We can extend the above results for the 8 Kbps vocoder case to the 13 Kbps vocoder case. In systems using 13 Kbps vocoders, the number of subscribers supported by a single CDMA RF carrier is smaller, thus, users on a single RF carrier will generate less access traffic. Therefore, approximately one access channel of a system using 13 Kbps vocoders can support about one and a half times as many CDMA RF carriers as compared to the systems using 8 Kbps vocoders. Of course, this capacity could vary with different assumptions on the access traffic.

5.4 Paging Channel Capacity

In this section, we discuss an approach to evaluate the capacity of an IS-95A CDMA paging channel. The capacity model developed in this section incorporates most of the salient features of this channel and can be used to quickly answer a variety of questions related to paging channel sizing. We can, for example, calculate the residual capacity available for SMS and voice mail services (VMSs) after accounting for the call-processing load associated with a single paging channel.

In a CDMA system, a paging channel conveys information from base stations to mobile stations. There are three major types of call-processing-related messages.

- The first is an overhead message. It contains information required for call setup (for example, system parameter messages, access parameter messages, neighbor list messages, channel list messages, and extended system parameter messages) and is updated periodically to ensure a successful call setup.
- The second is a page message (or general page message). The page message is used to page the mobile. The page message is sent when a mobile switching center (MSC) receives a call/service request for a mobile. Depending on the paging strategy, the page messages may be sent to a large area through the paging channel on all sectors.
- The third type is a channel assignment message and order message. These messages are important for interacting with a mobile to complete a call/service setup. The base station usually sends these messages only to a small area (a few sectors) during the call/service setup.

In addition to paging messages related to call processing, there are messages associated with supplemental services such as SMS or VMS, which can be sent through the paging channel as well.

In Section 5.4.1, we describe the characteristics of the paging channel that must be considered to formulate a relevant capacity model. In Section 5.4.2, we list all page messages and assumptions used for calculating the paging channel occupancy for each page message type. Section 5.4.3 provides the results for the paging channel capacity and the residual capacity for SMS and VMS after accounting for the call-processing load associated with a single paging channel. In Section 5.4.4, we briefly discuss the results and make some recommendations.

5.4.1 Paging Channel Characteristics

5.4.1.1 Paging Channel Structure

As specified in IS-95A [5.2], the data rate for the paging channel can be either 4800 bps or 9600 bps. Unless otherwise specified, we will assume that the paging channel data rate is 9600 bps, but the capacity model to be developed will be applicable to both transmission rates. Figure 5–14 illustrates the paging channel structure.

The paging channel is partitioned into 80 msec paging slots, and each slot consists of eight half frames, each of 10 msec duration. Each half frame begins with a synchronized capsule indicator (SCI) bit, and the first new message in a paging slot[7] must begin immediately following an SCI bit that is set equal to 1. Paging channel messages are carried in paging channel capsules that consist of the message body, an eight-bit length field that indicates the length in bits of the entire capsule, and a CRC code of thirty bits. As we will describe later, paging messages, channel assignments, and orders have lengths in the 100 to 150 bits range, and since a paging slot consists of 760 bits (eight half frames, each having ninety-five potential payload bits), it can potentially carry multiple pages, channel assignments, and orders.

A synchronized paging channel message capsule begins immediately following an SCI bit (in which case the SCI bit is set equal to 1). Since most page, channel assignment, and order message capsules occupy roughly one and a (typically small) fraction of a second half frame, insisting that all message capsules be synchronized would waste a good part of the second half frame. To avoid this inefficient use of a paging channel, the standard permits only the first new message capsules in a slot to be synchronized, and subsequent message capsules in the slot can be appended to the end of the preceding capsule. The message length field in a capsule indicates where the next message capsule in a slot begins. If a message capsule ends less than eight bits from an SCI bit, the standard dictates that the next message in the slot must be synchronized. The length of page and channel assignment capsules must be an integer number of bytes; both of

7. Paging channel messages may spill over from a previous slot.

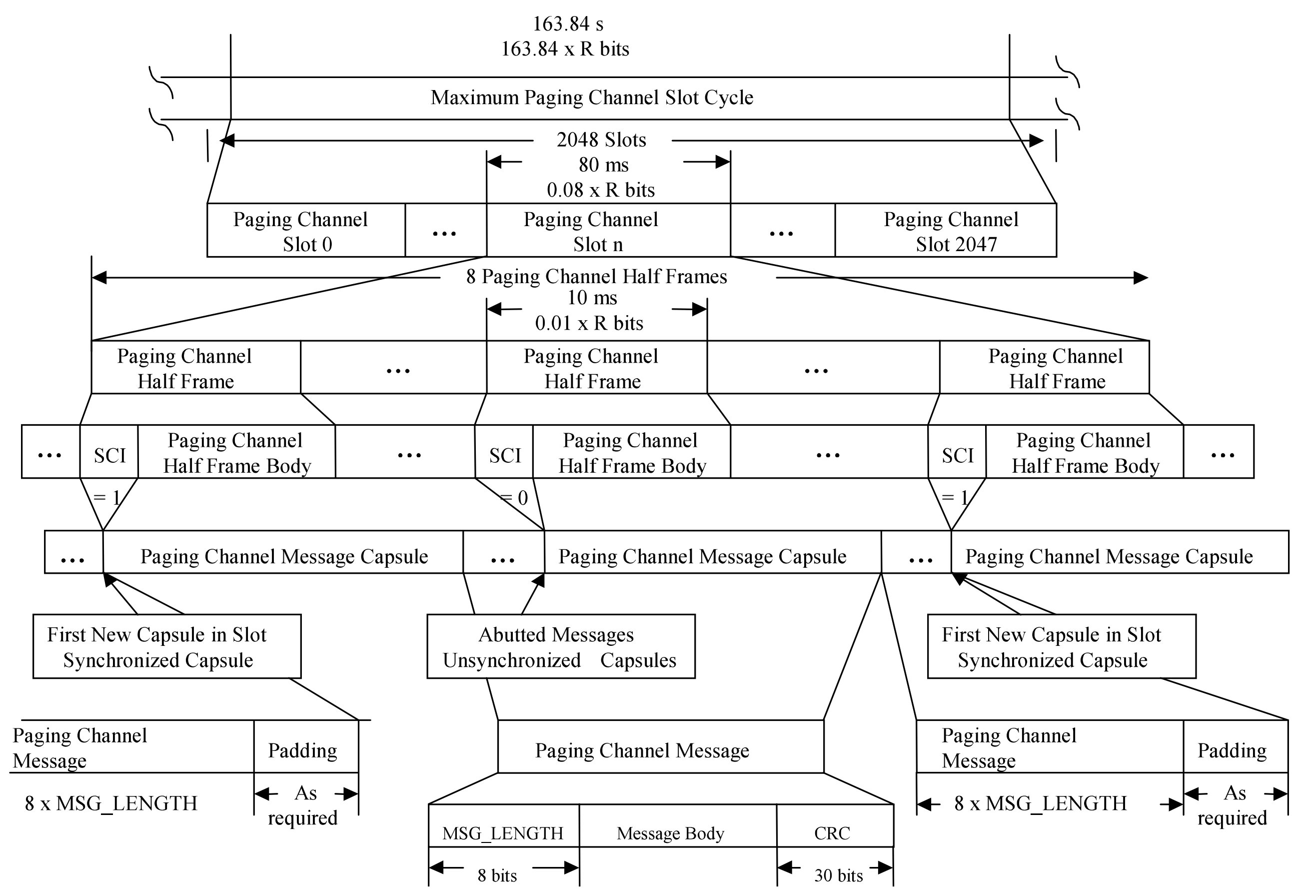

Figure 5–14 Paging Channel Structure Example

these message types have zero to seven bits reserved for padding to satisfy this requirement.

5.4.1.2 Slotted and Non-Slotted Mode

A mobile may operate in non-slotted mode, in which case the mobile reads all page slots while in the *mobile station idle state*. Alternatively, a mobile may (choose to) operate in the slotted mode while in the *mobile station idle state*, in which case the mobile wakes up periodically in specified slots to check for paging messages directed to it. Slotted mode permits the mobile to power down until its pre-specified slot comes along. The mobile wakes up for one or two slots in a slot cycle[8] the length of which can be negotiated between the mobile and the system. The minimum length of a slot cycle is sixteen slots (1.28 sec); for normal cellular/PCS service, this minimum length is likely to be widely used. Mobile stations may use longer slot cycles (maximum length permitted is 2,048 slots), but this would lead to significant delays in terminating a call to mobiles operating in the slotted mode.

Both the mobile and the MSC use the same hash function (see References [5.1] and [5.2]) with the mobiles MIN (or TMSI) as an argument to determine the slot (in the slot cycle) in which the mobile will next awaken. This permits the cellular system to determine the correct slot in which to page mobiles in slotted mode. Mobiles in slotted mode do not generally read the entire paging channel slot in which they awaken because the system sends a *_DONE* message after all messages scheduled for the slot have been sent (this is an empty general page message with the appropriate field set to indicate that all messages in the slot have already been sent). This permits mobiles in slotted mode to conserve even more battery power.

The requirement that a paging channel message must be contained in two successive slots (the message capsule cannot exceed 1,520 bits) constrains the size of a paging channel message. As indicated earlier, a mobile in slotted mode may read a message that continues onto the next slot; in this instance, the mobile may read the paging channel for as long as two slots.

When IS-95A was approved, it defined three distinct page messages: a slotted page message, a page message, and a general page message. From the viewpoint of paging channel usage, there is little to distinguish among these three distinct page message types because they all have approximately the same length.

8. In cases where a page message carries over to a second slot, a mobile would stay awake for the second slot to read the complete message.

Table 5–6 Paging Channel Messages

Message Name
System Parameter Message
Access Parameter Message
Neighbor List Message
CDMA Channel List Message
Slotted Page Message
Page Message
Order Message
Channel Assignment Message
SSD Update Message
Data Burst Message
Authentication Challenge Message
Feature Notification Message
Extended System Parameters Message
General Neighbor List Message
Status Request Message
Service Redirection Message
General Page Message
Global Service Redirection Message
TMSI Assignment Message
Null Message

5.4.2 Assumptions

Table 5–6 lists the twenty paging channel messages that the IS-95A (Reference [5.2]) defines. Of the twenty messages, the slotted page message and the page message are no longer in IS-95B (Reference [5.5]). Of the remaining eighteen messages, the following paging channel messages account for most paging channel usage:

Table 5–7 Assumptions and Message Lengths

	Numerical Values
General Assumptions	
a. Paging Channel Capacity	9600 bits/sec
b. Maximum Allowable Utilization	0.9
c. Paging Strategy (number of pages per users)	1.5
d. Termination Rate	0.35
e. Busy Rate	0.03
f. BHCA per subscriber	2
g. Number of Sectors per MSC	200
h. **General Page Message**	136 bits
i. **Overhead Message**	= j + k + l + m + n
j. System Parameter Message	264 bits
k. Access Parameter Message	184 bits
l. Neighbor List Message	216 bits
m. CDMA Channel List Message	88 bits
n. Extended System Parameter Message	112 bits
o. **Channel Assignment Message**	144 bits
p. **Order Message**	102 bits
Voice Mail Service q. Voice Mail Notification	720 bits
Short Message Services r. Data Burst Message (x = number of characters)	(7x + 380) bits
s. **_DONE Message**	72 bits

1. General Page Message,
2. Overhead Message,
3. Channel Assignment Message,
4. Order Message, and
5. Data Burst Message for SMS.

The remaining messages are not constantly used. Table 5–7 lists all assumptions and message lengths used for the later calculation.

5.4.3 Paging Channel Capacity

In this section, *we use ninety percent paging channel capacity to be the maximum allowable paging channel utilization*, which is indicated in Table 5–7. We reserve the remaining ten percent to accommodate potential burst paging traffic. The paging channel occupancy for each message is then calculated as a fraction of the maximum allowable paging channel capacity. In other words, if the calculated occupancy is twenty percent, it means that the twenty percent of the ninety percent physical paging channel capacity will be needed to transport the message.

In the following sections, we will evaluate the paging channel occupancy for each message. This will give us a quick answer to a variety of questions related to paging channel sizing. We will use the BHCA as a traffic reference for calculating paging channel capacity.

5.4.3.1 General Page Message (Call Termination)

Base stations use the general page message to page (find) a mobile when there is a terminating call or to notify the arrival of a special message service (for example, SMS or VMS). In general, the base station will send the message system-wide to locate the mobile. The paging channel occupancy (with respect to ninety percent paging channel utilization) for the general page message (Og) is calculated as[9]

$$\mathrm{Og} = \frac{\mathrm{BHCA} \times (\mathrm{d} - \mathrm{e}) \times \mathrm{c} \times \mathrm{h}}{3600 \times \mathrm{a} \times \mathrm{b}} . \tag{5.7}$$

From (5.7), we see that the paging channel occupancy for the general page message is linearly proportional to the growth of traffic demand (that is, BHCA). Figure 5–15 plots the paging channel occupancy for the general page message at different traffic demand. This shows that there is about thirty percent to forty percent occupancy at 150 K to 200 K BHCA. Note that if we can page a small area only (knowing where the mobile is), the reduction of paging channel occupancy can be substantial. For example, if the system pages only one-fourth of the areas, then there is about twenty percent to thirty percent paging channel usage reduction at the range of 150 K to 200 K BHCA traffic.

5.4.3.2 Overhead Message

As described in References [5.1] and [5.2], mobile stations need to update all overhead messages to have a successful call setup. Reducing call setup duration can improve successful call setup rate because the probability of losing a strong pilot is pro-

9. In equations (5.7) to (5.14), we use item indices in Table 5–7.

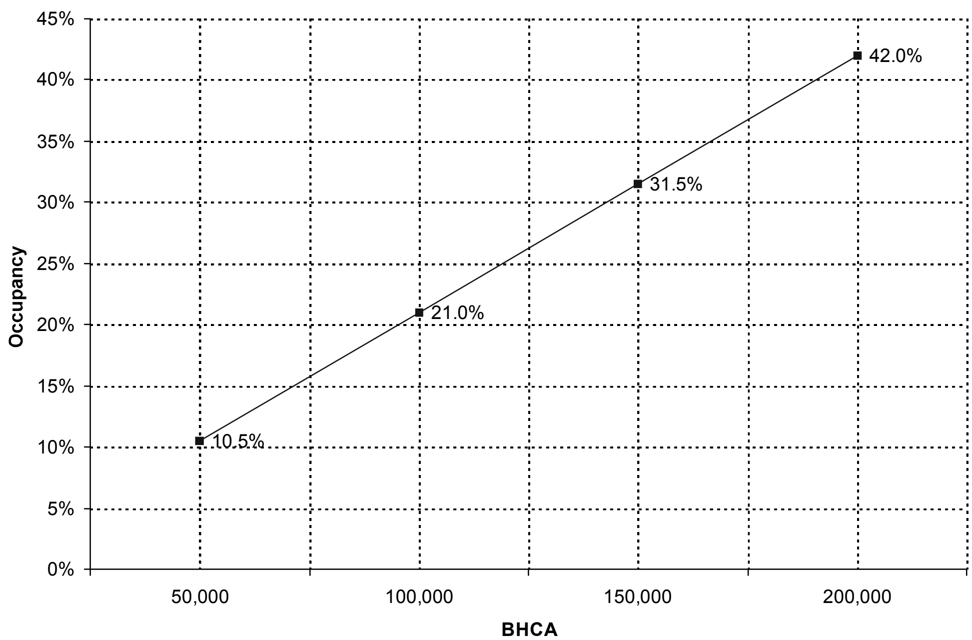

Figure 5–15 Paging Channel Occupancy—General Page Message (Call Termination)

portional to the setup duration. In this section, we will evaluate the impacts of different overhead cycles on the paging channel capacity.

The overhead message (which includes system parameter messages, access parameter messages, neighbor list messages, channel list messages, and extended system parameter messages) will be sent within every *n* slots[10] to a mobile. The occupancy is independent of the traffic demand. The system will continuously send overhead messages. The paging channel occupancy for the overhead message (Oo) is calculated as

$$\mathrm{Oo} = \frac{\mathrm{i} \times [1/(0.08 \times \mathrm{Slot\ Cycle})]}{\mathrm{a} \times \mathrm{b}}. \tag{5.8}$$

Equation (5.8) indicates that the paging channel occupancy for an overhead message is inversely proportional to the slot cycle duration. Figure 5–16 plots the paging channel occupancy versus varied overhead cycle slots. It shows that the paging channel occupancy grows exponentially with the reduction of the overhead cycle, which suggests that the overhead cycle slots should be greater than seven to avoid using too much

10. Each slot is 80 msec.

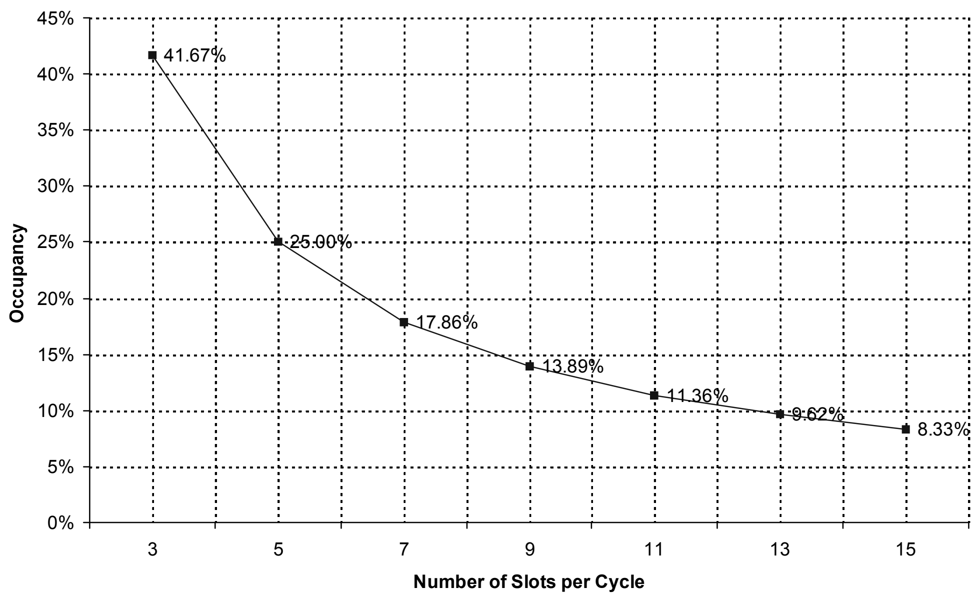

Figure 5–16 Paging Channel Occupancy – Overhead Message

paging channel capacity. Note that reducing the overhead message cycle from fifteen to seven results in approximately a nine and a half percent increase in paging channel usage.

5.4.3.3 Channel Assignment Message and Order Message

The base station sends channel assignment messages (CAMs) to the mobile during a call setup (either an originating or a terminating call). Order messages are used for registration reject and base station acknowledgments. The base station transmits CAMs and order messages, interacting during the call/service setup, to the mobile through current communicating sectors' paging channels. The channel assignment message and order message almost come as a pair for each call setup. Since order messages also include registration reject, it has slightly higher rates. For simplicity, we assume that the rates for a channel assignment message and order message are the same. We also assume that the system (one MSC) has two hundred sectors. The paging channel occupancy for channel assignment and order messages, Oco, is calculated as

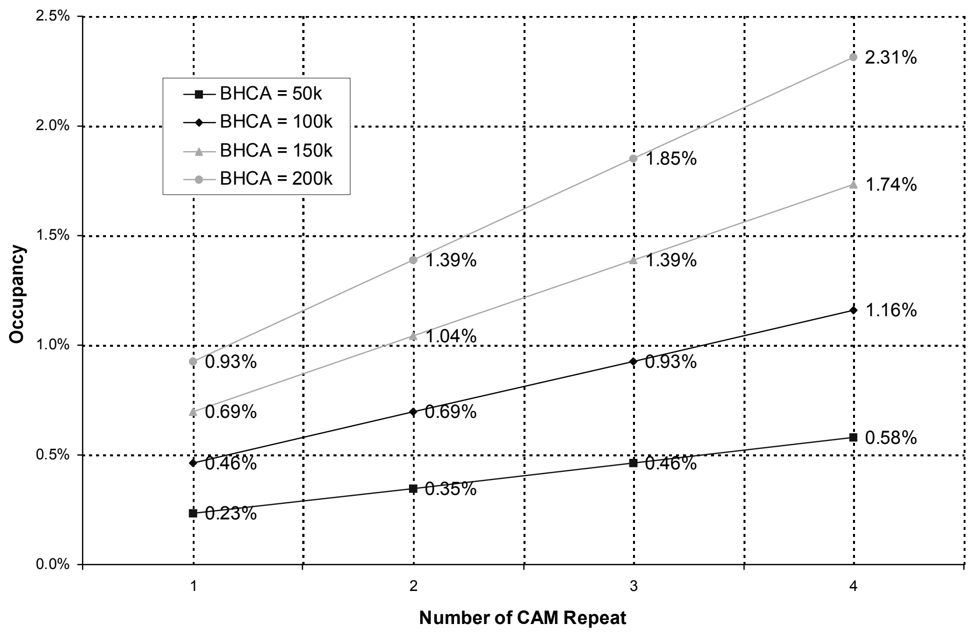

Figure 5–17 Paging Channel Occupancy—Channel Assignment and Order Messages

$$\text{Oco} = \frac{(\text{BHCA/g}) \times (N \times \text{o} + \text{p})}{3600 \times \text{a} \times \text{b}}, \tag{5.9}$$

where *N* is the number of repeats for channel assignment messages.

The first item on the right-hand side of (5.9) is a simple calculation for the rate of channel assignment and order messages. Clearly, it will tend to underestimate the areas with higher traffic. Figure 5–17 shows the paging channel occupancy for channel assignment messages and order messages with varied CAM repeats and different traffic demands (BHCA). The results show that the paging channel occupancy for channel assignment messages and order messages is low. Even with four repeats and 200 K BHCA, the occupancy is only 2.31 percent.

5.4.3.4 _DONE Message and SCI bit

As mentioned in Section 5.4.1.2, the base station sends the *_DONE* message after all messages scheduled for the slot have been sent. Here, we assume that there is a *_DONE* message in each slot. The SCI bit is inserted in each half frame. Therefore, the paging channel occupancy for *_DONE* message and SCI bits (Ods) can be calculated as

Table 5–8 Paging Channel Occupancy for *_DONE* Message and SCI bits

Message	Paging Channel Occupancy
_DONE Message (s)	10.42%
SCI	1.16%
Ods	11.58%

$$\text{Ods} = \frac{(1/0.08) \times s + 1 \times (1/0.01)}{a \times b}. \tag{5.10}$$

Table 5–8 lists the results for the paging channel occupancy due to *_DONE* messages and SCI bits.

5.4.3.5 Paging Channel Capacity (No SMS and No VMS)

Figure 5–18 plots the total paging channel occupancy (sum of those given by (5.7)-(5.10)) with different BHCA and overhead message cycles of seven and fifteen. Considering 150 K BHCA, the paging channel occupancy is about fifty-three percent for the overhead message cycle of seven and sixty-three percent for the overhead cycle of fifteen. Therefore, there is about thirty-seven percent to forty-seven percent residual capacity available for the services such as VMS and SMS.

5.4.3.6 Voice Mail Services (VMSs)

Voice mail service is a feature that allows callers to leave a voice mail message on a voice mail center. When a caller leaves a voice mail message, the voice mail center will then trigger a request to send a notification to the mobile.

There are several ways to send voice mail notification messages. Here, we will introduce two methods of VMS. The first one is simply using a call setup procedure. The system will send a general page message periodically until the mobile responds. After following the regular call setup procedure, the base station will then send the voice mail through a traffic channel.

The other method uses the SMS type transmission through the paging channel. In this method, no voice mail indication (VMI) message will be sent until the mobile powers on, registers, or sets up a call. The system will first send a general page message, which is followed by a VMI message (through the currently communicating sector's paging channel) upon receiving the response from the mobile.

Let Ov1 denote the paging channel occupancy for the first method and Ov2 denote the paging channel occupancy for the second method. Then,

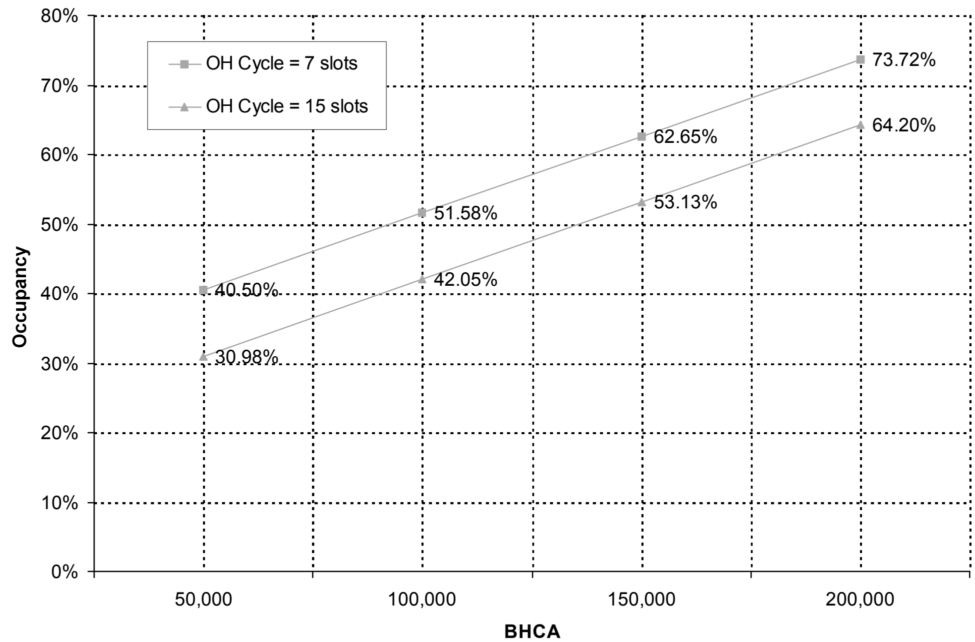

Figure 5–18 Paging Channel Occupancy (No VMS and No SMS)

$$\mathrm{Ov1} = \frac{[(\mathrm{BHCA}/\mathrm{f}) \times \mathrm{NOrate} \times 2 \times (\mathrm{d}-\mathrm{e}) \times (60/\mathrm{v}) + \mathrm{BHCA} \times \mathrm{e}] \times \mathrm{h}}{3600 \times \mathrm{a} \times \mathrm{b}} \tag{5.11}$$

$$\mathrm{Ov2} = \frac{\mathrm{BHCA} \times \mathrm{e} \times (\mathrm{h} + \mathrm{q}/\mathrm{g})}{3600 \times \mathrm{a} \times \mathrm{b}}, \tag{5.12}$$

where v is the VMS cycle duration and NOrate is the NO PAGE RESPONSE rate.

Figure 5–19 shows that, using method 1, the paging channel occupancy will substantially increase when the interval between two general page messages, v, is short. With the assumption of twenty percent no page response rate, there is a potential problem when the traffic demand is greater than 150 K BHCA. In this case, for a fifteen-minute page cycle, the paging channel occupancy is close to twenty percent. Most of them are used to notify (page) those mobiles that will never respond.

In method 2, with varied number of sectors in each MSC (that is, g), the SMS transmission can substantially reduce the paging channel occupancy from twenty percent to less than three percent as plotted in Figure 5–20. Note that it is almost insensitive to the number of sectors in one MSC.

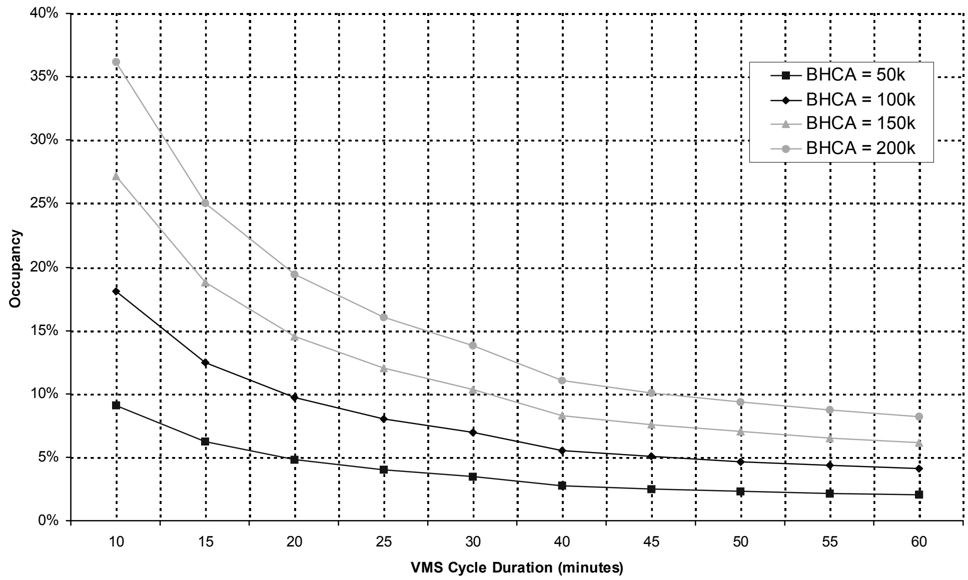

Figure 5–19 Paging Channel Occupancy for VMS (Call Setup Method)

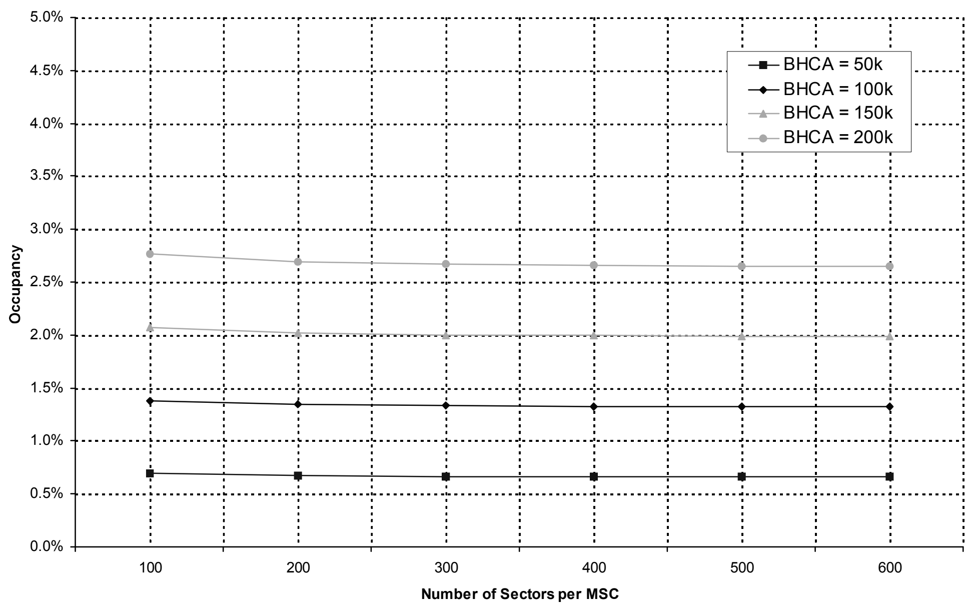

Figure 5–20 Paging Channel Occupancy for VMS (SMS Method)

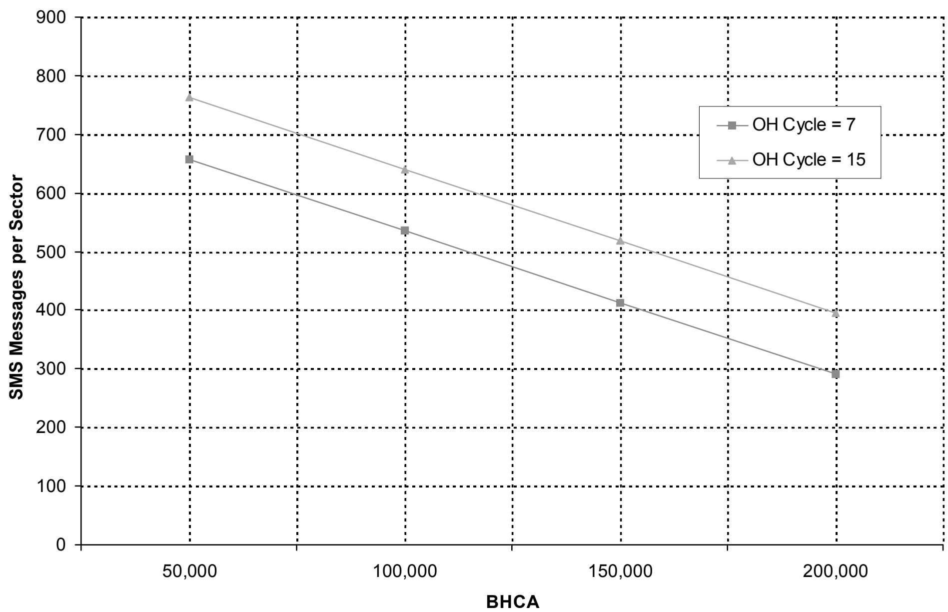

Figure 5–21 SMS Capacity (No VMS)

5.4.3.7 Data Burst Messages (Short Message Services)

The base station uses data burst messages to send SMS messages to a mobile. In addition to the seven bits sent for each character in the SMS message (the size of an SMS message in bits is denoted by r; each SMS message contains eighty characters), the data burst message capsule carries approximately 380 bits of overhead. (Of these bits, 232 are due to IS-637 [5.6] mandated overhead, 38 bits are due to the length field and the CRC, and the remaining 110 bits are due to fields in the data burst message). If we assume a flood-paging scheme, every CDMA paging channel in the MSC carries an SMS page for each delivered SMS message. In this case, every paging channel carries $g \times M$ SMS pages/sec. The paging channel occupancy for SMS, Os, can then be calculated as

$$\mathrm{Os} = \frac{M \times (\mathrm{r} + \mathrm{h} \times \mathrm{g})}{3600 \times \mathrm{a} \times \mathrm{b}}. \tag{5.13}$$

Given a residual capacity, the number of SMS messages for each sector can be obtained by

$$M = \frac{\mathrm{Os} \times (3600 \times \mathrm{a} \times \mathrm{b})}{\mathrm{r} + \mathrm{h} \times \mathrm{g}}. \tag{5.14}$$

Figure 5–21 shows the residual capacity for SMS messages (without including VMS). Given that each sector supports about 400 subscribers[11] for a system using 13 Kbps vocoders, the residual paging channel capacity can support about one SMS message per subscriber (at 150 K BHCA) during the busy hour.

5.4.4 Summary

At 150 K BHCA traffic, there is about a fifty-three to sixty-three percent paging channel occupancy used by messages related to call processing. The residual capacity for SMS is about one SMS message per subscriber during the busy hour. The SMS type transmission should be chosen for VMS to avoid unnecessary waste of paging channel capacity. Addition of new services such as SMS and VMS may have caused paging channel usage to reach its maximum allowable capacity.

This situation will be even worse in IS-95B in which the overhead message size is larger and the paging channel loading is higher due to the new access handoff and the soft CAM features. To ensure the appropriate paging channel performance, we need to carefully choose a transmission algorithm for each paging message.

5.5 References

[5.1] ANSI J-STD-008. *Mobile Station - Base Station Compatibility Requirements for 1.8 and 2.0 GHz CDMA PCS*, March 1995.

[5.2] EIA/TIA IS-95A. *Mobile Station – Base Station Compatibility Standard for Dual-Mode Wideband Spread Spectrum Cellular System*, March 1995.

[5.3] A. J. Viterbi. *CDMA: Principles of Spread Spectrum Communication*, Addison-Wesley Publishing Company, 1995.

[5.4] W.C.Y. Lee. *Mobile Cellular Telecommunications Systems*, McGraw-Hill, 1989.

11. For a system using 13 Kbps vocoders, the Erlang traffic is about 7.4. If we assume that each call holding time is seventy-two seconds, the number of subscribers for each sector is 7.4/0.02 = 370.

[5.5] TIA/EIA/SP-3693-1 (to be published as TIA/EIA-95-B). *Mobile Station – Base Station Compatibility Standard for Dual-Mode Wideband Spread Spectrum Cellular System*, July 17,1998.

[5.6] TIA/EIA/IS-637. *Short Message Services for Wideband Spread Spectrum Cellular Systems*.