MSAT and Cellular Hybrid Networking

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ABSTRACT

Westinghouse Electric Corporation is developing both the Communications Ground Segment and the Series 1000 Mobile Phone for American Mobile Satellite Corporation's (AMSC's) Mobile Satellite (MSAT) system. The success of the voice services portion of this system depends, to some extent, upon the interoperability of the cellular network and the satellite communication circuit switched communication channels. This paper will describe the set of user-selectable cellular interoperable modes (cellular first/satellite second, etc.) provided by the Mobile Phone and described how they are implemented with the ground segment. Topics including roaming registration and cellular-to-satellite "seamless" call handoff will be discussed, along with the relevant Interim Standard IS-41 Revision B Cellular Radiotelecommunications Intersystem Operations and IS-553 Mobile Station - Land Station Compatibility Specification.

INTRODUCTION

According to Frost and Sullivan International, in 1996 terminal sales for mobile satellite communications are expected to increase to $1 billion, with annual service revenues surpassing more than $472 million [1]. This will occur because we live in an information starved society that needs a means of seamless communications for land, sea, and air. Our current terrestrial cellular network covers significant portions of the United States and, although Inmarsat covers most of the planet, cost for terminals and service are excessive for many applications. For example, the least expensive Inmarsat voice terminal is the $15 thousand Standard M terminal with a $5.50 per minute phone rate [2].

The solution to this dilemma is a system that will provide both cellular and satellite coverage with user-selectable priority modes to determine which system has communications priority and under what circumstances, if any, a handoff to the backup system will occur. This is accomplished with a mobile phone tranceiver that contains both MSAT and cellular interactive equipment. The mobile must allow mode programming from the user handset and be capable of monitoring the status of either network. Then, the mobile phone can process status to generate registrations on the appropriate network or seamless call handoffs between networks.

This paper will discuss the details of MSAT and cellular interoperability by describing the five Series 1000 Mobile Phone modes of operation. The cellular only and MSAT only modes first must be described in enough detail to be referenced by the three hybrid modes. The hybrid modes, including MSAT Priority with Cellular Backup, Cellular Priority with MSAT Backup, and Cellular Home Location Register (HLR) Priority with MSAT Backup, will explain how similarity and flexibility between the MSAT and cellular networks allow an intricate scheme of priority allocation and handoff.

CELLULAR ONLY MODE

For day to day mobile voice communications in urban or suburban environments, cellular communications may be the network of choice. Cellular coverage is complete in most metropolitan areas and offers the most cost effective interface to the Public Switched Telephone Network (PSTN). In addition, a terrestrial network such as cellular eliminates the propagation delay associated with satellite communication (.25 seconds for a geostationary satellite). Thus, an individual confined to a metropolitan environment and performing voice communications may chance the dropped calls associated with cell to cell handoff and select the

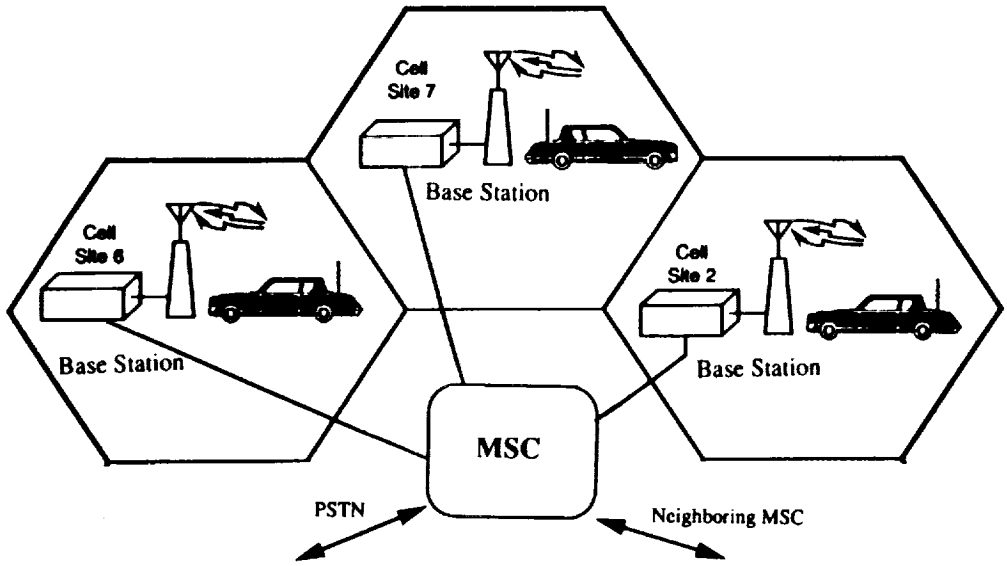

Figure 1: Cellular Network

cellular only mode.

The cellular network consists of a network of switches connected to the PSTN. These switches mimic the operation of PSTN End Office (EO) switches where calls routed throughout the PSTN are terminated and connected to the users. In the cellular network, all calls between a PSTN subscriber and a cellular mobile phone are still routed through the PSTN. The added feature is that the call terminates at a cellular Mobile Switching Center (MSC) which controls and connects directly to a network of cells encompassing and defining the MSC's region of coverage (Figure 1). Adjacent regions of cells are controlled by different MSC's. These cells contain base stations that provide the microwave links to the cellular mobile phone and T-1 trunks to shuttle this information to the MSC.

Upon mobile power-up, the cellular phone scans the preassigned control channels and locks onto the strongest channel which connects to the MSC through the control channel's base station. If the mobile phone is registered in the MSC's Home Location Register (HLR) database, all necessary information is already present to allow subscribed features like call waiting or conference calling to be implemented. If the mobile phone registers as a roamer in a visiting MSC, the visiting MSC requests permission for registration from the home MSC. Then, the mobile's status will be contained in the visiting MSC's Visitor Location Register (VLR) database. All PSTN calls, which are automatically routed to the home MSC, now will be forwarded to this visiting MSC.

Upon reply to a paging request or in response to a call initiation, the serving MSC will allocate a free voice channel from the mobile phone's resident cell. The forward and reverse voice channels contain enough bandwidth (20 kHz each) to allow transmission of voice and either status control data or Supervisory Audio Tones (SAT) and signalling tones.

As a mobile phone engaged in a conversation travels between cells, a seamless handoff process is required (Figure 2). Once the SAT tones transponded by the mobile phone are received by the MSC with less power than a predetermined handoff threshold, the MSC sends a Measurement_Request_Invoke message to the target (neighboring) MSC using an IS-41 data link. This command includes information regarding the serving cell and channel of the mobile phone. The target MSC then commands all cells within proximity to the mobile's cell to read and report the received SAT power level. The target MSC assimilates the readings and responds with a Measurement_Request_Return_Result message to submit the signal quality of a potential target cell. The serving MSC then determines that the target MSC contained the cell with the strongest reception, so it sends the target MSC a Facilities_Directive_Invoke message to indicate the source and destination cells and the mobile phone's identification. The serving MSC also uses this opportunity to allocate the specific voice trunk channel between the two MSC's to establish a connection between the PSTN and target MSC through the serving MSC. The target MSC responds with a Facilities_Directive_Return_Result message which includes an allocated voice channel for the mobile phone and requests SAT. The serving MSC relays this status information to the mobile on the control portion of its voice channel. The mobile then acknowledges with a signalling tone and retunes to the new channel.

The target cell began sending SAT on the new voice channel after transmission of the Facilities_Directive_Return_Result message, so the mobile phone tunes to this SAT and transponds it back to the target cell to indicate a successful handoff. This causes the target MSC to send a Mobile_On_Channel_Invoke message over the IS-41 link to the serving MSC. Upon reception of this message, the serving MSC switches the PSTN connection from the serving cell to the target MSC. The target MSC then allows full voice communication through the target cell to the mobile phone. Communications will occur on this cellular voice channel until the next handoff or until an on hook is noticed by a loss of SAT.

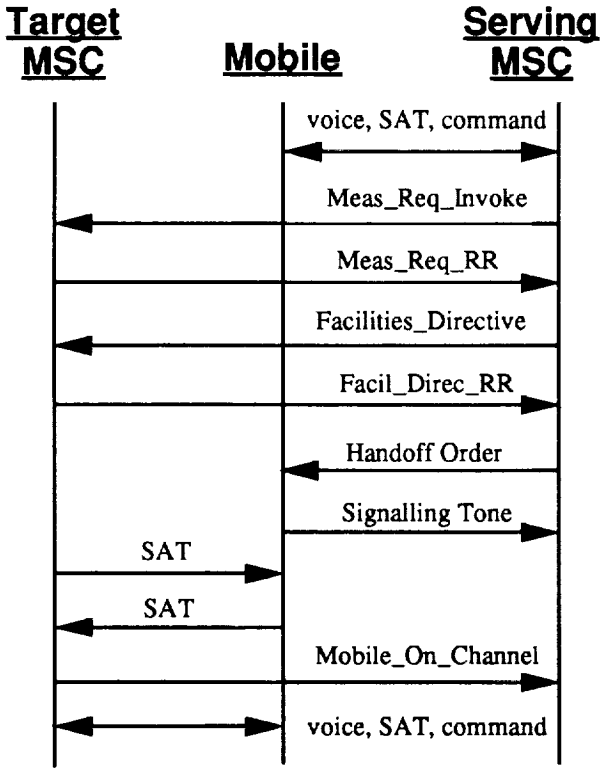

Figure 2: Cellular Call Handoff

MSAT ONLY MODE

Many applications for MSAT, including marine, airborne, rural, fax, and data communications, are difficult for cellular communications. In these circumstances, MSAT is the most consistent and possibly the only means of mobile communications to the PSTN. To avoid the added processing of hybrid modes, a user may choose to use the MSAT, only. He or she may not even purchase the optional cellular hardware.

The MSAT network consists of a Feederlink Earth Station (FES) that supplies all communication channels to the mobile phones via a geostationary satellite and allows communications to the PSTN through a Gateway Switch (GWS) that operates similar to an MSC. All allocations are controlled by a Network Control Center (NCC) that performs all processing and maintains all control channels (Figure 3). As the system expands, more satellites and FES's may be added.

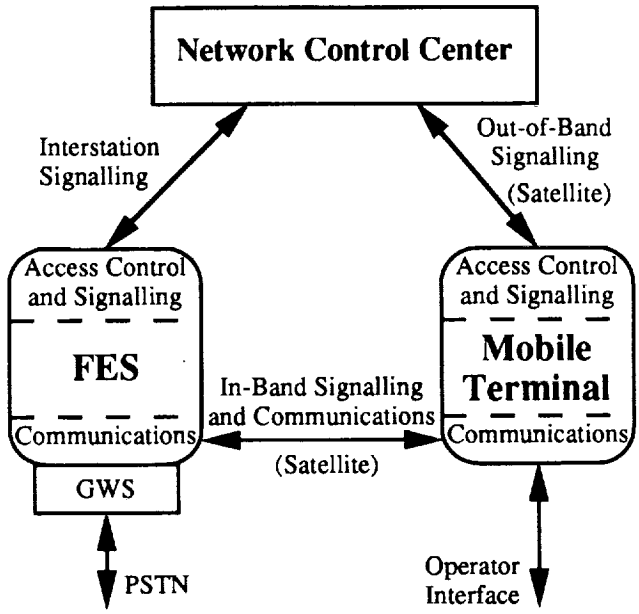

Figure 3. MSAT System Architecture

Upon power-up the mobile phone must find a control channel by first checking its previously assigned satellite beam, and if inaccessible, checking other beams. Before the mobile may access the system, it must read and update all system information from the control channel which includes congestion and configuration information. The mobile phone stores control channel and beam information in its non-volatile memory, and if a new channel is required, the mobile must perform a log-on procedure which tells the NCC who the mobile phone's identity and configuration.

At this point, the mobile phone is ready to make or receive phone calls. The structure of the MSAT system is similar to the cellular system because both contain separate control and voice channels with roaming information passed over the control channels and in-call information multiplexed over the voice channels. The main difference is that MSAT's voice channels cover thousands of square miles with beam overlap eliminating the need for a live-call handoff. Also, voice channels use Time Division Multiplexing (TDM) for control data and replace the SAT tone with a periodically required TDM unique word.

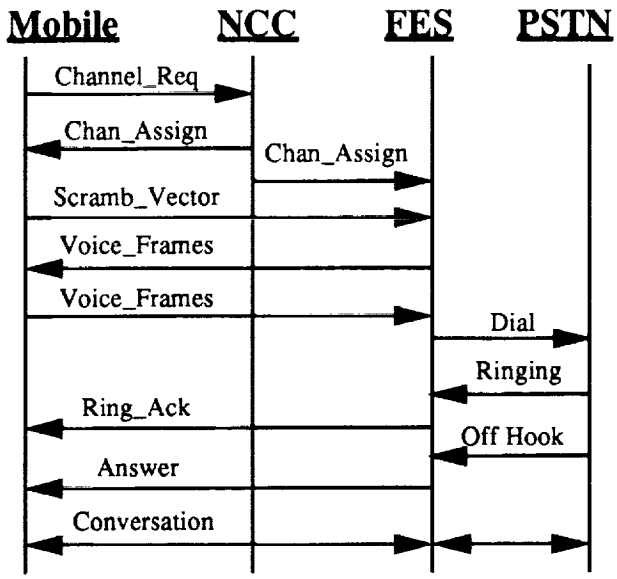

Figure 4: Mobile to PSTN Call Setup

When the mobile phone initiates a call (Figure 4), the called digits are sent with the mobile's identification to the NCC to request a voice channel. The NCC validates the identification number and assigns the voice channel for the mobile phone and the FES completes the call set up. The mobile phone then sends its security key and scrambling vector to the FES to verify database continuity and avoid fraudulent access. The FES and mobile then exchange voice frames containing off hook supervisory information causing the mobile to switch to voice mode. At this point, the FES dials the number through the PSTN and receives a response from the PSTN including ringing, busy, or operator recordings. The FES sends the response to the mobile phone which is passed to the user since the mobile phone is in voice mode. An off hook response from the PSTN to the FES causes the FES to change state to 'In Conversation' and requests a similar response from the mobile by sending an 'answer' unique word on the command portion of the voice frame. Conversation continues between the mobile phone and FES to the PSTN until a call release is issued by either party.

When a PSTN call is routed to the FES (Figure 5), the FES rings back the caller and requests a channel from the NCC which validates the mobile phones's identification number and determines its control channel. The NCC then verifies the mobile phone's availability by sending a call announcement to the mobile phone. The NCC validates the mobile based on its response and assigns the voice channel to both the mobile phone and the FES. The mobile phone retunes to the voice channel and sends its scrambling vector and access security key to the FES to be verified and allow secure, non-fraudulent communications. The mobile phone then switches to voice mode and conveys the ringing tone from the FES voice frames to the user. The mobile phone acknowledges the receipt of ringing to the FES, and once the user answers the phone, voice frames are sent to the FES with an 'off hook' unique word causing the FES to establish a voice connection between the two users. Conversation continues until a call release is issued by either party.

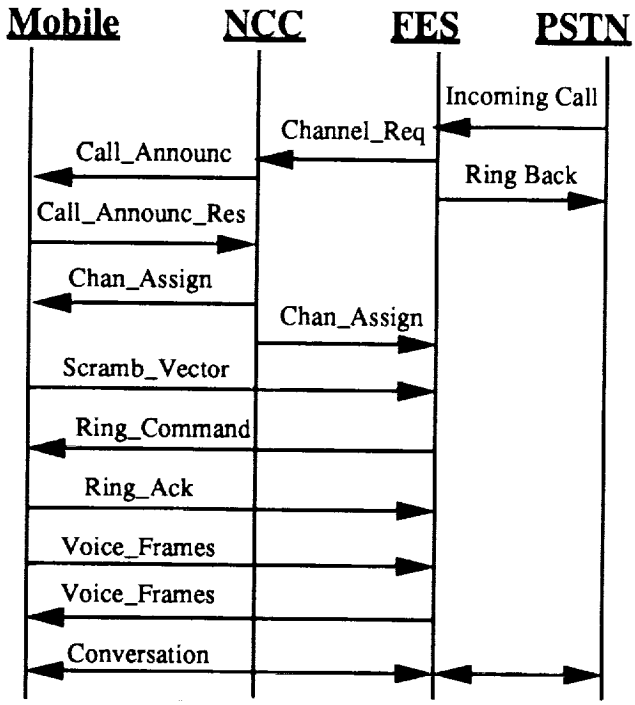

Figure 5: PSTN to Mobile Call Setup

When either the mobile phone determines that the user has hung up or the FES determines that the PSTN user has hung up, an 'on hook' unique word is sent on the voice control channel to request a call termination.

MSAT PRIORITY, CELLULAR BACKUP MODE

If a user is predominantly in a rural environment but occasionally visits urban areas, MSAT would be the preferred means of coverage but cellular would provide a potential redundancy. A user also may prefer the consistency of satellite coverage and only want cellular coverage as a backup to assure continuous communications availability. Every cell to cell handoff in the cellular network introduces a slight risk of dropping the call, so a user may prefer the consistency of a single satellite beam spanning thousands of square miles. If the user travels through a city where large buildings block the mobile phone's view of the satellite,

satellite coverage may temporarily wane and the cellular backup can be used.

Once the mobile phone is powered up, it attempts to operate in MSAT as described earlier. If all attempts to obtain a control channel fail or the MSAT refuses service based on the mobile's status or erroneous operation, the mobile phone automatically switches to cellular operation. If the mobile phone attempts to make a phone call and cannot obtain a voice channel, it will automatically switch to cellular mode and attempt the same phone call over the cellular network. Finally, if the mobile phone is roaming and notices loss of access to the control channel, it will attempt to find a new control channel, and if none exist, it will register on the cellular network. Once in the cellular system, the mobile phone will continually monitor the MSAT control signals and will periodically attempt to re-register on MSAT if a control channel is present.

Registration and re-registration is possible between these two systems because the GWS appears to be another MSC to the cellular network. When using MSAT, the HLR thinks that the mobile phone is in a VLR. When communications is lost with the satellite, the cellular transceiver attempts an autonomous registration which is received by the resident MSC and sent to the HLR. The HLR previously registered the mobile phone with the VLR in the GWS. Then, the HLR updates the database with the location of the resident MSC to allow all phone calls to be routed to this MSC rather than the GWS. The HLR treats the whole operation as if a cellular mobile just traveled from the coverage of one MSC to another. When the satellite coverage returns, the cellular portion of the mobile phone stops operating and the mobile phone registers with MSAT. This causes the GWS to send a registration notification to the HLR to re-register the mobile phone with the VLR of the GWS. This process also appears to be a cellular autonomous registration to the HLR. At this point all calls will be rerouted to the GWS from the HLR.

If a mobile phone roams into cellular coverage and then initiates a phone call, the MSC will determine network coverage. If the cellular call begins to fade, a seamless in-call handoff back to MSAT may be initiated. The details and occurrences of this seamless handoff are covered in the next mode and in figure 6.

While the satellite portion of the mobile phone is registered on the MSAT, the cellular portion of the mobile phone cannot independently register on an available MSC. This would cause the HLR to believe a mobile phone is fraudulently accessing the cellular network. From the HLR's point of view, the mobile phone is registered in one VLR (the GWS) and another mobile phone is trying to use the same mobile identification to register on another MSC. At this point, the home MSC would cancel both registrations. Without being able to register in the cellular network while being registered on MSAT, handoff from MSAT to cellular is impossible because the cellular network has no idea where the mobile phone is located or with which cell to establish registration. Consequently, MSAT to cellular in-call seamless handoffs are impossible without significantly changing the operation of the cellular network. To avoid this, once a call is in progress on the satellite, no seamless handoffs to the cellular network will be allowed. Instead, if satellite coverage wanes during a phone call, the call will be dropped and then the mobile phone will autonomously register on the cellular network.

CELLULAR PRIORITY, MSAT BACKUP MODE

Of the three hybrid modes, this mode should be the most common. This mode allows a cellular user to fortify communications capabilities by allowing regular cellular operation with a satellite fall-back if cellular coverage degrades. This mode allows roaming analysis and registration similar to the methods of MSAT Priority with Cellular Backup, but this mode also allows seamless call handoff from cellular to MSAT during a phone call as cellular coverage wanes. Thus, the user, who is typically covered by cellular coverage but wants redundancy to patch the gaps in the cellular network, can maintain continuous communications coverage.

As mentioned previously, this mode allows a roaming mobile phone to analyze its coverage, and when the coverage degrades, switch to the other system. This uses the same principles as the satellite priority mode except the cellular service has priority, so if cellular coverage wanes and the mobile phone reverts to MSAT, the cellular coverage must be periodically tested to determine the ability to re-register. The process of registering on cellular is the same as with the satellite priority mode. The only difference is that the mobile phone will attempt registration on an MSC before resorting to a GWS.

The new concept introduced by this mode is the seamless call handoff. Since internal MSC cells have coverage overlap, any situation extensive enough to cause a cellular call to be dropped would not allow a seamless handoff to MSAT; whereas, the MSC's border cells present a situation where a mobile phone gradually leaves coverage. Consequently, the MSC is equipped with provisions, including inert cellular handoff channels, to provide seamless handoff from these border cells when cellular coverage is waning and another cell cannot receive the handoff. These inert channels are cross referenced with each border cell such

that the channels are considered acceptable by the MSC but are used by cells distant enough from the serving cell to avoid any possible contention during the handoff process.

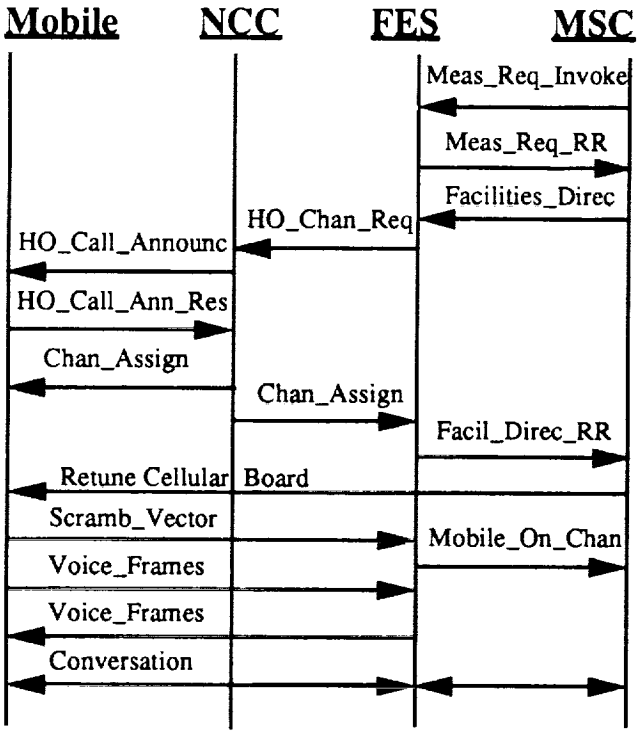

Figure 6: Cellular to MSAT Handoff

The ladder diagram (Figure 6) indicates that the cellular to MSAT handoff is a combination of MSC to MSC handoff (Figure 2) and PSTN to mobile call setup (Figure 5). This process succeeds in convincing the mobile that it is receiving a new phone call on the MSAT while convincing the serving MSC that it is handing off to a stronger target MSC. All can be accomplished with a single phone number shared between the cellular and MSAT networks.

Consistent with IS-41, the serving MSC begins searching other cells and neighboring MSC's whenever SAT degrades below a threshold. All MSC's will be fitted with software to petition the GWS whenever the border cells attempt handoff. The GWS will return the minimum value allowed by an MSC without deeming a call as lost, thus giving the adjacent MSC's top priority. If this nominal value is strongest, the mobile phone and MSAT perform call setup to assign a satellite voice channel. When the FES receives its channel, it sends a Facilities_Directive_Return_Result to the serving MSC to request the cellular portion of the mobile to change channels. This new cellular channel is inert but accommodates transparency with the MSC. Upon verifying the scrambling vector information, the FES requests activation of the voice trunk from the serving MSC to the GWS to allow connectivity from the MSAT voice channel to the PSTN through the MSC. After the FES and mobile phone exchange voice frames, they both switch to voice mode and allow conversation. The handoff is complete.

CELLULAR HLR PRIORITY, MSAT BACKUP MODE

This mode is similar to Cellular Priority with MSAT Backup except roaming in a visiting MSC is avoided. The mobile phone will monitor its location, and if it is roaming and notices a pending registration on a visiting MSC, the mobile phone will cease cellular activity and register on the MSAT. Consequently, the user will minimize cellular roaming charges and still enjoy continuous coverage. The mobile phone will periodically sample the cellular network to determine whether it has returned to the home MSC. If so, cellular registration will be reinitiated.

If the mobile phone leaves the HLR during a phone call, the HLR will petition to handoff to a VLR as well as MSAT. This is similar to the regular cellular priority mode to minimize call disruption. If registered in the VLR upon completion of the call, service immediately will be transferred to MSAT. Thus, this mode has unique roaming functions, but operates similar to the standard cellular priority mode during a call.

CONCLUSIONS

The current communications market has dynamic needs which are satisfied only partially by any given communications system. To better match society's communications needs with networks of varying cost, topology, features, and performance, hybrid networking is the obvious solution. By introducing interoperability to networking, the users will reap the benefits of diversity. MSAT was developed with cellular interoperability considerations lending toward an integrated system of national connectivity, inexpensive urban voice communications, and high speed data communications.

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Session 5
Advanced System Concepts and Analysis—I

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(continued)