Mobile communications: IS-95 and GSM

1. Introduction

Two second generation cellular systems are currently being deployed - the Global System for Mobile Communications (GSM) and the Code Division Multiple Access (CDMA) systems. These occupy frequency bands near 900 and 1900 MHz (at the higher band, they are known commercially as PCS). GSM is currently the most popular cellular system worldwide, with 50% of the market; CDMA is a newer standard, with a higher capacity, and widely used in North America.

The third generation of mobile systems, IMT-2000 (International Mobile Telecommunications at 2000Mhz)[1], is currently being developed and will integrate different methods and environments (cellular, cordless, satellite, Lan’s). It will offer a wide range of telecommunications services including voice, data, multimedia and Internet. Initial data rates will be up to 2Mbps. IMT-2000 shall provide global seamless roaming and services and increased security and performance. The principle objective of IMT-2000 is to provide an international standard to support a wide range of radio and service environments with global roaming (see Figure 1).
2. **IS-95 Cellular System**

The IS-95 standard describes a Code Division Multiple Access (CDMA) system in which the audio band data signal is multiplied by a high rate spreading signal. This spreading signal is formed from a pseudo-noise code sequence, which is then multiplied by a Walsh code for maximum orthogonality to (i.e. to have low cross-correlation with) the other codes in use in that cell. Typically, CDMA pseudo-noise sequences are very long, thereby giving excellent cross-correlation characteristics. (IS-95 uses a $2^{42}-1$ chip period, derived from a 42 bit mask.)

The IS-95 system can be thought of as having many layers of protection against interference. It allows many users to co-exist, with minimal mutual interference. They can be described by the signal conditioning sequence that occurs on forward and reverse channels (Figure 1 and Figure 2, respectively). The forward channel carries information from the base station to the mobile unit; the reverse channel carries information from the mobile unit to the base station[2]. The transmission channels are shown; the reception of each channel follows the reverse sequence.

The forward channels are between 869 and 894 MHz, while the reverse channels are between 824 and 849 Mhz. Within these bands, four sub-bands are available for CDMA, of widths 1, 0.1, 9 and 10 MHz; in the U.S., 1.25 MHz sub-bands near 849 and 894 MHz are employed. All cells in the same area can employ the same spectral band, because the various signals are sorted out by the spread spectrum process rather than by frequency discrimination.
Forward channel transmission sequence:

1. Convolution encoder
   - Encodes the data from one stream to two, doubling the nominal rate from 9.6 kbps to 19.2 kbps, 4.8 kbps data to 9.6 kbps, etc.

2. Repetition circuit
   - Repeats coded symbols, so lower rate encoded data is increased from 9.6, 4.8 or 2.4 kbps to 19.2 kbps.

3. Block Interleaver
   - Reads data into the rows of a 24 x 16 array, and out of the columns; introduces a 20 msec delay, but spreads important bits (as produced by modern speech encoders) over time as proof against deep fades or noise bursts.
4. Data scrambling
The data are Modulo 2 added to every 64th bit of a pseudo-noise (PN) sequence created from a 42 bit shift register. (The resulting $2^{42}-1$ bits repeat once per century after initiation.) The data rate at this point is still 19.2 kbps.

5. Power control
Every 1.25 msec, or 24 data symbols, a power control bit is inserted, in order to instruct the mobile unit to raise or lower its power (to equalize the power received from every mobile unit in the cell.) The location of the power control bit is determined from the PN sequence.

6. Orthogonal covering
The 19.2 kbps data are spread with a 1.2288 Mbps Walsh function, so that each one bit data symbol is spread by 64 Walsh chips. The Walsh function provides 64 mutually orthogonal binary sequences, each of length 64.

7. Quadrature spreading
The data are split into two bit streams, which are Modulo 2 added to two different but well defined “Pilot” pseudo-noise sequences generated from 15 bit shift registers. The code repeats 75 times every 2 seconds, or at 26.7 msec intervals.

8. Quadrature modulation
The binary I and Q outputs are mapped onto four phases of a quadrature modulator, at $\pm \pi/4$ and $\pm 3\pi/4$, using quadrature phase shift keying (QPSK).

9. RF modulation
The baseband quadrature data are raised to the forward cellular radio band, 869 to 894 MHz. The IS-95 channel occupies 1.25 MHz within this band, the rest of which is occupied by other cellular services such as AMPS.

Of the 64 available orthogonal channels (ie. channels which have minimum mutual interference), one is assigned to the pilot channel and one to the synchronization channel. Several low numbered channels are assigned to paging.

The pilot channel corresponds to the all zeros Walsh code (Walsh channel 0), and contains the unmodulated quadrature PN spreading code. It is transmitted at higher power than the user channels, and is provided so that each subscriber within the cell can determine and react to the channel characteristics while employing coherent detection.

Walsh channel 32 is assigned to the sync channel, which provides time and frame synchronization to the mobile unit. Time of day and station identification are continuously broadcast on this channel.

As users are added to the system, they are assigned user channels from the available Walsh channels. When over 60 users are present, the channels
are assigned to multiple users, and protection from mutual interference within the same Walsh channel is provided by the private PN sequences that encode each user link. The number of users can therefore rise to large values, while reasonable quality is maintained.

**Figure 3: Reverse CDMA Channel**

Reverse channel transmission sequence:

1. Speech encoder  
   Produces nominal 9600 bps data stream, dynamically reduced to 4800, 2400, or 1200 bps during pauses and gaps in speech; quiet periods correspond to 1200 bps data.
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Note that there is continuous transmission from a cell phone when a conversation is in progress. The lowest data rate is 1200 bps, with three 1.25 msec “power control” groups being transmitted in every 20 msec frame. A mobile phone is therefore not silent during conversations, and can be located by its telltale emissions.

**Spectral Considerations**

A generic spread spectrum occupies most of the available 1.25 MHz bandwidth. The spectral shape is best described by a $\sin x/x$ function, with many variations, such as pulse shaping, to curb out of band components. The CDMA spectrum is nearly flat-topped, and does not have the prominent sidelobes (Figure 5).

The final spectral shape of the CDMA forward link spectrum is given by the QPSK (quadrature phase shift keying) modulation process. The I and Q Pilot codes, at 1.2288 MHz, modulate the I and Q channels independently, and the QPSK process spreads out the spectral peaks left by the Walsh code.

![Figure 5: Spectral Shape of a generic Spread Spectrum signal [3] and a CDMA signal](image)

The 1.2288 MHz Walsh code modulates the 19.2 kbps data to produce an “orthogonal covering”. While separate Walsh codes have low cross-correlation, the Walsh code has a characteristic spectral signature (Figure 6).
3. **Global System for Mobile Communications (GSM)**

The most popular second generation system installed worldwide is the GSM, Global System for Mobile Communications. The GSM system is based on 125 frequency allocations and eight timeslots per channel, giving a total of 1000 Channels. These may be message-carrying traffic channels, or control channels.

The frequency allocations (ARFCN, or absolute radio frequency channel number), are each 200 kHz in bandwidth. The forward ARFCNs are between 935 and 960 MHz; the reverse ARFCNs are between 890 and 915 MHz, so that a given mobile unit receives at a frequency exactly 45 MHz greater than the one that it transmits.

Since 1995, new bands have opened up at 1800 and 1900 GHz. Known as PCS (Personal Communication Services), vendors have been free to choose from a variety of standards. IS-95 is the standard used for CDMA applications, with some modification for higher rate data, while the GSM standard has also been moved up to the higher bands, under the names DCS 1800 and DCS 1900 (for 1800 and 1900 MHz, respectively). The principles described here also apply for the upper bands.

If there are multipath problems in a cell, then the cell is designated as a “hopping cell”. Hops occur on a frame by frame basis, up to 217.6 hops per second, over a selection of 64 hop carrier frequencies.

The timeslots (TS) are each 576.96 microseconds (µsec) in duration. Eight timeslots make a frame, 26 frames make a multiframe. Because GSM is essentially a time division multiple access (TDMA) system, rather than a spread spectrum system, the time frame structure is shown in Figure 4. With guard times of 8.25 µsec on the end of a timeslot, a timeslot carries 148 usable bits of information; 114 of these are the message payload, the remainder are 26 bits of midamble for frame synchronization, 6 start/stop bits, and 2 “stealing bits” for inserting priority control messages.
Control channels are TS0 on 34 designated carrier frequencies (ARFCN’s); that is, of 1000 physical channels, 34 are set aside for paging and broadcast, frequency correction, and timing synchronization. Some are for the handshaking process to initiate calls - paging, acknowledgement, and granting access to a regular traffic channel. Several are holding channels, to maintain a connection while the setup process is underway.

Traffic channels are of various rates, according to the need. They support data at 9.6, 4.8 and 2.4 kbps, and speech at 6.5 and 13 kbps.

| Hyperframe | 3½ hours | 2048 superframes |
| Superframe | 6.12 seconds | 51 multiframes |
| Multiframe | 120 milliseconds | 26 frames |
| Frame | 4.615 milliseconds | 8 timeslots |
| Timeslot | 576.92 microseconds | 156.25 bits |

![Figure 4: GSM Frame Structure](image)

Like IS-95, the GSM system has many layers of protection against interference. They can be described by the signal conditioning sequence that occurs from speech to transmission. Unlike IS-95, forward and reverse channels handle data in an identical manner; dissimilarities occur only in the transmission and handling of control messages. (Figure 1 and Figure 2, respectively). The forward channel carries information from the base station to the mobile unit; the reverse channel carries information from the mobile unit to the base station [2]. The transmission channels are shown; the reception of each channel follows the reverse sequence. A speech channel is shown; control and data channels are encoded in different ways in Steps 1 to 5; thereafter, the procedure is similar.

GSM speech signal conditioning sequence:

1. Speech encoder Produces nominal 13 kbps data stream, with 260 bits for each 20 msec of speech.

2. Bit prioritizor Of 20 msec of speech, the most important 50 bits are Type 1a, the next 132 bits are Type 1b, the last 78 bits are Type II

3. Error protection Type 1a bits get 3 parity bits; Type 1b, are
4. Convolution encoder  The 119 Type 1 bits are encoded from one stream to two, doubling the number of bits to 378.

5. Frame setup  The 78 Type II bits are added, to form a 20 msec frame of 456 bits.

6. Block Interleaver  Two blocks are “diagonally interleaved” by breaking the 456 frames in each block into eight 57-bit sub-blocks, and packing the first sub-block of one with the fifth block of the other, etc. so that eight successive groups of 114 bits each are available; each group goes into a time slot.

7. Ciphering  The contents of each group is ciphered by a technique specific to the mobile base station; the encryption algorithm is changed from call to call.

8. Burst formatting  Binary data are added to the ciphered blocks, to aid in synchronization and equalization. These are the “mid-amble bits” in each time slot.

9. Pulse shaping  The data are split into two bit streams, I and Q, then converted to NRZ (non-return to zero) format and passed through a Gaussian shaping filter to reduce sidebands.

10. Quadrature modulation  The binary I and Q outputs are mapped onto four phases of a quadrature modulator, at $\pm \pi/4$ and $\pm 3\pi/4$, using minimum shift keying (MSK). (Like OQPSK, the Q channel is shifted by half a chip, but frequency components are trimmed to leave half-sinusoidal pulses.)

11. RF modulation  The baseband quadrature data are raised to the cellular radio bands, 935 to 960 MHz for forward links and 890 to 915 MHz for reverse links.

References


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1 This text is in part based on a document on cellular systems by I. Sinclair, MPB.