5ESS®-2000 Switch Cellular Gateway

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U. S. cellular networks continue to expand exponentially, with subscriber growth increasing more than 30 percent per year, while international wireless networks are experiencing even more remarkable growth, with many world networks expanding more than 100 percent per year. The growth in the subscriber base and service demand clearly carries with it a corresponding and similar growth in the network equipment used to provide wireless/cellular services. And, as networks grow in size, their trunk connectivity, mobile call delivery, and internode signaling become more complicated. As a result, some of the larger cellular network operators are implementing a hierarchical network structure that incorporates a cellular gateway switch to optimize trunking and signaling links. This paper describes the cellular gateway switch and how it is being used to resolve the problems associated with large cellular networks. A brief overview of a cellular service network is given, followed by a comparison of the switching node call traffic loads and trunking requirements of a theoretical network, with and without a cellular gateway switch.

Introduction

The growth in the number of subscribers in cellular networks—sometimes known internationally as wireless or Personal Communications Services networks—averages about 30 percent per year in the U. S. and as much as 100 percent per year in some international markets. Cellular networks with as many as one million subscribers, and more, are now a reality. To meet the rapidly increasing growth in cellular networks, service providers must add switching equipment, intranetwork and internetwork trunking and signaling connections, and points of presence for connection to the public landline network, called the Public Switched Telephone Network (PSTN). (See Panel 1 for definitions of abbreviations, acronyms, and terms.) As the cellular network grows, it becomes more important to implement a hierarchical network for resources such as trunking, announcements, and Mobile Application Part (MAP) signaling messages. (See Panel 2 for a comparison of MAP and Interim Standard 41 [IS-41] and their uses.)

A hierarchical network might consist of one switch acting as a tandem trunk switch for all traffic between the cellular network and the local PSTN, and for all traffic between mobile switching centers in the cellular network. A tandem switch allows each mobile switching center to be connected only to the tandem switch, rather than directly connected to each of the other mobile switching centers and one or more PSTN switches. Ideally, this tandem switch would support remote switching capabilities to provide several points of presence for intranetwork and internetwork traffic on a single, centrally controlled switch. If the traffic is then concentrated onto several large trunk groups rather than many smaller trunk groups, the same amount of traffic can be supported with significantly fewer interswitch trunks.

Although the tandem switch concept is not new in telephony networks, the

Panel 1. Abbreviations, Acronyms, and Terms

AMPS—Advanced Mobile Phone Service, the U. S. cellular standard.

busy-hour calls—a unit of measure used to describe the call load on a switch or a set of trunk facilities.

GSM—Global System for Mobile Communications. GSM uses a reference model similar to the AMPS model, along with an equipment identity register, for equipment number verification, and an authentication center to verify subscriber identification module (SIM) cards. SIM cards, inserted in the mobile unit, are needed to make calls. The GSM interfaces are similar to the AMPS network interfaces, although the protocols are all based on European Telecommunications Standards Institute (ETSI), rather than North American, standards.

home location register—the subscriber database in the home system that contains the subscriber data and the address of the system currently serving each subscriber.

home system—the mobile switching center that contains the record of the subscriber's home location register.

IS-41—Interim Standard 41 (see Panel 2 for a description)

MAP—Mobile Application Part (see Panel 2 for a description)

MIN—mobile identification number, dialed when attempting to call the mobile subscriber.

mobile switching center—the switch and associated cellular control complex providing cellular service.

MTP—message transfer part.

point of presence—a switch in the network that connects the Public Switched Telephone Network and the cellular network.

PSTN—Public Switched Telephone Network, the public land-line network.

roaming—a term used to describe the position of subscribers when they are in a location served by a mobile switching center other than their home system.

SS7—Signaling System No. 7, a layered protocol used for message-oriented signaling in telephone networks. SS7 supports trunk control, mobile networks, and the intelligent network.

SCCP—signaling connection control part.

TCAP—transaction capability application part.

TLDN—temporary local directory number, used to route a call to a mobile subscriber in a visited system. The TLDN is used between cellular network nodes and is not visible to the calling or called subscriber.

visitor location register—a subscriber database that contains the temporary subscriber data record for users that are visiting in a system.

visited system—the mobile switching center that is currently serving the subscriber if the subscriber is roaming out of his/her home system.

cellular network brings new aspects to it. Subscribers are "mobile," and cellular call delivery requires a more intelligent network, one that can execute a search stage in the process of routing terminating calls. Because mobile subscribers move from the area of their home mobile switching center into visited mobile switching centers, it is useful to have intelligent call delivery in the hierarchy of the cellular network.

The "roaming" factor makes the delivery of calls from the PSTN to a subscriber more difficult, because the PSTN has no way of knowing which mobile switching center should receive the call. Normally, a call is delivered from the PSTN to the home mobile switching center, or nearest mobile switching center, and then rerouted to the visited mobile switching center on another trunk. By inserting a tandem switch with intelligent call delivery between the PSTN and the mobile switching centers, the appropriate databases at the home mobile switching center can be queried via MAP protocol without using trunking resources to set up the call. Once the visited mobile switching center is identified, the tandem switch can route the call directly to it without wasting trunking resources into and out of the home mobile switching center. During the time that the intelligent tandem switch is "locating" the called mobile subscriber, the switch provides a *comfort tone* to the calling party, a tone that assures the party that his or her call is being processed.

The Signaling System No. 7 (SS7) network used to coordinate the cellular system's mobility is much like the trunking network. Each mobile switching center must have connections to the other mobile switching centers and, potentially, to other cellular networks. If a

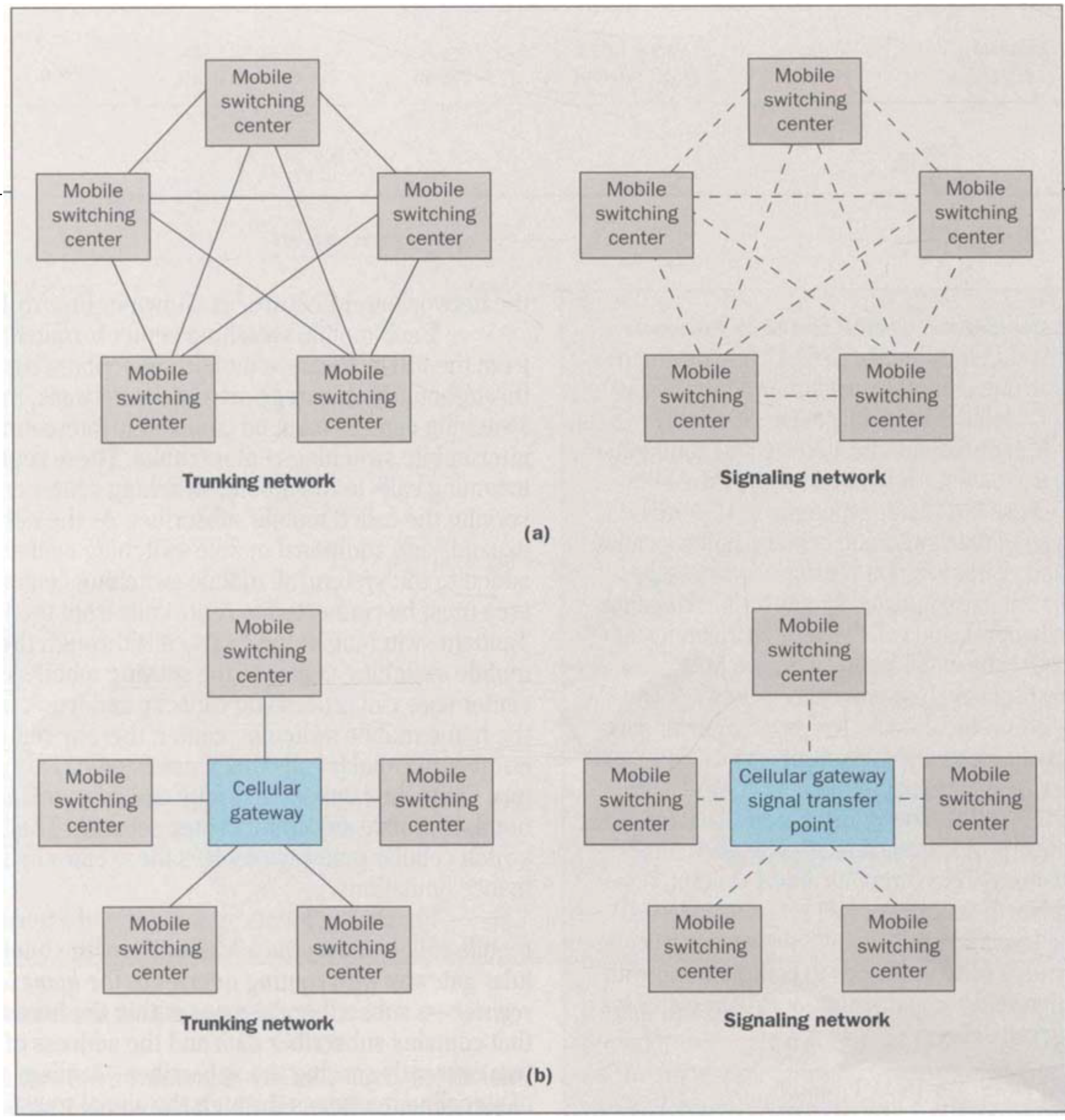

Figure 1. Fully interconnected network (a) without a cellular gateway and (b) with a cellular gateway.

hierarchical signaling network can be installed, the number of signaling links from each mobile switching center can be drastically reduced and concentrated onto a tandem packet switch, called the signal transfer point. The signal transfer point acts as a tandem switch for signaling messages, both between the mobile switching centers in the network and between mobile switching centers in this network and those in other cellular networks.

The intelligent tandem switch optimally centralizes the announcement systems for the entire cellular network. Because most announcements made by the cellular network are played to PSTN subscribers trying to call mobile subscribers, the tandem switch is in a position to play the announcement while using as little of the network trunking facilities as possible. Finally, operator services and intelligent network functionality can be easily integrated into the cellular gateway. Operator services can be more cost-effective when they are centralized. When integrated into the cellular gateway, the intelligent network switch service point provides the originating cellular subscriber with a logical, cost-effective location for intelligent network services.

AT&T's 5ESS®-2000 switch cellular gateway, with its optional signal transfer point, has all four of the capabilities described:

- Trunk tandem,
- Intelligent call delivery,
- An SS7 signal transfer point, and
- Centralized announcements,

and is ideally positioned to evolve with operator and intelligent network services.

Panel 2. Comparison of MAP and IS-41 Protocols

MAP and Interim Standard-41 (IS-41) MAP provide the nontrunk control signaling used for the special needs of a cellular or mobile network. Global System for Mobile Communications (GSM) communities tend to use only the term MAP, while the AMPS communities use IS-41 MAP, or simply IS-41. MAP is used between mobile switching centers, home location registers, and visitor location registers for messages that support database updates for subscriber roaming, interswitch handoff, and call delivery for roaming subscribers. MAP is the application layer, and MAP messages are transported between cellular network entities on the SS7 protocol stack—message transfer part (MTP),[2] signaling connection control part (SCCP),[3] and transaction capability application part (TCAP).[4] The diagram in this panel shows the protocol stack for IS-41 MAP. A similar protocol stack is used for GSM MAP, with International Telecommunications Union (ITU)—rather than North American—MTP, SCCP, and TCAP used for the lower layers.[5] The 5ESS®-2000 switch cellular gateway uses MAP messages to communicate with home location register and visitor location register systems during call delivery.

OSI Layer	IS-41 Protocols
7	MAP
6 • 4	North American 7 TCAP
Network 3	North American 7 SCCP Connectionless North American 7 MTP
Data 2	North American 7 MTP
Physical 1	North American 7 MTP

5ESS-2000 Switch Cellular Gateway

The 5ESS-2000 switch cellular gateway brings focus to the cellular network. It concentrates the trunking and the signaling connections to reduce the call load, the links, and the announcement resources and to simplify the network architecture, as shown in Figure 1.

Each mobile switching center terminates trunks from the PSTN. Because mobile subscribers roam throughout the coverage area of the network, mobile switching centers must be completely interconnected by intermobile switching center trunks. These route any incoming calls to the mobile switching center currently serving the called mobile subscriber. As the network expands and additional mobile switching centers are added to the system, all mobile switching centers in the area must be connected to route calls from the PSTN. Tandem switching of the PSTN calls through the home mobile switching center to the serving mobile switching center uses call processing capacity and trunk facilities of the home mobile switching center, thereby reducing the number of cellular calls that it can handle. This architecture limits the trunking capacity and performance of a multiple mobile switching center network. The 5ESS-2000 switch cellular gateway resolves these capacity and performance limitations.

Figure 2 presents an overview of a normal land-to-mobile call. It shows the added value of the intelligent cellular gateway with routing queries to the *home location register*—a subscriber database within the home system that contains subscriber data and the address of the system currently serving the subscriber—tandem switching of signaling messages through the signal transfer point, and the direct trunking connection to the visited mobile switching center.

Using Cellular Gateways in Networks

The cellular gateway was first used in the Korea Mobile Telecom (KMT) Advanced Mobile Phone Service (AMPS) cellular network. With more than one million subscribers calling at rates as high as four times the U. S. average, its call volumes can easily approach four million per hour. The network has both AT&T's Autoplex® System 1000 mobile switching center and Motorola equipment, with 35 cellular switches in the AT&T portion of the network and 4 switches in the Motorola portion. Before the cellular gateway was used, calls transmitted from the PSTN to the KMT network were delivered to the mobile switching center closest to the land-line caller. Thus, only a small percentage of the land-to-mobile or mobile-to-mobile calls arrived at the called mobile subscriber's visited system.

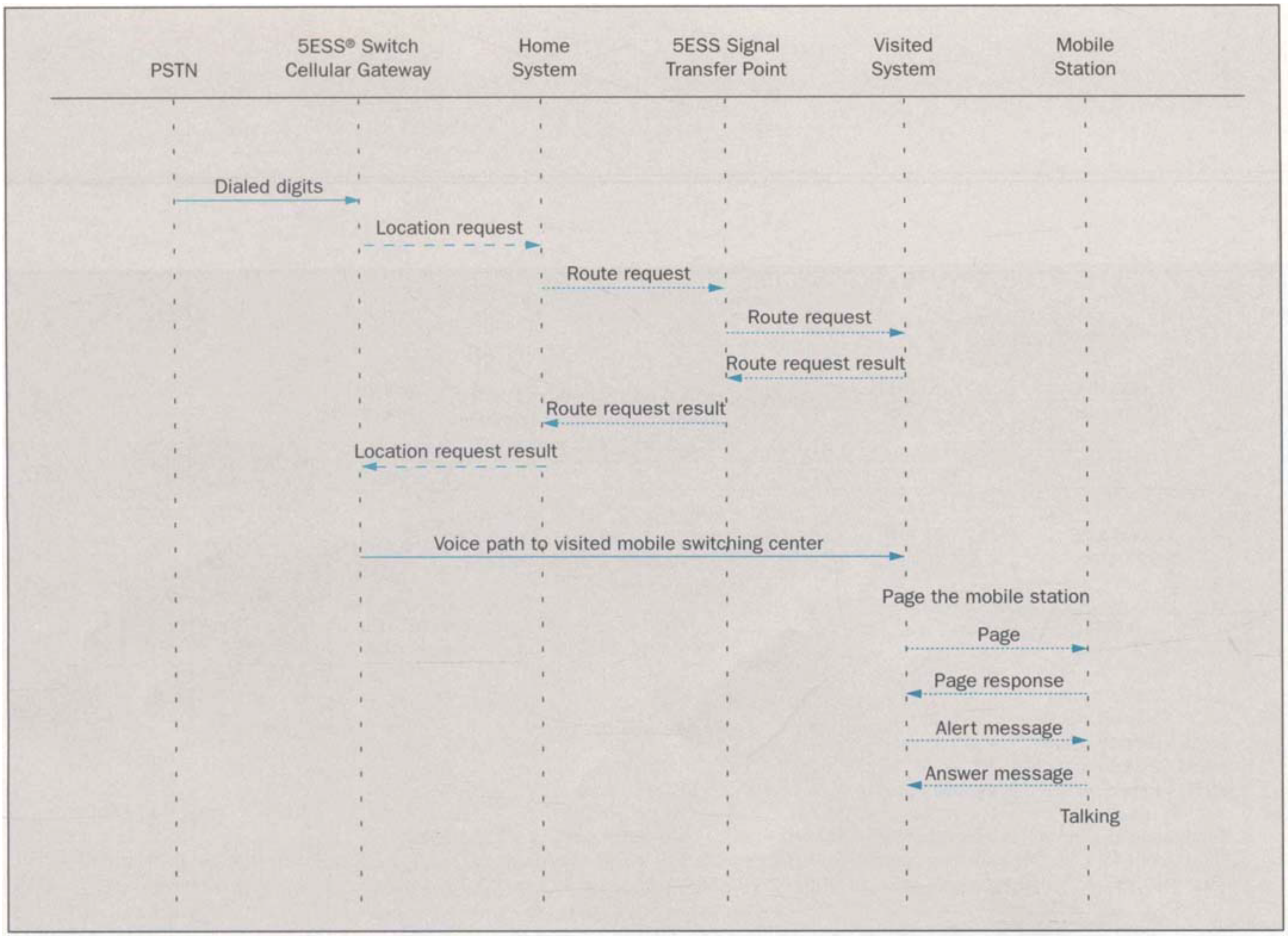

Figure 2. Successful land-to-mobile call.

In this environment, it was extremely inefficient to deliver calls by providing a direct trunked connection between each mobile switching center pair. The formula for the required trunking of two-way trunk groups is $N \times (N-1)/2$, where N is the number of switching points. If $N = 39$, then 741 two-way groups are required. If one-way trunking is used, this would double to 1,482 one-way trunk groups. As the number of trunk groups increases, the number of trunks per group must decrease, resulting in trunking inefficiencies. The cellular gateway was added to the KMT network early, at first as a tandem, then as an intelligent call delivery vehicle, before the numbers of trunk groups became unmanageable. Adding the cellular gateway maintained the trunking efficiencies and relieved the strain on the mobile switching centers, removing the call load caused by the initial switching of traffic from the PSTN.

When the first cellular gateway switch was installed, remote switching modules (RSMs) provided geographic points of presence throughout Korea, allowing the KMT to meet Korean Ministry of Information and Communications (MIC) requirements for the wireless provider to supply call transport on long distance calls. As the network continued to grow, some RSMs were expanded to full switches and achieved independent cellular gateway status. The operation of the cellular gateway could easily handle a cellular network that included switching equipment from any number of vendors, as long as the vendors could meet the IS-41 MAP intervendor networking specification.

Sample Theoretical Network

This section compares the mobile switching centers, trunks, and traffic patterns of a theoretical cellular network both with and without a cellular gateway. The network of signaling and trunking facilities is simplified by introducing the cellular gateway into a medium-sized network. Several assumptions are also simplified to keep the calculations straightforward.

Sample Network Without a Cellular Gateway. The sample network without a cellular gateway has six mobile switching centers, each of which is connected to two PSTN point-of-presence switches. At any one time, five-sixths (83 percent) of the subscribers are in

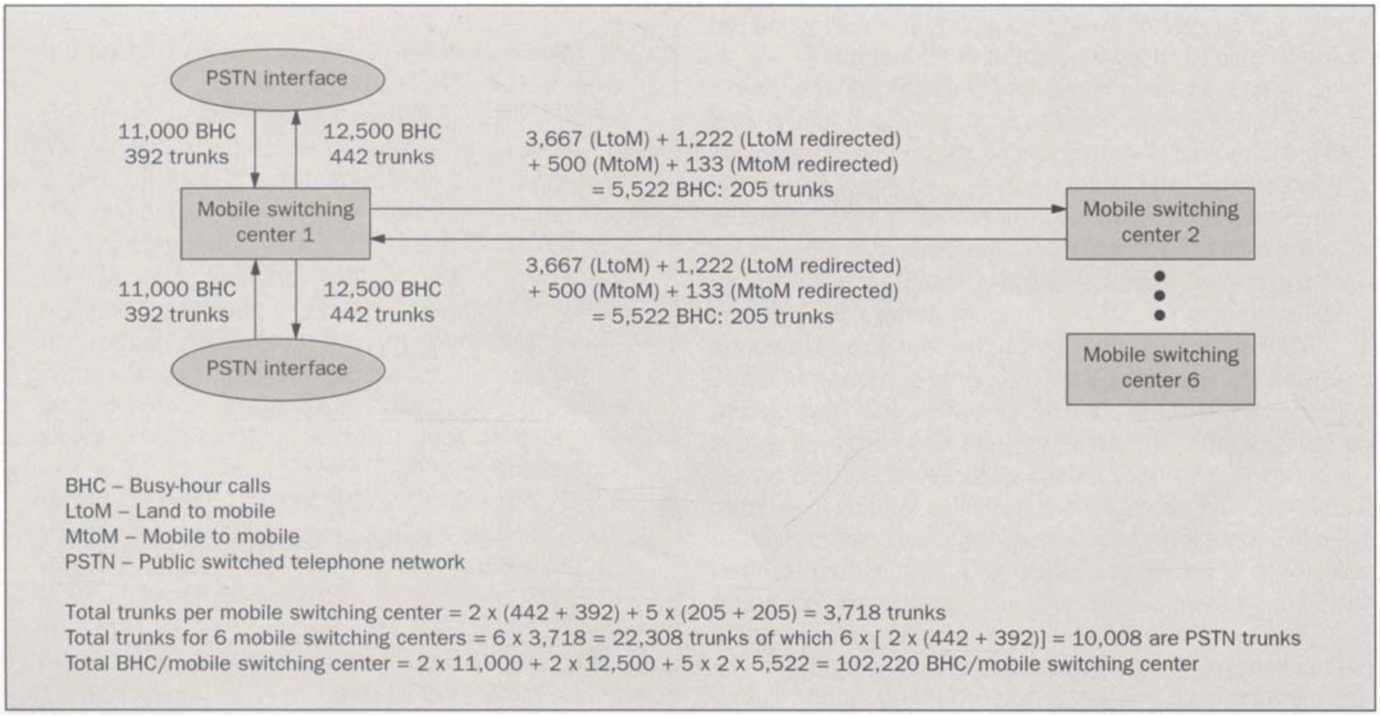

Figure 3. Sample network without a cellular gateway.

visited systems, that is, at another mobile switching center. Roamers into and out of this network are ignored, as if the system were closed. Each mobile switching center carries 50,000 busy-hour calls, and the probability of blocking any call is 0.01. The average holding time per call is 120 seconds. The mobile-to-land calling rate is 25,000 calls.

The land-to-mobile calling rate is 22,000 calls. One-sixth (3,667) of the land-to-mobile calls terminate at this mobile switching center, and an equal number initially routed to this mobile switching center terminate at each of the other five mobile switching centers. Of the 3,667 land-to-mobile calls that go to each of the other mobile switching centers, 1,222 calls are redirected (because they were not answered) to other mobile switching centers, and 1,222 calls are terminated to announcements at the visited mobile switching center. In turn, this mobile switching center receives 3,667 calls from each of the other five mobile switching centers, of which 1,222 calls get redirected to other mobile switching centers, and 1,222 calls get terminated to announcements at this mobile switching center. Finally, this mobile switching center gets 1,222 calls redirected to it from each of the other mobile switching centers.

The mobile-to-mobile calling rate is 3,000 calls. One-sixth (500) of the calls terminate at this mobile switching center, and an equal number are sent to and received from each of the other mobile switching centers (500 calls in and 500 calls out). Of each of those 500 calls received, 133 calls are redirected to another mobile switching center, and 133 calls are terminated to announcements on this mobile switching center. Finally, 133 calls from other mobile switching centers are redirected to this mobile switching center.

As Figure 3 shows, each mobile switching center needs 3,718 trunks to support the traffic and assumptions described above, bringing the total busy-hour calls per mobile switching center to 102,220. The number of trunks was derived using the Erlang B distribution[1] with 0.01 probability of blocking.

Sample Network with Cellular Gateways. In this example, a cellular gateway is added to the same sample network and is connected to eight PSTN point-of-presence switches. At any one time, five-sixths of the subscribers

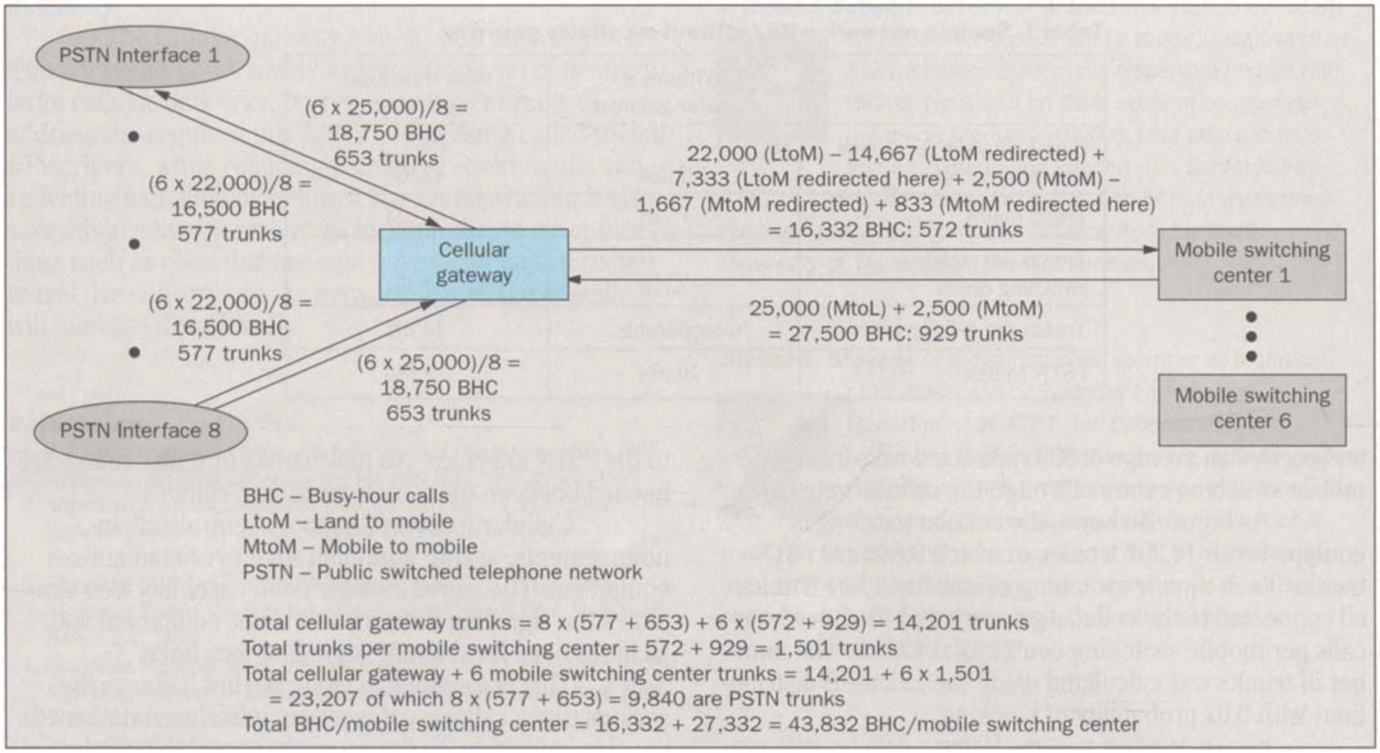

Figure 4. Sample network with a cellular gateway.

are in visited systems, that is, at another mobile switching center. Roamers into and out of this network are ignored, as if the system were closed. Each mobile switching center carries 50,000 busy-hour calls, and the probability of blocking any call is 0.01. The average holding time per call is 120 seconds. The mobile-to-land calling rate is 25,000 calls, with all calls for each mobile switching center running through the cellular gateway to the various PSTN point-of-presence switches.

The land-to-mobile calling rate is 22,000 calls, with all calls for each mobile switching center running through the cellular gateway from the various PSTN point-of-presence switches to each of the six mobile switching centers. Of the 22,000 busy-hour calls originally destined for each mobile switching center, one-third (7,333) are redirected by the cellular gateway to another mobile switching center without using any trunking facilities between the cellular gateway and the original mobile switching center. An additional one-third are redirected by the cellular gateway to its announcements using trunking facilities between the cellular gateway and the mobile switching center for only 5 to 10 seconds. Therefore, 14,667 calls are not routed to the originally destined mobile switching center. Each mobile switching center does receive an average of 7,333 redirected calls from other mobile switching centers through the cellular gateway.

The mobile-to-mobile calling rate is 3,000 calls. One-sixth (500) of the calls are terminated in the originating mobile switching center; the remaining 2,500 calls to and from each mobile switching center are routed through the cellular gateway to the other mobile switching centers. Of the 2,500 calls originally destined for each mobile switching center, one-third (833) are redirected to another mobile switching center without using any trunking facilities between the cellular gateway and the original mobile switching center. An additional one-third (834) are redirected to announcements at the cellular gateway using almost no trunking facilities between the cellular gateway and the originally destined mobile switching center. Therefore, 1,667 calls are not routed to the originally destined mobile switching center. Each mobile switching cen-

Table I. Sample network with/without a cellular gateway

	Without a cellular gateway	With a cellular gateway
Busy-hour calls per mobile switching center	102,220	43,832
Trunk routes	48	14
Trunks per mobile switching center	3,718	1,501
Trunks per cellular gateway	Not applicable	14,201
PSTN trunks	10,008	9,840

ter receives an average of 833 redirected calls from other mobile switching centers through the cellular gateway.

As Figure 4 shows, the cellular gateway is equipped with 14,201 trunks, of which 9,840 are PSTN trunks. Each mobile switching center has 1,501 trunks, all connected to the cellular gateway, and the busy-hour calls per mobile switching center total 43,832. The number of trunks was calculated using the Erlang B distribution[1] with 0.01 probability of blocking.

Sample Network Results. Using a cellular gateway saves network resources in several ways, as Table I shows. The number of PSTN trunks is decreased, and the number of PSTN interface points is increased from two to eight per mobile switching center. The cost of PSTN connections is difficult to control because these connections are charged to the cellular service operator by the PSTN operator. As a result, any configuration that can lower this cost is valuable. The number of trunks and call load on each mobile switching center is reduced by about 60 percent. This offloading of tandem calls from specialized mobile switching centers allows the mobile switching centers to handle more mobile calls. The total number of trunks in the network increased slightly, as is the case whenever an extra switching point is added to the trunking path.

Introducing a cellular gateway into the cellular network also simplifies network facilities and routing plans, decreasing the number of trunk routes from 48 to 14. Reducing the number of trunk routes allows such savings as negotiating fewer rights-of-way and installing fewer cables. If new mobile switching centers are added, trunks are also added from the cellular gateway to the mobile switching centers, and from the cellular gateway to the PSTN interface. No new trunks or trunk routes are needed between the mobile switching centers.

Cellular gateways support centralized announcements, saving administrative overhead and equipment. The signal transfer point capability also simplifies the signaling network and saves equipment and facilities used for the MAP signaling data links.

This is a simplified example, but it shows the savings that a cellular gateway can introduce into a medium-sized network. As the network grows beyond six mobile switching centers, the advantages of the cellular gateway increase exponentially.

Cellular Gateway and GSM

The advantages of the cellular gateway are somewhat diminished for GSM networks. For unanswered mobile calls, the GSM standards do not provide for a redirection (also known as a *dropback*) to the cellular gateway—the announcement will take place at the *visited* mobile switching center, or the call will be forwarded from the *visited* mobile switching center. (In AMPS networks, the call is typically redirected by the cellular gateway.) This leads to a slightly higher usage of trunks.

However, GSM networks would still benefit from the hierarchical structure of cellular gateways: mobile switching centers can still be used more efficiently, and network management becomes easier. In addition, GSM phase 2+, the next version of the GSM standard, will standardize "optimal routing"—the ability to provide announcements and redirections at the cellular gateway. When this becomes available, the GSM cellular gateway will have the same benefits as AMPS gateways.

Summary

The cellular gateway switch, with an integrated signal transfer point, meets a clear, strong set of needs in large cellular networks. It provides efficient ways to address the required intelligence of locating called mobile subscribers, while reducing trunking requirements and collecting signaling links into a star configuration. It also saves total network resources by centralizing other functions such as recorded announcements for calls directed to inactive subscribers. As networks grow, the benefits will increase dramatically.

References

1. R. F. Rey, technical editor, *Engineering and Operations in the Bell System*, AT&T Bell Laboratories, Murray Hill, New Jersey, 1983.
2. American National Standards Institute (ANSI), *T1.111–1988, Signaling System 7—Message Transfer Part*, New York, New York, 1988.
3. American National Standards Institute (ANSI), *T1.112–1988, Signaling System 7—Signaling Connection Control Part*, New York, New York, 1988.
4. American National Standards Institute (ANSI), *T1.114–1988, Signaling System 7—Transaction Capability Application Part*, New York, New York, 1988.
5. International Telecommunications Union (ITU) Blue Book, *Specifications of Signalling System No. 7*, Volume VI—Fascicle VI.7, November 1988.

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