

System Performance

9.1 Introduction

This chapter addresses several topics related to system performance, and it will focus on those topics that are specific to the operation of an IS-2000 system. Section 9.2 describes how the system supervises a channel and makes decisions regarding whether or not to continue transmitting and receiving the channel. In addition because IS-2000 has added a host of new physical channels that can operate at different data rates, the administration of orthogonal codes becomes an important issue, and Section 9.3 explains how the different orthogonal codes are allocated to different physical channels. Lastly, Sections 9.4 and 9.5 discuss the codes and transmit diversity used by IS-2000.

9.2 Channel Supervision

9.2.1 Forward Link: Traffic Channel

In Chapter 7 (Section 7.4.2.3), we first mentioned the parameter `FPC_PRI_CHAN`; this parameter specifies the traffic channel (F-DCCH or F-FCH) that carries the forward power control subchannel. It turns out that `FPC_PRI_CHAN` is also the traffic channel (F-DCCH or F-FCH) that the mobile monitors in performing forward traffic channel supervision. The mobile performs forward traffic channel supervision in the mobile station control on the traffic channel state because it is in this state that the forward traffic channel is active.

While in the mobile station control on the traffic channel state, the mobile monitors each received frame on the traffic channel (F-DCCH or F-FCH). If the mobile decides that the received frame has insufficient frame quality, then it declares that the received frame is a *bad* frame. Otherwise, the received frame is a *good* frame [1]. For each frame, the mobile checks the frame quality indicator (also known as CRC) bits in making its decision. If the mobile receives consecutive bad frames for a period of 240 ms (or 12×20 ms), then it must shut off its transmitter. The mobile can only turn on its transmitter again if, after receiving consecutive bad frames for a period of 240 ms, it receives consecutive good frames for a period of 40 ms (or 2×20 ms).

In addition, the mobile keeps a fade timer for the forward traffic channel (F-DCCH or F-FCH) being monitored. The timer is initialized when the mobile first turns on its transmitter while in the traffic channel initialization substate of the mobile station control on the traffic channel state. The fade timer is set to 5 seconds and then counts down. It is reset to 5 seconds every time the mobile receives consecutive good frames for a period of 40 ms (or 2×20 ms). If the timer expires, then the mobile must shut off its transmitter and declare a loss of the forward traffic channel [2].

The mobile performs forward traffic channel supervision while in all the substates (i.e., traffic channel initialization substate, traffic channel substate, and release substate) of the mobile station control on the traffic channel state. If the mobile declares a loss of the forward traffic channel, then the mobile returns to the system determination substate of the mobile station initialization state [2].

9.2.2 Forward Link: Common Channel

The mobile performs forward common channel supervision in the mobile station idle state and system access state by monitoring the F-PCH, F-CCCH, or F-BCCH. So how does a mobile determine whether or not it has lost the F-PCH, F-CCCH, or F-BCCH? It does so by keeping a timer whenever it starts to monitor the F-PCH, F-CCCH, or F-BCCH. The timer is kept as follows: it is initially set for 3 seconds; the timer is reset to 3 seconds whenever the mobile receives a valid message on the F-PCH, F-CCCH, or F-BCCH; the timer is stopped when the mobile is not monitoring the F-PCH, F-CCCH, or F-BCCH. The mobile decides that it has lost the F-PCH, F-CCCH, or F-BCCH if the timer expires [2]. Note that different equipment vendors can also have their own algorithms for determining whether or not a mobile still has a usable F-PCH, F-CCCH, or F-BCCH.

9.2.3 Reverse Link

The same kind of channel supervision also occurs on the reverse link (i.e., the base station also supervises the reverse traffic channels [e.g., R-DCCH and/or R-FCH] and reverse common channels [e.g., R-EACH and/or R-ACH]). Although the IS-2000 standard specifies that the base station has to supervise the channels, it does not specify how the base station should do so. Each equipment vendor may have different ways of performing reverse traffic and common channel supervisions.

9.3 Code Management

Readers will recall that, in a DS-CDMA system, orthogonal (or near-orthogonal) sequences are used to channelize the different users that are in the same RF band. In IS-95, the system uses Walsh codes for channelization on the forward link and pseudorandom noise (PN) codes for channelization on the reverse link. In IS-2000, the system mostly uses Walsh codes for channelization on both the forward link and the reverse link. Therefore, this section focuses on how IS-2000 manages the assignment of Walsh codes.

9.3.1 Generation of Walsh Codes

A group of orthogonal Walsh codes is a set of N binary orthogonal sequences, $\mathbf{w}_k^N$, where k denotes the k th sequence in the set. Walsh codes can be derived using the Hadamard matrix in that higher order matrixes can be recursively generated from lower order ones [3],

$$\mathbf{H}_{2N} = \begin{bmatrix} \mathbf{H}_N & \mathbf{H}_N \\ \mathbf{H}_N & \overline{\mathbf{H}}_N \end{bmatrix} \quad (9.1)$$

where $\overline{\mathbf{H}}_N$ contains the inverted elements of $\mathbf{H}_N$, and the seed matrix is

$$\mathbf{H}_2 = \begin{bmatrix} 0 & 0 \\ 0 & 1 \end{bmatrix} \quad (9.2)$$

To generate a set of four Walsh codes $\mathbf{w}_0^4$, $\mathbf{w}_1^4$, $\mathbf{w}_2^4$, and $\mathbf{w}_3^4$, we need to generate a Hadamard matrix of order 4, or

$$\mathbf{H}_4 = \begin{bmatrix} \mathbf{H}_2 & \mathbf{H}_2 \\ \mathbf{H}_2 & \overline{\mathbf{H}}_2 \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 1 \\ 0 & 0 & 1 & 1 \\ 0 & 1 & 1 & 0 \end{bmatrix}$$

The four Walsh codes in this Walsh code set are taken from the rows of the matrix $\mathbf{H}_4$, and each Walsh code has a length of 4,

$$\begin{aligned} \mathbf{w}_0^4 &= [0 \ 0 \ 0 \ 0] \\ \mathbf{w}_1^4 &= [0 \ 1 \ 0 \ 1] \\ \mathbf{w}_2^4 &= [0 \ 0 \ 1 \ 1] \\ \mathbf{w}_3^4 &= [0 \ 1 \ 1 \ 0] \end{aligned}$$

Another way to generate Walsh codes is using a *recursive tree* shown in Figure 9.1. Each node at each level of the tree has two branches below it, resulting in two nodes at the next level. The left node at the next level consists of two instances of the node above it. The right node at the next level consists of one instance of the node above it and one *inverted* instance. The root node of the tree is 0.

Figure 9.2 shows an example of generating Walsh codes using a recursive tree. The root of the tree is 0 (at level 0). This results in 0, 0, 0, and 1 at the next level (level 1). When one repeats this procedure, the Walsh code set of order 4 is

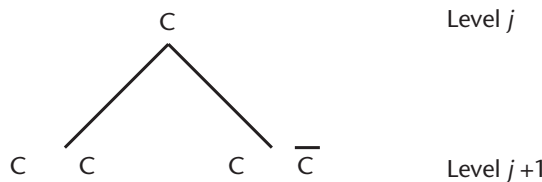


Figure 9.1 Recursive tree.

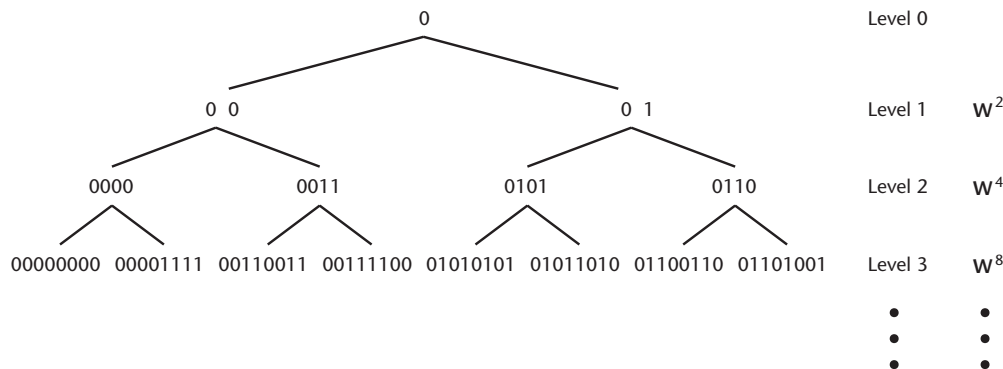


Figure 9.2 An example of generating Walsh codes using a recursive tree.

generated at level 2. This set of Walsh codes contains the codes [0 0 0 0], [0 0 1 1], [0 1 0 1], and [0 1 1 0]. At level 3, the Walsh code set of order 8 (or 2^3) is generated. In general, a Walsh code set of order $N = 2^j$ is generated at level j of the recursive tree.

9.3.2 Assignment of Walsh Codes: Forward Link

To have effective channelization, the system needs to ensure that all channelization codes *in use* are orthogonal to each another. In IS-2000, this task is complicated by the fact that at any given time, there may be more than one type of channel operating on the link, and these channels may be operating at different data rates. For example, on the forward link, both the F-DCCH and the F-SCH may be simultaneously active for a user. For Spreading Rate (SR) 1, the final chip rate is fixed at 1.2288 Mcps in order to fit the RF carrier in a 1.25-MHz band. If Radio Configuration (RC) 3 is used, then the F-DCCH can operate at a data rate of 9.6 Kbps, and the F-SCH can operate at 153.6 Kbps (see Chapter 2). To obtain a final chip rate of 1.2288 Mcps, the system needs a processing gain of 128 ($= 1.2288 \text{ Mcps} / 9.6 \text{ Kbps}$) for the F-DCCH, and a processing gain of 8 ($= 1.2288 \text{ Mcps} / 153.6 \text{ Kbps}$) for the F-SCH. Because the processing gain of the F-DCCH is *greater* than that of the F-SCH, the length of the Walsh code used by the F-DCCH must be *longer* than that used by the F-SCH. In fact, in this case the F-DCCH uses a Walsh code of length 64, and the F-SCH uses a Walsh code of length 4. Although the above example deals with the forward link, similar situations also exist on the reverse link.

Because IS-2000 supports different data rates simultaneously and the final chip rate is fixed at 1.2288 Mcps (at least for SR1), the system must be able to use Walsh codes of different lengths simultaneously (i.e., a lower data-rate channel requires a longer Walsh code, and a higher data-rate channel requires a shorter Walsh code). Therefore, an IS-2000 system employs Walsh codes of different lengths for different channels. Table 9.1 shows the different Walsh code lengths that different forward link channels support.

To prevent mutual interference, the system needs to ensure that all Walsh codes *in use* are orthogonal to each another. Because IS-2000 can use Walsh codes of different lengths simultaneously, the system needs to make sure that active Walsh codes

Table 9.1 Lengths of Walsh Codes Used on the Forward Link

<i>Channel</i>	<i>SR1 (RC1, 2, 3, 4, and 5)</i>	<i>SR3 (RC6, 7, 8, and 9)</i>
F-SCH	128, 64, 32, 16, 8, or 4	256, 128, 64, 32, 16, 8, or 4
F-FCH	128, 64, 32, 16, 8, or 4	256, 128, 64, 32, 16, 8, or 4
F-DCCH	128 or 64	256 or 128
F-CCCH	128, 64, 32, or 16	256, 128, or 64
F-BCCH	64 or 32	128
F-CACH	128 or 64	256
F-CPCCH	128 or 64	128
F-QPCH	128	256
F-SCCH	64	—
F-PCH	64	—
F-SYNCH	64	64

of different lengths are also orthogonal. This requirement places constraints on which specific Walsh codes can be used when one or more Walsh codes are already in use. For example, let's say that F-SCH 1 is currently active and operating at 307.2 Kbps¹. The Walsh code being used by F-SCH 1 is of length 4. This results in a final chip rate of 1.2288 Mcps ($= 614.4 \text{ Kbps} \times 4$).

Now the mobile requests a second F-SCH (or F-SCH 2) to be operated simultaneously with F-SCH 1. F-SCH 2 operates at a lower rate of 153.6 Kbps¹, and the Walsh code to be used by F-SCH 2 needs to be of length 8 in order to keep the final chip rate at 1.2288 Mcps ($= 153.6 \text{ Kbps} \times 8$). Figure 9.3 shows the bit streams and chip streams for F-SCH 1 and F-SCH 2.

If a channel uses a Walsh code, then a simultaneous channel cannot use any Walsh code that is related directly or indirectly by branching on the recursive tree. For example, if an active channel is using Walsh code [0101] for channelization, then another channel cannot use [01], [01010101], [01011010], and so on (see Figure 9.2). The reason is that, based on the way a recursive tree is constructed, at least a part of a given Walsh code is always identical to a Walsh code above it; when the two Walsh codes are aligned in the transmission, it is possible that some bits of one of the channels would be multiplied by identical Walsh chips, thus rendering the corresponding bits unrecoverable later on. Figure 9.4 shows an example of this situation. R-SCH 1 is channelized using Walsh code [0101]. R-SCH 2 is channelized using Walsh code [01011010] (which is below [0101] on the recursive tree).

One can see in Figure 9.4 that the Walsh chips multiplying the first and fourth bits of F-SCH 1 are identical to the corresponding Walsh chips on F-SCH 2. This will make it impossible to recover the first and fourth bits of F-SCH 1 later on at the receiver. To guarantee orthogonality for all corresponding bit positions among simultaneously active channels, we can only use Walsh codes that are not related directly or indirectly by branching. In our example, if Walsh code [0101] is

1. This rate would be the modulation symbol rate in either the *I* path or the *Q* path right before Walsh code spreading, not the baseband data rate.

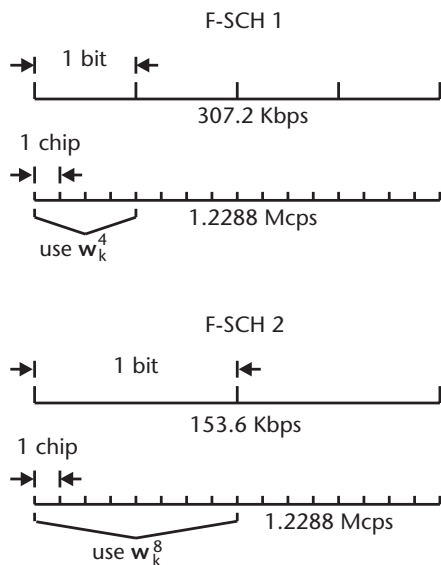


Figure 9.3 Example: F-SCH 1 operating at 307.2 Kbps and F-SCH 2 operating at 153.6 Kbps.

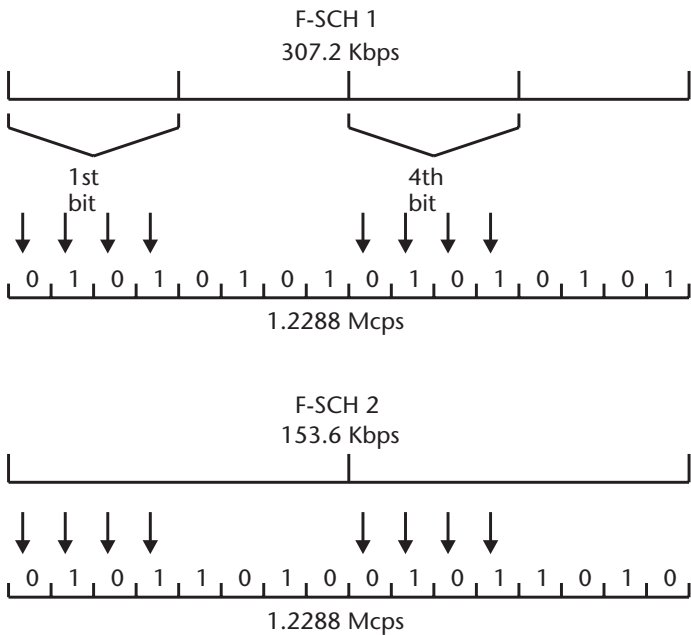


Figure 9.4 An example of nonorthogonal anomaly when two Walsh codes related by direct and indirect branching are used simultaneously.

already in use, then we can assign Walsh code (length 8) [00001111], [00110011], [00111100], [01100110], or [01101001].

Readers should recognize now that, to guarantee orthogonality among all bit positions in all bit streams, the system needs to dynamically assign Walsh codes subjected to the constraints described above. Furthermore, the IS-2000 standard has preassigned Walsh codes to some channels. For example, the F-PCH uses Walsh

code w_1^{64} . The existence of these preassigned Walsh codes further reduces the number of freely available Walsh codes on the recursive tree.

9.3.3 Quasi-Orthogonal Functions

Even with these Walsh codes made available by IS-2000, it is still possible to run out of Walsh codes. Exhausting Walsh codes could happen when interference is relatively low and the forward link can sustain more channels than there are available Walsh codes. In this case, the forward link is limited by the number of available Walsh codes (*Walsh code limited*) instead of limited by interference (*interference limited*).

When the forward link is Walsh code limited, more channelization codes can be generated by multiplying a set of Walsh codes by a specific masking function. In other words, a new set of channelization codes can be derived by the multiplication of a set of Walsh codes and a masking function. This new set of channelization codes (or “masked” Walsh codes) is called a set of quasi-orthogonal functions (QOFs).

The derivation of specific masking functions is beyond the scope of this book. It suffices to say that for a set of Walsh codes, there are more than one masking functions. For example, given a set of Walsh codes one can generate two sets of QOFs: one set by multiplying the set of Walsh codes with one masking function, and another set by multiplying the set of Walsh codes with another masking function. Quasi-orthogonal functions drawn from the *same* set of QOFs are orthogonal, but quasi-orthogonal functions drawn from *different* sets of QOFs are not completely orthogonal (hence the term *quasi*-orthogonal functions). In addition, quasi-orthogonal functions have constant (hence predictable) and minimal mini-max cross correlation with the set of Walsh codes. Note that if the original set of Walsh codes contains 256 Walsh codes, then the above process has generated 512 additional channelization codes or quasi-orthogonal functions.

The base station will use Walsh codes for channelization until they are exhausted. Then the base station will generate a set of QOFs and use quasi-orthogonal functions drawn from that set. If that set of QOFs is exhausted, then the base station will use quasi-orthogonal functions from a different set of QOFs.

The IS-2000 standard specifies three masking functions. These three masking functions are defined such that quasi-orthogonal functions drawn from different sets of QOFs have minimal cross correlation with each other and with the set of Walsh codes. In addition, the cross correlation of any two quasi-orthogonal functions drawn from different sets of QOFs has constant magnitude [4]. Quasi-orthogonal functions are used by the forward dedicated control channel, forward fundamental channel, and forward supplemental channel.

9.3.4 Assignment of Walsh Codes: Reverse Link

The IS-2000 reverse link (for RC3, RC4, RC5, and RC6) is fundamentally different from that of IS-95. On the IS-95 reverse link, only one channel is active at a time (i.e., either the access channel or the traffic channel). Therefore, there is no need to distinguish individual channels transmitted by a mobile since each mobile can only