Master's Thesis

Performance Analysis of a Hybrid Cellular Satellite System:
Hybrid Cellular Satellite Handoffs

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ABSTRACT

Title of Thesis: Performance Analysis of a Hybrid Cellular Satellite System:
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As technological advances are made in the world, communication needs tend to extend with the technology available. Mobile communications has potential for very rapid growth. Many companies are participating in ventures, experiments, and developments that will expand mobile communications services globally. At the University of Maryland, Center for Satellite and Hybrid Communications, a component of Institute for Systems Research, through research these efforts are being facilitated, particularly in the area of Hybrid Cellular-Satellite Communication Networks. This paper discusses progress made in cellular systems, satellite systems, and the networking between them. The functionality of the cellular system and the satellite system is explained, followed by a description of a simulation study involving the hand-off aspect between the cellular and satellite systems. Within the description of the simulation study, the system roles and relationships are described. The simulation study is specifically for monitoring the performance and operation of the Cellular Radio Telecommunication Intersystem Operations IS-41.2-B protocol, used for handoffs in cellular systems, in a hybrid system environment. The main performance issue at hand is the delay to setup a call handoff. The study serves also for developing a model in which a hybrid network intersystem operation can be studied. Final results show the types of analysis that the model can be used to determine.

Performance Analysis of a Hybrid Cellular Satellite System:
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by

Molly Meredith Ramona Bryson

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of the University of Maryland in partial fulfillment
of the requirements for the degree of
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Advisory Committee:

Professor John S. Baras, Chairman/Advisor
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Professor Steven Marcus

DEDICATION

I would like to dedicate my thesis to my mother,

Cecilia Bryson,

my fiance, Fred M. Dorsey Jr. and his father,

Fred Dorsey Sr. for their continued support

throughout my graduate studies and thesis preparation

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Chapter 1

Introduction

Since the advent of cellular systems, they have had several problems limiting the growth of the systems. One of the main problems has been insufficient bandwidth to accommodate the system needs, therefore, not allowing the cellular system to expand with the demand of its clientele. With the customers to whom service was able to be provided for, there was still other limitations. Users were given limited coverage, which allowed for services to be possible only in a limited region.

With the growth of cellular systems came methods for making service possible while dealing with the limitations. One method included frequency reuse, which allowed the use of the same frequency on two or more channels a certain distance apart. This methodology and others will be further discussed in chapter 2. This method ultimately allowed the capability for having more channels to service more customers.

These solutions, however, did not solve all cellular problems. Today, we see that cellular systems can communicate among each other provided that they meet certain specifications. With this communication, there is a greater region of coverage for mobile users. With lots of the new features of cellular systems, users are provided with similar functions to those of the public telephone system. However, the increased region of coverage is limited to urban areas.

With the introduction of satellite systems into the terrestrial market, communications have been expanded to cover the Continental United States (CONUS) or even worldwide. Satellite systems themselves have their own inconveniences and limitations. Much like cellular systems, bandwidth usage is a problem for satellite systems. Users are most concerned with the cost of using satellite systems. The cost on a satellite system channel often tends to be higher than cellular system channel.

Many companies today are proposing satellite systems that will either aid cellular networks or even compete with them for providing mobile telephone services. These systems vary in size, type and number of satellites, frequencies and other system functions. If these ventures are successful, the world will have improved communication. This will be useful to many third world nations that lack ability to communicate due technical reasons.

The motivation for this research evolves from the need to pursue methods for improving personal communication in the CONUS and world wide. The particular approach used in this research is the use of cellular and satellite system resources incorporated together to provide extended mobile telephone services. In doing so, methods for expanding communication across cellular network are studied between the cellular and satellite systems. The model of this process is explained later in chapter 3. Through the use of simulation, evaluations are conducted to measure the probability of completing an intersystem handoff between a cellular and satellite system, along with the handoff delay experienced by those mobile users that completed an intersystem handoff.

1.1 Systems Engineering Approach

The system engineering approach is a methodology geared to the development of a wide range of projects. The approach involves doing extensive background research, feasibility analysis and other types of forecasting prior to beginning the project. The use of this knowledge become necessary during the project development process. The systems approach also covers the full length of a project for conceptions to implementation and maintenance. The role of the system engineer is to use the tools provided and knowledge gained on the subject matter to guide them through the project from conception to implementation. Appendix C shows the systems engineering process and different sub process involved. This thesis follows a similar format to the systems approach by presenting background research, conception, project definition, design, implementation and analysis for a hybrid network model. The hybrid network model is used to analyze several configurations of the hybrid cellular satellite system. Finally, the results from the model is presented.

1.2 Overview

The description, elements and operation of cellular, satellite and both systems networked together as a hybrid system are the main focus of the study. In Chapter 2, a system overview on the functionality and operation of cellular systems, satellite systems and hybrid cellular satellite systems is discussed. The information found in these fields is very extensive. This chapter serves as an introduction for people who are not familiar with these systems. It also serves as a review of the concepts in each of these systems for people who are familiar with the systems.

Chapter 3 addresses the basic methodologies used in research and development of the project. A full description of the hybrid system and elements to be modeled is given. Systems design and modeling tool tradeoff analysis is performed for the selection of an appropriate tool to conduct simulation studies.

The simulation models designed to describe the hybrid network in the BONeS Simulator are described in Chapter 4. This chapter describes all experiment processes performed. In the study the main parameters for intersystem handoffs between cellular and satellites systems are studied. A performance analysis has been done to determine the probability for completing an intersystem handoff and the mean delay experienced by those users completing an intersystem handoff. A summary of the all results from the experiments is presented in this chapter. Chapter 5 summarizes the entire thesis study with recommendations on future research growth and challenges in the area of hybrid cellular satellite communications.

Chapter 2

Literature Review

A review of literature pertaining to cellular systems, satellite systems and hybrid systems can be broken into two main categories:

- System Components and Functionality
- System Operation

System components reflect the elements that are in the network and comprise the entire system. The way each component functions contributes to the system operation. Each component adds its own complexity at the same time aiding in completing the service objective of the system.

These two categories are essential in understanding the system or any limitations the system may have. The significant factors, operation, components and limitations are discussed in this chapter. This chapter serves as introduction for readers who are unfamiliar with the three systems and as a review for readers who are familiar with the three systems.

2.1 Cellular System Overview

Cellular systems saw their conception in the 1940's. The concept of cellular radio stemmed from radio broadcasting which was used by police in the early 1920's. Extensive planning and development took place in the 1960's and the first analog system was deployed in the 1980's. With the deployment in the 1980's, the early stages of mobile communications was a slow booming business.

In today's market, mobile telephony is looked upon as one of the places for rapid investment and growth. However like any other business, mobile telephony has suffered its share of ups and downs due to several major reasons such as:

- o Multipath Fading
- o Co-Channel Interference
- o Limited System Bandwidth and Capacity

In order to understand why some of these difficulties arise, a full overview of cellular systems and their operational environment will now be discussed. Some of the problems mentioned above will be examined in greater depth.

2.1.1 Cellular System Components

The concept of cellular mobile systems developed with the advent of mobile radio systems. The cellular system consists of three main components: Mobile Switching Center (MSC) , Cell Site (Base Station Equipment), and Mobile User Equipment. The three components work together to provide cellular service. The system can be visualized functionally as seen in figure 1(Walker, 1988).

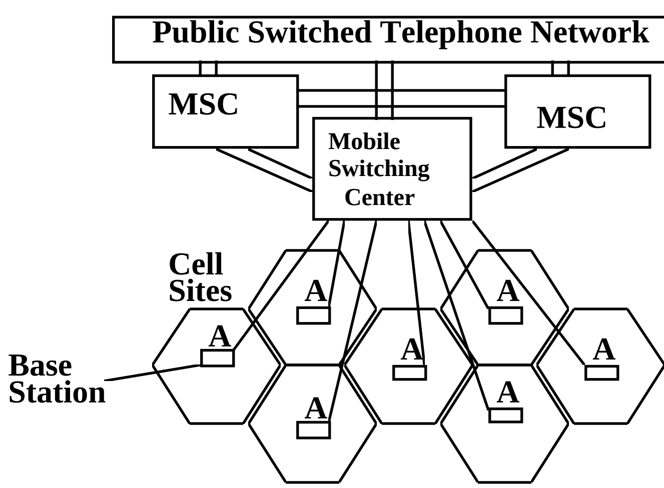
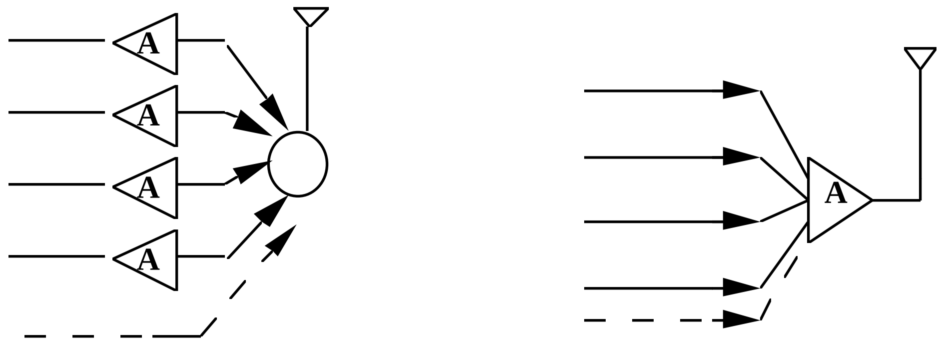


Figure 1. Cellular System Structure

The MSC coordinates all cellular system activities between mobile users, cell sites and the Public Switched Telephone Network (PSTN). These activities include establishing connections, assigning channels, verification of users and handoff coordination to name a few. These activities and others will be discussed in further detail later in this chapter. The MSC incorporates the features of a regular telephone switching center with added capabilities to handle the activities throughout the system. The MSC software controls the necessary signaling needed to perform the activities which are sent to the cell sites and the mobile users. Cellular systems operate in the frequency region of 825-890 MHz with a difference of 45 MHz between transmitting and receiving frequencies. In the cellular system, the MSC provides connection to the PSTN via land lines and to the cells sites and other MSC's via land lines or microwave links.

The cell site serves as the location for the base station equipment. The base station equipment consists of antenna (about 30 to 91 m. or 100 to 300 ft. high), transmitters, receivers, combiners and a power supply. The cell site also has a computer processor equipped with software to handle the necessary functions it has to perform. The cell site has 16 about channels, 1 control channel for signaling and 15 voice channels. These channels are usually full duplex allowing two way communications and having two different frequencies ranges, one for transmitting and one for receiving. At the base station, it is possible to have an amplifier for each channel that feeds into a single combiner for a transmitting antenna or a single amplifier for all channels that use a single transmitting antenna. The first scenario is known as a channelized scheme and the latter scenario is known as a frequency division multiplexed scheme as seen in figure 2 (Williams, 1986). The dashed lines in each scheme are control channels.



(a) Channelized Scheme **(b) Multiplexed Scheme**

Figure 2. Channel Schemes

The base station antenna has several set ups, the most common being an omnidirectional combination of antennas, with two antennas for receiving and one for transmitting. Depending on the placement of the antennas, cells are considered center excited, edge excited, or umbrella cells. The center excited cells use the omnidirectional configuration discussed above. Edge excited cells use directional antennas placed in the corner of a cell site, which is best for co-channel interference. The umbrella cells use tilted beam pattern antennas that provide a shadow effect of the cell site area. The amplifier(s) in each scheme provide enough gain to each channel frequency. The combiner then serves the function of combining all individual channels and sending them to the transmitting antenna. The receivers at the base station receive the incoming electromagnetic signals and convert them to perceptible forms.

The mobile user unit equipment consist mainly of an antenna, transceiver circuitry, diplexer, feedline with handset. The handset consists of a microphone, an earphone, a liquid crystal display and an array of buttons. The transceiver circuitry has the main functions of frequency synthesizing, intermediate frequencies, and power amplifier. Within the mobile unit there are also demodulator and modulator units. These functional components can be seen in figure 3 (Walker, 1991). There are three main types of mobile unit antennas: roof mounted whips, roof mounted gain, and glass mounted gain antennas. The roof mounted whips are the least used antennas because of the low gain that is achievable. The roof mounted gain provides better service, however, the mounting usually requires the user to drill a hole into the roof top of the vehicle. Therefore, this is the least popular among consumers. The most common antenna used is the glass mounted gain. The antenna is coupled to the transceiver through the glass with the pad on the outside and the coupler on the inside. There are also portable mobile units available with built in circuitry, an antenna and rechargeable power batteries.

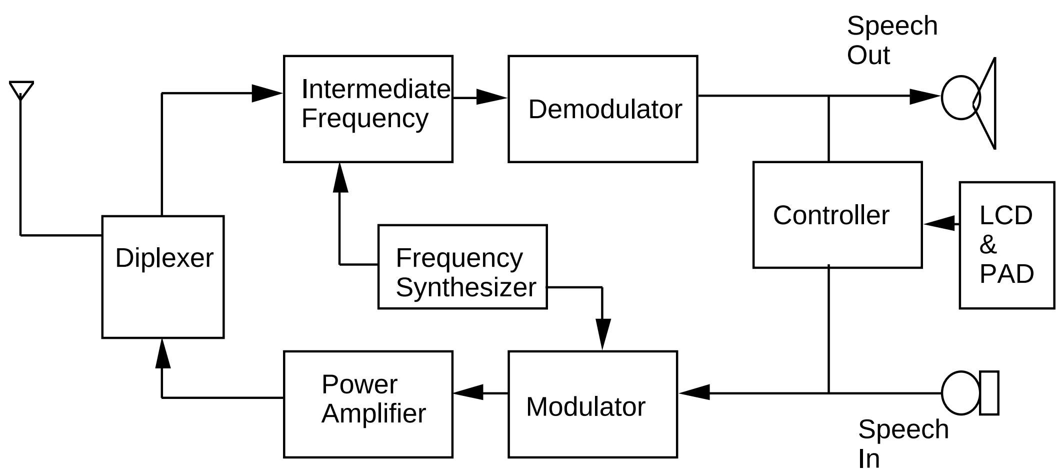


Figure 3. Mobile Equipment

2.1.2 Cellular System Operation

The components discussed in section 2.1.1 are the main components of the cellular system. These components must be configured in such a way as to provide the necessary communication mediums. There are several approaches to this task. A popular approach is to determine the nominal amount of customers, which in turn dictates the amount of cell sites necessary to provide service above a certain blocking principle. Therefore, by determining the average number of customers, the coverage area can be determined. After determining the coverage area, other factors come into consideration such as cell splitting , frequency reuse, and access schemes to control channel access.

In determining a coverage area, there are two main factors to be considered: the size of the cell sites and the call blockage. The size of the cell site is dependent on the amount of traffic for the proposed area. The call blockage is based on the amount of calls completed vs. the amount of calls attempted. This blockage factor is usually kept below 2% for best customer satisfaction. The following formula is used to calculate this blockage known as the Erlang B formula:

$$P = \frac{A^n / n!}{\sum_{x=0}^{n} A^x / x!}$$

where:

A = traffic density

P = Probability that calls will be lost (blocked)

n = number of channels

x = variable representing the number of busy channels.

Assuming that there are 30,000 potential users per hour and 80 percent of those users make a call in a hour. This equates to 24,000 calls per hour. The average length of a cellular call, as determined by CTIA survey, is 1.75 minutes. If in this scenario a possible load of 2400 calls per hour, it is possible to compute the probable load:

(2400 * 1.75)/ 60 = 70 erlangs.

With this calculation, use of an Erlang table and the 2% blockage limit, 82 channels will be necessary. Increasing to 83 will allow for some buffer space. Since each cell site can accommodate 16 channels, 83/16 = 5.1875. No more than 6 cells will be required to handle the 2400 calls per hour.

Once the amount of cells is determined, the next key to the cellular operation is cell splitting and frequency reuse. These situations are directly dependent on each other. Cell splitting and frequency reuse are parallel methods for increasing service and minimizing interference. Cell splitting allows for enormous gain when used with frequency reuse. Cell splitting occurs when large radius cells are divided into smaller cells of equal radii. However, cell splitting is not always the best solution because the cost of the base station remains the same for large or small cells. Some would argue that the customer population should be sufficient to cover this cost, while others would say it is not an economical benefit.

Frequency reuse is the ability to reuse the same frequency in cells that are a certain distance apart. This is possible as long as the distance is great enough to avoid interference or degradation of service. If the same frequencies are used on channels in adjacent cells the energy from the carrier spills over. The interference makes it impossible to communicate effectively. This is called adjacent channel interferences. The other type of interference is co-channel interference, which occurs when two mobiles are operating at the same frequency without enough distance between them. This distance is referred to as the frequency reuse factor a = D/R, where D is the distance between the two cells and R is the radius of the cells. At the MSC, the manner in which channels are accessed is controlled. The most common access control methods found in a cellular architecture are Frequency Division Multiple Access (FDMA), Time Division Multiple Access (TDMA), and Code Division Multiple Access (CDMA). These schemes have various cost and other system tradeoffs associated with their implementation .

Using FDMA to control multiple access by mobile users to a control channel within each cell is done on a demand basis. The demand for use of each channel is a combination of mobile users trying to initiate call or receiving calls. Each frequency carries a single call at a time which is known as single circuit per carrier. Mobile users may be assigned to any channel randomly. Figure 4 , shows a view of a FDMA system (Calhoun, 1988).

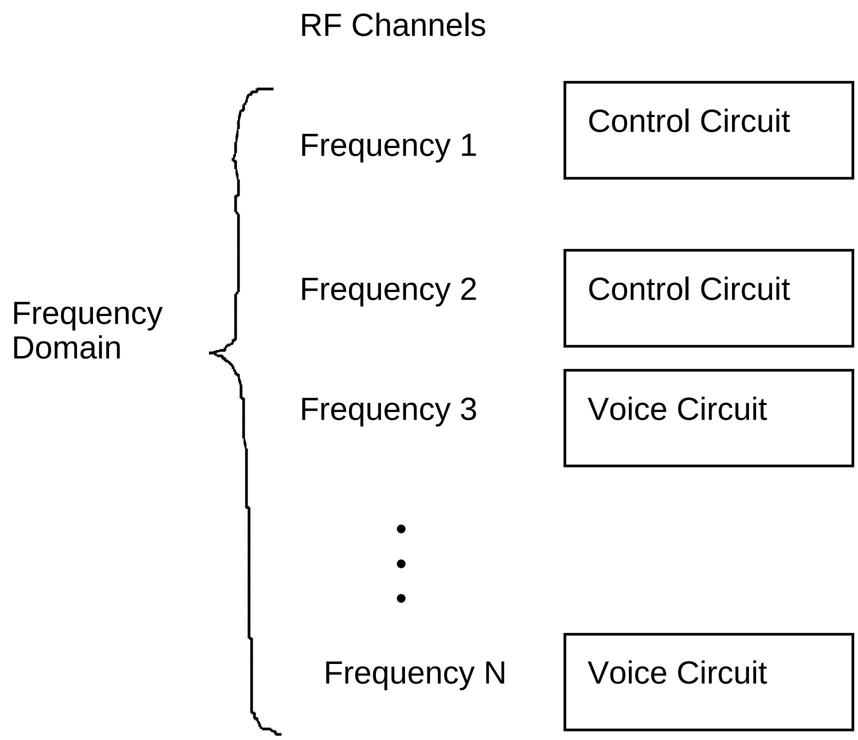


Figure 4. FDMA Cellular System Architecture

FDMA architecture provides continuous and simultaneous transmissions and uses relatively narrower bandwidth channels compared to other systems. Table 1 contains the advantages and disadvantages of a FDMA system (Calhoun, 1988).

Advantages	Disadvantages
Less Complex Mobile Units	Duplexer necessary
Lower Transmission Overhead	Handoff Complexity
	Higher Overall System cost

Table 1. Advantages and Disadvantages of FDMA

" In TDMA, each radio channel carries a number of telephone trunk circuits which are multiplexed" (Calhoun, 1988). Since the channels are multiplexed, it allows TDMA systems to have several (anywhere from 2 to 8) time slots on each channel depending upon implementation. The manner in which the mobile user transmits is known as a " buffer and burst " transmission . Due to this mode of transmission, transmissions are not permitted on a continuous basis, making transmissions of data difficult on a TDMA system. Figure 5 is an example of a four circuit per channel TDMA Architecture (Calhoun, 1988). The bandwidth on each channel can range anywhere from 20 to 300 KHz. Table 2 contains the advantages and disadvantages related to TDMA architecture as compared to FDMA and CDMA systems (Calhoun, 1988).

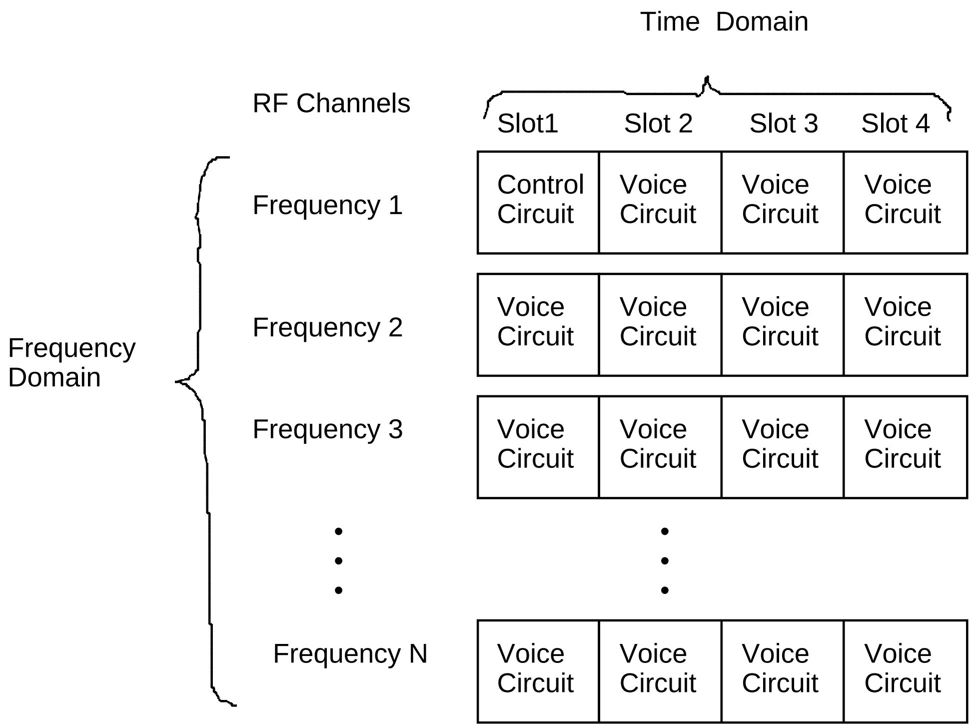


Figure 5. TDMA Cellular System Architecture

Advantages	**Disadvantages**
Multiple Carriers per Channel	Higher Mobile Unit Complexity
Less Handoff Complexity	Higher Transmission Overhead
Lower Overall System cost	

Table 2. Advantages and Disadvantages of TDMA

Using CDMA to control channel access in a cellular system is one of the newer techniques. CDMA, also known as Spread Spectrum, involves a randomized code that is given to each mobile. This randomized code is used to determine a pattern for frequency hopping. A CDMA system can be envisioned as seen in Figure 6 (Calhoun, 1988). These schemes are not the only schemes that can be used in a cellular architecture. One may refer to (Calhoun, 1988) for additional information on access control methods.

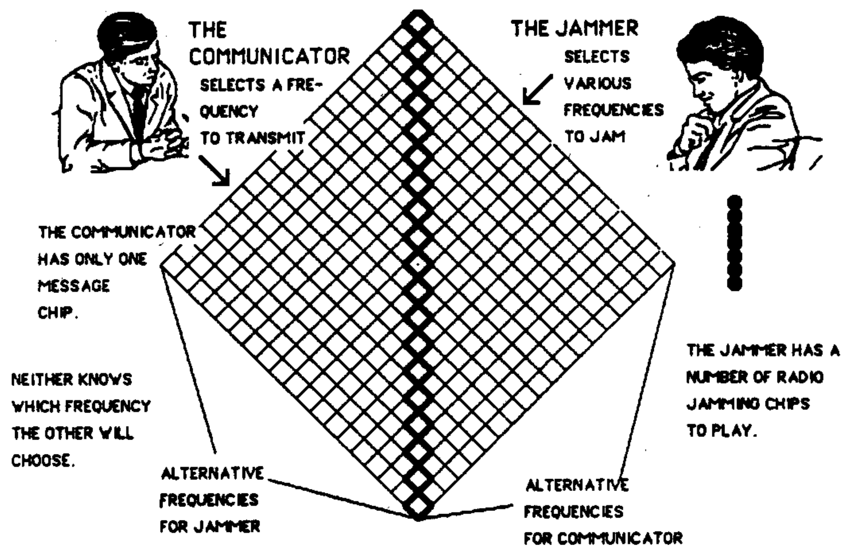


Figure 6. CDMA Cellular System Architecture

Once a scheme is selected, this will play an important role in the services the system will provide. These services vary across systems. The basic services necessary for mobile telephony provided by any system are:

- Registration
- Call Setups
- Call Termination
- Call Release
- Handoffs

Registration is the process of sending a signal to certify identity and location of the mobile unit in the cellular system. This is done by scanning for a control channel, selecting the strongest signal and then sending registration signals. This process aids in the verification of the mobile user and unit equipment. This area has become an area for network security, due to the difficulty with hackers scrambling codes and mobile identification numbers to infiltrate the cellular network.

A call setup is the procedure for establishing a connection initiated by mobile user to the Public Switched Telephone Network or to another mobile user. This procedure can be seen in Figure 7. Provided that the mobile unit is on, the receiver will monitor the control channel for an available channel and a quality signal. If this is possible, the receiver will lock on to the frequency of the available channel. When the mobile user wishes to establish a call, the mobile user enters the digits into the mobile units and pushes the send button. The average mobile user will double check the number entered to be sure that it is valid prior to pressing the send button. The send button in turn causes the transmitter to transmit a service request to the base station. The base station forwards the request to the MSC. The MSC then selects an available voice channel to establish the connection to the PSTN or mobile unit. The selected channel is returned to the base station which forwards the information to the mobile unit. The base station will then transmit a Supervisory Audio Tone (SAT) on the selected channel for the mobile to tune in on. Once the mobile is tuned in an acknowledgment to the SAT is returned to notify the base station that mobile unit is currently tuned to the current channel. Upon receipt of the SAT acknowledgment the base station notifies the MSC that the mobile unit is "OFF HOOK", meaning the receiver is lifted and tuned to the correct channel. Simultaneously, since the MSC has received the number for the party being called, the MSC will set up the connection through PSTN or to a mobile unit through its network.

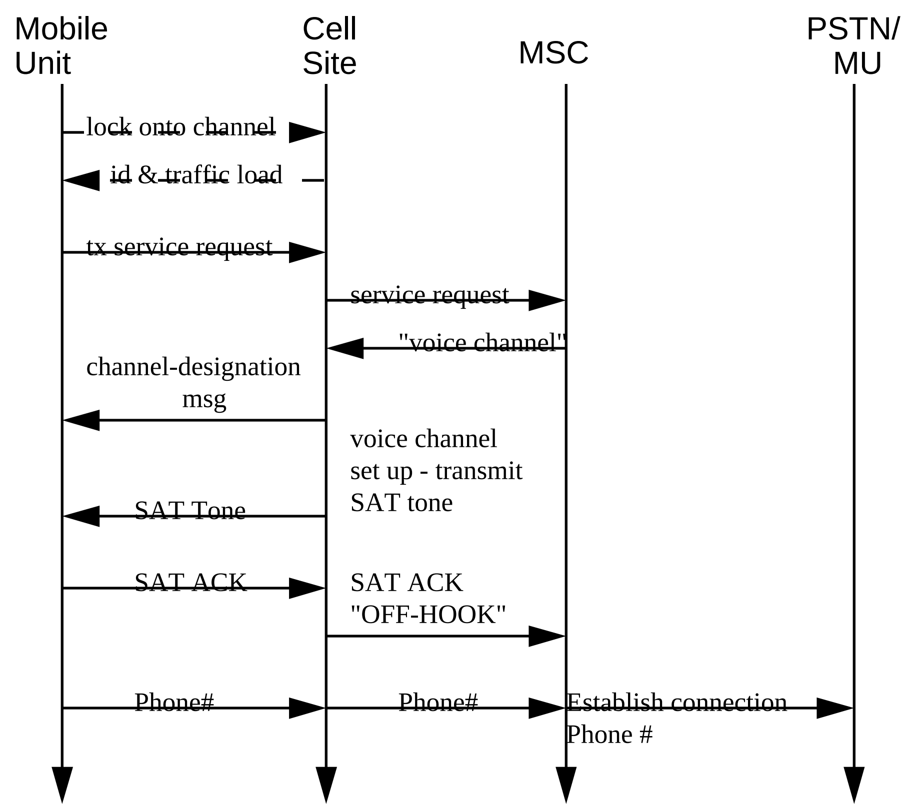


Figure 7. Mobile Call Setup

The scenario in figure 7 is a best case scenario. Complications may arise if there is not an available voice channel with a quality signal , then the receiver would rescan for another control channel. If all the control channels are busy, the receiver would get a busy signal in return. Finally, if a channel is not available to establish the call the mobile user will be considered blocked.

The next service is call termination. This process is the opposite of a call setup. Call termination is delivering a call to a mobile unit within the mobile network. Although it is referred to as a termination, this is true only in the sense of completing the call by reaching the party being called. Figure 8 shows the process of a call termination. If the call is coming from the PSTN or from another mobile unit, the MSC that the mobile unit is registered on would receive an incoming call message. This message contains a telephone number, that is converted to a mobile identification number (MIN). The MSC then sends out a page request to the base station where the mobile unit is located. The base station will then forward the page to the mobile unit. Upon recognition of the page request, the mobile unit returns a page request acknowledgment to the base station, which is forwarded onto the MSC. The MSC then assigns a voice channel for which the call will be connected and forwards the information to the base station. Much like in a call setup, the base station forwards the channel information to the mobile along with a SAT tone. The mobile returns a SAT acknowledgment and waits for the incoming call signal, usually ringing. The base station forwards the SAT Acknowledgment to the MSC, which allows the MSC to know that the connection has been set up. The MSC will then forward a ringing tone to the PSTN or the mobile unit from where the call was established. The voice connection is then completely established when the mobile unit answers the call.

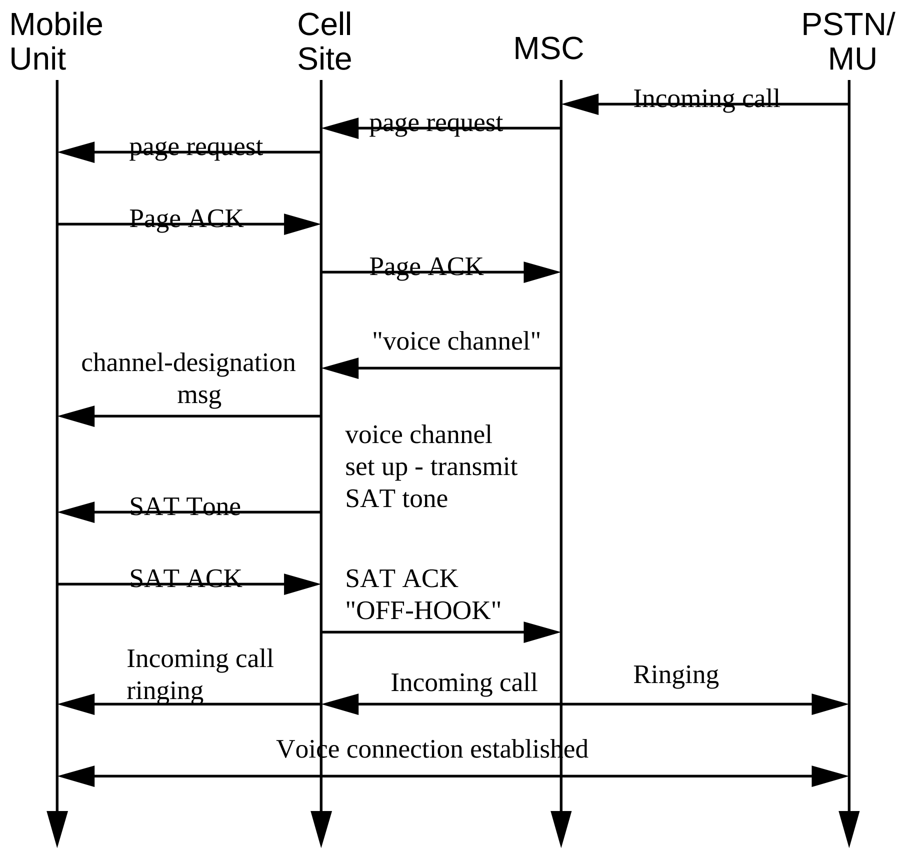


Figure 8. Mobile Call Termination

Call Release, known more commonly as hanging up the phone, is the procedure of disconnecting all call connections that were established. In the background, the mobile equipment will transmit a tone for approximately 1.8 seconds after the receiver has been hung up. Then the mobile unit leaves the channels after this period has expired. This tone notifies the base station and the MSC that the mobile has completed the call. The MSC marks the mobile unit as "ON HOOK" and sets up the proper billing for the call. The mobile unit will proceed to rescan for another control channel. Figure 9 shows the procedure for a call release.

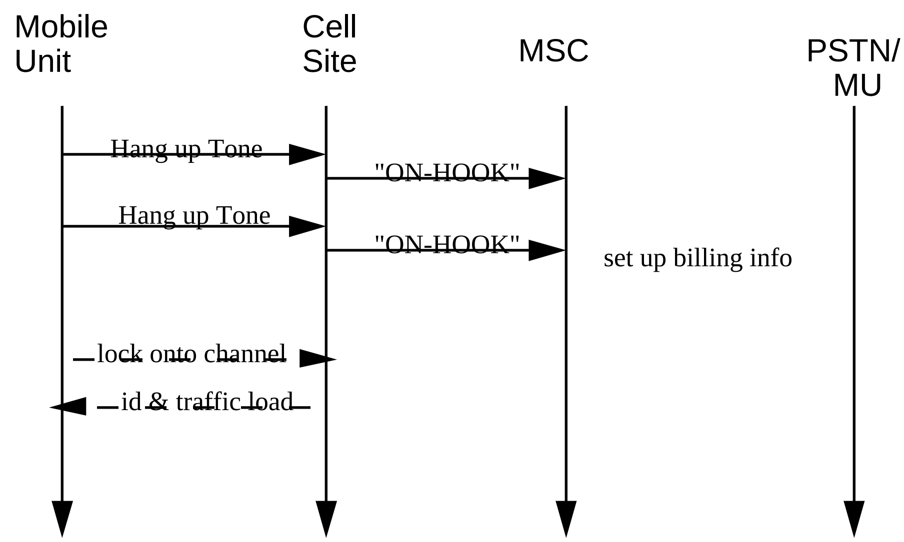


Figure 9. Mobile Call Release

During the call, the mobile user will probably move throughout several cells. As the mobile user travels from cell to cell within the cellular network, the call will be transferred between base stations within the network. This process is known as handoffs. The process is initiated when the signal strength of the mobile users call fall below a certain threshold level, usually around 32 dB. The base station then notifies the MSC that a call handoff will be necessary. The MSC then sends out a handoff measurement request to the adjacent base stations for a measurement of the strength on a specific channel. In return, all the base stations send the signal strength level on the channel. The MSC then goes through a selection process to select the base station with the best signal level. Once the base station is selected, it is notified of the call transfer that is necessary and the channel it will be on. The MSC also forwards the same information to the base station that is currently carrying the call, which forwards the information about the new channel to the mobile unit. Once the mobile is tuned to the new channel the process is completed. This process may happen several times within a call due to the mobile user's movement. Since the handoff process is initiated by a drop in signal strength, base stations generally look for a consistent pattern of decrease in the signal strength around 10 dB per decade. The assumption made by the base station monitoring this pattern is that the mobile unit is moving toward the boundary of the cell. Figure 10 shows the process of a call handoff within the coverage of a single MSC.

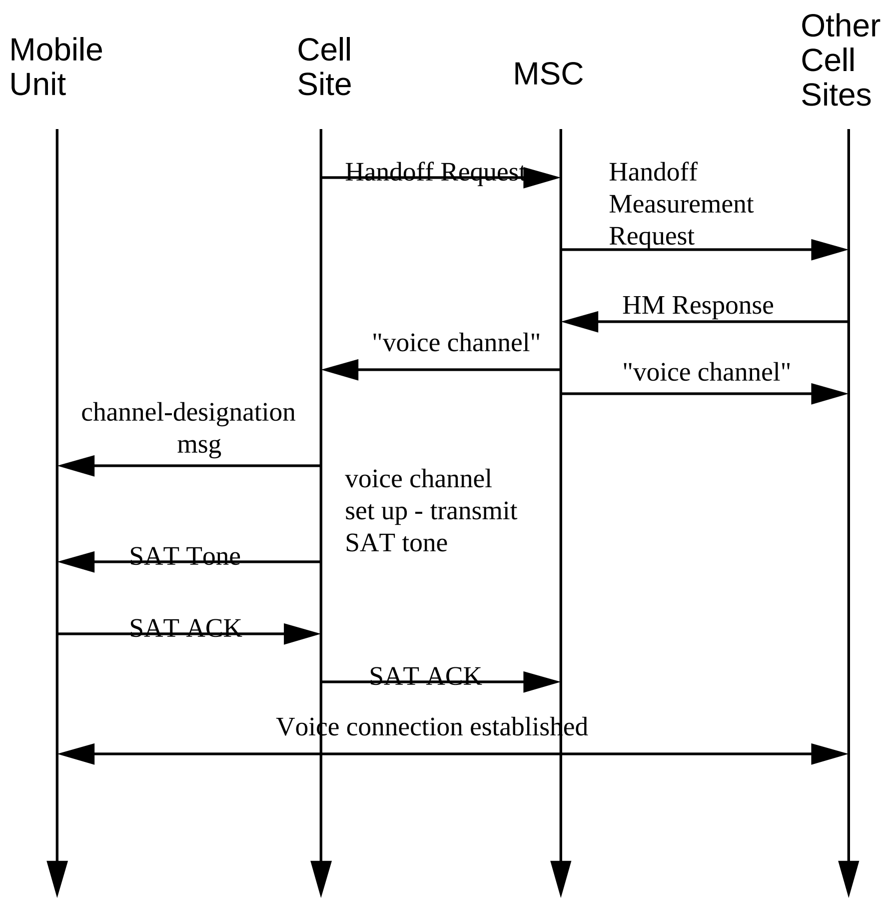


Figure 10. Mobile Call Handoff

Within the network, several things affect a call and its signal strength. The most common of these problems include:

- Propagation Path Loss
- Co-Channel Interference
- Multipath Fading
- Raleigh Fading
- Doppler Shifts

Propagation path loss is the dropping of the signal level due to the terrain and man made noise (buildings, bridges, etc.). The main drivers of propagation path loss are the distance of the mobile unit from the base station and the frequency of the channel. Co-channel interference involves disturbances occurring from two mobile units operating on the same channel. Another type of channel interference is adjacent channel interference, which occurs when energy from a carrier spills over into another carrier. Solutions to deal with channel interference involve a method of channel schemes either multiplexed or channelized, which was previously discussed. Multipath Fading involves disturbances due to the multiple paths of the signals between the transmitter and the receiver as a result of the terrain and man-made noise. Raleigh Fading are rapid fluctuations in the signal strength that occur in statistical distribution known as Raleigh. Finally, Doppler Shifts are variations in the frequency of the received signal caused by the relative motion of the mobile unit. These problem all bear an effect on the signal strength of the mobile unit.

2.2 Satellite System Overview

Satellite systems saw their conception as early as the 1950's. Much like cellular systems, satellite systems initially had slow growth. Satellite systems began to serve for purposes of communication as early as the 1960's. The first communication satellite was the EARLY BIRD from the International Telecommunications Satellite Organization (INTELSAT). This launch shed some light on the power of satellites. Early Bird was followed by the launch of 5 more satellites from INTELSAT in a 5 year period. However, the cost of using satellite resources was very high. The cost of satellite usage dropped significantly with the realization that in order to compete with terrestrial systems, cost would need to be reduced.

Many satellites followed the INTELSAT generation, including experimental testing for mobile satellite systems in the 1960's and early 1970's. The first mobile satellite service was established in 1976 by the US Communication Satellite Corporation (COMSAT) used for experimental purposes. This system was followed by International Maritime Satellite Organization (INMARSAT) in 1979. It provided mainly maritime services but is now expanding the horizon to include aeronautical and land mobile services. The need to expand cellular systems has evolved and satellite systems are available as a solution for expansion into rural areas. Organizations are developing MSAT service for Canada and the United States to be operational in late 1994 and early 1995 respectively. MSAT systems will be operational in Australia in late 1993. This section focuses mainly on the fundamental elements and operation of mobile satellite services. Issues involving propagation, bandwidth and other related problems in the mobile satellite service area will be discussed.

2.2.1 Satellite System Components

Within the satellite system, there are two major segments, the ground segment and the space segment. These elements are comprised of parts that make the system complete and operational. The space segment consists of the launch vehicle and satellite components. The satellite components include the Attitude and Orbit Control Subsystem (AOCS), Telemetry, Tracking and Command (TTC), Power Subsystem (PS), Communication Subsystem (CS) and Antenna Systems (AS). The satellite components are shown in figure 11 (Ha, 1990). The ground segment, similar to the cellular systems, consists of mobile terminals, network control center and the hub station.

The AOCS serves to maintain accurate satellite and antenna positioning for the Attitude control subsystem and to remain in the correct orbital plane for the Orbit control system (Ha, 1990). The TTC consists of three subsystems: telemetry for monitoring all satellite subsystems for continuous transmission of information to the earth for determination of the satellite status; tracking for purposes of locating the current position of the satellite and command for executing orders received from the ground station on telemetry and tracking. The PS is used to supply the satellite subsystems with electrical power supply. The power is usually provided through the use of solar panels, cells or arrays. The CS consists of a communication antenna and a communication repeater that are used to provide the satellite coverage. The communication antenna serves as an interface between the hub station and various satellite subsystems during operations and the communication repeaters serve as an interconnection of many channelized transponders (Ha, 1990). Finally, the AS provides the coverage on the earth, for certain zones and geographical locations.

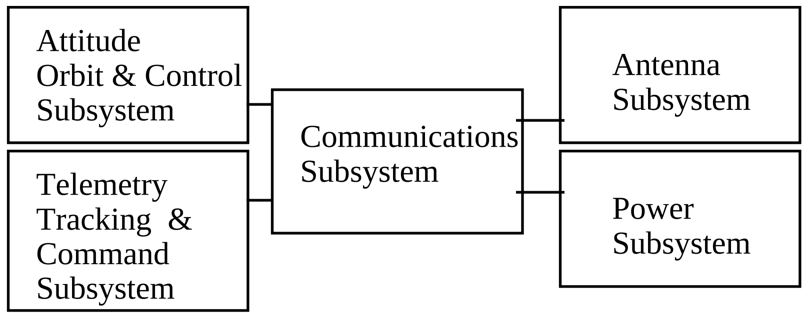


Figure 11. Satellite Components

The network control center monitors and directs the hub station traffic. The hub station is "any transmitting or receiving system that sends signals to or receives from a satellite" (Gordon, 1989). Figure 12 illustrates the components of a possible gateway hub station (Walker, 1991). The antenna of the hub station is the main means of transmitting and receiving signals, to and from the satellite. The amplifiers are used by the transmitters to increase the power of the signals being sent. The baseband equipment allows the hub station to communicate with the terrestrial network. The baseband equipment are used to modulate, demodulate and multiplex signals. The up and down converters are for translating signals from/to VHF frequencies to/from microwave carriers. The mobile units or terminals are very similar to mobile units in a cellular network with added convertors and amplifiers for dealing with the higher frequency ranges. The mobile terminal components are shown in Figure 13 (Walker, 1991).

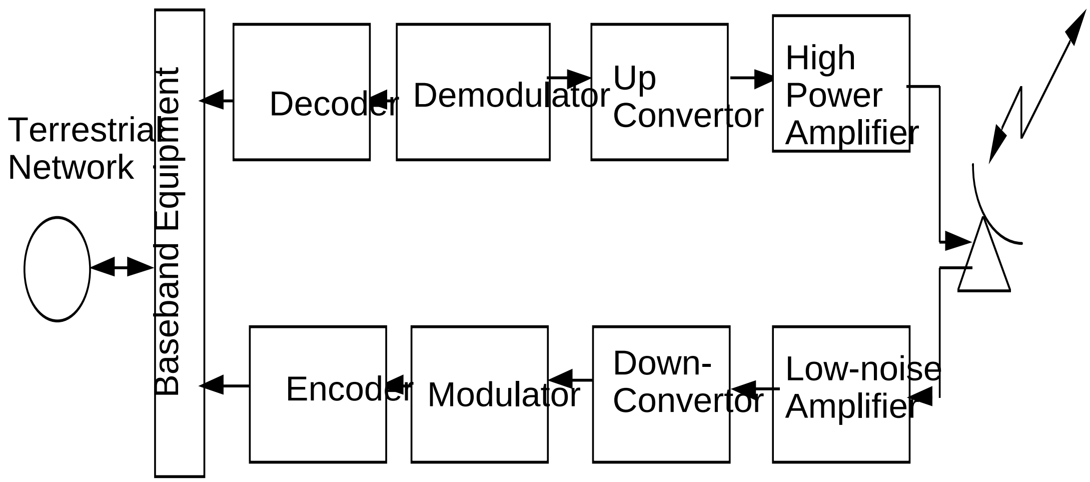


Figure 12. Gateway Hub Station

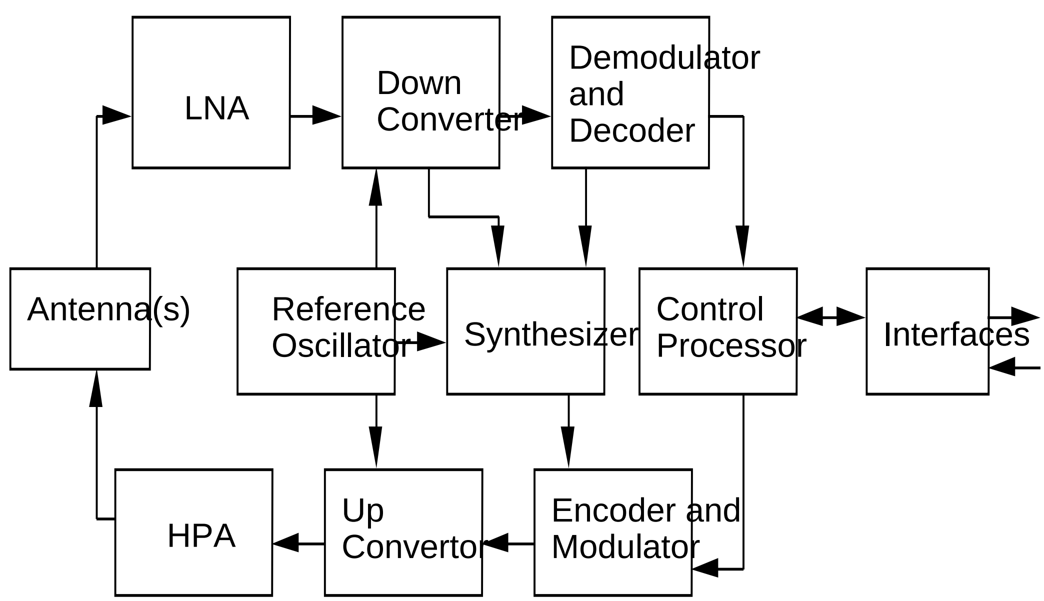


Figure 13. Satellite Mobile Terminal

2.2.2 Satellite System Operation

There are two methods of satellite operation: fixed satellite networks and mobile satellite networks. In a mobile network, a mobile terminal and antenna can be located almost anywhere, on a truck, ship, or building. The location of the antenna sometimes determines the size. In fixed satellite networks, antennas are usually located on the ground or on the roof tops of buildings and the stations are within the building. In mobile satellite networks, hub stations are located relative to the network control center in order to provide access to the satellite and terrestrial networks.

In the satellite network, the network control center has protocols that guide access to the satellite resources. Satellites are considered broadcast nodes; therefore multiple access protocols are necessary to control access. Some of these protocols are used in the cellular network.

The TDMA method is a scheme that uses time slots which are assigned to each user. During this slot, the user is free to broadcast, and the complete resource is controlled by the user. The time slots which are allocated to each user are preassigned. As time continues, the slot arrangements follow the preassigned pattern. "When a pattern is repeated this is referred to as a cycle or frame" (Rom, 1990). This can be seen in Figure 14.

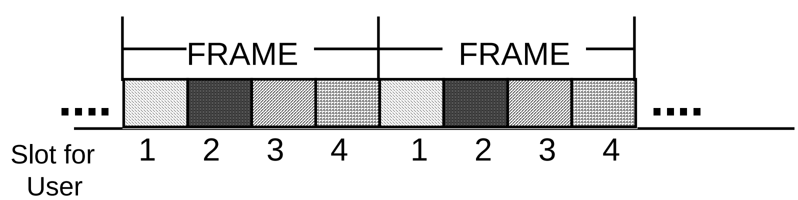


Figure 14. TDMA Satellite System Architecture

A modification of TDMA is that each user can be assigned a number of slots on which they can transmit within a frame. This is called Generalized TDMA. "For proper operation of a TDMA scheme, the users must be synchronized so that each one knows when and for how long he can transmit " (Rom, 1990). TDMA schemes are rarely used in a Mobile Satellite Network (MSAT) because too much power is necessary to operate the mobile terminal (Ha, 1990).

In FDMA the available bandwidth is divided into frequency bands. Each of these bands, allocated from the total bandwidth, are then assigned to each user. These allocation assignments are also done in a predetermined fashion. Unlike TDMA, FDMA does not require any synchronization of users. This is relevant to the fact that each user has its own frequency band, therefore allowing no interference or collision during transmission. FDMA can be seen in figure 15. The system can be modeled as M independent queues because of independent transmissions among users.

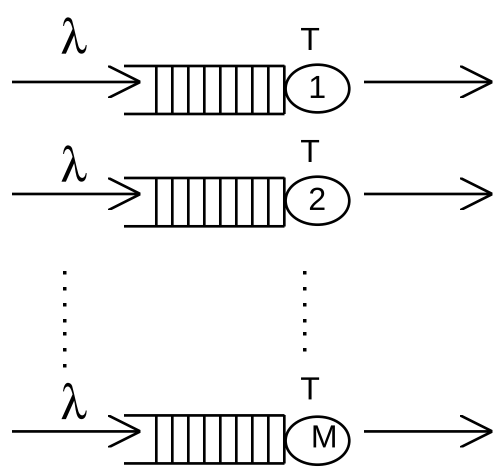


Figure 15. FDMA Satellite System Architecture

CDMA is another type of assignment technique, also known as the Spread Spectrum Multiple Access (SSMA). CDMA is sort of a split between TDMA and FDMA. CDMA provides each user with a partition of the total bandwidth and for a portion of the time. The partition of the bandwidth is called a specific code address wave form. "Information is transmitted by superimposing the code address wave form onto the address wave form and modulating the combined wave form onto the station carrier" (Gagliardi, 1984). This allows for only the receiving station to be able to demodulate with the proper address wave form. "The address wave forms tend to produce a carrier spectra over a relatively wide bandwidth" (Gagliardi, 1984). Due to this CDMA is often referred to SSMA. A CDMA system is shown in figure 16 (Gagliardi, 1984).

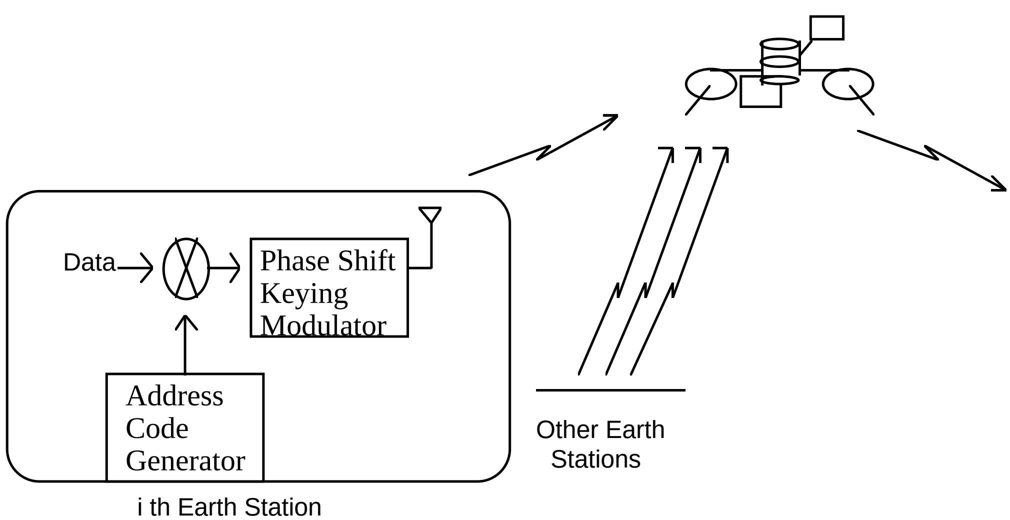


Figure 16. CDMA Satellite System Architecture

There are many other protocols that can be used for controlling satellite access. The network control center acts as an interface between the terrestrial networks and the satellite resources. Figure 17 shows a possible scenario for a mobile satellite network (Kumar, 1990).

MSAT systems operate in two frequency ranges known as L-band and Ku-band.

L-Band is used for mobile terminal to transmit to and receive from the satellite. The range for L-band is 1600 MHz. The band for receiving is 1530 - 1559 MHz and 1631.5 - 1660.5 MHz for transmission. Ku-Band is used for transmitting and receiving between the satellite and NCC. Ku-Band ranges around 13000 MHz, 10750 - 10950 and 13000 - 13250 MHz ranges are used for transmitting and receiving respectively. This can be seen in figure 17.

Call procedures on an MSAT system is similar to cellular in that all call setup and termination are handled under the control of the NCC. The following are call setup and termination procedures taken from (Ha, 1990):

"1. To establish call connection between the mobile terminals and the hub stations, the NCC employs signaling circuits in both L- and Ku-bands. Call requests by mobile terminals to the NCC is carried out via an L/Ku request channel using a random access technique. The NCC signals the called hub station and receives the hub station response on a Ku/Ku signaling circuit. After the called party answers, The NCC sets up a duplex satellite circuit between the mobile terminal and the hub station via a Ku/L assignment channel for the mobile terminal and the Ku/Ku signaling channel, mentioned above, for the hub station. The NCC monitors the call duration using the Ku/Ku signaling circuit.

2. Call request by the hub station to the NCC may be done via a Ku-band polling or TDMA signaling channel. The NCC signals the mobile terminal on a Ku/L

signaling circuit. When the mobile terminal acknowledges, the NCC assigns a duplex satellite circuit via the Ku/L assignment channel for the mobile terminals and the Ku/Ku signaling channel for the hub station."

Calculating the amount of satellite channels is also dependent on the expected traffic. With an average call holding time of 2 min. for mobile satellite terminal and possible load of 200 calls per hour:

(2000 * 2 min.)/60 = 66.7 erlangs per hour.

With a 2% blocking probability for telephony about 79 channels will be needed to support 67 erlangs of traffic. This calculation is taken from a basic Erlang table. Satellite channels are sometimes divided in 24 channel subbands, therefore 4 subbands would be necessary to support this traffic. With 4 - 24 channel subbands the resulting amount of channels is 96, which would have a blocking probability of approximately .001% compared to 2%.

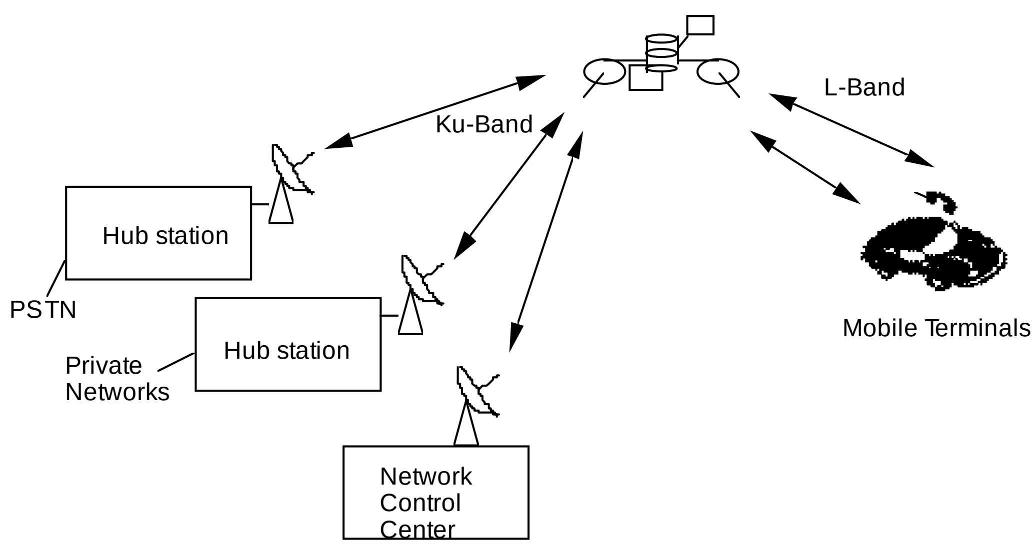


Figure 17. Mobile Satellite Network

2.3 Hybrid Cellular Satellite System Overview

Hybrid signifies being of mixed composition. System shows that exists some form of interrelated network of structures. Finally cellular and satellite describe the types of structures to be interrelated. A hybrid network signifies that "the user has a means of accessing two communication mediums" (Hughes Network Systems, 1990). According to the above definitions, if a user is capable of accessing cellular system media and satellite system media, this would constitute a hybrid network. This section addresses the components, equipment and operation of a hybrid cellular satellite system.

2.3.1 Hybrid System Components

The components of a hybrid system constitute the components of each of the individual stand alone systems. For the case of the hybrid cellular satellite system, the components include a MSC; cell sites; base stations; mobile units from the cellular system and an NCC, hub station and mobile terminals from the satellite system. These components have all been previously described. The equipment of these components, however, may or may not need additional modification in order to allow the communication between the two mediums to be possible. In cellular satellite hybrid scenarios, main modifications are made in the mobile terminals that must be capable of using both mediums and in the NCC of the satellite system to allow the conversion of cellular frequencies to that of the satellite system.

2.3.2 Hybrid System Operation

In system operation, communications within the bounds of each system continues as previously described. Communication across the systems increases in complexity. The network control facilities are made interoperable to the degree necessary to allow hybrid operation and seamless transitions between the two media. The hybrid user should be able to initiate and receive calls directed to them from either system and transition between them when required (Hughes Network Systems, 1990). Access to each system is controlled by schemes used in each system. Access across the system is controlled by the availability of resources needed to provide the communications. The frequency range of operation continues to be the same for each system with the conversion of frequencies when communication is being done across the systems. A hybrid system faces the problems faced in both of the media. Figure 18 shows a possible configuration for a hybrid cellular satellite network (Hughes Network Systems, 1990).

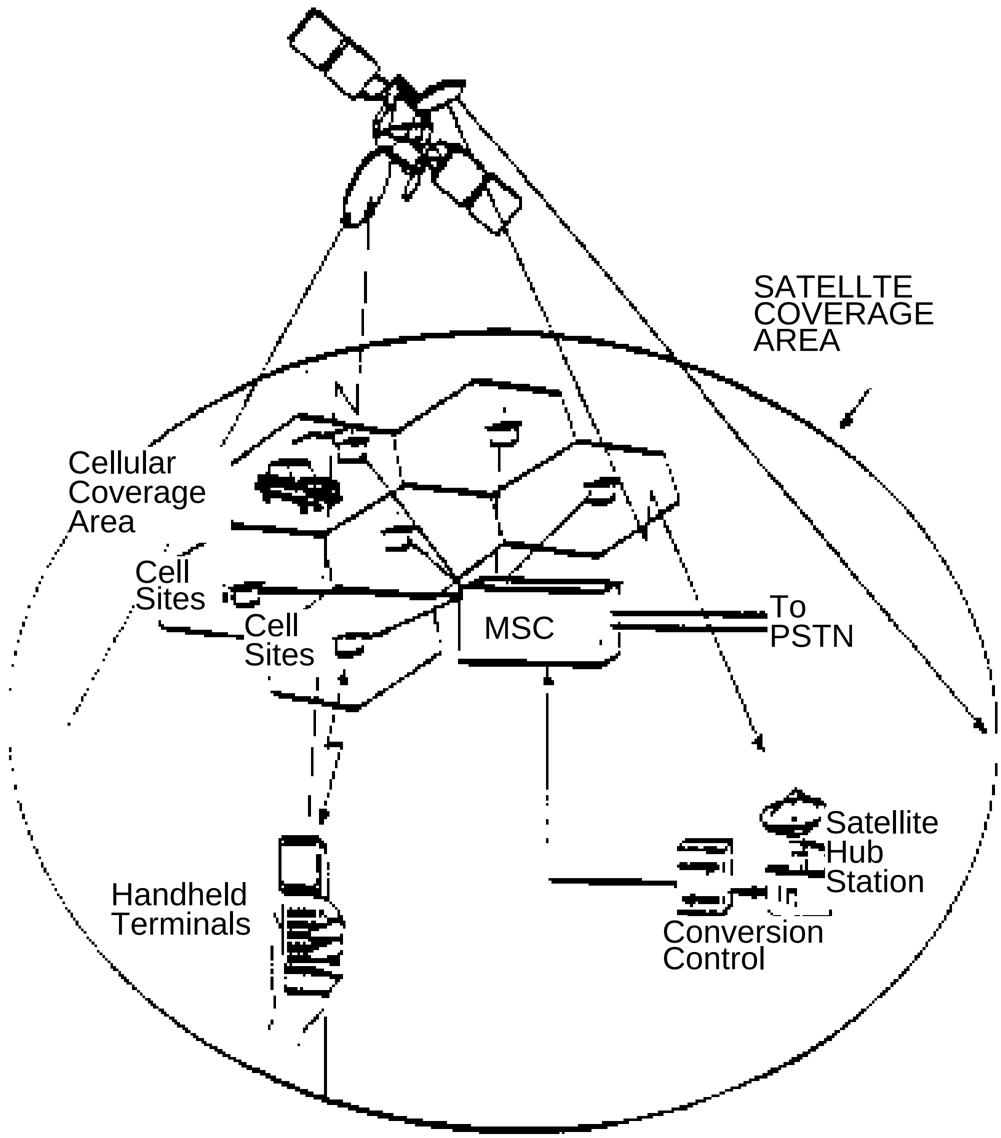


Figure 18. Hybrid Cellular Satellite Network

Chapter 3.

Basic Methodology

In order to study the performance of a hybrid system, it can either be prototyped or simulated. Simulation is often the more viable method due to the cost of prototyping different systems, especially those that involves cellular and satellite components. This chapter addresses the approach taken in the development of the hybrid system to be modeled and studied.

3.1 Hybrid Cellular Satellite System Design

The hybrid network will be comprised of a cellular and a mobile satellite system. The components of the hybrid network will include all components of each system. The cellular system components will include: (1) a MSC, (2) several base stations, (3) mobile units and (4) connections. Mobile satellite system components will include: (1) a NCC, (2) hub stations, (3) mobile terminals, (4) satellite(s) and (5) connections. For the hybrid system, there will also exist mobile units that can access both media. These will be called hybrid mobile units. The hybrid system shall provide coverage for CONUS. This is mainly capable through the use of the satellite systems since the cellular system has limited coverage within the CONUS region. The hybrid system will interface with the PSTN and Private Networks. It will connect the users of the independent systems with users on opposite systems and users in the PSTN. Connections will offer connectivity between mobile units, base stations and MSCs, also between the hub station and the NCCs. Radio links carry signals between the mobile units and the base station. Microwave links carry signals between the base station and the MSC. Voice trunks similar to those used in the

PSTN are used between the MSCs. For the satellite system, high frequency radio links are used between mobile terminal and the satellite, between satellite and the NCC and also between the NCC and the hub station.

3.1.1 Network Operations

The Hybrid Network will have the following operation:

There is no particular network operation control center that will control the entire hybrid network. Much like the cellular network and the PSTN, which are independent of each other with communication stemming across them, the hybrid network will be similar. The cellular network and the satellite network will operate independent of each other as regular entities. However, with the introduction of hybrid cellular satellite mobile terminals, the MSC of the cellular network and the NCC of the satellite network are made interoperable. Communications for signaling will be done through the use of packet switching across the X.25 network to allow seamless transitions from cellular to the satellite network.

Calls within each network are handled according to previous operation methods described in chapter 2. Hybrid cellular satellite and satellite mobile terminals can establish calls from anywhere in the CONUS. Call handoffs do exist between the two systems. Handoffs are only possible from the cellular system to the satellite system and not vice versa. When a call is handed off from the cellular system to the satellite system, connections are established from the hybrid cellular satellite terminal to the satellite (using L-Band) to the respective NCC (using Ku band) to the former MSC the hybrid cellular satellite terminal was connected on out to the PSTN or other mobile unit with whom the call was established.

3.1.2 Network Topology

The topology of the hybrid network is as follows:

The network will be comprised of two main systems. For the satellite network topology will include:

One geostationary or multiple low earth orbiting satellites, two hub stations, satellite mobile terminal and connections.

The two location for the hub station will be:

(1) Nevada

(2) Washington, D.C.

Satellite locations for the geostationary options include:

(1) 101^{o} W Longitude

(2) 62^{o} W Longitude

The topology of the satellite systems is representative of the topology in the article by Lunsford, et. al.

For the cellular network, topology will include:

One MSC; several base stations, mobile units and connections. This configuration is representative of a typical cellular network.

Hybrid cellular satellite and satellite mobile users can travel anywhere in CONUS.

3.1.3 Network Routing

Routing for the hybrid network is as follows:

1. Satellite calls are routed by the nearest NCC using satellite resources to the PSTN or the cellular network.
2. Cellular calls are routed by the respective MSC to other cellular companies, the satellite network or to the PSTN.

3. Handoffs within the cellular network are handled by the MSC.

4. Hybrid cellular satellite handoffs are routed by the MSC to the satellite NCC.

5. East coast calls are routed to the NCC in Washington, DC.

6. West Coast calls are routed to the NCC in Nevada.

3.2 System Modeling Tools Trade Off Analysis

The products addressed in this section are packages that are on the market. They are either network simulators or simulation languages that can be used to develop a model for communication simulations. There are three tradeoffs that will be made:

1) the selection of a simulation language

2) the selection of the best network simulation package

3) the tradeoff of developing a simulator in the simulation language selected or purchasing the best network simulation package select.

The simulation languages analyzed were FORTRAN, Simscript II.5, and Sim++. The network simulation packages analyzed were OPNET, BONeS and Communications Network Simulation Testbed. These languages and network simulation packages are all described in this section.

3.2.1 Simulation Languages

FORTRAN is a structured programming language that has been used to perform modeling. FORTRAN was widely used for simulation because of its processing power. Many mathematical computations can be done quickly through the use of FORTRAN. However, many people would say that FORTRAN is pretty much extinct. It is still used but many languages have been developed that have proven more efficient than FORTRAN. Newer languages also outweigh FORTRAN because of the lines of code necessary to perform the same function. FORTRAN has a lot to offer, however all functions such as random distribution and status reports have to be coded. Other structured programs have more to offer, therefore FORTRAN is often not used currently.

Simscript II.5 is a discrete event simulation language developed by the CACI Products Company (Russell, 1990). It has a simple English-like format and is not dependent on any predefined coding forms. Simcript II.5 has been used for several types of simulation which extend from single queue and server to complex communication networks. It has several built in features such as event schedules, report generator and random distribution functions. Simscript II.5 allows for user defined functions and subroutines. These functions can be written in C or FORTRAN. The language is very structured and modular, which helps to keep coding orderly and manageable.

Sim++ is a language developed by the JADE Simulations. Sim++ is a discrete event object oriented simulation language. The core of Sim++ is based on C++, which is then based on core language C. By using C as a basis, Sim++ tends to be very portable and also efficient. This object-oriented language interfaces to TimeWarp, another Jade product, to allow high speed parallel simulation. TimeWarp allows for multiple processes to run on different processors which are able to communicate and synchronize action by scheduling and receiving events. This type of environment provides a close-to-real-time simulation. Sim++ has all the features of a simulation language and the features of an object-oriented language that allows for complete structured programming. Some of these features include event management and queuing, simulation time, entity management, random distributions and reporting. Additional features include parallel execution, general programming language use of C++, and graphical analysis tools. Sim++ is designed to run off a single Sun/3 Workstation or a network of workstations.

Of the previously mentioned languages, Sim++ was the primary selection. Sim++ was selected due to its programming environment. The object oriented language provides for an easier interface to develop communication entities and simulations. This allows for simpler expansion of the network when new entities are introduced. The programming environment allows easy modifications and recompilation relatively faster. Sim++ interfaced with TimeWarp also provides a close to real time simulation environment that is difficult to achieve with the other languages previewed. Finally, since Sim++ is based on C++, it has all the features of being fast, efficient and portable.

3.2.2 Simulation Network Modeling Tools

OPtimized Network Engineering Tools (OPNET) is a communication network simulator developed by MIL3. OPNET is useful in simulating large communication networks with detailed protocol modeling and performance analysis. The features of OPNET include graphical model specifications, a dynamic, event-scheduled simulation kernel, integrated data analysis tool and hierarchical, object based modeling. The OPNET interface, called the MIL3 User Interface, allows for user defined functions in the C language. OPNET can be used to model diverse application which stem from local area networks to mobile packet radio networks.

BONeS is a Block Oriented Network Simulator developed by COMDISCO Systems Incorporated. It was mainly developed to provide a visual environment for modeling and simulating the flow of information or traffic in communication networks and distributed processing systems. BONeS is an event-driven network simulator. BONeS allows for rapid network configuration through the use of its communications building blocks in a graphical environment. It also allows the user to define new blocks in C language which can be incorporated into the modeling environment. Features of BONeS include network modeling blocks such as traffic; channels; queues; timers through the Block Diagram Network Editor; graphical interfaces and report statistics generation.

Communication Network Simulation Testbed is currently under development at the University of Maryland. The effort is lead by Mr. Scott M. Corson. The Testbed is being developed in Sim++ with the use of TimeWarp. This project was undertaken to characterize in an object-oriented fashion, common elements of communication networks. By having the testbed available, individuals would be able to conduct specialized communication simulation through the use of the testbed communication objects. The flexibility to create additional necessary objects is also available.

Through the trade studies, it has been determine that BONeS would be well suited for conducting the simulation. Therefore, simulations will be conducted through the use of BONeS Designer Framework. Of the network simulators, BONeS models allows for rapid model development and simulations. It was designed for conducting the typing of simulations that are necessary for evaluating the hybrid network. Finally, the block oriented design and example models provided the fastest learning ability for new users.

Chapter 4
Simulation Experiments

When simulations are conducted, the probability for completing an intersystem handoff for hybrid mobile users will be computed. The average handoff delay experienced will also be computed for the percentage of hybrid mobile users having completed a handoff. These results should show whether conformance to the IS-41 timing regulations is possible. The model system aids in the development process to determine the required capacity necessary to support hybrid intersystem handoffs. This chapter shows how the network described in chapter 3 is represented and simulated on the BONeS Designer Platform. The Hybrid Network System is very similar to the BONeS Designer Mobile Telephone System, therefore some of the assumptions, terminology and descriptions to be used may be similar or taken directly from the BONeS Designer Mobile Telephone Model description.

4.1 Introduction to Hybrid Network Simulation Models

This model represents a Mobile Cellular Telephone System interconnected with a Satellite system. Together, the two systems in the model constitute a Hybrid Network System. The model is used to measure the probability of completing an intersystem handoff between a cellular and satellite system, along with the handoff delay experienced by those mobile users that completed an intersystem handoff. Using BONeS Designer to model these systems, the NCC and MSC are modeled only to a limited extent. The representation of the NCC and MSC are mainly for the control procedures involved in the handoff process. The model also includes mobile users, base stations and hub stations, whose attributes are contained within BONeS Designer data structures.

During development of the Hybrid Network System model the following assumptions were made:

1. Traffic to the system is generated from an infinite population using a Poison distribution.
2. Ninety percent of the traffic is a mixture of cellular and hybrid mobile users and ten percent is always satellite mobile users.
3. Mobile users travel along a straight line for the duration of their sessions.
4. Mobile users that are out of the coverage area of the cellular system have bad signal quality, therefore an intersystem handoff is necessary.
5. Attributes for the mobile users, such as x and y coordinates, speed of motion, direction of motion, and session length are randomly distributed from the appropriate uniform distributions.
6. Satellite coverage is unlimited, therefore there is no need to check if the mobile satellite users are within the satellite coverage area.
7. X.25 and cellular travel delays experienced by the mobile users are all generated randomly from normal and uniform distributions. These values represent delays for the best performance.
8. The Handoff model assumes best case for message transfers therefore no process for error correction is implemented as in the IS-41 specifications.

The Hybrid Network System model operates as follows:

As mobile users are generated they will be routed, as determined by their hybrid flag attribute, to the cellular system or satellite system. The mobile users will then be assigned to a base station, if routed to the cellular system, or a hub station, if routed to the satellite system. Regardless of which system, the mobile user will be assigned to a channel. If a channel is available, the channel will be assigned to the mobile user. If a channel is not available, the mobile user will be considered blocked. As the mobile user moves within the cellular system, the user location is periodically checked. If the mobile user is within the coverage area of the cellular system, the channel quality will be checked. If the channel quality is okay, the user continues to use the same channel. Otherwise, the current channel will be released and the mobile user will be assigned to another base station and another channel will be reassigned. This is considered a handoff within the cellular system. On the other hand, if the mobile user is not within the coverage area of the cellular system, an intersystem handoff is initiated. This triggers the process for the mobile user's call to be transferred to the satellite system.

In the satellite system portion of the model, after users are assigned to a channel, the mobile users are delayed. After the delay, mobile users whose sessions are complete exit the system. If the session is not over, the mobile user's position is updated and the mobile user is delayed once more. This process repeats itself until the mobile user's session is completed.

Mobile users mainly depart from the Hybrid Network System in three ways:

1. When the mobile users session has been completed.
2. If the mobile user attempting an intersystem handoff is ineligible, it will therefore be considered out of the coverage of the cellular system.
3. The mobile user is blocked. The mobile user can be blocked in the cellular system, satellite system or attempting an intersystem handoff.

The Hybrid Network System is shown in figure 19. The BONeS Designer System model consists of several modules. These modules comprise the entire system. The modules in the model create all the base stations; the cellular coverage area; all the hub stations; the mobile users with defined attributes; route mobile users, assign mobile users to base and hub stations; assign mobile users to channels; delay the mobile users; remove the mobile users whose sessions have expired; update the mobile users position; check the signal quality; release bad channels; and finally handoff eligible mobile users to the satellite system.

The system starts by determining the location of the base stations and identifying the coverage area; this is done based on parameters such as Base Station Matrix Size, Distance between Base Station (miles), and the x and y coordinates of the initial base station in the "Create & Save All Base Stations" and "Create Coverage Area" modules. These modules are taken from the Mobile Project Group of the BONeS Designer blocks. All other modules in the system have been created or modified to handle the Hybrid Mobile Unit data structure and are located in the Hybrid Network Group of the BONeS Designer Block Diagram Editor.

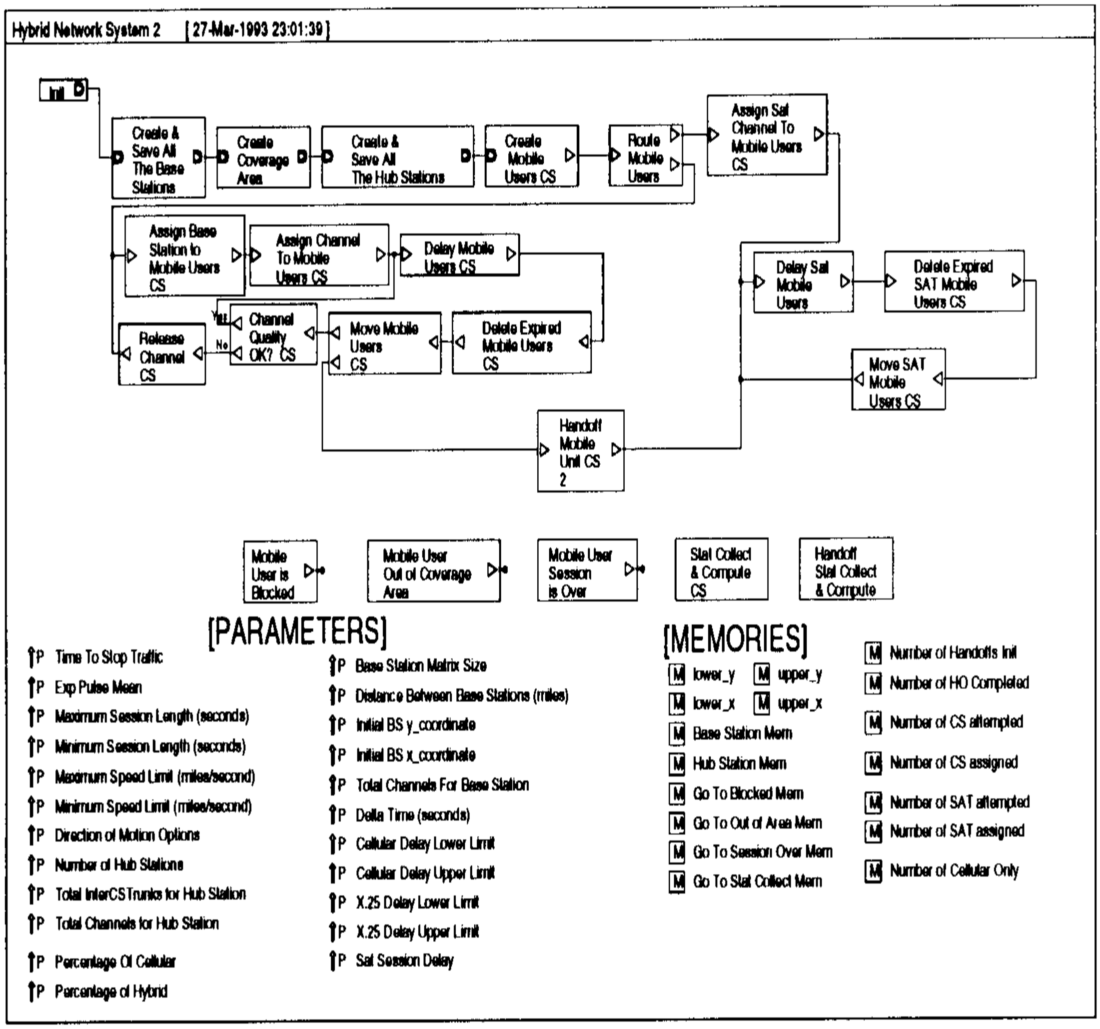


Figure 19. Hybrid Network System Model

The system continues by creating all the hub stations that will be included in the satellite system; this is done based on the parameter Number of Hub Stations. Then the system begins generating mobile users and defining their attributes according to the specified parameters. As mobile users exit the "Create Mobile User CS" module, the mobile users are routed to the appropriate system, cellular or

satellite, by the "Route Mobile Users" module. The routing is based on the mobile user's hybrid flag value. The hybrid flag can take on three possible values:
1- Cellular Only, 2- Hybrid (Cellular/Satellite), and 3- Satellite Only. The module assigns satellite-only mobile users to a hub station prior to routing the mobile unit to the satellite system. Mobile users who are cellular or cellular/satellite are routed to the cellular system.

If the mobile user is routed to the cellular system, the mobile user will then be assigned to a base station by the "Assign Base Station to Mobile Users CS" module. As the mobile user exits this module, a channel will be assigned by the "Assign Channel to Mobile Users CS" module. Within this module, if there are no available channels, the mobile user is considered blocked and exits the system at this point.

If the mobile user is assigned a channel, the next module visited is the "Delay Mobile Users CS" module. This module delays the mobile user for a period of time equal to the Delta Time parameter. After being delayed, the mobile user is checked to determine if the entire session length has expired. This is done in the "Delete Expired Mobile User CS" module. If the session length has expired, the mobile user exits the system normally. Otherwise, the mobile user has time remaining in the session and is passed on to the next module, "Move Mobile User CS". This module updates the mobile user's position and determines if the mobile user is still within the coverage area of the cellular system. The mobile user path is then determined by its position. These are the possibilities, which are the outputs of this module:

1: Within the coverage area:

If the mobile user is within the coverage area of the cellular system, the user's channel quality will be evaluated for an acceptable level by the "Channel Quality OK? CS" module. With an acceptable level, the mobile user will continue to use the same channel and be delayed for another Delta Time period. If the channel quality level is not acceptable, the mobile user's channel is released, the mobile user is reassigned to another base station and assigned to a new channel.

2. Outside the coverage area:

If the mobile user is outside of the coverage area of the cellular system, the mobile user is sent to the "Handoff Mobile Unit CS" module to attempt an intersystem handoff. This module will be described later in section 4.2. If the mobile user successfully completes the intersystem handoff, the mobile user enters the satellite system. The mobile user will remain in the satellite system for the remainder of its session. If the mobile user is not successful with the intersystem handoff, the mobile user will be considered blocked.

In the satellite system, after the mobile user exits the "Route Mobile User" module, a channel on the current hub station will be assigned. This is done in the "Assign Sat Channel to Mobile Users CS" module. If a channel is available, the mobile user will be delayed. Otherwise, a channel is not available and the mobile user will be considered blocked. Mobile users assigned a channel will be delayed by the "Delay Sat Mobile Users" module. This module is delays mobile unit for a constant time period. After being delayed, mobile users whose sessions are completed are deleted by the "Deleted Expired Sat Mobile Users" module. If the session is not completed, the mobile user's position is updated by the "Move Sat Mobile User CS" module and the mobile user is delayed once more. Satellite mobile users exit the system by either being blocked or when their sessions have expired.

As mobile users exit the system for any of the various reasons explained, statistics are collected and computed for the Hybrid Network System by the "Stat Collect and Compute CS" module. The "Handoff Stat Collect and Compute" module collects and computes statistics based on the "Handoff Mobile User CS" module. The three blocks labeled "Mobile User is Blocked", "Mobile User Out of Coverage Area" and "Mobile User Session is Over" are for visual effect and useful in simulation animation. Most of the system parameters are self explanatory, however, a brief description of each parameter is provided in Appendix A.

In the Hybrid Network System, there are three data structures: Hybrid Mobile Unit-DS, Base Station Unit-DS, and Hub Station Unit-DS. Each of the data structures can be seen in figures 20, 21, and 22 respectively. The attributes of each data structure are for the most part self-explanatory, however, a brief description of the attributes of each data structure is provided in Appendix A.

Name: Hybrid Mobile Unit-DS [Hybrid CS Network]
Date: Wednesday, 3/17/93 11:40:17 am EST

Name	Type	Subrange	Default Value
mobile ID	INTEGER	[0, +Infinity)	...
x_coordinate	REAL	(-Infinity, +Infinity)	...
y_coordinate	REAL	(-Infinity, +Infinity)	...
in region?	INTEGER	[0, 1]	1
base station ID	INTEGER	[0, +Infinity)	...
old base station ID	INTEGER	[0, +Infinity)	...
base station distance	REAL	[0, +Infinity)	...
channel available?	INTEGER	[0, 1]	1
direction	REAL	[0, +Infinity)	...
speed	REAL	[0, +Infinity)	...
session length	REAL	[0, +Infinity)	...
time to exit	REAL	[0, +Infinity)	...
total handoffs	INTEGER	(-Infinity, +Infinity)	-1
hybrid flag	INTEGER	[1, 3]	...
signal quality	INTEGER	[0, 150]	50
hub station ID	INTEGER	[0, +Infinity)	...
MSC-Sat channel available?	INTEGER	[0, 1]	1
Sat Channel available?	INTEGER	[0, 1]	1
handoff init time	REAL	[0, +Infinity)	...
handoff complete time	REAL	[0, +Infinity)	...

Figure 20. Hybrid Mobile Unit-DS

Name: Base Station Unit-DS [Mobile2.0]
Date: Wednesday, 3/17/93 11:40:15 am EST

Name	Type	Subrange	Default Value
base station ID	INTEGER	[0, +Infinity)	...
x_coordinate	REAL	(-Infinity, +Infinity)	...
y_coordinate	REAL	(-Infinity, +Infinity)	...
channels available	INTEGER	[0, +Infinity)	...
channels used	INTEGER	[0, +Infinity)	0

Figure 21. Base Station Unit-DS

Name: Hub Station Unit-DS [Hybrid CS Network]
Date: Wednesday, 3/17/93 11:40:16 am EST

Name	Type	Subrange	Default Value
hub station ID	INTEGER	[0, +Infinity)	...
x_coordinate	REAL	(-Infinity, +Infinity)	...
y_coordinate	REAL	(-Infinity, +Infinity)	...
channels available	INTEGER	[0, +Infinity)	...
channels used	INTEGER	[0, +Infinity)	0
InterCSTrunks available	INTEGER	[0, +Infinity)	...
InterCSTrunks used	INTEGER	[0, +Infinity)	0

Figure 22. Hub Station Unit-DS

4.2 Functional Description of Modules

All modules used in describing the Hybrid Network System model are functionally described in this section.

Create & Save All Base Stations:

This module uses the parameter Base Station Matrix Size, Distance Between Base Station (miles) and Initial Base Station x and y coordinates to create all the Base Stations and write each base station data structure into memory. This module is shown in figure 23.

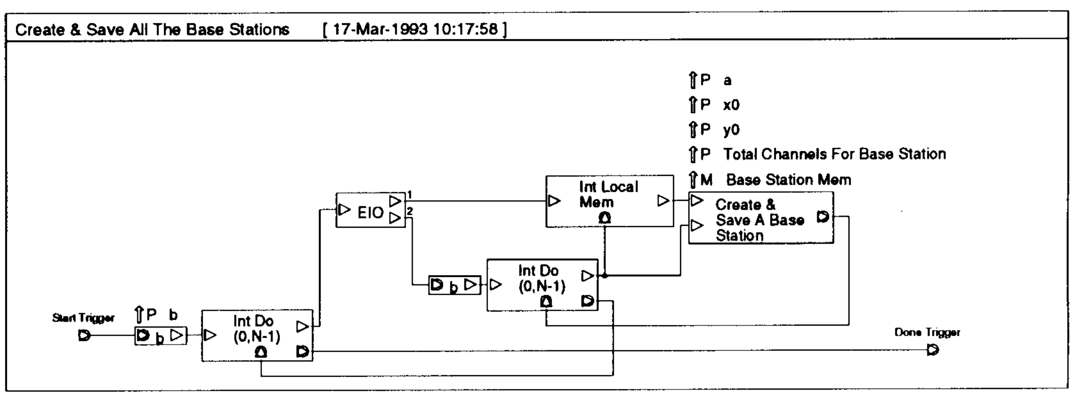


Figure 23. Create & Save All Base Stations

Create Coverage Area

This module creates the entire coverage area to be supported by the cellular system. The module determines the upper x, upper y, lower x, and lower y boundaries. This module is shown in figure 24.

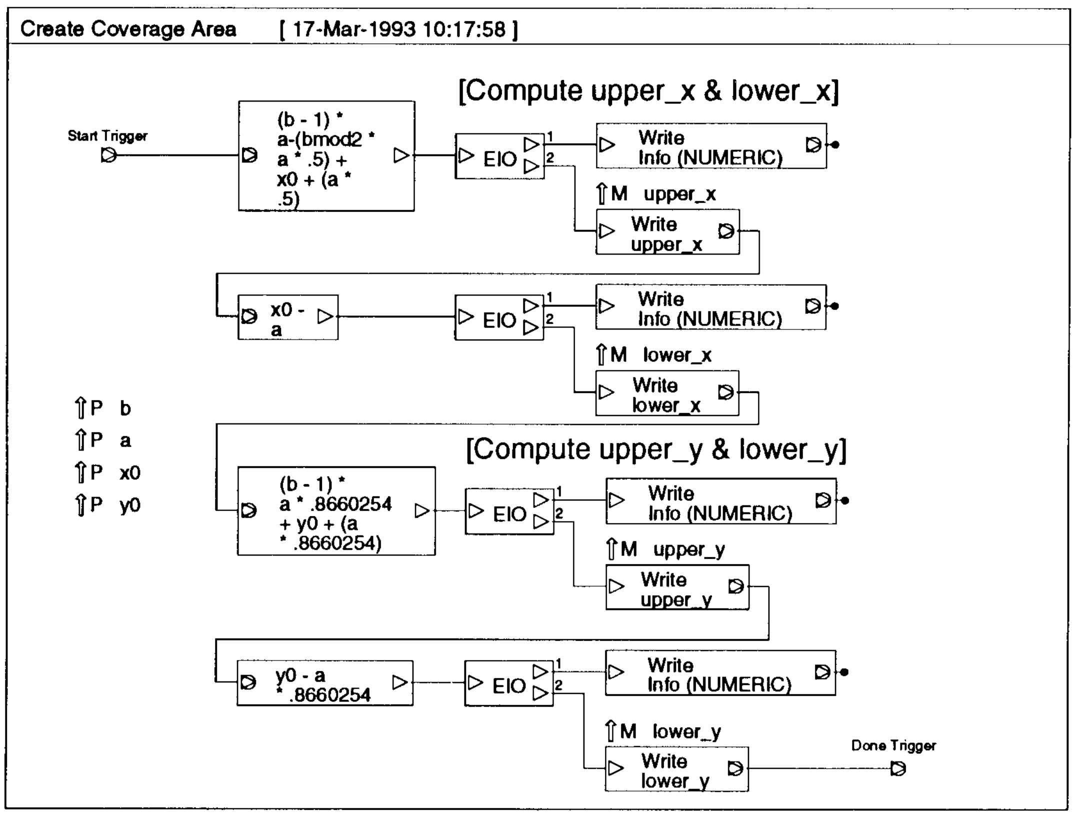


Figure 24. Create Coverage Area

Create & Save All Hub Stations

This module creates all the hub stations as specified by the parameter, Number of Hub Stations. Once a hub station is created, the data structure is written into memory. This module is shown in figure 25.

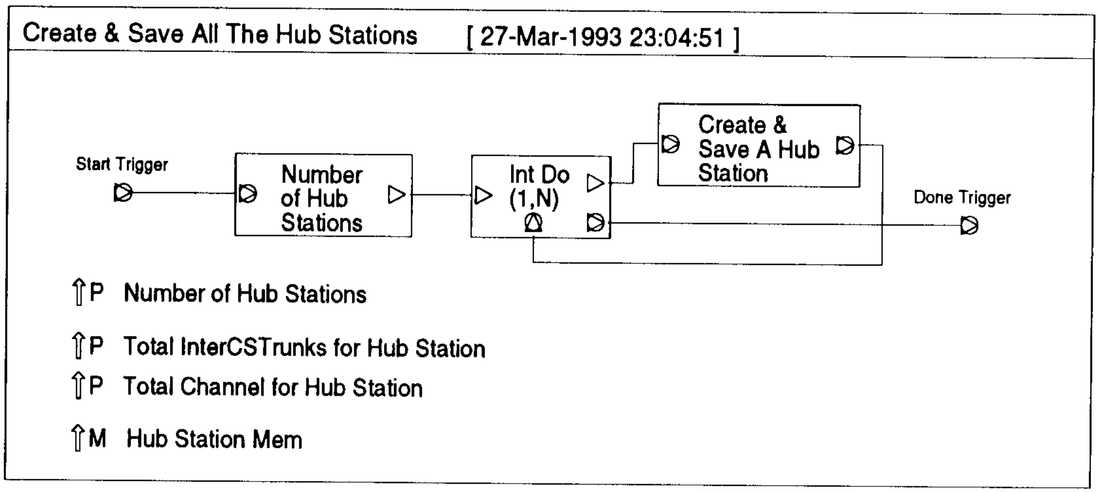


Figure 25. Create & Save All Hub Stations

Create Mobile Users CS

This module generates mobile user traffic with time between arrivals being exponentially distributed with mean of Exp. Pulse Mean parameter. The traffic is generated until the Time to Stop parameter is reached. The mobile user's attributes are assigned values based on the specified distribution for the specific parameter. This module is shown in figure 26.

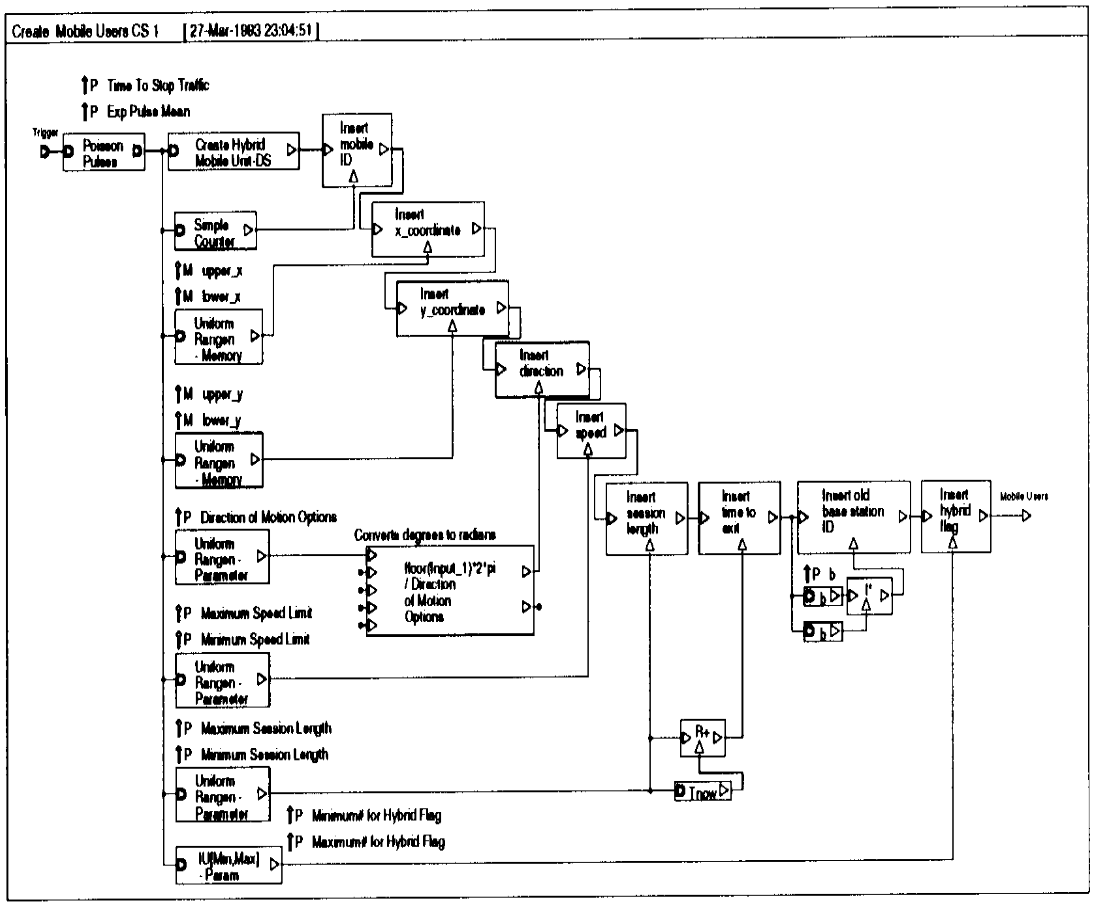


Figure 26. Create Mobile Users CS

Route Mobile User

This module routes the mobile users based on their hybrid flag. Mobile users with a hybrid flag value of 1 or 2 are routed to the cellular system. All mobile users with a hybrid flag value of 3 are routed to the satellite system. Mobile users routed to the satellite are assigned to a hub station. This is done prior to exiting this module. This module is shown in figure 27.

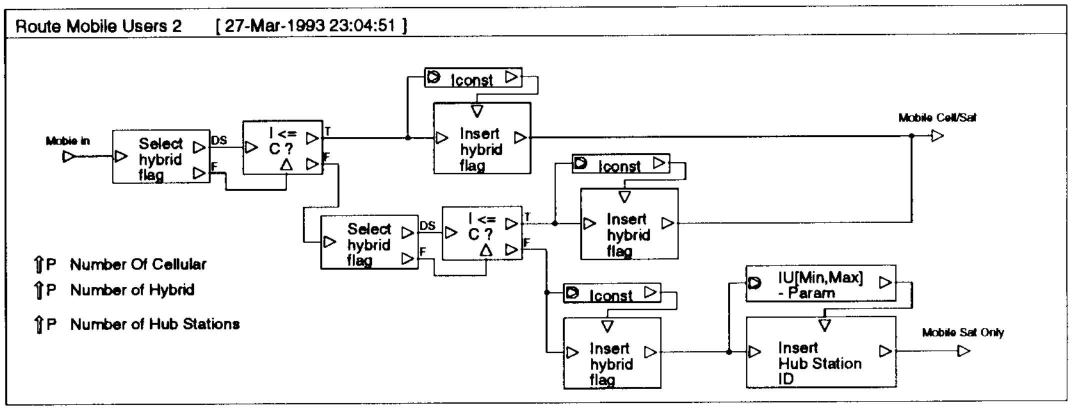


Figure 27. Route Mobile Users

Assign Base Station to Mobile User CS

This module is identical to the Mobile Project Module "Assign Base Station to Mobile User". This module has been modified to handle a hybrid mobile unit data structure. Each mobile user is assigned to a designated base station. The assignment is based on the distance between the mobile user and each of the base stations. The base station that is closest to the mobile user is then assigned. The module uses the x and y coordinate of the mobile user and the base station to compute the distance. This module is shown in figure 28.

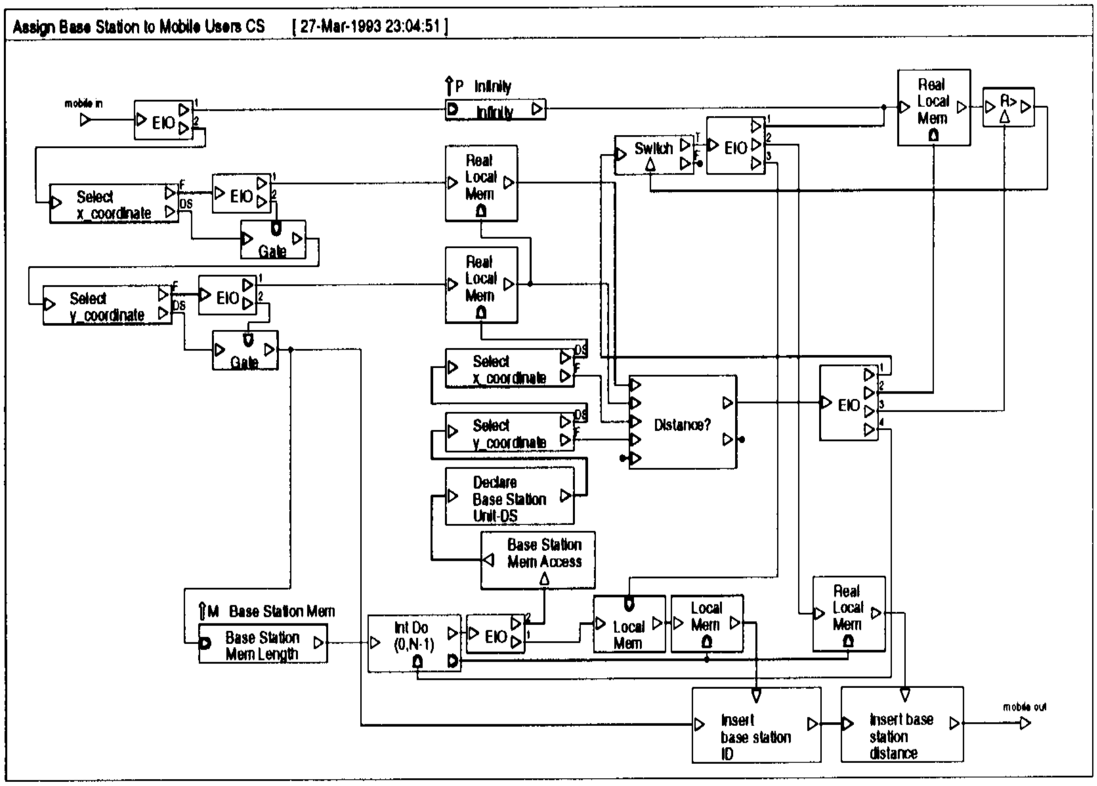


Figure 28. Assign Base Station to Mobile User CS

Assign Channel to Mobile User CS

This module assigns an available cellular channel to an incoming mobile user. Channel availability is based on the Base Station Unit-DS "channel available" attribute. If a channel is available, the "channel available" attribute is decreased by one and the mobile user is forwarded to the next block. If a channel is not available, the mobile user is considered blocked. This module is shown in figure 29.

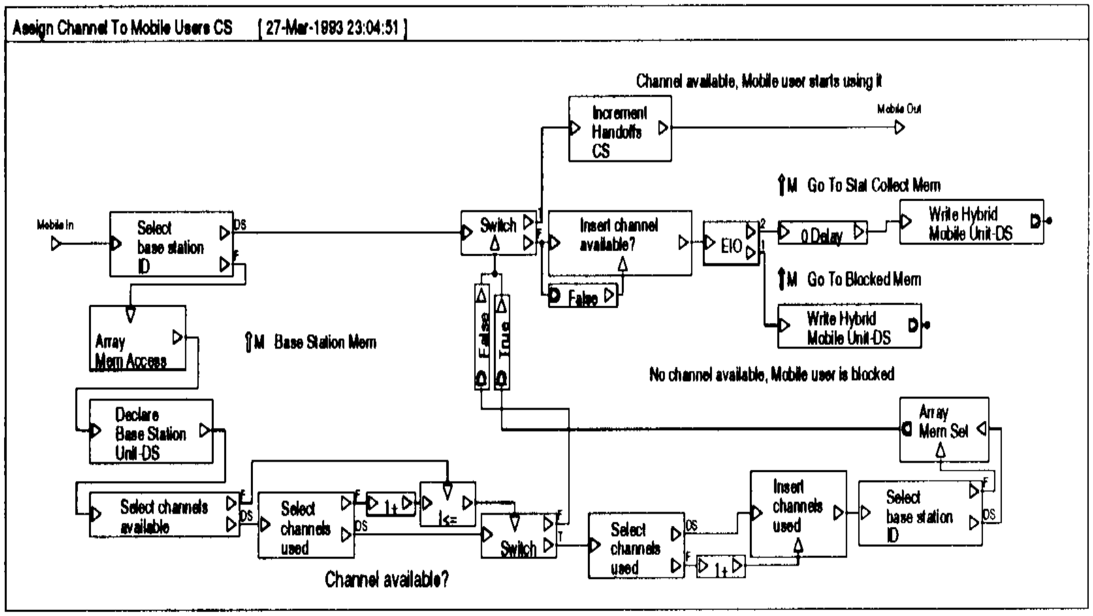


Figure 29. Assign Channel to Mobile User CS

Delay Mobile Users CS

This module delays incoming mobile users for a period of simulation time. The period is equivalent to the value of the Delta Time parameter. This module is shown in figure 30.

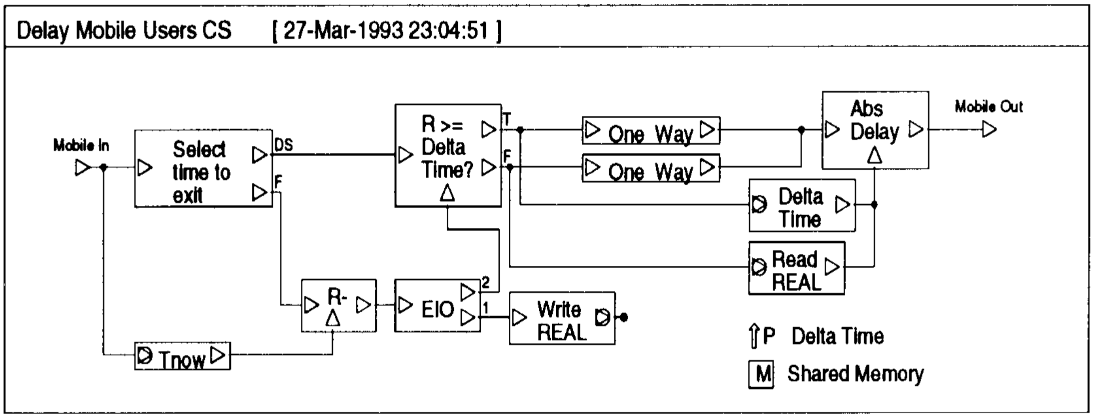


Figure 30. Delay Mobile User CS

Delete Expired Mobile Users CS

This module verifies whether or not the mobile user session is over. The module uses the Hybrid Mobile Unit-DS "time to exit" attribute to determine if it is time for the mobile user to exit the system. The calculation is done by deleting the current simulation time from the time in system value. If the difference is greater than or equal to zero, the mobile user time in system has expired. If the difference is less than zero, the mobile user still has time remaining in the system. Expired mobiles are deleted and cellular channels are released. This module is shown in figure 31.

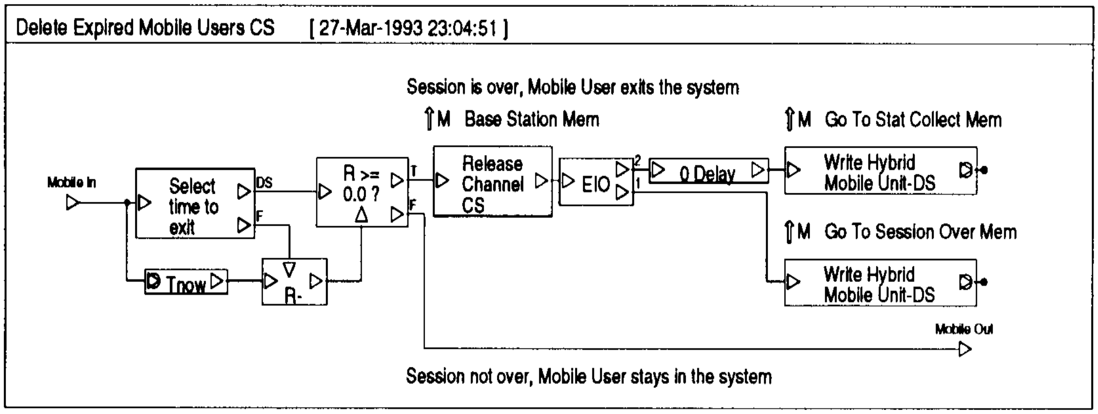


Figure 31. Delete Expired Mobile User CS

Move Mobile User CS

This module updates the mobile user's location. The user's new location is computed by the "New Mobile Position?" module, shown in figure 33, with the assumption that the mobile user is moving along a straight line. The user's new location is checked against the boundaries of the coverage to determine if the user is outside of the coverage area. The Move Mobile User CS module is shown in figure 32.

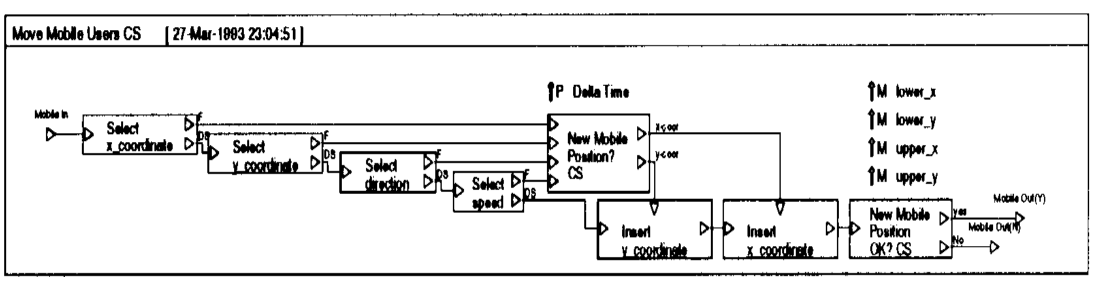


Figure 32. Move Mobile User CS

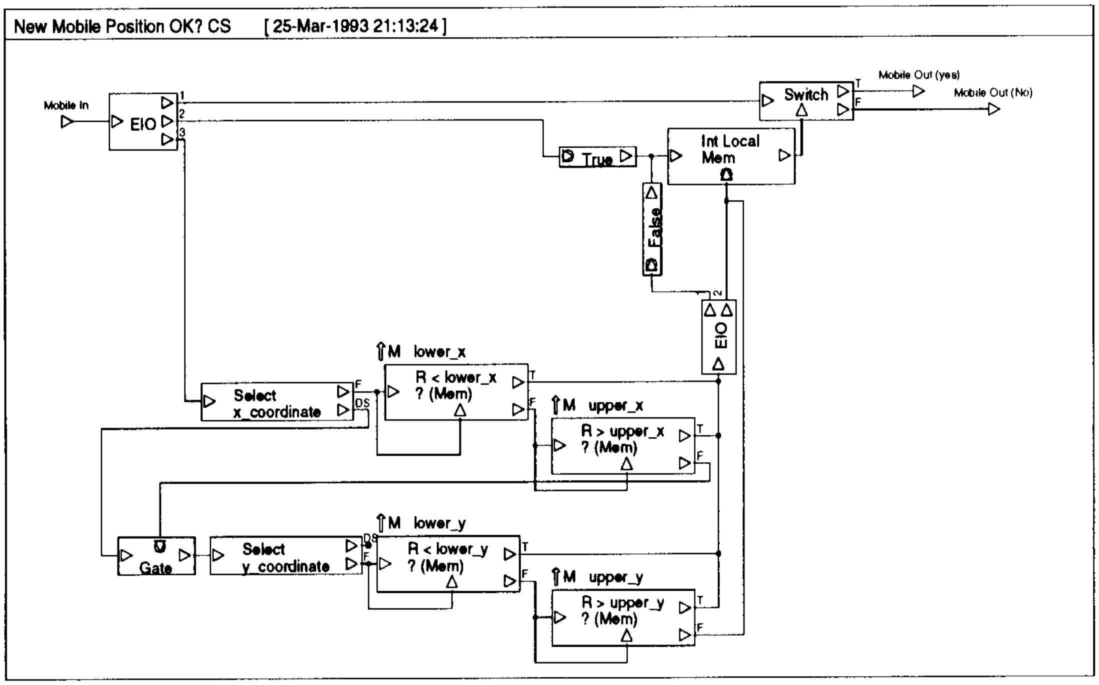


Figure 33. New Mobile Position

Channel Quality OK?

This module determines if the quality of the channel used by the incoming mobile user is acceptable. The calculation is based on a ratio between the distance between two base stations and the distance between the base station and the mobile user. If the ratio is less than or equal to (a/1.7320508; where (a) is equal to the distance between two base stations), then the channel quality is okay. This module is shown in figure 34.

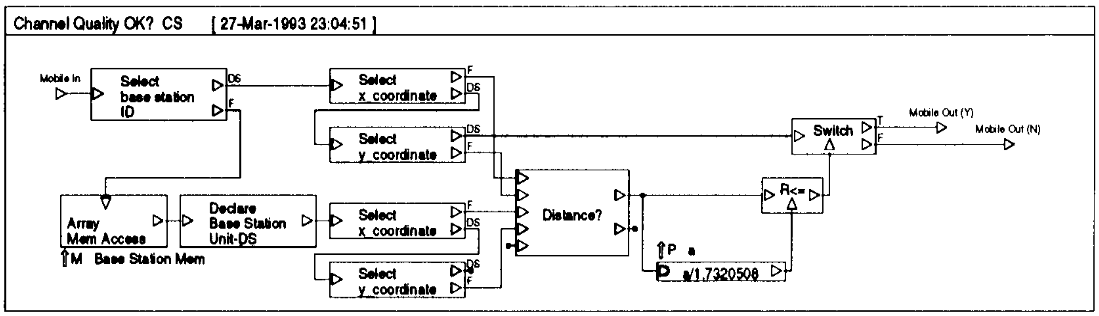


Figure 34. Channel Quality OK? CS

Assign Sat Channel to Mobile Users CS

This module assigns an available satellite channel to an incoming mobile user. Channel availability is based on the Hub Station Unit-DS "channel available" attribute. If a channel is available, the "channel available" attribute is decreased by one and the mobile user is forwarded to the next block. If a channel is not available, the mobile user is considered blocked. The module is shown in figure 35.

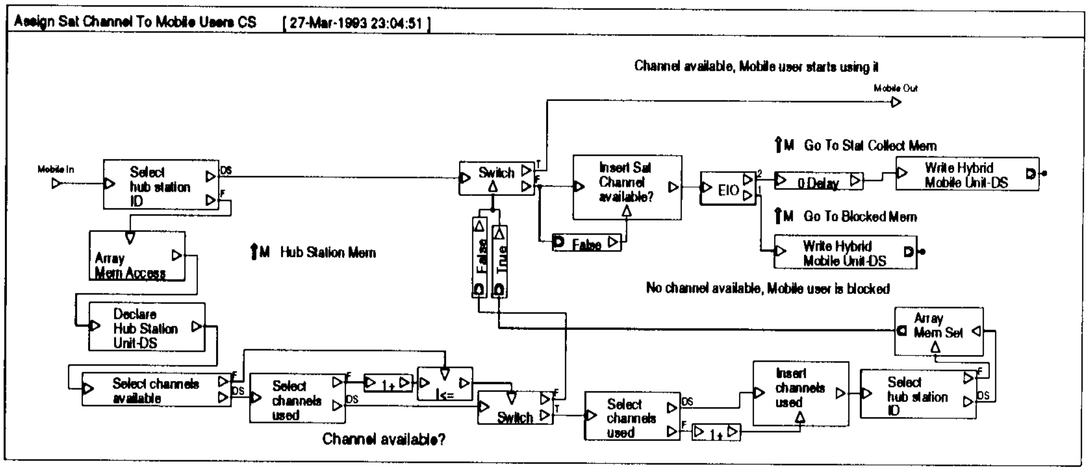


Figure 35. Assign Sat Channel to Mobile Users CS

Delay Sat Mobile Users

This module delays satellite mobile users for a fixed period of the simulation time. This module is a BONeS Designer primitive call Fixed Abs Delay and is shown in figure 36. The period of simulation time is equivalent to the Sat Session Delay parameter.

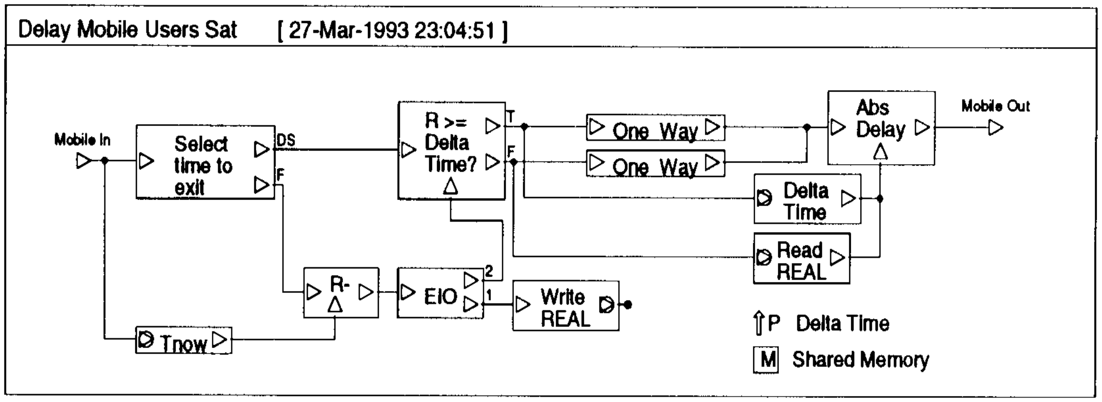


Figure 36. Delay Sat Mobile Users

Delete Expired Sat Mobile Users CS

This module verifies whether or not the mobile user session is over. The module user the Hybrid Mobile Unit-DS "time to exit" attribute to determine if it is time for the mobile user to exit the system. The calculation is done by deleting the current simulation time from the "time to exit" value. If the difference is greater than or equal to zero, the mobile user time in system has expired. If the difference is less than zero, the mobile user still has time remaining in the system. Expired mobiles are deleted and satellite and/or InterCSTrunks channels are released. This module is shown in figure 37.

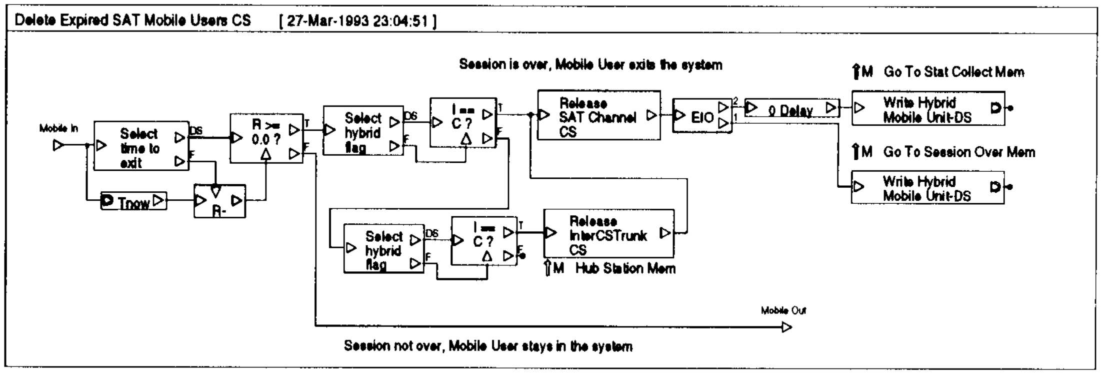


Figure 37. Delete Expired Sat Mobile Users CS

Move Sat Mobile Users CS

This module determines the new position of the incoming mobile user. It uses the old x and y coordinates, direction of motion, and speed of motion. The mobile user's new position is not checked because the satellite is assumed to have unlimited coverage. This module is shown in figure 38.

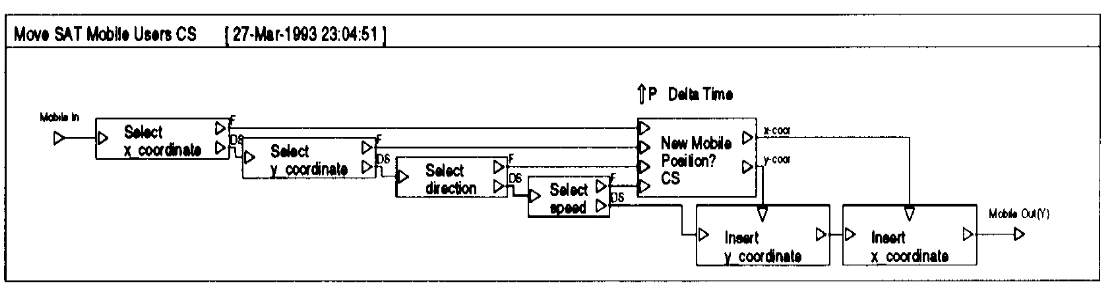


Figure 38. Move Sat Mobile Users CS

Handoff Mobile Unit CS

This module accepts candidate handoff mobile users. The module models the interaction between the MSC and Hub or Gateway Station or NCC necessary for completing the handoff. All timers are set according to the specification in the IS-41-B specifications. The MSC request a location mobile measurement request to determine if the satellite can be considered as a candidate system to handoff. This is determined by the signal level returned by the satellite. Therefore, the satellite returns the signal quality of the mobile user and a candidate hub station for the mobile user to be handed off too. If the signal quality level is acceptable, the MSC assigns an InterCSTrunk to the mobile user. If a trunk is not available, the mobile user is considered as blocked. If a trunk is available, this information is sent to the Hub station with the mobile user's identification. The Hub station will verify by the mobile user's hybrid flag, the eligibility of the mobile user for an intersystem handoff. If the hybrid flag is not equal to 2, the mobile user will be considered out of coverage area of the cellular system. If the hybrid flag is equal to 2, the mobile user will be assigned a satellite channel. If a channel is not available the mobile user will be considered blocked. If a channel is available, the channel information is sent back the MSC. The MSC then forwards the channel information to the base station and then to the mobile user. The MSC will await the mobile on channel acknowledge prior to establishing the complete call connection path. Once a mobile on channel acknowledgment is received, the cellular channel is released and the call will use an InterCSTrunk and a satellite channel for the duration of the call. During the handoff process, if any of the timers expire, mobile users are considered out of the coverage area of the cellular system. The "Out of Coverage CS 1, 2, and 3" modules are used to release the proper channels when the mobile user is out of coverage. Out of Coverage CS 1 only releases cellular channels. Out of Coverage CS 2 releases cellular channels and InterCSTrunks that have been assigned. Out of Coverage CS 3 releases cellular channels, InterCSTrunks and satellite channels that have been assigned. The Handoff Mobile Unit CS module is shown in figure 39. The IS-41-B process for Intersystem Handoff can be seen in Appendix B, along with the specifications for the Intersystem Handoff Process.

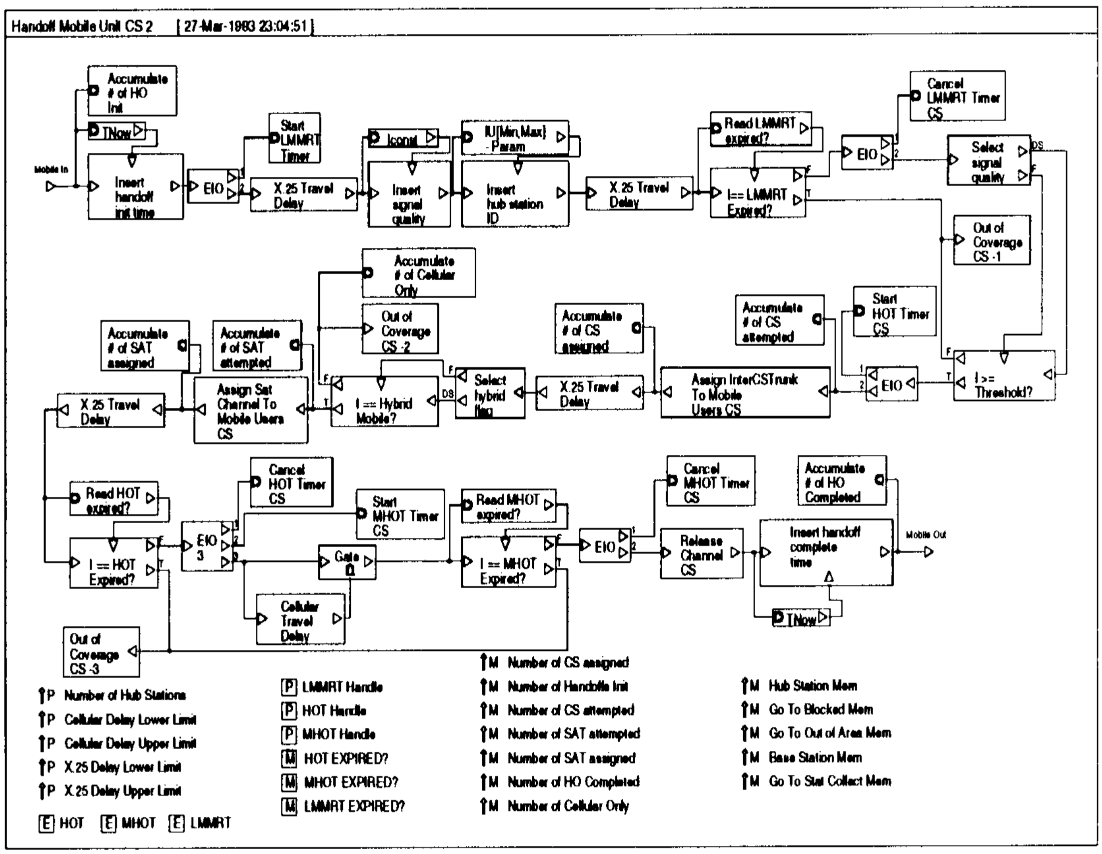


Figure 39. Handoff Mobile Unit CS

Release Channel CS

This module releases a channel that was being used by a mobile user. The channel is being released due to the following reasons.

1. The mobile user's session has expired.
2. The mobile user has poor channel quality.
3. The mobile user has gone outside of the coverage area of the cellular system.

When a cellular channel is released, the channels available? attribute of the Base Station Unit-DS is incremented by one and the channels used attribute is decremented by one. This module is identical to the Mobile Project module "Release Channel" and has been modified to handle Hybrid Mobile Unit data structures. This module is shown in figure 40.

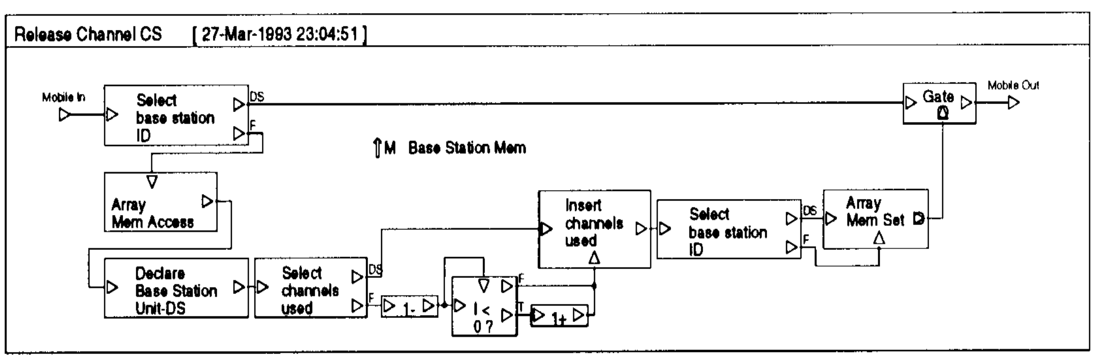


Figure 40. Release Channel CS

4.3 Hybrid Network Simulation and Results

The Hybrid Network System model will be used to several different parameter combinations. The different combinations will be used to be determine the probability of completing a handoff and the mean handoff delay in these varied situations. A description of each parameter can be found in Appendix A. Simulation parameters include:

Time To Stop Traffic

Exp. Pulse Mean

Maximum Session Length

Minimum Session Length

Minimum Speed Limit

Maximum Speed Limit

Direction of Motion Options

Number of Hub Stations

Total Number of InterCSTrunks

Total Channel for Hub Station

Base Station Matrix Size

Percentage of Cellular

Percentage of Hybrid

Distance Between Base Station (miles)

Initial BS y_coordinate

Initial BS x_coordinate

Total Channels for Base Station

Delta Time(seconds)

Cellular Delay Lower Limit

Cellular Delay Upper Limit

X.25 Delay Lower Limit

X.25 Delay Upper Limit

TSTOP

Global Seed

All parameters not mentioned in a simulation run will remain constant. The simulation run will be as follows:

Run 1:

Iterations will be based on the number of InterCSTrunks and the Percentage of Cellular mobile users. This will determine an optimal number of channels and InterCSTrunks necessary to provide the maximum probability for completing an intersystem handoff. All other parameters will remain the same as in Run 1. Parameters are shown in Table 3

Simulation Parameters	**Parameter Values**
Time To Stop Traffic	’TSTOP’
Exp. Pulse Mean	1.0
Maximum Session Length	240.0
Minimum Session Length	30.0
Maximum Speed Limit	70.0/3600.0
Minimum Speed Limit	20.0/3600.0
Direction of Motion	8.0
Number of Hub Stations	2
Total Number of InterCSTrunks	(15,30,45,60,75,90,100,125,150)
Total Channel for Hub Station	150

Table 3. Simulation Parameter Values for Run 1.

Simulation Parameters	Parameter Values
Percentage of Cellular	(75,65,55,45,35,25,15)
Percentage of Hybrid	90 - ’Percentage of Cellular’
Base Station Matrix Size	4
Distance Between Base Station (miles)	2
Initial BS y_coordinate	2
Initial BS x_coordinate	1
Total Channels for Base Station	12
Delta Time(seconds)	(Distance Between Base Station (miles)/Maximum Speed Limit)/ 10
Cellular Delay Lower Limit	0.25
Cellular Delay Upper Limit	0.75
X.25 Delay Lower Limit	1.0
X.25 Delay Upper Limit	3.0
Sat Session Delay	30.0
TSTOP	1800.0
Global Seed	9876549

Table 3. continued.

Results from the simulation run is as follows:

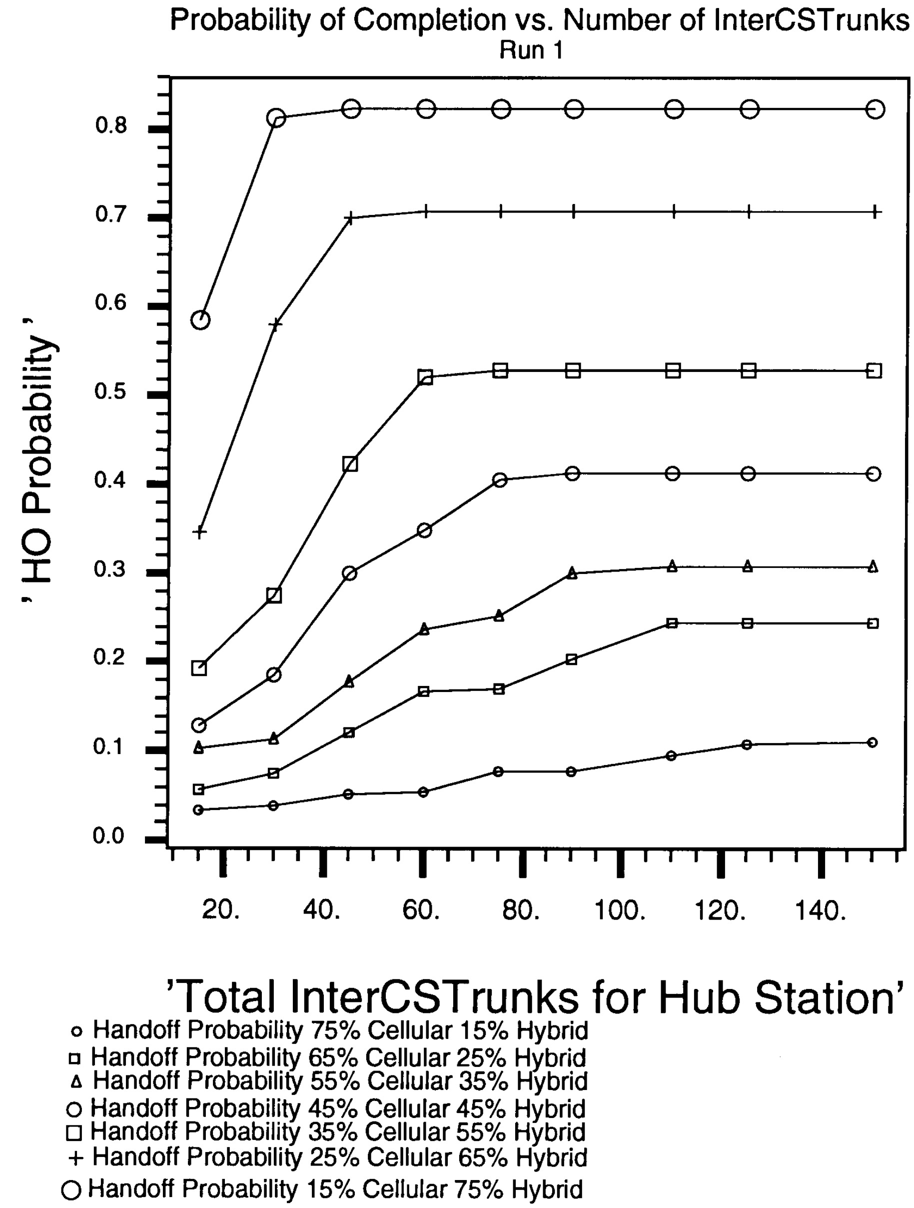
Results for Run 1:

Grpah 1 shows a graphs of the probability to complete an intersystem handoff based on the seven different combinations of InterCSTrunks and a fixed amount of Hub station channels. The percentage of cellular verses hybrid traffic is identified by the different shapes represented on the graph. Below the graph, there is text identifying the percentages with the associated shapes. Two things can be noted in graph 1:

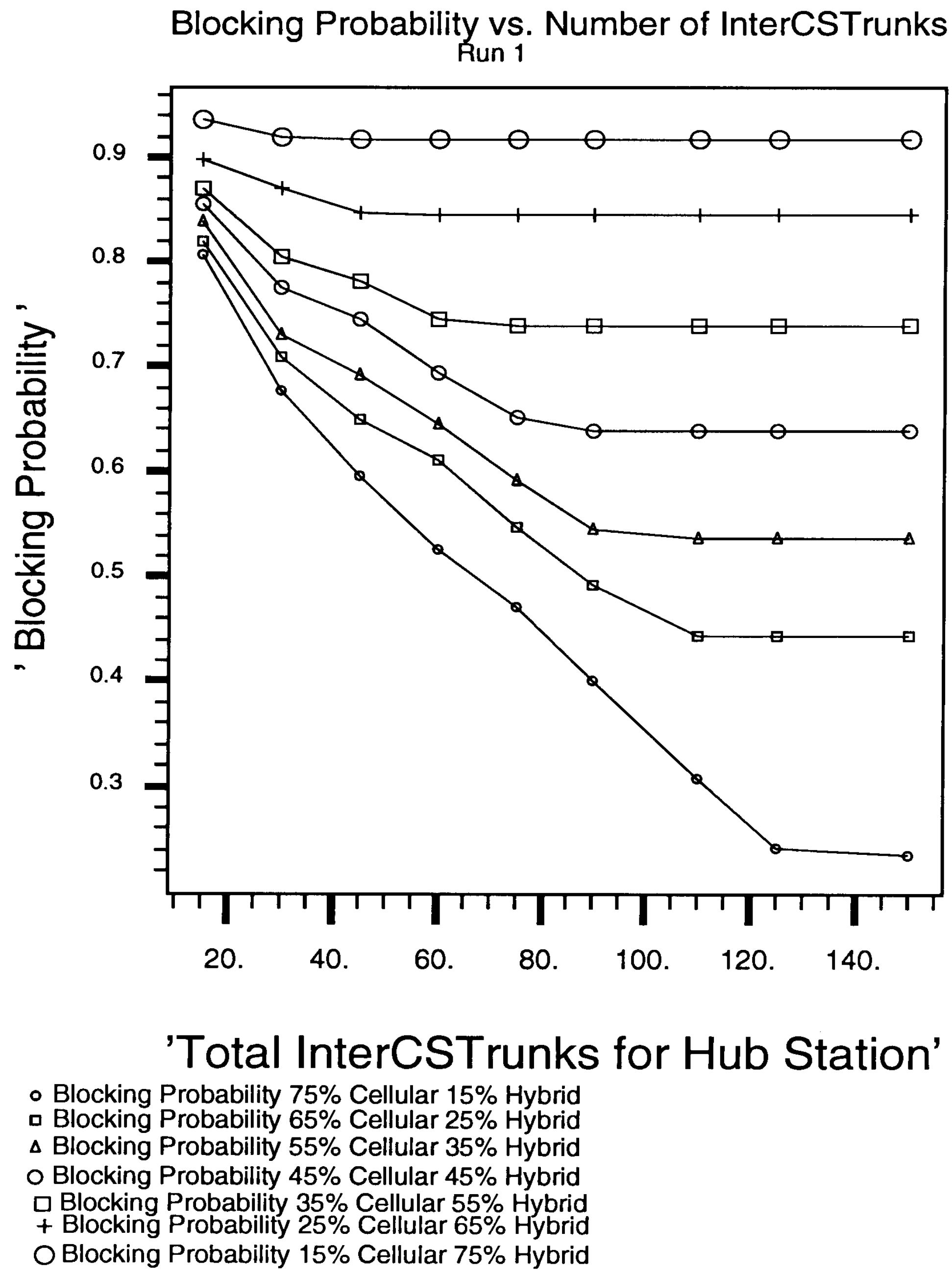
1) As the amount of InterCSTrunks capacity increase the probability of completing a handoff increases. This shows as the system capacity increases more channels are available for intersystem handoffs.

2) As the percentage of hybrid vs. cellular traffic increases the probability of completing a handoff increases. This shows that as the percentage of hybrid mobile users increases more of the intersystem handoffs requested are eligible therefore increase the probability of completing an intersystem handoff.

Graph 2 shows the blocking probability for access to the channel capacity available for completing an intersystem handoff. The channel capacity is a combination of the number of InterCSTrunks and satellite channels. It can be seen that as the number of InterCSTrunks increases that the blocking probability decreases because there is more system capacity for handling call attempts. Also, as the percentage of hybrid increases the blocking probability increases because you have a greater percentage of eligible users competing for the same resources. The blocking probability remains constant after a certain amount of InterCSTrunks because the satellite capacity is always fixed. This means that only part of the system capacity is increased therefore improving the blocking probability slightly.

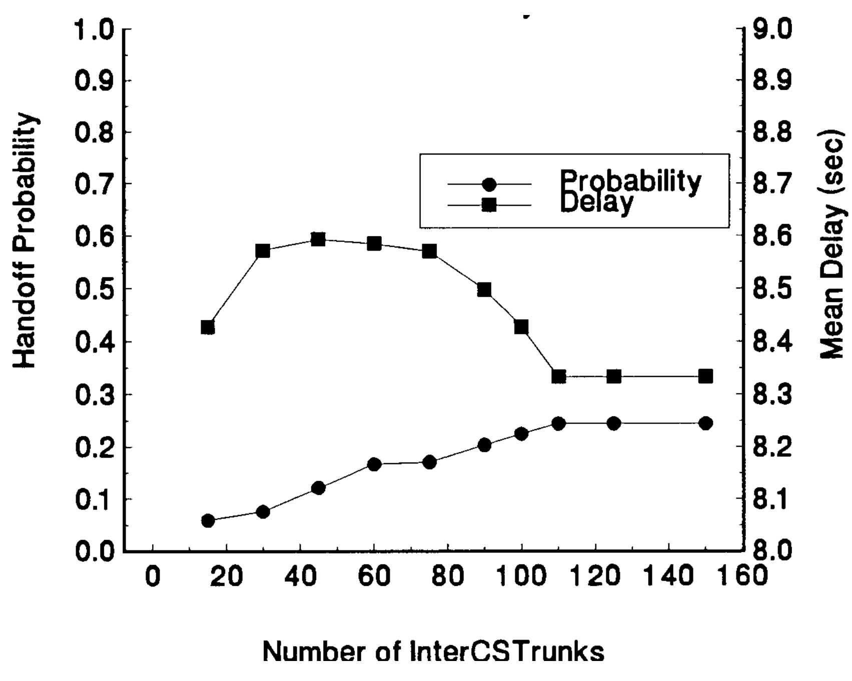


Graph 1. Intersystem Handoff Completion Probability



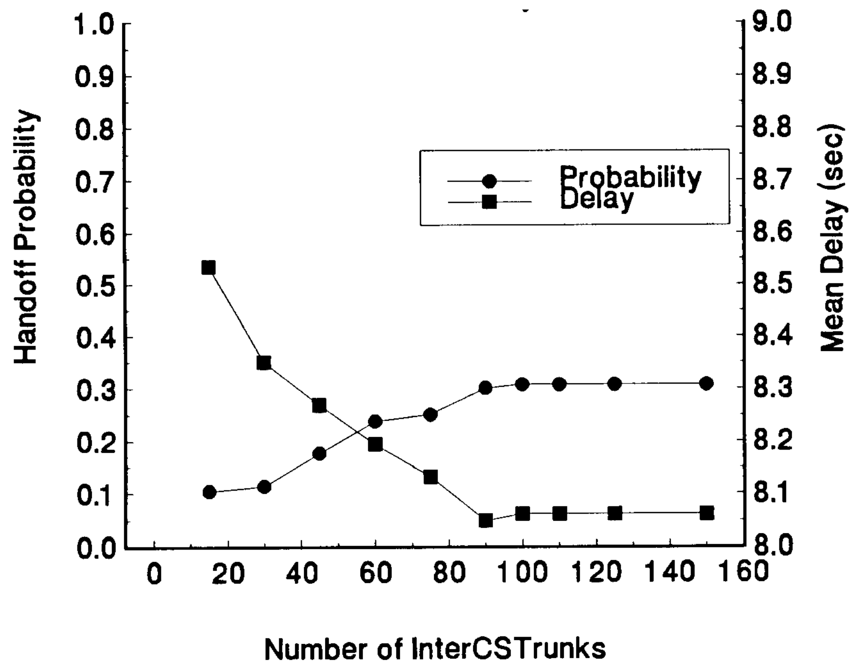
Graph 2. Channel Access Blocking Probability

Graph 3 - 6 shows the mean delay experienced by the percentage of users that completed an intersystem handoff vs. the amount of InterCSTrunks available along with the associated handoff probability graph for the specific percentages. By illustrating both graphs in a three dimension form aids in the interpretation of the simulation results for the mean handoff delay. The mean delay is dependent on the percentage mixture of cellular to hybrid mobile users, the handoff probability (which reflects the percentage mixture) and the capacity of the system. When the percentage of cellular mobile user is greater than the percentage of hybrid mobile user the mean handoff delay has similar curves. This is also the case when the hybrid mobile user percentage is greater than the cellular mobile user percentage. Due to this, only 4 combinations of cellular and hybrid mixture percentages.



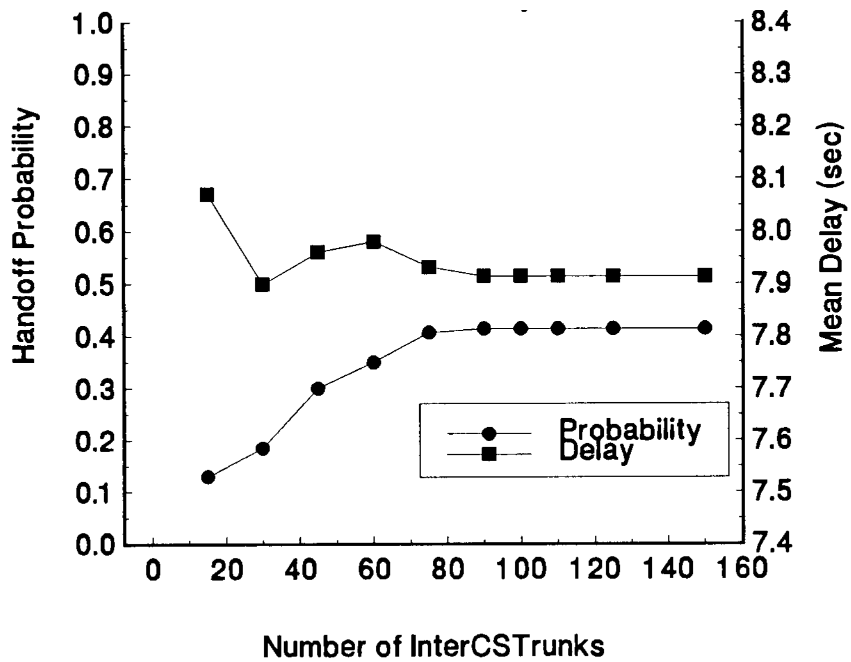
Graph 3. Mean Handoff Call Setup Delay

65% Cellular and 25% Hybrid



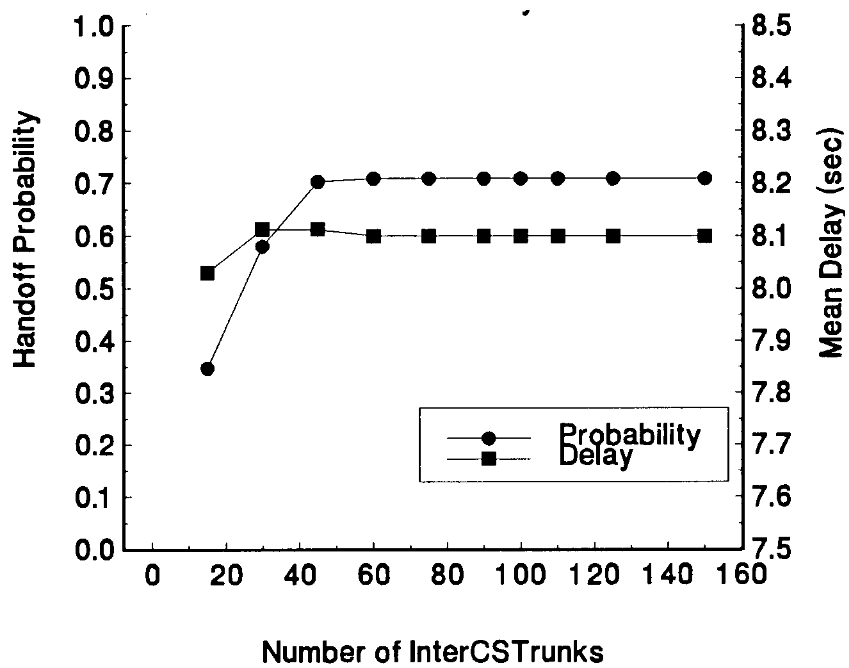
Graph 4. Mean Handoff Call Setup Delay

55% Cellular and 35% Hybrid



Graph 5. Mean Handoff Call Setup Delay

45% Cellular and 45% Hybrid



Graph 6. Mean Handoff Call Setup Delay

25% Cellular and 65% Hybrid

Chapter 5
Recommendations
and Future Growth

This chapter presents the methods for how the model can be used in aid the system development. The methods are based on the purposes of simulation model development. The recommendations focus on how the model is used to achieve studies and the future growth section presents methods on how to expand the model to extend into areas for more analysis.

5.1 Recommendations

The Hybrid Network System can be used in several scenarios. The main purpose of the model is to determine key performance measures. These measures include the handoff probability of completion, the mean delay experienced by mobile that complete handoff, and the blocking probability for the channel access with the "Handoff Mobile Unit CS 2" module. The model can be used to represent different combination of cellular mobile users and hybrid mobile users. These results are based on the assumption that the model is verifiable and can be validated against cellular or hybrid system data. For each variation of percentages, the model can be used to determine:

1. the probability of completing an intersystem handoff.
2. the mean delay experienced by mobile users completing an intersystem with more accurate delay times.
3. the blocking probability for channel access between the cellular and satellite system

4. the optimal number of channels at which a maximum probability of handoffs is achieved across all the combination of cellular and hybrid traffic.

This model can be used by cellular corporation or satellite corporations interested in analyzing a possible system. The model allows engineers options for several parameter combination, to analyze the system architecture using the quantitative data analysis.

5.2 Future Growth

Although the model covers a varied amount of options for providing simulations studies, additional improvements can be made to the model to allow more in-depth studies. There are several directions in which the model can be expanded. The areas of importance for growth of the model and its usage is presented here.

Initially, the current model can be expanded to include the error detection procedures explained in the IS-41.2-B specifications. With this expansion, the model will move toward more specific concepts in the specifications. The model will begin to represent the an idealized intersystem handoff operations.

Secondly, after error correction has been implemented, the model can be expanded to receive data from several different systems. Each system can also have the capability of the current system to control the percentages of cellular to hybrid mobile users. With the increase in traffic for other systems, the model can aid the analysis of the performance of the interaction between several cellular systems and the satellite system. The model will allow for the same type of measurements to be evaluated. This model will allow system developers to decide on optimal parameter combinations to achieve best system performance.

Finally, the model can be expanded to interact with the BONeS SatLab Low Earth Orbiting Satellite Tracker. Currently the model provides evaluations for geostationary satellite system combination. By interfacing the model with the SatLab satellite tracker, the model can be used to study a hybrid network in which the satellite system would be a LEO system. The SatLab tracker provides information of satellite locations and updates coverage zones that are seen by the satellites. It provides an interfaces to see where satellites are currently located as their positions are updated. The tracker also show visually, how many satellite are provided coverage to a particular area. The model would still evaluate the optimal parameter combinations and also allow for determining an optimal number of LEO satellites necessary for providing the best system performance.

Appendix A: System Parameters and Data Structures

System Parameters

Time To Stop Traffic -The time to stop generating traffic, i.e. mobile users.

Exp. Pulse Mean- The mean time between arrivals to create mobile users to enter the system.

Maximum Session Length - The maximum time (exclusive) of a mobile user's session length in seconds.

Minimum Session Length - The minimum time (inclusive) of a mobile user's session length in seconds.

Minimum Speed Limit - The lower limit (inclusive) on the mobile user's speed to be generated in miles per second.

Maximum Speed Limit - The upper limit (exclusive) on the mobile user's speed to be generated in miles per second.

Direction of Motion Options - The total number of choices the mobile users have when selecting the direction of motion. Direction of motion is a random number uniformly selected between 0 and this parameter, multiplied by 2pi and divided by the Direction of Motion Options parameter. Direction of motion for the mobile user is the radians of the angle between the direction of movement and the x axis.

Number of Hub Stations - the number of hub station to be created in the satellite network.

Total Number of InterCSTrunks - The amount of trunks available per hub station for conducting intersystem handoffs.

Total Channels for Hub Station - the amount of channels available per hub station for regular satellite call sessions.

Base Station Matrix Size - the square of this parameter is the total number of Base Stations

Distance Between Base Station (miles) - the distance between base stations in miles

Initial BS y_coordinate - the y coordinate of the initial base station

Initial BS x_coordinate- the x coordinate of the initial base station

Total Channels for Base Station- the number of channels available per base station.

Delta Time(seconds) - the time in seconds that the mobile user will be delayed.

Cellular Delay Lower Limit - the lower limit (inclusive) of the travel time of a message between the MSC and a mobile unit.

Cellular Delay Upper Limit - the upper limit (inclusive) of the travel time of a message between the MSC and a mobile unit.

X.25 Delay Lower Limit - the lower limit (inclusive) of the travel time of a message between the MSC and the satellite hub station.

X.25 Delay Upper Limit - the upper limit (inclusive) of the travel time of a message between the MSC and the satellite hub station.

Sat Session Delay - The time to delay satellite users equivalent to a period of simulation time.

TSTOP - the system parameter time to stop the simulation

Global Seed - the global random number seed used to generate random numbers.

Hybrid Mobile Unit-DS Attributes

base station ID - the ID of the base station currently serving the mobile user.

old base station ID - the ID of the previous base station that was serving the mobile user.

channel available? - the value of this field determines whether a channel has been assigned to the mobile user. There are 2 possible values: 1 implies a channel is available on the base station, a 0 implies there are no channels available, therefore the mobile user will be blocked.

direction: - the direction of motion of the mobile user. This field is given in the form of radians.

speed - the speed of the mobile user's motion in miles per second.

session length - the duration of the mobile user's session in seconds.

time to exit - the expected time for the mobile user to exit the system. It is the sum of the arrival time of the mobile user plus the session length. The mobile user time in system may terminate prematurely due to exiting the coverage area or being blocked.

total handoffs - the total number of handoffs a mobile user has had during the duration of its session. This includes intersystem handoffs.

hub station ID - the ID of the hub station selected to serve the mobile user.

MSC-SAT Channel available - same as channel available? in reference to InterCSTrunks.

Sat Channel available - same as channel available in reference to satellite channels

handoff init time - the time the mobile user's handoff attempt was initiated.

handoff complete time - the time the mobile user's handoff attempt was completed if the mobile user was successful.

Base Station Unit-DS Attributes

base station ID - the ID number of base station, beginning at 0 and increasing by one.

x_coordinate - the x_coordinate of the base station.

y_coordinate - the y_coordinate of the base station.

channels available - the number of channels available on the base station.

channels used - the number of channels being used on a base station.

Hub Station Unit-DS Attributes

hub station ID - the ID number of hub station, beginning at 0 and increasing by one.

x_coordinate - the x_coordinate of the hub station.

y_coordinate - the y_coordinate of the hub station.

channels available - the number of channels available on the hub station

channels used - the number of channels being used on a hub station.

InterCSTrunks available - the number of channels available on the hub station

InterCSTrunks used - the number of channels being used on a hub station.

Appendix B: Cellular Radio Telecommunications Intersystem Operation IS-41.2-B

The appendix presents a partial handoff excerpt from the Cellular Radio Telecommunications Intersystem Operation IS-41.2-B. Figure C.1 presents a representation of the intersystem handoff process. The process of the IS-41.2 Intersystem Handoff Operation is taken from the documentation specification Interim Standard 41.2-B Cellular Radio Telecommunications Intersystem Operations: Intersystem Handoff.

The Intersystem Handoff process is as follows:

Location Phase:

Handoff Measurement Request.

If a serving MSC elects, using internal algorithm to determine if a handoff to Candidate MSC is appropriate, the Serving MSC may initiate a Handoff Measurement Request INVOKE to the Candidate MSC (the serving MSC may send several handoff measurement requests to different candidate MSCs):

1) Send a Handoff Measurement Request Invoke.

2) Set Location Measurement Maximum Response Timer (LMMRT)

3) While timer (LMMRT) has not expired:

  a) if Handoff Measurement Request Return Result is received:

    Stop Timer

    Exit this task and process the measurement response in accordance to MSC's internal algorithms.

4) If (LMMRT) expires:

  a) Exit this task and process the measurement response in accordance with the MSC's internal algorithms.

Handoff Measurement Reply

If a Handoff Measurement Reply Invoke is received:

1) Identify the Candidate Cell Sites corresponding to the Serving Cell Site specified in the Handoff Measurement Request Invoke.
2) Perform location measurements in accordance with the MSC's internal algorithm.
3) When all expected internal responses are received:
    a) If the best candidate cell site does not meet quality criteria of the Candidate MSC, the Candidate MSC may elect to end the location process and exit this task.
    b) Otherwise, convert the location quality values to the appropriate "signal quality" parameter values with respect to the candidate cell's power levels and station class marks.
    c) Return a Handoff Measurement Request to the Serving MSC, and exit this task.

Handoff Phase:

Serving MSC Initiation of a Handoff:

The Serving MSC shall determining if the call should be handed off using the MSC's internal algorithm.

If the Serving MSC elects to handoff the call to the Target MSC, it should perform one of the following:

1) If the Target MSC is the same MSC to which the Serving MSC is connected via the inter-MSC trunk for that call, then the Serving MSC initiates a Handoff Back (See Section 4.2.1.1 of IS-41.2-B, this option

is not implemented in the Hybrid Network Model for the case of satellite to cellular)

2) If the Target MSC is not the same MSC to which the Serving MSC is connected via the inter-MSC trunk for that call, then the Serving MSC initiates a Handoff To Third (See Section 4.2.1.2 of IS-41.2-B, this option is also not implemented in the model) or Handoff Forward (this option is the option that the intersystem handoff logic for the Hybrid Network Model is implemented according to.)

Serving MSC Initiation of a Handoff-Forward

1) Examine the InterSwitchCount parameter to determine if a handoff is permitted. If InterSwitchCount value at the Serving MSC is not less than MAXHANDOFF

    a) Exit this task and continue to process other potential handoff candidates.

2) Allocate an inter-MSC trunk:

    a) If inter-MSC trunk is not available:

    Exit this task to process other potential handoff candidates

3) Set the Handoff Order Timer (HOT)

4) Send a Facilities Directive Invoke to the Target MSC

    a) If the Serving MSC is the Anchor MSC:

    Set the value of the InterSwitchCount parameter transmitted in the message to 1.

    Set the value of the Segment Counter of the BillingID parameter as follows:

    - If this is the first handoff segment, set the value to 0.

- If this is not the first handoff segment, set the value to be the same as the value stored in the BillingID.

b) If the Serving MSC is not the Anchor MSC:

Set the value of the InterSwitchCount parameter transmitted in the message to the value of InterSwitchCount stored at the Serving MSC with an increment of 1.

Set the value of the Segment Counter of the Billing ID parameter to be the same as the value stored in the BillingID.

5) While time (HOT) has not expired:

a) If a Facilities Directive return error is received :

Stop time (HOT)

Execute recovery procedures for the Serving MSC

Exit this task.

b) If a Facilities Directive return result is received:

Stop timer (HOT)

Set the Mobile Handoff Order Timer (MHOT)

Send Cellular Subscriber a Handoff Order.

c) If a Mobile On Channel Invoke is received for the Target MSC:

Stop Time (MHOT)

Connect the call path to the interMSC trunk

Exit this task

d) If the (MHOT) timer expires:

Release associated inter-MSC facilities

Execute recovery procedures for the Serving MSC.

Exit this task.

6) If the (HOT) timer expires:

Release associated inter-MSC facilities

Execute recovery procedures for the Serving MSC.

Exit this task.

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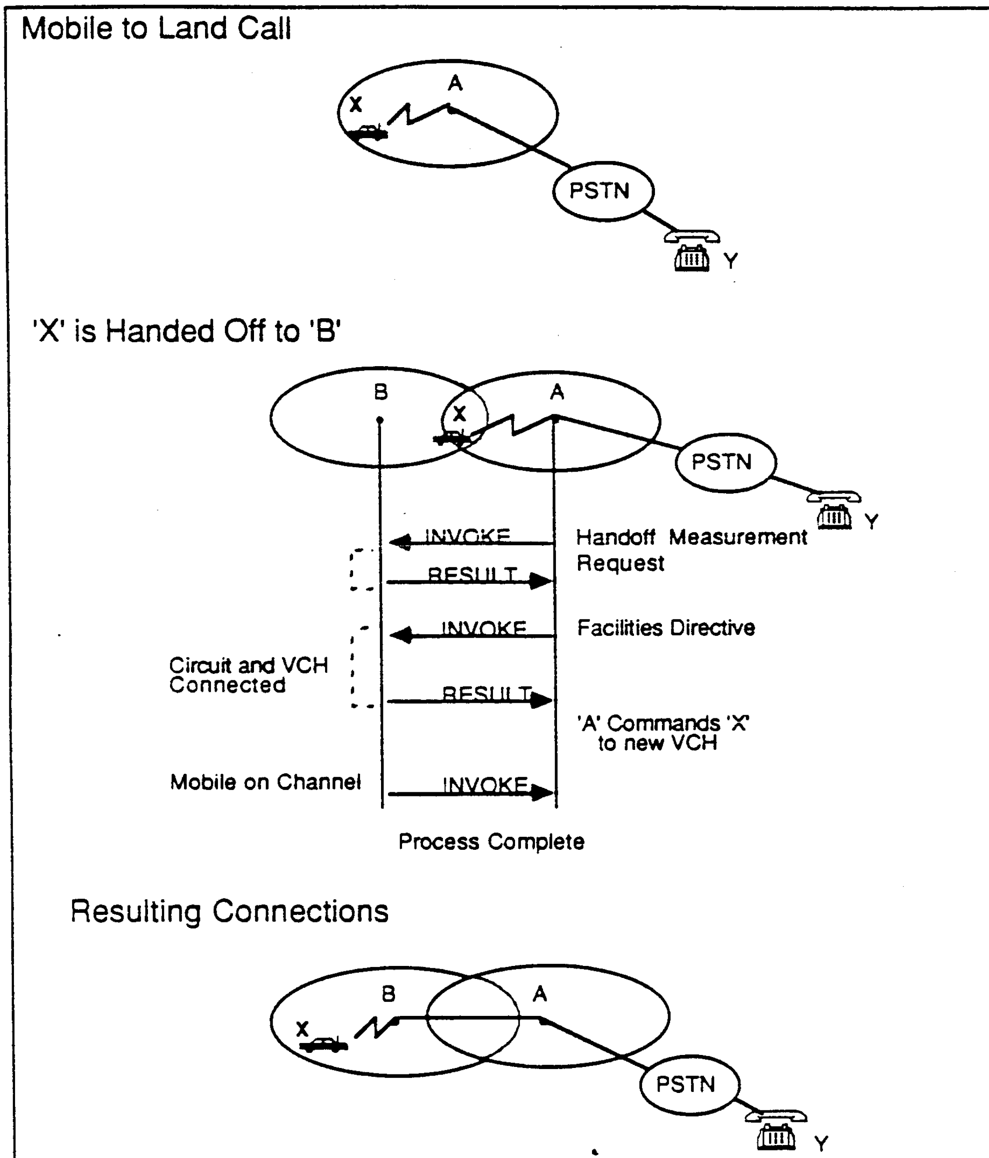

Figure 1. Mobile to Land Call: Handoff-Forward is performed on X from MSC-A to MSC-B.

This is provided to illustrate the basic procedures required to facilitate a Handoff-Forward.

Figure B.1 IS-41.2-B Intersystem Handoff Procedures

Appendix C: Systems Engineering Approach

This a pictorial view of the stages of the systems engineering approach.

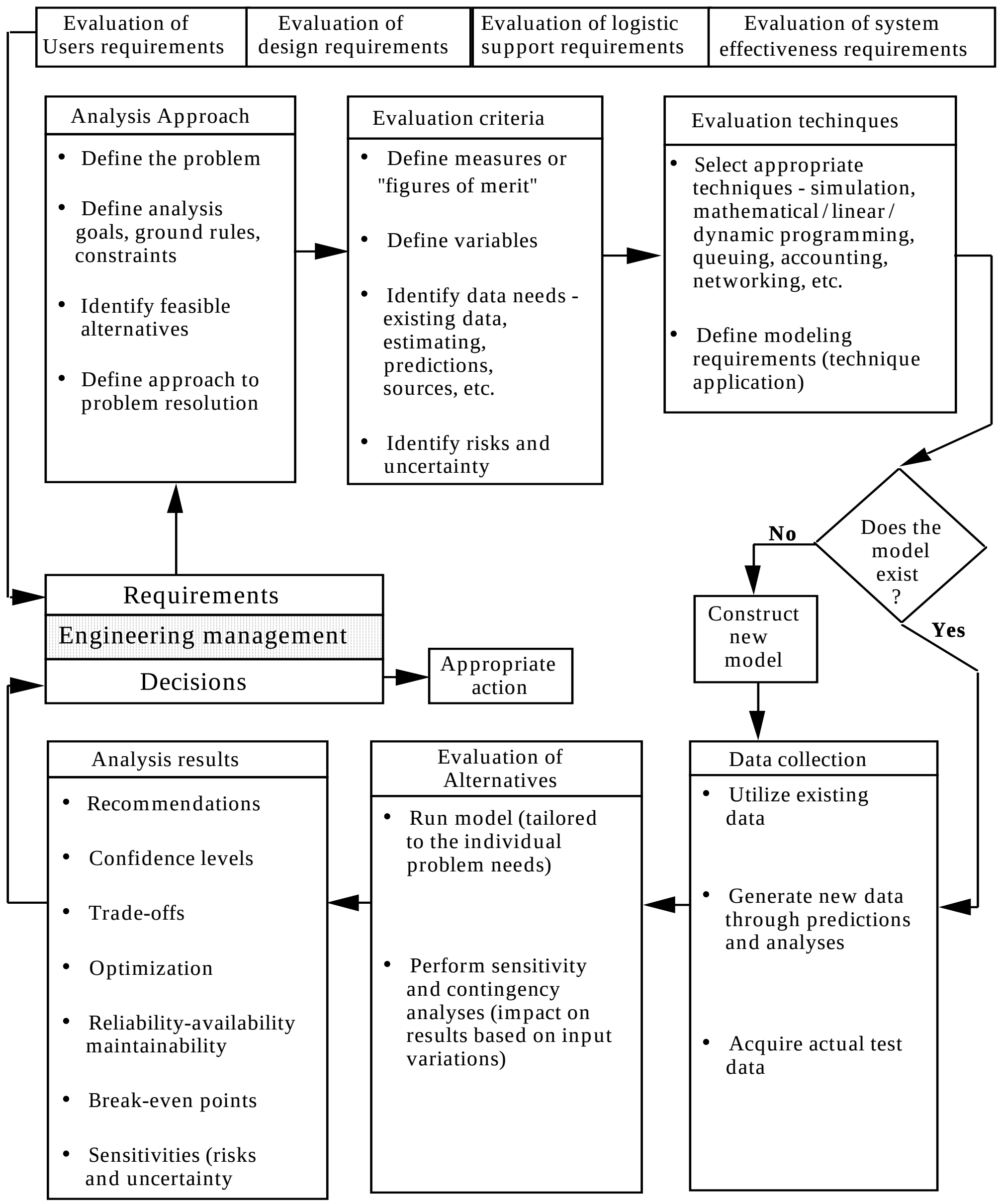

Figure C..1 The systems analysis process (Blanchard and Fabrycky, 1985)

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