often not a major concern.

It is the loss of traffic due to decreased trunking efficiency that causes some operators to shy away from the sectoring approach, particularly in dense urban areas where the directional antenna patterns are somewhat ineffective in controlling radio propagation. Because sectoring uses more than one antenna per base station, the available channels in the cell must be subdivided and dedicated

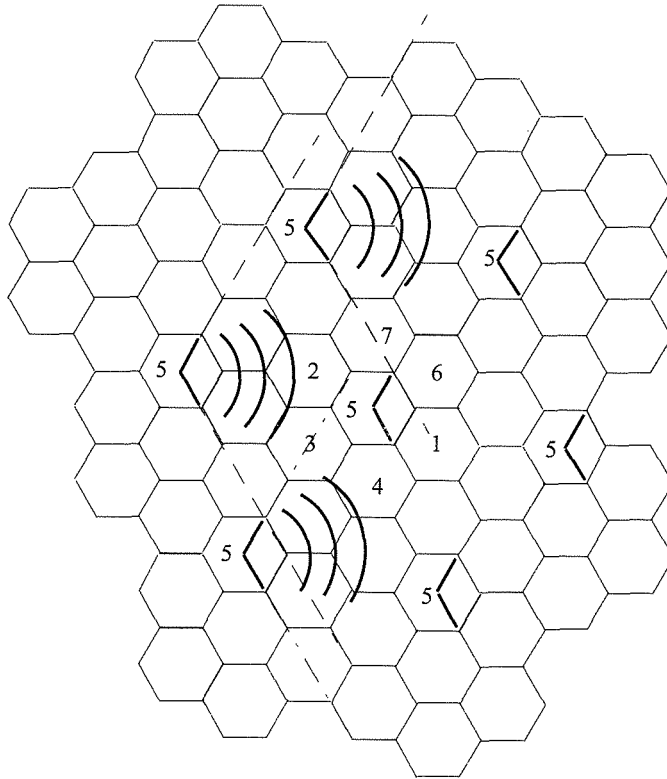


Figure 2.11

Illustration of how 120° sectoring reduces interference from co-channel cells. Out of the 6 co-channel cells in the first tier, only 2 of them interfere with the center cell. If omni-directional antennas were used at each base station, all 6 co-channel cells would interfere with the center cell.

to a specific antenna. This breaks up the available trunked channel pool into several smaller pools, and decreases trunking efficiency.

Example 2.9

Consider a cellular system in which an average call lasts 2 minutes, and the probability of blocking is to be no more than 1%. Assume that every subscriber makes 1 call per hour, on average. If there are a total of 395 traffic channels for a 7-cell reuse system, there will be about 57 traffic channels per cell. Assume that blocked calls are cleared so the blocking is described by the Erlang B distribution. From the Erlang B distribution, it can be found that the unsectored system may handle 44.2 Erlangs or 1326 calls per hour.

Now employing 120° sectoring, there are only 19 channels per antenna sector (57/3 antennas). For the same probability of blocking and average call length, it can be found from the Erlang B distribution that each sector can handle 11.2

upper and lower end of the GSM spectrum, and only 124 channels are implemented. Table 10.3 summarizes the GSM air interface.

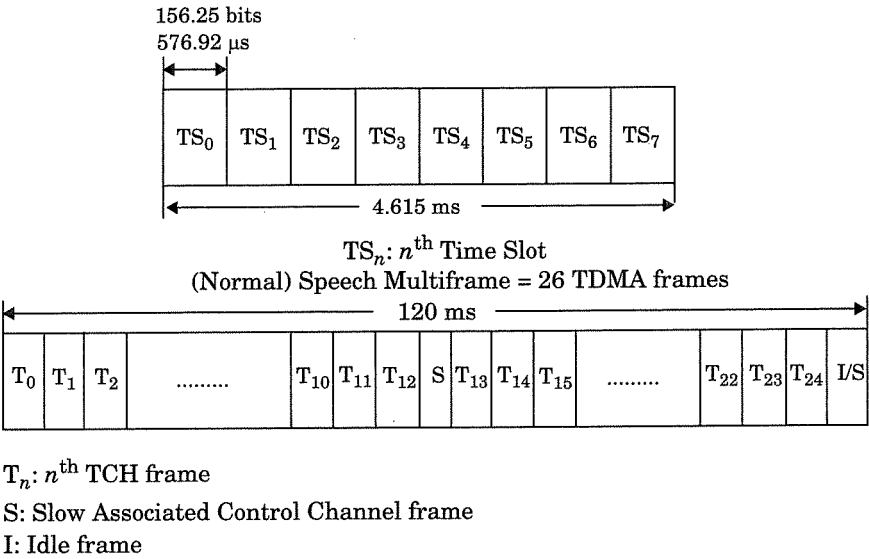


Figure 10.7
The Speech Dedicated Control Channel Frame and multiframe structure.

Table 10.3 GSM Air Interface Specifications Summary

Parameter	Specifications
Reverse Channel Frequency	890 - 915 MHz
Forward Channel Frequency	935 - 960 MHz
ARFCN Number	0 to 124 and 975 to 1023
Tx/Rx Frequency Spacing	45 MHz
Tx/Rx Time Slot Spacing	3 Time slots
Modulation Data Rate	270.833333 kbps
Frame Period	4.615 ms
Users per Frame (Full Rate)	8
Time slot Period	576.9 μs
Bit Period	3.692 μs
Modulation	0.3 GMSK
ARFCN Channel Spacing	200 kHz
Interleaving (max. delay)	40 ms
Voice Coder Bit Rate	13.4 kbps

facility in a multi handset environment. The interface recommended by the CCITT is the G.732 based on ISDN protocols.

- **Supplementary Services** — This provides centralized authentication and billing when DECT is used to provide telepoint services, and provides mobility management when DECT is used in multilocation PABX network.

Since the system is limited by C/I , the capacity can be increased and the interference from other systems decreased by installing the RFPs in closer proximity. This is illustrated in Figure 10.19.

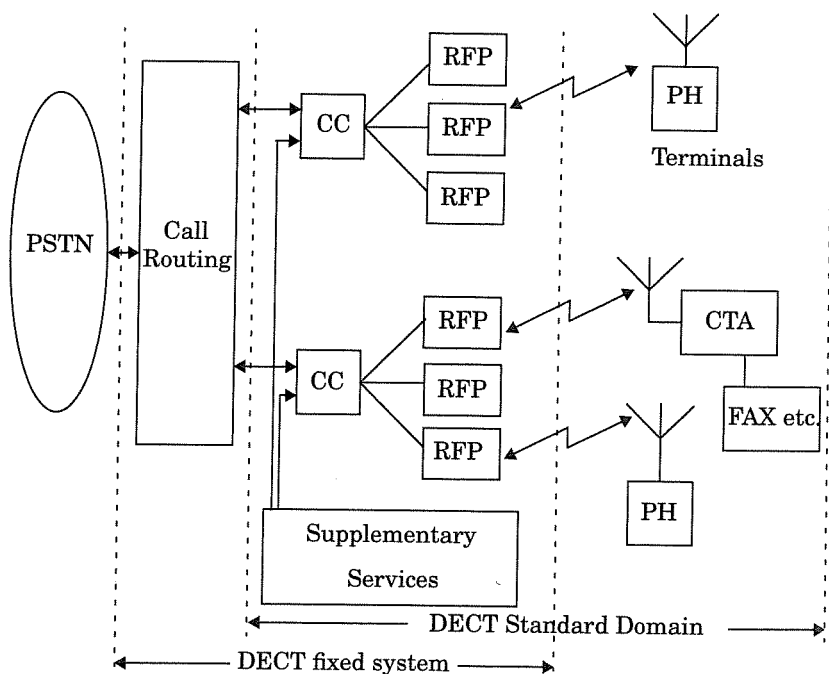


Figure 10.19
DECT functional concept.

10.6.4 DECT Radio Link

DECT operates in the 1880 MHz to 1900 MHz band. Within this band, the DECT standard defines ten channels from 1881.792 MHz to 1897.344 MHz with a spacing of 1728 kHz. DECT supports a Multiple Carrier/TDMA/ TDD structure. Each base station provides a frame structure which supports 12 duplex speech channels, and each time slot may occupy any of the DECT channels. Thus, DECT base stations support FHMA on top of the TDMA/TDD structure. If the frequency hopping option is disabled for each DECT base station, a total of 120 channels within the DECT spectrum are provided before frequency reuse is

required. Each time slot may be assigned to a different channel in order to exploit advantages provided by frequency hopping, and to avoid interference from other users in an asynchronous fashion.

Channel Types — DECT user data is provided in each B-field time slot (see Figure 10.18). 320 user bits are provided during each time slot yielding a 32 kbps data stream per user. No error correction is provided although 4 parity bits are used for crude error detection.

DECT control information is carried by 64 bits in every time slot of an established call (see Figure 10.18). These bits are assigned to one of the four logical channels depending on the nature of the control information. Thus, the gross control channel data rate is 6.4 kbps per user. DECT relies on error detection and retransmission for accurate delivery of control information. Each 64 bit control word contains 16 cyclic redundancy check (CRC) bits, in addition to the 48 control data bits. The maximum information throughput of the DECT control channel is 4.8 kbps.

Speech Coding — Analog speech is digitized into PCM using a 8 kHz sampling rate. The digital speech samples are ADPCM encoded at 32 kbps following CCITT G.721 recommendations.

Channel Coding — For speech signals, no channel coding is used since DECT provides frequency hopping for each time slot. Channel coding and interleaving are avoided because the DECT system is meant for use in indoor environments where the tolerable end-to-end system delay is small and the channel may be modeled as “on” or “off” (see Chapter 6). However, the control channels use 16 bit cyclic redundancy check (CRC) codes in each time slot.

Modulation — DECT uses a tightly filtered GMSK modulation technique. As discussed in Chapter 5, minimum shift keying (MSK) is a form of FSK where the phase transitions between two symbols are constrained to be continuous. Before the modulation, the signal is filtered using a Gaussian shaping filter.

Antenna Diversity — In DECT, spatial diversity at the RFP (base station) receiver is implemented using two antennas. The antenna which provides the best signal for each time slot is selected. This is performed on the basis of a power measurement or alternatively by using an appropriate quality measure (such as interference or BER). Antenna diversity helps solve fading and interference problems. No antenna diversity is used at the subscriber unit.

10.7 PACS — Personal Access Communication Systems

PACS is a third generation Personal Communications System originally developed and proposed by Bellcore in 1992 [Cox87], [Cox92]. PACS is able to support voice, data, and video images for indoor and microcell use. PACS is designed to provide coverage within a 500 meter range. The main objective of PACS is to integrate all forms of wireless local loop communications into one sys-

Table 10.8 DECT Radio Specifications Summary

Parameter	Specification
Frequency Band	1880 — 1900 MHz
Number of Carriers	10
RF Channel Bandwidth	1.728 MHz
Multiplexing	FHMA/TDMA 24 slots per frame
Duplex	TDD
Spectral Efficiency	500 Erlangs/km ² /MHz
Speech Coder	32 kbps ADPCM
Average Transmitted Power	10 mW
Frame Length	10 ms
Channel Bit Rate	1152 kbps
Data Rate	32 kbps Traffic Channel 6.2 kbps Control Channel
Channel Coding	CRC 16
Dynamic Channel Allocation	Yes
Modulation	GFSK ($BT = 0.3$)
Speech Channel/RF Channel	12

tem with full telephone features, in order to provide wireless connectivity for local exchange carriers (LECs). Bellcore developed PACS concept with LECs in mind and named it *Wireless Access Communication System* (WACS), but when the Federal Communications Commission introduced an unlicensed PCS band (see section 10.10), the WACS standard was modified to produce PACS. In the original WACS proposal, ten TDMA/FDM time slots were specified in a 2 ms frame, and a 500 kbps channel data rate was proposed for a channel bandwidth of 350 kHz using QPSK modulation. In PACS, the channel bandwidth, the data rate, the number of slots per frame, and the frame duration were altered slightly, and $\pi/4$ QPSK was chosen over QPSK.

10.7.1 PACS System Architecture

PACS was developed as a universal wireless access system for wide spread applications in private and public telephone systems which operate in either licensed or unlicensed PCS bands. PACS may be connected to a PBX or Centrex, and may be served by a Central Office in residential applications [JTC95].

The PACS architecture consists of four main components: the *subscriber unit* (SU) which may be fixed or portable, the *radio ports* (RP) which are connected to the *radio port control unit* (RPCU), and the *access manager* (AM), as shown in Figure 10.20. Interface A, the air interface, provides a connection between the SU and RP. Interface P provides the protocols required to connect

the SUs through the RPs to the RPCU, and also connects the RPCU with its RPs by using an Embedded Operations Channel (EOC) provided within the interface.

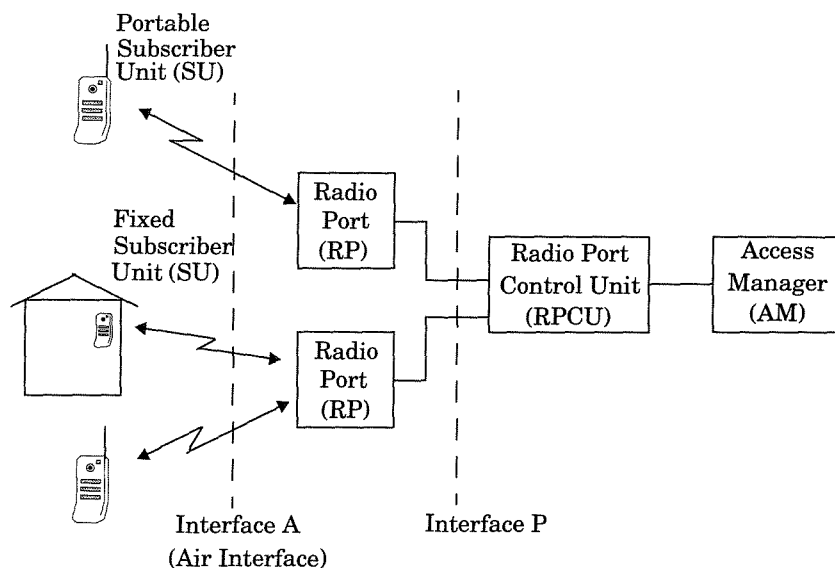


Figure 10.20
PACS system architecture.

The PACS PCS standard contains a fixed distribution network and network intelligence. Only the last 500 m of the distribution network is designed to be wireless.

10.7.2 PACS Radio Interface

The PACS system is designed for operation in the U.S. PCS band. A large number of RF channels may be frequency division multiplexed with 80 MHz separation, or time division multiplexed. PACS and WACS channel bandwidth is 300 kHz [JTC95].

WACS originally used TDMA with frequency division duplexing (FDD), with eight time slots provided in a 2.0 ms frame on each radio channel. When used with FDD, the reverse link time slot is offset from its paired forward link time slot by exactly one time slot plus 62.5 μ s. The forward link covers 1850 MHz to 1910 MHz and the reverse covers 1930 MHz to 1990 MHz.

The version of PACS developed for the unlicensed U.S. PCS band (PACS-UB) between 1920 and 1930 MHz uses TDD instead of FDD [JTC95]. The PACS time slot and frame structure are shown in Figure 10.21.

Modulation — PACS uses $\pi/4$ -DQPSK modulation. The RF signal is shaped using a raised cosine rolloff shaping filter (rolloff factor of 0.5) such that 99% of the transmitted signal power is contained within a channel bandwidth of 288 kHz. Eight time slots, each containing 120 bits, are sent in a 2.5 ms frame.

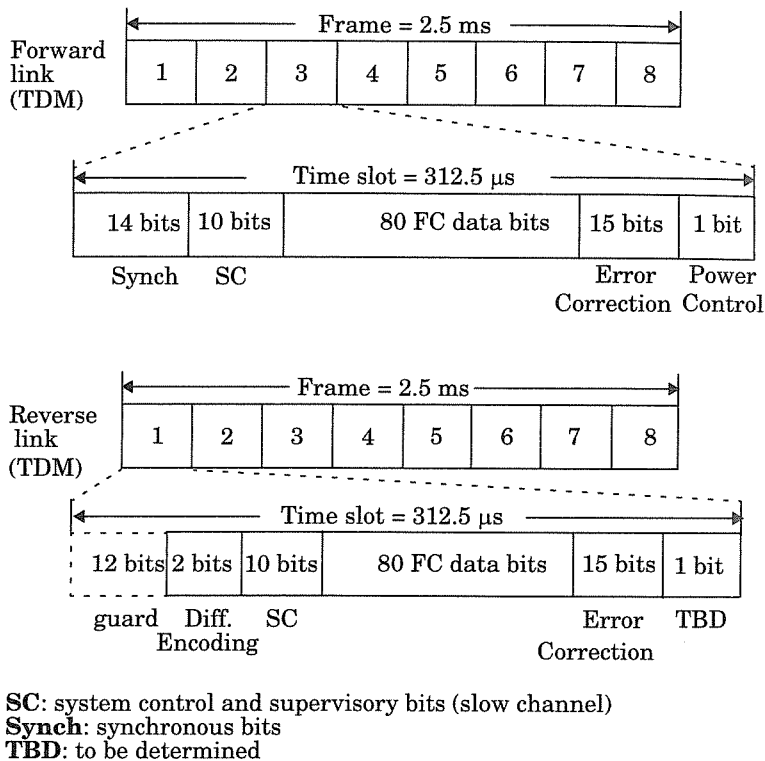


Figure 10.21
PACS Frame Structure

When used with TDD, the time offset between the forward and reverse time slot for each user is exactly two time slots (625 μ s) apart.

Speech Coding — WACS uses 32 kbps ADPCM for digital speech encoding. ADPCM provides low complexity, minimum cost, and radio link privacy.

PACS Channels — PACS provides *system broadcasting channels* (SBC) which are used primarily on the forward link to broadcast paging messages. A 32 kbps SBC provides alerting and system information for up to 80,000 users. A *synchronization channel* (SYN) and the *slow channel* (SC) are used on the forward link to synchronize each subscriber unit. User information is transmitted only in the *fast channel* (FC) on both the forward and reverse links. As shown in Figure 10.21, each PACS time slot contains eighty fast channel bits and ten slow bits. There are several other special purpose logical channels defined in PACS [JTC95].

Multiple Access — PACS is a TDMA based technology that supports either FDD or TDD. Many portable handsets and data terminals may be served from one installation of fixed radio equipment at the end of a feederline from a

central office. The radio links may be shared among customers on the basis of individual user activity, and are designed to provide a wide range of user transmission rates within a common architecture.

Power Control — The PACS subscriber unit uses adaptive power control to minimize battery drain during transmissions and to reduce the co-channel interference on the reverse path.

Table 10.9 PACS Radio Specifications (FDD or TDD implementation)

Parameter	Specification
Multiple Access	TDMA
Duplexing	FDD or TDD
Frequency Band	1 — 3 GHz
Modulation	$\pi/4$ DQPSK
Channel Spacing	300 kHz
Portable Transmitter Average Power	200 mW
Base Station Average Power	800 mW
Probability of Coverage Within Service Area	greater than 90%
Channel coding	CRC
Speech coding	16 bit ADPCM
Time Slots per Frame	8
Frame Duration	2.5 ms
Users per Frame	8 (FDD) or 4 (TDD)
Channel Bit Rate	384 kbps
Speech Rate	32 kbps
Bit Error	Less than 10^{-2}
Voice Delay	less than 50 ms

10.8 Pacific Digital Cellular (PDC)

The Pacific Digital Cellular (PDC) standard was developed in 1991 to provide for needed capacity in congested cellular bands in Japan [Per92]. PDC is also known as Japanese Digital Cellular (JDC).

PDC is somewhat similar to the IS-54 standard, but uses 4-ary modulation for voice and control channels, making it more like IS-136 in North America. Frequency division duplexing and TDMA are used to provide three time slots for three users in a 20 ms frame (6.67 ms per user slot) on a 25 kHz radio channel. On each channel, $\pi/4$ DQPSK is used, with a channel data rate of 42 kbps. Channel coding is provided using a rate $9/17$, $K = 5$ convolutional code with CRC. Speech coding is provided with a 6.7 kbps VSELP speech coder. An additional 4.5 kbps is provided by the channel coding, thereby proving 11.2 kbps of combined

speech and channel coding per user. A new half-rate speech and channel coding standard will support six users per 20 ms frame.

PDC is allocated 80 MHz in Japan. The low PDC band uses 130 MHz forward/reverse channel splits. The forward band uses 940 MHz to 956 MHz and the reverse band 810 MHz to 826 MHz. The high PDC band uses 48 MHz channel splits and operates in 1477 MHz to 1501 MHz for the forward link and 1429 MHz to 1453 MHz for the reverse link. PDC uses mobile assisted handoff (MAHO) and is able to support 4-cell reuse.

10.9 Personal Handyphone System (PHS)

The Personal Handyphone System (PHS) is a Japanese air interface standard developed by the Research and Development Center for Radio Systems (RCR). The PHS network interface was specified by the Telecommunications Technical Committee of Japan [Per93].

The PHS standard, like DECT and PACS-UB, uses TDMA and TDD. Four duplex data channels are provided on each radio channel. $\pi/4$ DQPSK modulation at a channel rate of 384 kbps is used on both forward and reverse links. Each TDMA frame is 5 ms in duration, and 32 kbps ADPCM is used in conjunction with CRC error detection (without correction).

PHS supports seventy-seven radio channels, each 300 kHz wide, in the 1895 MHz to 1918.1 MHz band. Forty channels in the 1906.1 MHz to 1918.1 MHz are designated for public systems, and the other thirty-seven channels are used for home or office use in the 1895 MHz to 1906.1 MHz band.

PHS uses dynamic channel assignment, so base stations are able to allocate channels based on the RF (interference) signal strength seen at both the base and portable. PHS uses dedicated control channels (unlike DECT) which all subscribers lock to while idle. Handoffs are supported only at walking speeds, as PHS is designed for microcell/indoor PCS use [Oga94].

10.10 U.S. PCS and ISM Bands

In the mid 1980s, the Federal Communications Commission provided unlicensed radio spectrum in the Industrial, Scientific and Medical (ISM) bands of 902 MHz to 928 MHz, 2400 MHz to 2483.5 MHz, and 5725 MHz to 5850 MHz. As long as radio transmitters use spread spectrum modulation and power levels below 1W, they may share ISM spectrum on a secondary basis. Part 15 of the FCC rules govern the use of unlicensed transmitters in the ISM band.

In 1993, the FCC allocated 140 MHz of spectrum for PCS. Figure 10.22 shows the frequencies between 1850 MHz and 1990 MHz which were licensed in 1994 and 1995. The 30 MHz A and B blocks are designated for large cities, called major trading areas (MTAs), while blocks C through F are licensed for large rural BTAs (basic trading areas). There are 51 MTAs and 492 BTAs in the U.S. In addition to the 120 MHz of licensed spectrum, a total of 20 MHz is allocated