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DESIGN MOBILE SATELLITE SYSTEM ARCHITECTURE AS AN INTEGRAL PART OF THE CELLULAR ACCESS DIGITAL NETWORK

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ABSTRACT

The Cellular Access Digital Network (CADN) is the access vehicle through which cellular technology is brought into the mainstream of the evolving integrated telecommunications network. Beyond the integrated end-to-end digital access and per call network services provisioning of the Integrated Services Digital Network (ISDN), the CADN engenders the added capability of mobility freedom via wireless access. One key element of the CADN network architecture is the standard user to network interface that is independent of RF transmission technology.

Since the Mobile Satellite System (MSS) is envisioned to not only complement but also enhance the capabilities of the terrestrial cellular telecommunications network, compatibility and interoperability between terrestrial cellular and mobile satellite systems are vitally important to provide an integrated moving telecommunications network of the future. From a network standpoint, there exist very strong commonalities between the terrestrial cellular system and the mobile satellite system. Therefore, the MSS architecture should be designed as an integral part of the CADN. This paper describes the concept of the CADN, the functional architecture of the MSS, and the user-network interface signaling protocols.

1. EVOLUTION OF CELLULAR TECHNOLOGY

Historically, the development of cellular technology dates back to the early 1940's when AT&T Bell Laboratories' engineers explored various means to increase the availability of radio telephone service in vehicles in metropolitan areas [MacDonald, 1979]. As a result of these studies, the fundamental elements of cellular technology emerged as: (a) frequency reuse in small geographic areas (i.e. cells) to increase the capacity of a limited frequency spectrum to serve many users, and (b) automatic switching of channels when an active user crosses a cell boundary (i.e. hand-off). The first United States commercial cellular system began operations in Chicago in October 1983. Since then, the market for cellular service has grown steadily at a pace far exceeding the expectations of the industry.

Coincidental with the growth of the cellular market, there has been a change in technology usage. The original purpose of cellular technology was to provide voice telephone service to automobiles in metropolitan areas. However, in the past few years, there has been increasing use of briefcase-mounted and hand-held cellular telephones. Furthermore, the high quality of cellular radio channels has encouraged cellular service subscribers to use the channels for other telecommunications applications such as the transmission of voiceband data. Quality and convenience are the reasons why cellular systems are being introduced to smaller and smaller cities where the need for frequency reuse is less imperative compared to congested metropolitan areas.

Therefore, it is clear that market forces are moving cellular service from a means of voice communication in vehicles to a general means of communication for people and machines on the move, or at locations where wired telecommunications services are not practical or readily available. This application evolution requires the definition of a new cellular network architecture that supports an integrated *moving* access as a complement to the traditional *fixed* access telecommunications network. This architecture, which is referred to as the Cellular Access Digital Network (CADN) [Chien, 1987a,b], provides a generalized moving access via the CADN Digital Subscriber Channel.

2. CELLULAR ACCESS DIGITAL NETWORK

Modern telecommunications networks are migrating toward an infrastructure where various network resources can be used as an integrated entity to convey all types of information among people and machines. For fixed networks, the Integrated Services Digital Network (ISDN) has defined a means by which such integrated network resources are accessible via a single standard user-network interface. Through this interface, the network can provide the user integrated end-to-end digital access and per call network service provisioning. In a complementary and parallel fashion, the CADN provides the integrated service access capability similar to ISDN in conjunction with user mobility. As a moving access network, the CADN merges the wireless transmission and user location capability of cellular systems with the resources of fixed telecommunications networks.

The control architecture and internal communications structure of the CADN is designed to (a) provide compatibility and interoperability with the ISDN and (b) provide sufficient flexibility to accommodate a broad and evolving range of RF environments. Figure 1 identifies three environments, which in ascending order of traffic density but in descending order of rigor concerning their communications channels, are (a) moving terminals in remote areas communicating with a mobile communications satellite, (b) moving terminals in rural, suburban, or urban areas served by terrestrial base stations (or "cell sites"), and (c) moving terminals within or near buildings served by indoor wireless communications systems. To provide the best possible service in a given environment, a specific combination of RF transmission techniques, speech code, modulation format, channel code, and multiple access method will have to be carefully selected to achieve an effective balance among the goals of quality, cost, and capacity for that particular environment. Nevertheless, moving access users should be able to enjoy consistent service access and capabilities across the various environments (e.g. mobile satellite, terrestrial, and indoor wireless systems), as well as the compatibility and interoperability between the *fixed* ISDN and the *moving* CADN network. To accomplish this service transparency, the concept of a CADN Digital Subscriber Channel has been proposed (see Figure 1). Section 4 of this paper will describe in detail the standards proposed for this CADN Digital Subscriber Channel in the Mobile Satellite System (MSS) environment.

3. MSS AS AN INTEGRAL PART OF THE CADN

Because of the wide coverage attainable by a satellite-based base station, the Mobile Satellite System can easily provide cellular services to remote or thinly populated areas where terrestrial cellular systems are not economically feasible [Bell, 1985]. Thus the MSS plays a very important role in making cellular service a *ubiquitous* service so that moving access users can obtain telecommunications services regardless of where they are. However, this will be possible only if consistent service capabilities and service access are provided to moving access users through a standardized user-network interface. Therefore, it is imperative that the architecture of the MSS be designed as an integral part of the CADN. In the following sections of this paper, the MSS will be treated as a specific implementation of the CADN, and the term MSS will be used synonymously with the term CADN.

3.1 MSS Functional Architecture

As shown in Figure 2, functionally the MSS consists of a switching system, a base station, network terminations, and user equipment.

3.1.1 Network Termination As noted in the preceding sections, the most important aspect of the CADN architecture is the user-network interface. This interface must be designed so as to enable the user terminal to be transparent to the specific RF transmission technology of the MSS.

The network termination provides the *physical* appearance of a wireless access channel for the MSS user. Working as a complementary pair with the satellite RF channel equipment, the MSS network termination equipment (MNTE) controls all of the cellular RF channel functions. Examples of these functions are access to common control channels, assignment of traffic channels, and control of transmitter power. In addition to providing RF transport for its own signaling and control messages, the MNTE provides RF transport for user information and signaling through information (I) channels and control (C) channels.

3.1.2 MSS User Terminal An MSS user terminal is very similar to an ISDN terminal in providing access to voice and data services with signaling and control capability. However, it differs from the ISDN terminal in that it will not have access to a fixed "2B+D", 144 kb/s capability due to the limited availability of RF spectrum. Instead, it will provide a CADN basic access via a "2I+C" format. In most environments, the rates of the I and C channels will be significantly lower than the corresponding B and D channels of ISDN. For example, the voice will be processed from 64 kb/s down to, say, 4 kb/s before interfacing with the network termination equipment. In addition, depending on user service requirements, the network will provide just enough RF resource for either 2I+C, I+C, or a mere C channel for each connection.

3.1.3 MSS Switching System Like the Mobile Telephone Switching Office (MTSO), the MSS switching system will coordinate the connections of MSS users to the landline network, terrestrial cellular network, or other MSS users. It will also control cellular functions such as paging, handoff, and RF channel assignment. In addition, it will provide ISDN-like integrated voice, data, and signaling service capabilities. Since the MSS switching system will interconnect with other CADN networks as well as with public and private networks, it should support international signaling standards such as ISDN, Signaling System 7 (SS7), and the Mobile Application Part [CCITT, 1988].

One implementation of the MSS switching system consists of a Network Management Center (NMC) and a Gateway Switch [Bell, 1985], where the former is mainly responsible for the control functions while the latter is responsible for cross connection and interface to other networks. The significant deviation of this implementation from terrestrial cellular systems is that all links between the MSS switching system and the base station are based on radio links.

3.1.4 MSS Base Station In addition to terminating RF channel links and performing cellular functions under the control of the MSS switching system, the MSS base station performs several autonomous functions. For example, it determines the user movement direction in preparation for a handoff.

One implementation of the MSS base station consists of a mobile satellite and a Telemetry, Tracking and Control (TT&C) station [Bell, 1985]. The significant deviation of this implementation from the terrestrial cellular system is that the MSS has only one base station with cells created via multiple spot beams.

4. MSS DIGITAL SUBSCRIBER CHANNEL STANDARDS

The key aspect of the CADN Digital Subscriber Channel is the separation of RF channel technology and subscriber access. RF channel technology reflects technology dependent multiple access schemes, modulation and encoding methods, and bandwidth allocations. For the MSS, such functions can be aggregated into functional modules that comprise the MSS network termination equipment (MNTE). In a similar fashion, subscriber access is comprised of functions that are intrinsic to moving access networks regardless of which specific RF channel technology is used. Having specified a functional separation between network channel specific and user terminal specific functions, a reference point by which to identify the MSS user-network interface is created (see Figure 2). It is at this reference point that the *Cellular ISDN standards* can be defined. This point not only supports the same level of services and capabilities associated with the fixed ISDN within the limitation of the RF channel, but also accommodates the user location schemes associated with the moving access point in the MSS. Similarly, the RF channel specific functions that are defined by *Cellular Digital RF standards* accommodate the resource allocation and control schemes associated various RF channel technologies (e.g. TDMA, FDMA, etc.). The combined functionality of both standards is the basis for MSS Digital Subscriber Channel Standards.

4.1 Cellular ISDN Standards

The Cellular ISDN standards define an ISDN-like basic access structure via a virtual connection that supports a "2I+C" capability. The Cellular ISDN information (I) and control (C) channels are analogous to the ISDN bearer (B) and data (D) channels. The unique terminology for Cellular ISDN (i.e. I and C) emphasizes the fact that the MSS environment will not support the defined ISDN bit rates due to the scarcity of radio frequency spectrum. To maximize spectrum usage in the MSS as well as other CADN environments, channel flexibility is provided for by defining I and C channels as multiples of unit (U) channels at the rate of 1 kb/s. In this way, the access rate and channel usage can vary according to environmental constraints and per-call user service needs. Similar to the ISDN protocol model, the Cellular ISDN protocol model is also based on the Open System Interconnection (OSI) reference model [Jenkins, 1984]. The Cellular ISDN protocol architecture is comprised of three layers which are 1. the Virtual Physical Layer, 2. the Data Link Layer, and 3. the Message Layer (see Figure 3).

4.1.1 Layer 3 The Cellular ISDN Message Layer provides the requisite functionality for coordination of all call processing and data transport activities. In the same fashion that ISDN supports user packet data transport on the D channel, the Cellular ISDN supports user packet data transport on the C channel.

4.1.2 Layer 2 The Data Link Layer provides the logical connection by which Cellular ISDN messages are exchanged across the CADN user-network reference point. The logical connection conforms to the set of procedures defined by Link Access Procedures on the Cellular ISDN Control channel (LAPC). Functionally, LAPC supports the exchange of Layer 3 call control and user information in data link frames, acknowledged exchange of information based on logical data link connections, logical channel initialization and termination, logical error checking and recovery, and channel supervision concerning Layer 1.

4.1.3 Layer 1 Layer 1 of the Cellular ISDN protocol provides the means by which "peer" Data Link Entities can exchange Cellular ISDN frames across the MSS user-network reference point. Functionally, it provides a virtual physical connection that specifies the characteristics of I and C channels. Channel variability is supported by the specification of I and C channels as multiples of the U channel rate (i.e. 1 kb/s). An I channel comprised of 16 U channels is specified as I(16) and supports a 16 kb/s rate. Similarly, a C channel comprised of 2 U channels is specified as C(2) and supports a 2 kb/s rate. In this fashion the rates of I and C channels can vary in accordance with environmental constraints and call-by-call user service needs. In addition to the "2I+C", other basic access configurations of "I+C" and "C" are also defined for Cellular ISDN.

4.2 Cellular Digital RF Standards

Functionally, the MSS network termination provides wireless physical transport for the Cellular ISDN I and C channels. It performs standard functions such as carrier frequency synthesis, and modulation and demodulation. In addition, it provides the capability to control and manage the RF channel that is unique to the cellular system. The Cellular Digital RF standards, as in the case of Cellular ISDN, are also structured in a layered fashion. Since the MSS RF channel technology will evolve with time, Cellular Digital RF standards provide the flexibility to support such RF technology advancements.

In accordance with the OSI reference model, the Cellular Digital RF standards are comprised of three layers which are 1. the RF Physical Layer, 2. the RF Data Link Layer, and 3. the RF Channel Management Message Layer (refer to Figure 4). Unlike the ISDN, however, prior to the establishment of a dedicated point-to-point resource, call control signaling must first request the resource via the Common Access and Control (CAC) channel. This channel is a shared resource among all users in a given cell. Once the dedicated resource is allocated, the terminal then relies upon the User Specific Control (USC) channel for message transport, and the associated I channels for user traffic transport. The combined functionality of both CAC and USC channels is the transport vehicle for the Cellular ISDN C channel.

4.2.1 Layer 3 The Cellular Digital RF Channel Management Message Layer provides the requisite functionality for coordination of all RF channel related activities, such as: channel address assignment (e.g. frequency, time slot), bandwidth allocation, power level control, forward error correction, etc., so as to make the MSS RF environment transparent to the MSS user-network interface.

4.2.2 Layer 2 The RF Data Link Layer provides the logical connection by which Cellular Digital RF Channel Management messages are exchanged across the MSS digital RF channel. The logical connection is governed by a set of procedures as defined by the Link Access Procedures on the Radio Control channel (LAPRC). Functionally, LAPRC supports the exchange of Layer 3 RF Channel Management messages in data link frames, acknowledged exchange of information based on data link connections, channel initialization and termination, error checking and recovery, and channel supervision concerning the RF media.

4.2.3 Layer 1 The Physical Layer of the Cellular Digital RF standards provides the interface to the MSS RF environment for transport of Cellular ISDN I and C channel information. This layer provides for the variability in RF environments identified in Figure 1. For the MSS environment, Layer 1 provides for the capability to conform to satellite transmission directionality and power constraints. In addition, it also provides for overcoming channel impairments due to sunspots and thick clouds, as well as multipath effects.

5. MSS SERVICE CAPABILITIES

With digital RF transmission and low bit rate speech processing schemes, the MSS can protect voice service from any "casual" listener. With the Cellular ISDN standards, the MSS can provide a fuller set of data services to the user, ranging from circuit-switched data service to packet-switched data service. They can be used for applications such as data base inquiry/response, location update, vehicular alarm reporting, electronic mail/message, navigation, etc. The cellular ISDN C channel not only provides the service capability for user packet data transport but also provides the signaling capability for end-to-end connection and service control.

With the MSS Digital Subscriber Channel standards, the call control messages are separated from the RF channel control messages (see Figure 5), which facilitates the application of advanced digital encryption schemes to the user traffic without causing difficulties in cellular channel management.

Because the MSS can provide ISDN-like simultaneous voice, data and signaling capabilities, it could even become a viable candidate for providing fixed telecommunications services to residents in remote and rural areas.

6. DISCUSSIONS

This paper has described the Mobile Satellite System architecture as an integral part of the Cellular Access Digital Network (CADN). The most significant breakthrough of the new architecture and associated channel structure is the separation of RF channel technology and user access based upon the CADN Digital Subscriber Channel concept. This paper has also described the MSS Digital Subscriber Channel Standards which consists of Cellular ISDN standards and Cellular Digital RF standards. The Cellular Digital RF standards can easily accommodate RF technology advancements envisioned for the MSS environment as well as other RF technologies required by other applications such as terrestrial cellular systems and indoor wireless systems. The Cellular ISDN standards can support a user-network interface that remains unchanged across the various RF environments and provide ISDN-like services. With the MSS Digital Subscriber Channel standards, the MSS not only can provide advanced telecommunications services to the MSS users in a consistent manner but will also facilitate the interworking between the MSS and other CADN environments. Through such interworking and compatibility, the MSS and other CADN systems together form a ubiquitous moving access network to provide telecommunications services to people and machines on the move.

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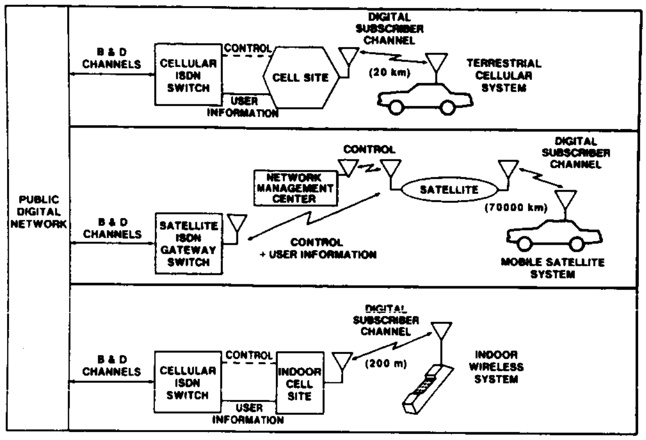


Figure 1. CADN Environments

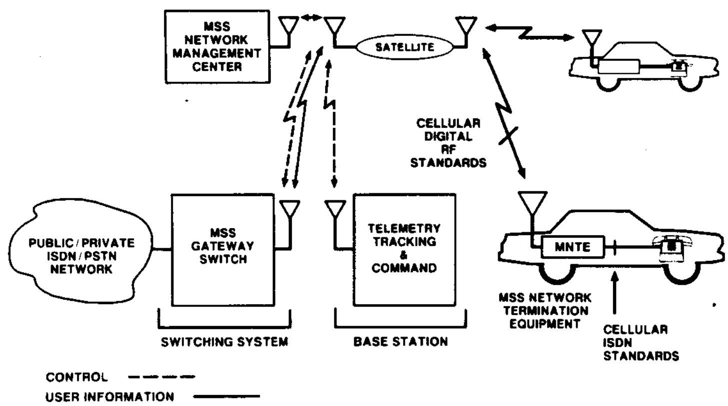


Figure 2. MSS Functional Architecture

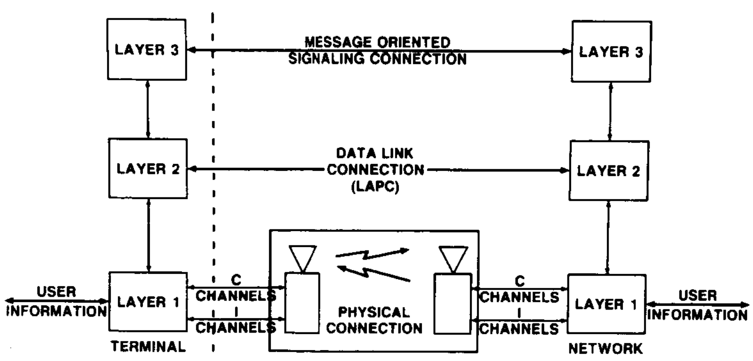


Figure 3. Cellular ISDN Protocol Architecture

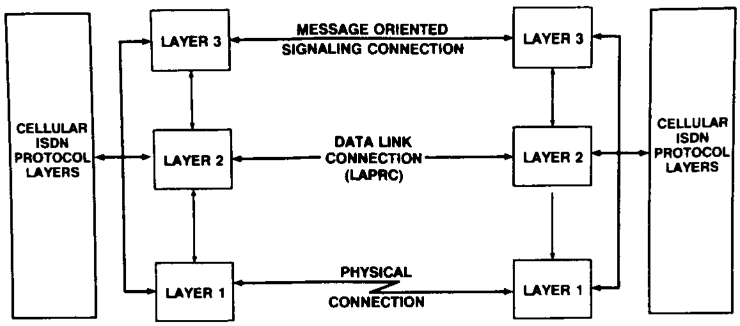
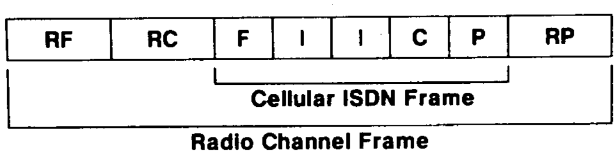


Figure 4. Cellular Digital RF Protocol Architecture



RF	Radio Framing Bits
RC	Radio Control Signalling Bits
F	CISDN Framing Bits
I	CISDN Information Channel Bits
C	CISDN Control Channel Bits
P	CISDN Parity Bits
RP	Radio Channel Error Correction Coding Bits

Figure 5. Digital Subscriber Channel Format