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Integration of Mobile Satellite and Cellular Systems

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ABSTRACT

By integrating the ground based infrastructure component of a mobile satellite system with the infrastructure systems of terrestrial 800 MHz cellular service providers, a seamless network of universal coverage can be established. Users equipped for both cellular and satellite service can take advantage of a number of features made possible by such integration, including seamless handoff and universal roaming.

To provide maximum benefit at lowest possible cost, the means by which these systems are integrated must be carefully considered. Mobile satellite hub stations must be configured to efficiently interface with cellular Mobile Telephone Switching Offices (MTSOs), and cost effective mobile units that provide both cellular and satellite capability must be developed.

INTRODUCTION

Commercial cellular systems have been in operation in North America for over ten years. Coverage has extended beyond urban centers to rural areas, with more territory falling under cellular coverage each year. Nonetheless, there are still vast stretches of land without cellular coverage in North America, and in many parts of the world cellular is limited to the largest cities.

A number of satellite systems have been proposed to provide mobile telephone service to remote areas of land as well as to ocean and airborne traffic. Because each of these is to a certain extent limited in capacity, it makes sense to use cellular, where it is available, for mobile traffic and to limit the use of mobile satellites to other locations. Current technology allows for very small, lightweight, and inexpensive cellular mobile terminals, so that adding cellular capability to a mobile satellite terminal should not pose a significant penalty. Integration of the cellular and satellite infrastructure systems will provide to the suitably equipped user the ability to operate without coverage boundaries, and to roam anywhere while receiving and making calls in a truly seamless network.

MOBILE TERMINAL ARCHITECTURE

To operate in both satellite and cellular systems, a mobile terminal must, of course, include radio equipment compatible with both. While some mobile unit baseband processing functionality, such as speech codecs, may be common for the two systems, the antenna and radio frequency (RF) portions will likely be so dissimilar as to require separate mobile hardware. This requirement suggests an architecture for dual mode satellite/cellular mobile terminals as shown in Figure 1.

A single handset/control unit, along with suitable system operating protocols, allows for a single user interface, both in terms of hardware and functionality. From the user's standpoint, operating procedures in satellite and cellular systems can be identical.

A common controller manages the interface to both the satellite and cellular transceivers and houses common functional components such as, possibly, the crystal frequency standard, baseband processing, repertory dialing memory, etc.

The cellular transceiver may operate using one or more of the North American or international analog or digital cellular standards. For reasons examined below, the cellular transceiver must be capable of operating in the cellular "idle" mode even while the satellite transceiver is in conversation mode.

The mobile satellite transceiver must be capable of "idle" mode operation even while the cellular transceiver is in conversation mode. It must also be capable of determining at any time the presence or absence of suitable satellite coverage.

INFRASTRUCTURE INTEGRATION

Calls to and from mobile satellite terminals are interconnected to the public switched telephone network (PSTN) at one or more satellite hub stations (SHS). Calls to and from cellular mobile terminals are interconnected to the PSTN at a mobile telephone switching office (MTSO). To support seamless handoff to and from cellular, the SHS must be connected to the MTSO by dedicated voice trunks. This is because the PSTN does not support rerouting of calls in progress. A call that originates on cellular, through an MTSO, will have to continue to be interconnected to the PSTN through that MTSO even after it is handed off to the satellite system.

To provide the connectivity required for satellite/cellular handoff, the SHS may appear to the cellular system either as an MTSO or as a cell site.

Hub Station as MTSO

Figure 2 illustrates the connection of an SHS as an MTSO. Connection to various MTSOs serving areas subtended by the satellite service is by IS-41 handoff links. "IS-41" refers to the industry standard that governs intersystem operation, including MTSO-to-MTSO handoff, for North American cellular systems.

Using this configuration, calls originated through the SHS would be handed off to cellular through the use of a voice trunk on the dedicated handoff link connecting the SHS to the "target" MTSO. Similarly, calls originated through an MTSO would be handed off to satellite service using a voice trunk on the handoff link connecting that MTSO to the SHS.

Hub Station as Cell Site

Figure 3 suggests an alternative interconnection between SHS and MTSO. Here, the link is the same used to connect cell sites to the MTSO. In North American systems, there is currently no standardization for this link, so details of the connection would be proprietary to the manufacturer of the cellular system.

While Figure 3 shows direct interconnection between the SHS and the PSTN, the MTSO could provide such interconnection for calls originated on the satellite system, just as it does for cellular calls. In addition, this configuration would allow the MTSO to perform switching and subscriber data base maintenance functions for the SHS. Such an arrangement could significantly reduce the cost of a hub station.

Hub Station Distribution

In cellular, intersystem handoffs generally occur between MTSOs serving adjacent areas, since it is the movement of a mobile between such areas that precipitates the handoff in the first place. Thus, to fully support intersystem handoff, each MTSO needs handoff links only to adjacent MTSOs, typically a manageable number.

If the mobile satellite system to be integrated with cellular makes use of a single, centrally located hub station, then this SHS would require handoff links to each of the potentially hundreds of participating MTSOs in the national cellular network, as illustrated in Figure 4. The impracticality of this arrangement could be mitigated somewhat through tandem switching of intersystem links. However no protocols currently exist for such tandeming, and the adjacency limitation on MTSO-to-MTSO handoff described above limits its potential economic advantage.

The mobile satellite system may employ multiple, regionally distributed hub stations, as suggested in Figure 5. Such distribution may be a requirement of the satellite system architecture or may be by design in order to optimize integration with cellular. At any rate, each such regional SHS would have to maintain handoff links only to the MTSOs that service the same areas as the SHS. While the number of such links may still be large, especially if the number of regional SHSs is small, the average length of the required link will be greatly reduced compared with the single, centrally located SHS configuration.

In some mobile satellite systems it may be practical to use a large number of small, low capacity hub stations, perhaps modeled after VSAT terminals, for PSTN interface and cellular integration. In such a system, each participating MTSO could be equipped with its own SHS, most likely connected to the MTSO as a cell site. Such an arrangement is illustrated in Figure 6.

While the "SHS per MTSO" configuration is architecturally attractive for handling handoffs between satellite and cellular systems, it raises a number of difficulties as well. Primary among these is positional ambiguity. A call originated on the satellite system must be interconnected through one of perhaps dozens of SHSs within the service area of the geostationary satellite's beam or the low earth orbit satellite's coverage footprint. To allow for subsequent handoff of the call to cellular, the SHS selected for the point of interconnect must be the one nearest to the position of the mobile unit being served. However, barring the addition of positioning capability such as GPS or LORAN, neither the mobile unit or the infrastructure equipment can make this determination.

INTERSYSTEM CALL PROCESSING

Registration and Call Delivery

In the cellular system, seamless roaming requires that incoming calls for a roaming mobile be automatically forwarded, or "delivered" from the mobile's home system to the system on which it is currently operating. The call delivery system relies on the mobile's manual or autonomous registration upon entering a "foreign" system. When a mobile so registers, its home system is alerted through an administrative data network to set up call forwarding to a temporary directory number that routes the mobile's incoming calls, via the PSTN, to the appropriate MTSO.

Integration of mobile satellite service into the cellular network creates some added complexity for call delivery. A roaming mobile may be intermittently in cellular coverage while traveling at the fringe of a system's service boundary, and simultaneously be in continuous satellite coverage. It is in just such situations that integration of satellite and cellular systems provides maximum advantage. However, frequent registration, and subsequent frequent changing of call delivery target numbers as a mobile moves in and out of cellular coverage, is impractical.

One possible approach to addressing this problem is "hierarchical call delivery". In this scheme, the roaming satellite/cellular mobile registers as usual on the cellular system with the exception that the registration message is expanded to include identification of current satellite coverage, if any, and an indication of whether the user wishes calls to be delivered to the satellite system if the mobile is not currently in cellular coverage. If the mobile is outside of cellular coverage for a predetermined time, it registers on the satellite system. When a call to the satellite/cellular mobile is received by its home system, it is forwarded first to the system (cellular or satellite) on which it last registered. If the target is a cellular system, and if the mobile's registration included a satellite coverage indication, then the call could be forwarded again to the satellite service if it fails to respond to a page on the cellular system.

Satellite/Cellular Handoff

Handoff of calls in progress between satellite and cellular is required to extract maximum benefit from integration of the two systems. When a mobile operating on cellular reaches the limit of coverage, the call is dropped - a situation that need not occur if the call could be handed off to a mobile satellite system. On the other hand, when a mobile originates or receives a call while momentarily in a cellular coverage "hole" there is no need for the entire call to be conducted over scarce and expensive satellite channels if a handoff to cellular could be initiated upon leaving the coverage hole.

Coverage and propagation characteristics of the satellite and cellular systems are quite dissimilar. Therefore, handoff from cellular to satellite will require a different protocol than handoff from satellite to cellular, and both will necessarily be different from conventional cellular handoff.

Protocols for satellite/cellular handoffs can take advantage of the practical requirement for separate cellular and satellite transceivers in the mobile unit, as suggested in Figure 1. Thus, while engaged in conversation mode on one system, the mobile unit can scan for, monitor, and communicate on the control channels of the other.

Cellular to Satellite Handoff

In conventional cellular handoff, the system must determine the location of the mobile relative to coverages of the surrounding cells in order to determine the correct "target" cell. When a mobile is to be handed off from cellular to the mobile satellite system, no such location process is required, because the coverage of even the most tightly constrained satellite coverage beam will be vastly larger than, and totally subtend, even the largest cell. What is required, however, is a determination that, at the time of the handoff, the mobile is within satellite coverage and not, for instance, shadowed by overhead structure or terrain. A handoff from poor cellular coverage to satellite could substantially improve the quality of a call. On the other hand, if the mobile is parked under an overpass at that moment, such a handoff could result in an unnecessary dropped call.

One way to ensure that the mobile is receiving satellite coverage prior to a handoff is to query the mobile using the data messaging feature of cellular voice channels. The mobile would then respond with a data message that indicated the quality of its current reception of the satellite's control channel. Based upon this information, the cellular system could make a determination as to whether a handoff to satellite is warranted.

Satellite to Cellular Handoff

Two characteristics make satellite to cellular handoff unique. First of all, to conserve scarce satellite channels, such a handoff will ideally occur when the mobile enters or reenters adequate cellular coverage. Second, there is no practical way that the satellite system can by itself determine which of potentially hundreds of subtended cells should be the handoff target. To address these characteristics, satellite to cellular handoff most likely will be initiated by the mobile unit, possibly as follows.

While engaged in conversation on the satellite system, a mobile unit will scan for cellular control channels using its cellular transceiver. When a channel is received with suitable signal level as indicated by a predetermined formula, the mobile unit will send a message on that cellular control channel requesting a handoff from the satellite system. Using an administrative data link, the cellular system will forward the request to the serving satellite system, which will, in turn, set up the handoff to the MTSO and cell defined by the mobile's control channel transmission.

CONCLUSION

The integration of mobile satellite and cellular systems appears to provide advantages to the mobile user. Such integration will require appropriate configuration of a dual mode mobile unit, the integration of satellite and cellular infrastructure systems, and the development of protocols to handle intersystem call processing. This paper, in suggesting possible (but not necessarily optimal) approaches to each requirement, indicates that full satellite/cellular integration is practical.

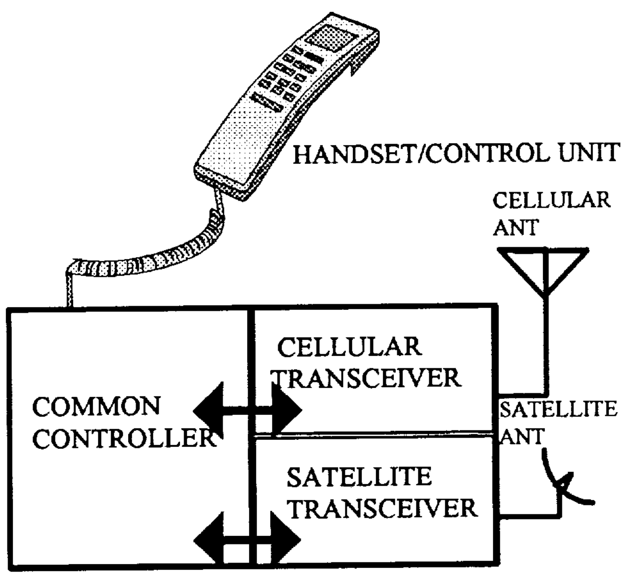

Figure 1. Satellite/Cellular mobile architecture

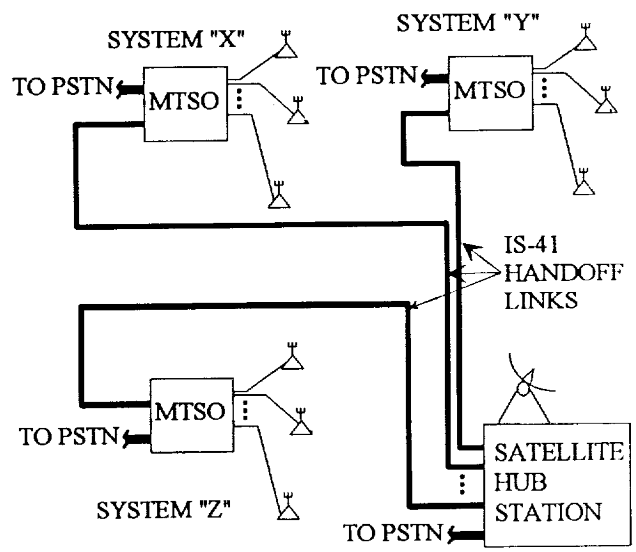

Figure 2: SHS connected to cellular as MTSO

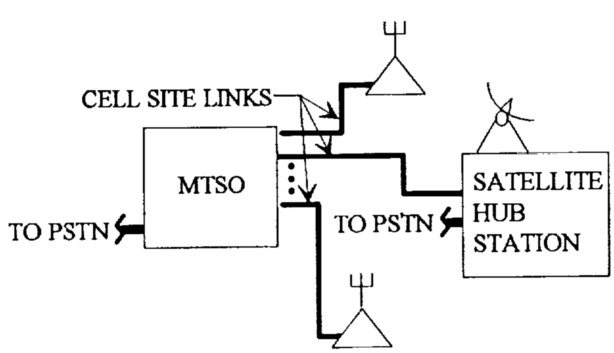

Figure 3: SHS connected to cellular as cell site

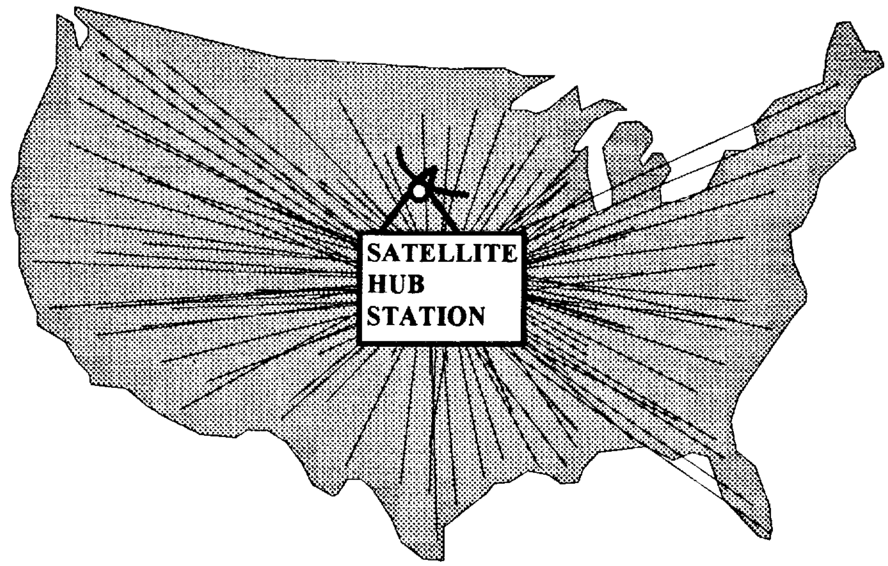

Figure 4: IS-41 links from single, centrally located SHS

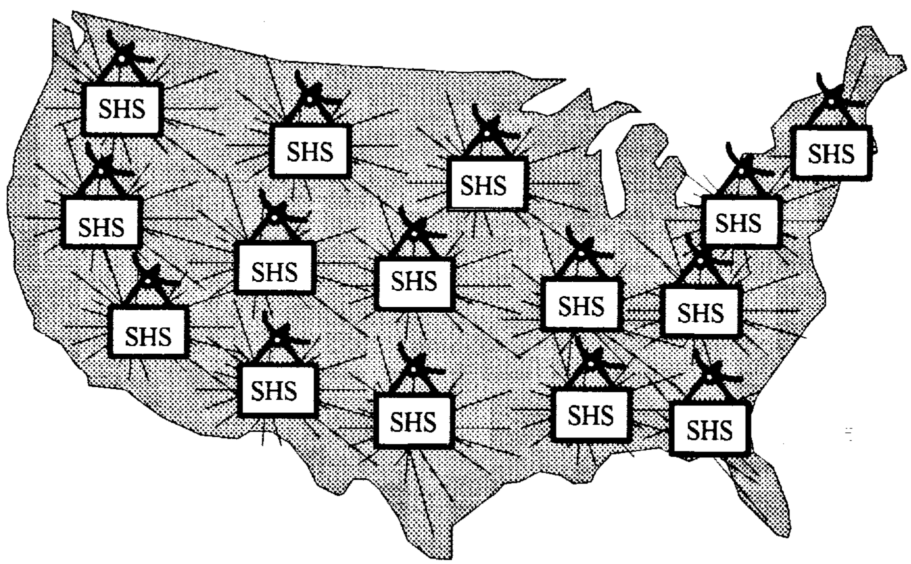

Figure 5: IS-41 links from regional satellite hub stations

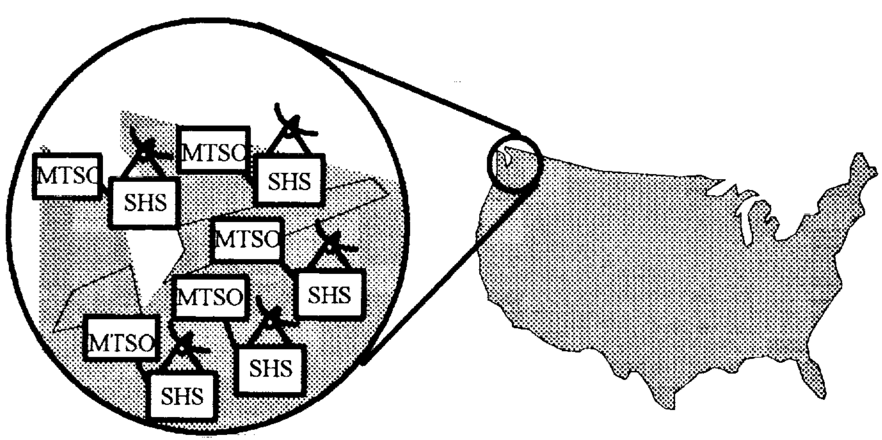

Figure 6: Satellite hub station at each MTSO