Design and system operation of Globalstar™ versus IS-95 CDMA – similarities and differences *

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The Globalstar™ system provides telephone and data services to and from mobile and fixed users in the area between ±70 degrees latitude. Connection between user terminals and the PSTN is established through fixed terrestrial gateways via a constellation of low earth orbiting (LEO) satellites. Globalstar uses an extension of the IS-95 CDMA standard that is used in terrestrial digital cellular systems. The LEO satellite link is sufficiently different from the terrestrial cellular link that certain departures from IS-95 were needed both in signal design as well as in system operation. This paper describes some of the similarities and differences of Globalstar air interface versus IS-95.

1. Introduction

The Globalstar™ system is a low earth orbiting (LEO) satellite system that provides voice and data communications to and from mobile and fixed users [14,19]. Connection between user terminals and the PSTN is established through fixed terrestrial gateways via a constellation of LEO satellites. The Globalstar system consists of a space segment, a user segment, and a ground segment (see figure 1). The Globalstar space segment consists of 48 satellites that are placed at 1414 km altitude circular orbits, with an orbital period of about 114 minutes. The satellites operate as repeaters in space without involving complex on-board processing and call setup procedures. The satellites are placed in 8 orbital planes at an inclination of 52 degrees, with 6 equally spaced satellites per orbital plane. The satellite orbits are optimized to provide highest link availability in the area between ±70 degrees latitude on earth. Each satellite pass as viewed from a user location on earth typically lasts about 10–15 minutes. Users in temperate areas of the earth always get at least two satellites in view above 10 degrees elevation angle, providing satellite diversity benefits. Users in other areas, too, usually get two satellite coverage. The visibility statistics of multiple satellites at different latitudes are shown in figure 2. As can be seen, the advantage of multiple satellite coverage is sacrificed a little at near-equatorial latitudes and at latitudes above 60 degrees. The Globalstar user terminals include hand held units, mobile units (consisting of a hand held unit and an adapter kit in the vehicle), and fixed units. The Globalstar network is connected to the existing PSTN/PLMN systems through the Globalstar gateway stations. Ground operations control centers (GOCC) perform the planning and management of the communications resources of the Globalstar satellite constellation. This is coordinated with the satellite operations control center (SOCC) which manages the satellites.

The satellite footprint is divided into "beams" through the use of beam forming antennas on the satellite. The forward link (gateway-to-user terminal) and the reverse link (user terminal-to-gateway) beam patterns are shown in figures 3 and 4, respectively. It is noted that satellites and beams in Globalstar are analogous to base stations and sectors, respectively, in cellular [10]. The user terminal to satellite transmission (reverse uplink) is on the L-band (1610–1626.5 MHz), and the satellite-to-user terminal transmission (forward downlink) is on the S-band (2483.5–2500 MHz). The 16.5 MHz bandwidth on the L and S bands is divided into 13 FDM channels, each 1.23 MHz wide. Within each FDM channel, spread spectrum is used to carry multiple voice and data circuits, each identified by unique spreading sequences. C-band frequencies in the range 5091–5250 MHz for gateway-to-satellite (forward uplink), and 6875–7055 MHz for satellite-to-gateway (reverse downlink) are used for the feeder links. Both right hand circular polarization (RHCP) and left hand circular polarization (LHCP) are used in C-band which allows 8 frequencies to connect 16 beams on the satellite. Thus, spread spectrum and frequency reuse are effectively employed for efficient spectrum usage in Globalstar.

The Globalstar air interface uses an extension of the IS-95 CDMA standard which is adopted in terrestrial digital cellular systems [16]. Since many Globalstar user terminals are envisaged to support multi-mode operation (e.g., Globalstar mode, IS-95 cellular mode, etc.), it is desirable to have minimum divergence between the signals and system procedures in different modes. This will allow maximum commonality in the user terminal design with a concomitant reduction in cost and size. Nevertheless, there are many aspects of the user-to-satellite link that are significantly different than the user-to-base station link in terrestrial cellular. These differences have resulted in some changes for Globalstar compared to the methods used in

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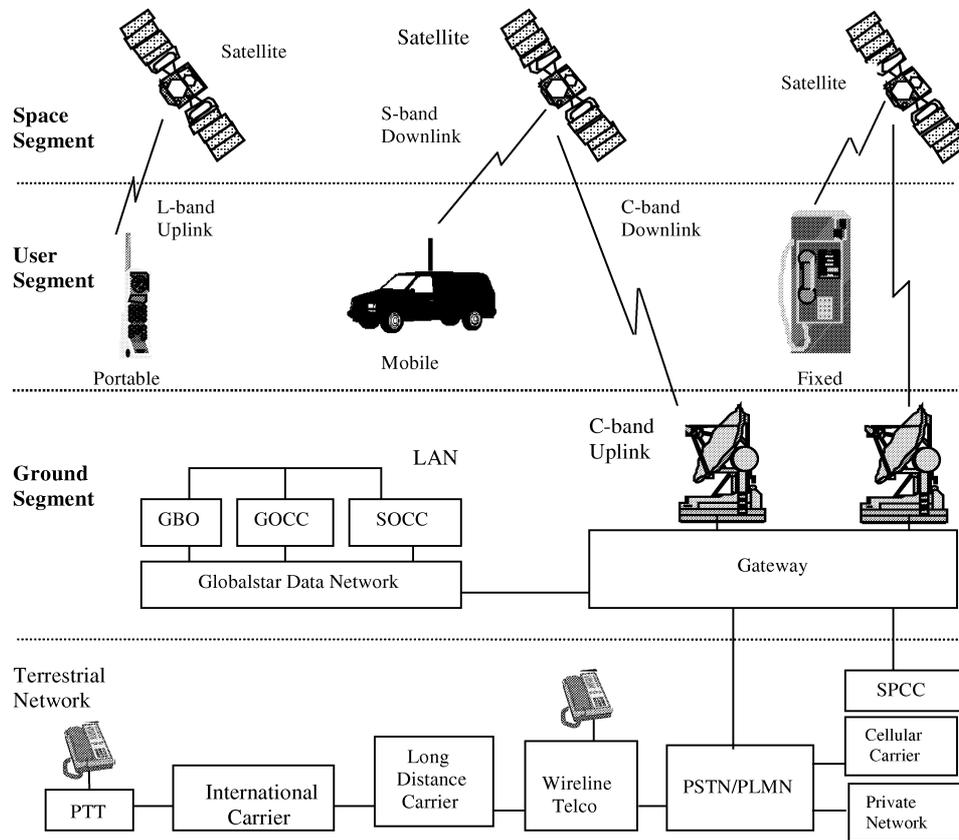
Figure 1. Globalstar system diagram.
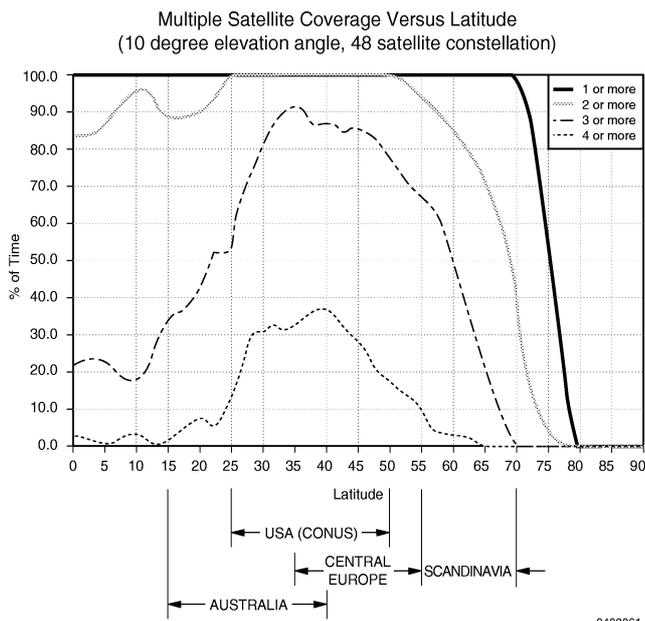
Figure 2. Multiple satellite coverage versus latitude in Globalstar.

Figure 3. S-band beam pattern on the forward link.
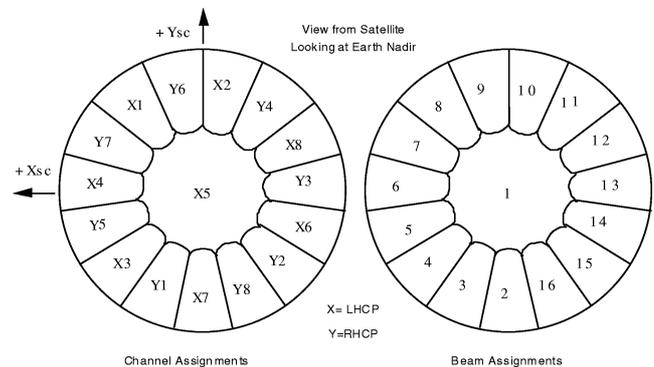
Figure 4. L-band beam pattern on the reverse link.

terrestrial cellular, both in signal design as well as system procedures – handoff procedures, power control, access channel signal design, and search strategies, to name a few. The purpose of this paper is to describe some of these differences and the reasons and causes that brought them about.

The rest of the paper is organized as follows. Section 2 briefly describes the differences between LEO satellite channels and terrestrial cellular channels. The forward and reverse link CDMA waveform design in Globalstar is described in section 3. In section 4, the Rake receiver concept and the handoff mechanisms as applied in Globalstar and IS-95 are discussed. Section 5 deals with the power control issues. Section 6 highlights some of the other issues including lower effective data rate, continuous reverse link transmission, access channel preamble, and protocol stack for data services. Section 7 provides the conclusions.

2. LEO satellite/terrestrial cellular channels

Several studies on both statistical as well as measurement based channel models for terrestrial cellular channels [1,5,9] and mobile satellite channels [7,8,11–13] are widely available in literature. In this section, we highlight the differences between LEO satellite channels and terrestrial cellular channels that were instrumental in bringing about some changes in the signal design and link budget for Globalstar compared to IS-95.

Both LEO satellite and terrestrial cellular channels are affected by random varying losses due to distance, shadowing, and multipath. Shadowing loss is caused by obstacles in the propagation path, such as buildings, trees, etc., and the loss variation strongly depends on the type of environment. In typical urban cellular environments, the variations in the shadow loss is shown to follow a log-normal distribution. The standard deviation of the log-normal distribution has been found to vary in the range 4–12 dB [9]. Most studies assume a standard deviation of 8 dB [3,6]. In LEO satellite environments, the percentage of shadowed areas on the ground depends mainly on the type of environment and the satellite geometry. Because of the movement of the nongeostationary satellite, the geometry of shadowed areas will continuously change with time. For example, shadowing is larger at low satellite elevation angles than at high satellite elevations. For urban and suburban streets, shadowing also depends on the azimuth angle of the satellite [12]. Typically, distance and shadow loss variations are slow which could be easily tracked and compensated for.

Losses due to multipath fading (caused due to differences in the phases of signals received through multiple reflected paths) can vary rapidly depending on the user speed. In cellular environments, the received signal variation due to multipath is shown to follow a Rayleigh distribution [9]. The amount of correlation in the fading process depends on the Doppler bandwidth $f_D = v/\lambda$, where v is the user speed, and λ is the carrier wavelength. For example, at a carrier frequency of 900 MHz (i.e., λ = speed of light/carrier frequency = 1/3 m), a user moving at a speed of 60 km/h will experience a Doppler of 50 Hz. If left untracked, such rapid fading can significantly hurt CDMA performance. In IS-95, closed-loop power control at 800 Hz update rate is employed on the reverse link to equalize the

signal variations due to multipath fading. On the other hand, in LEO satellite channels a line-of-sight (LOS) component, in addition to the diffused signal component due to multipath, is usually present; that is, the multipath fading in a LEO satellite environment is Rician distributed. Measurements have shown that Rice factors, defined as the ratio of the signal power in the LOS component to the signal power in the diffused component, in the range 5–20 dB are common on mobile satellite channels [13]. The Rician nature of the channel is particularly advantageous because it offsets some of the drawbacks introduced by large propagation delays (on the order of tens of milliseconds) that are inherent to LEO satellite systems. For example, large values of Rice factors render power control to track multipath fading less critical. Note that closed-loop power control becomes less effective when propagation delays are large [3]. Also, large delays result in increased time uncertainty space in the access channel search in Globalstar.

In cellular, since the base station remains static[1], Doppler is due to user movement only. For typical operating frequencies (900–2000 MHz) and user speeds (<100 km/h), the resulting Doppler is less than 200 Hz in cellular. Whereas in LEO satellite systems, even if the user remains static (e.g., fixed user terminals), there is Doppler due to relative satellite motion. The resulting Doppler due to satellite motion is quite high (e.g., of the order of several tens of KHz in Globalstar L-band). This large Doppler results in increased frequency uncertainty space in the access channel search in Globalstar.

Another characteristic of LEO satellite channels is specular reflections [8]. User terminal antennas with wide angle patterns tend to collect more reflected power than directive antennas. Hand held user terminal antennas may pick up strong specular reflections from bounce off paths from the ground. The net effect of strong specular reflection is a slow and cyclically varying signal strength as a function of satellite elevation angle over time. The signal variation is more pronounced at low elevation angles and when the surrounding earth surface has a high reflection coefficient (e.g., an empty parking lot). This phenomenon has an impact on the handoff algorithm design in Globalstar because this potentially can cause an undesired "ping-pong" effect during handoffs.

3. CDMA signal design in Globalstar

The Globalstar air interface uses a modified form of IS-95 CDMA standard [16]. Similar to IS-95, Globalstar uses a combination of frequency division, code division, and orthogonal signal multiple access techniques. The available spectrum is divided into 1.23 MHz bandwidth radio channels (frequency division). Note that in IS-95 the available bandwidth is divided into 1.25 MHz channels.

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[1] There may be special terrestrial cellular applications where the base stations themselves can be moving, e.g., in tactical and emergency communications, base stations could be mounted on vans, jeeps, tanks [4].

The chip rate, however, remains the same 1.2288 Mcps in both IS-95 and Globalstar. In this section, we present the forward link and the reverse link signal design in Globalstar.

3.1. Forward link waveform

On the forward link, pseudorandom noise (PN) codes (code division) are used to distinguish between signals from different beams, different satellites, and different gateways. Individual users within each beam are distinguished by different Walsh codes (orthogonal signalling). In Globalstar, the Walsh function is 128 chips long (compared to 64 chips long in IS-95) and there are 128 different orthogonal codes (compared to 64 Walsh codes in IS-95).

The "Forward CDMA Channel" transmitted by the gateway on each beam consists of one Pilot Channel, one Sync Channel, up to seven Paging Channels, and a number of Forward Traffic Channels (see figure 5). Each of these channels is orthogonally spread by the appropriate Walsh function and outer PN sequence and is then spread by a quadrature pair of PN sequences at a chip rate of 1.2288 Mcps. Multiple Forward CDMA Channels may be used by a gateway in a frequency division multiplexed manner.
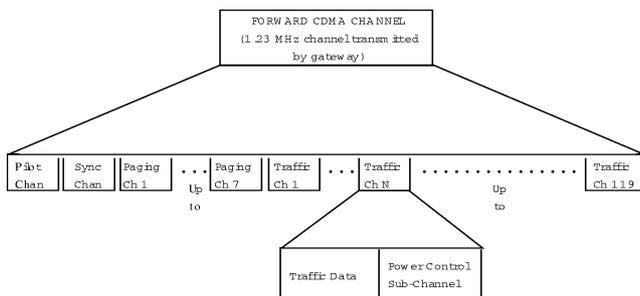
The Pilot Channel is transmitted continuously by each gateway on each beam. Pilot Channel is used by the user terminals to acquire the timing of the forward channel and to provide a phase reference for coherent demodulation. In addition, Pilot strength measurement made at the user terminal is used to decide when to make a handoff. The Pilot Channel is assigned the zero Walsh code consisting of 128 zeros. The Sync Channel is a convolutionally encoded (rate $r = 1/2$ and constraint length $K = 9$), interleaved in 20 ms fraames), spread and modulated signal that is used by the user terminals to acquire system time synchronization. The Sync Channel data is generated at 1200 bps rate and consists of system time, gateway ID, and assigned paging channel. The Paging Channel is used for transmission of control information and pages from a gateway to the user terminals. The Paging Channel data rate is 4800 bps which is convolutionally encoded ($r = 1/2$, $K = 9$), interleaved, spread, and modulated. On Forward Traffic Channels, Globalstar supports two different rate sets: Rate Set 1 and Rate Set 2. Rate Set 1 supports 4800 and 2400 bps rates. Rate Set 2 supports 9600, 4800, and 2400 bps rates. In addition, both rate sets support a "zero" bps rate in which the frame carries null data except for a punctured power control bit. Within a rate set, variable data rate operation is supported. Forward Traffic Channels are convolutionally encoded ($r = 1/2$, $K = 9$), interleaved (in 20 ms frames), spread and modulated. Long codes with different masks perform scrambling function on both Paging and Traffic Channels. Figures 6 and 7 show the structure of the Forward link Traffic Channel for Rate Set 1 and 2, respectively.

For a given Forward CDMA Channel, the spreading and modulation process is applied as shown in figure 8. The spreading sequence structure is comprised of an inner PN sequence pair and an outer PN sequence. The inner PN

Figure 5. Forward CDMA channel on each beam.
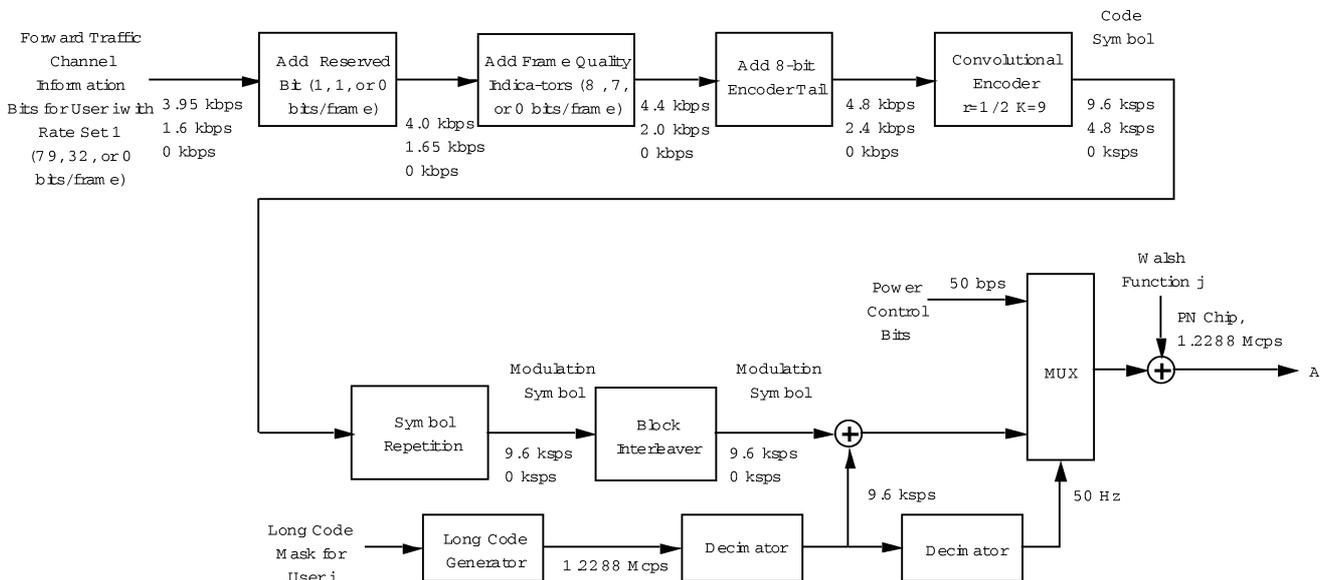
Figure 6. Forward Traffic Channel structure – Rate Set 1.
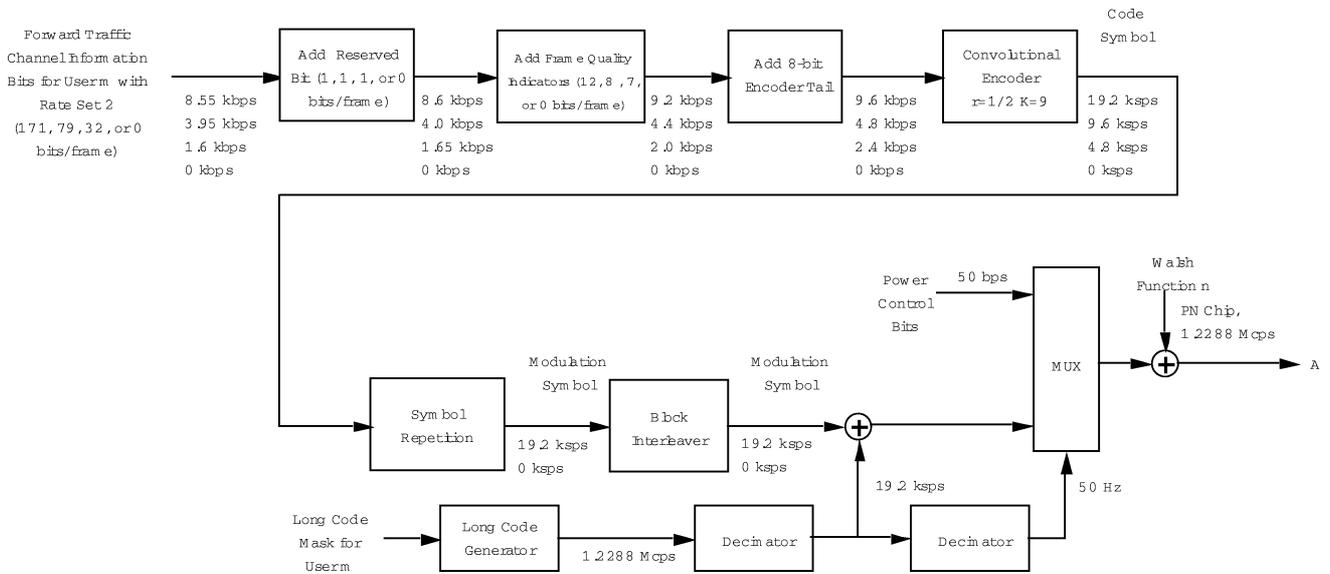
Figure 7. Forward Traffic Channel structure – Rate Set 2.
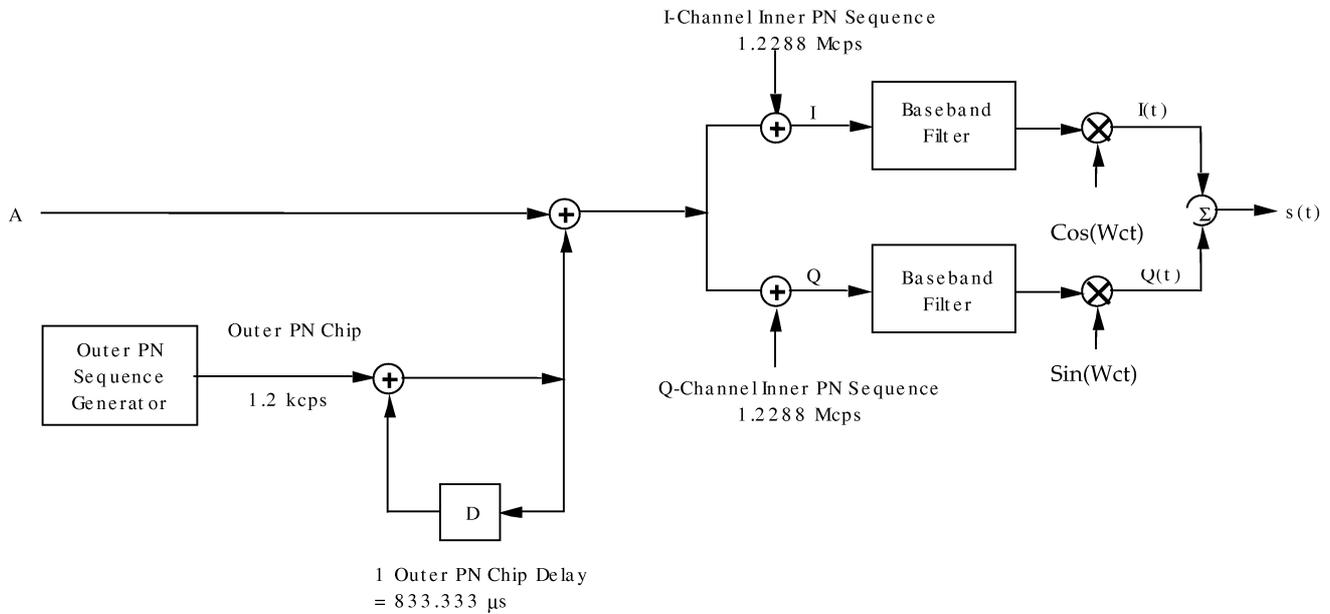
Figure 8. Forward link spreading and modulation.

sequence has a chip rate of 1.2288 Mcps and a length of 2^{10} chips. The outer PN sequence has 1200 outer chips per second and a length of 288 outer PN chips. One inner PN sequence period exactly fits into a single outer PN chip. The outer PN modulates the inner PN sequence to produce the actual spreading sequence resulting in a period of 240 ms. It is noted that the inner PN sequence pair identifies the satellite orbital plane; there are eight different pairs. The outer PN sequence identifies the satellite. Each satellite beam is identified by a time offset of the outer PN sequence for the corresponding orbit. The gateways perform precorrection of time and frequency in their transmitted waveform to compensate for time delay and Doppler variations due to satellite motion for the feeder link.

3.2. Reverse link waveform

The "Reverse CDMA Channel" on each beam consists of Access Channels and Reverse Traffic Channels. Multiple Reverse CDMA Channels may be used by a gateway in a frequency division multiplexed manner. Access Channels are meant for the user terminals to send access packets to the gateway, using a slotted random access protocol, either autonomously (e.g., for purposes like registration, call origination) or in response to a gateway command (e.g., response to pages). The Access Channel structure and the Reverse Traffic Channel structure are shown in figures 9 and 10, respectively. Access Channel uses a fixed data rate of 4800 bps. The Reverse Traffic Channel, on the other hand, supports 9600, 4800, and 2400 bps rates. In addi-
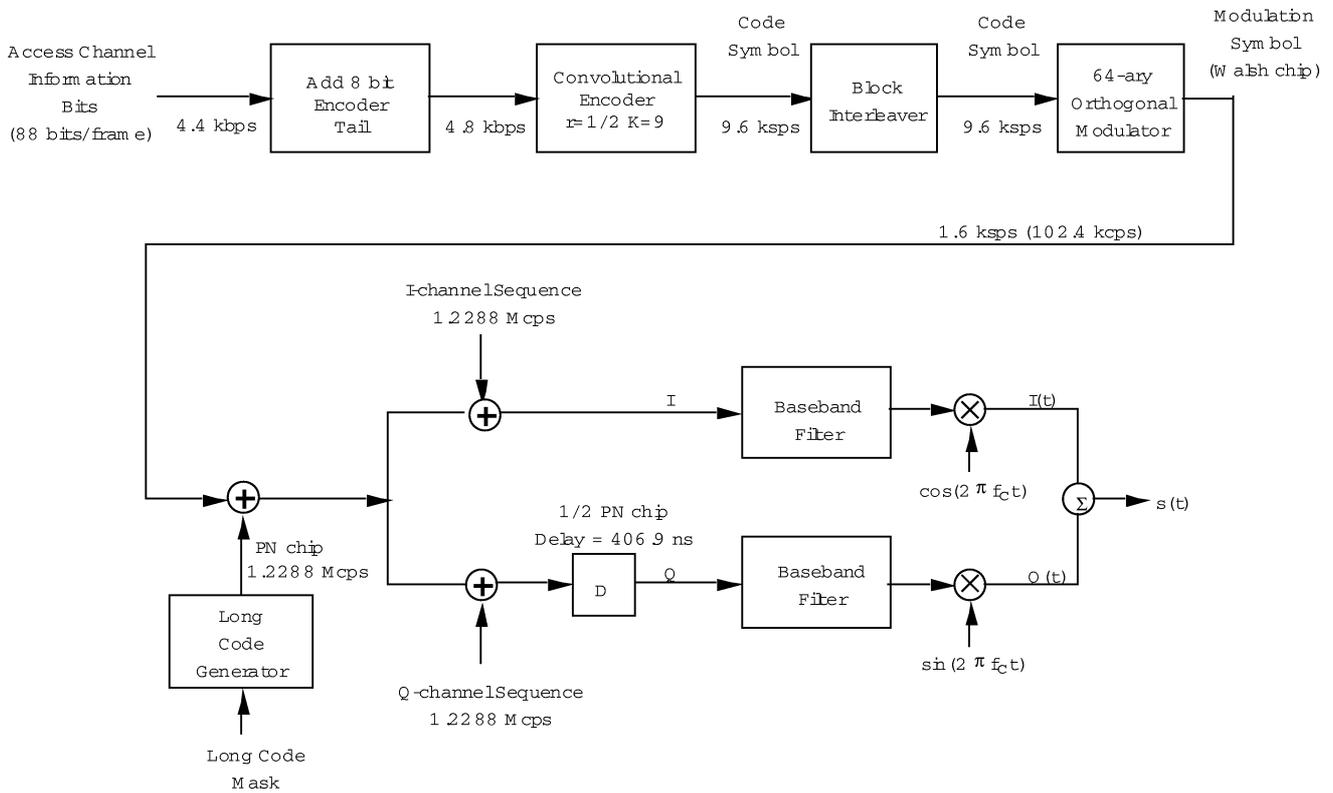
Figure 9. Reverse Access Channel structure.
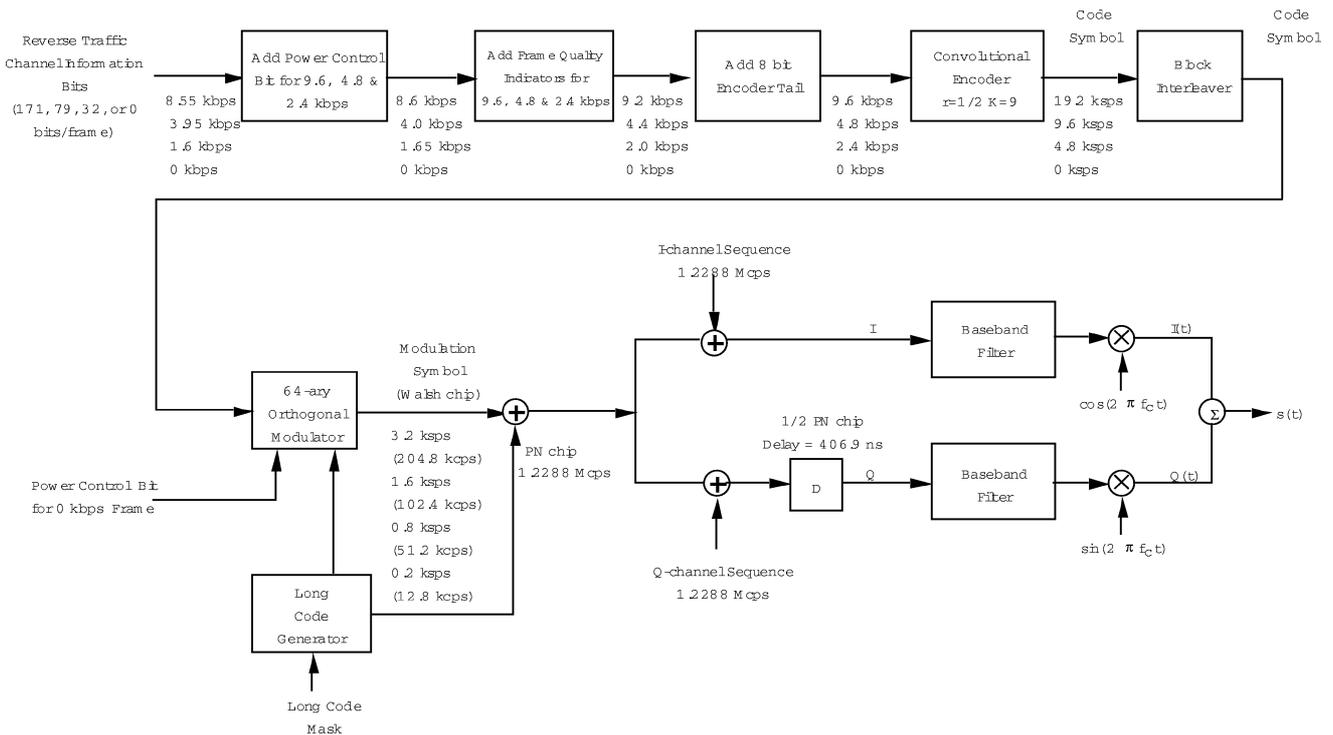
Figure 10. Reverse Traffic Channel structure.

tion, the Reverse Traffic Channel supports a "zero" bps rate where the frame stays on only a fraction of the time and is able to send only the power control bit. Data transmitted on the reverse link is encoded using an $r = 1/2$, $K = 9$ convolutional code. This is in contrast to IS-95 where an $r = 1/3$ and $K = 9$ convolutional code is used on the reverse link. The rate $1/3$ code used in IS-95 performs better on a Rayleigh fading channel because it offers greater cod-

ing and diversity benefits. The rate $1/2$ code used on the Globalstar reverse link, however, will perform better on an AWGN-like channel, which is typical of Globalstar, by taking advantage of longer coherence times of the channel. The encoded information is block interleaved and grouped into six symbol groups or code words. These code words are used to select one of 64 different orthogonal Walsh functions for transmission. The Walsh function chips are then combined with the long and short PN codes. Note that this use of Walsh function is different from the Walsh code use on the Forward CDMA Channel. On the Forward CDMA Channel, the Walsh function is determined by the assigned user terminal whereas on the Reverse CDMA Channel the Walsh function is determined by the information symbols being transmitted. This is a simple way of obtaining 64-ary orthogonal modulation which can be demodulated by a Fast Hadamard Transform. Fast Hadamard Transform is similar to a Fast Fourier Transform except that it requires only additions and subtractions and thus simplifies demodulator implementation.

Signals from different user terminals are distinguished by the use of a very long $(2^{42} - 1)$ PN sequence whose time offset is determined by the channel type on which the user terminal is transmitting. Following the long code spreading, Access Channels and Reverse Traffic Channels are offset quadrature spread as shown in figures 9 and 10. Each channel is identified by the long code as well as its quadrature spreading codes. The sequences used for quadrature spreading the Access Channel are periodic with a period of 256 chips. The sequences used for quadrature spreading the Reverse Traffic Channel are periodic with a period of 2^{15} chips.

4. RAKE receiver and handoff

Perhaps the most significant differences between Globalstar and IS-95 lie in the area of how normal reception is carried out and how handoff is performed. The IS-95 standard brought the first practical implementation of the notion of combating multipath fading with a RAKE receiver [15] in terrestrial cellular. The "fingers" of the Rake receiver are put on the most significant resolvable multipath components. These multipath components, which would otherwise cause destructive interference, are made to constructively add to the received signal energy thereby enhancing the receiver performance. It is noted that Rake combining is effective only when the time delay difference in the multipath components is resolvable, i.e., the delay difference is larger than the one chip duration. The Rake receiver concept is implemented in both the user terminal equipment and the base station.

In Globalstar, the time delay difference of multipath signals and the direct path signal is small compared to one chip duration. This means that it is not really possible to resolve the multipath components in order to harness them. Fortunately, this diffused energy is usually quite small. In experiments conducted by us and others, the diffused energy component is most typically found to be less than 10 dB below the energy of the direct LOS component. Low values of Rice factors are seen only at very low elevation angles to the satellite. However in Globalstar, the Rake receiver concept is exploited by *intentionally* creating diversity paths through alternate beams or satellites. As pointed out in figure 2, most user terminals will have at least two satellites in view. In the forward direction, the gateway can choose to transmit the same data signal through multiple satellites. A Rake finger may be assigned at the user terminal to each satellite and the signal energies received through different satellites are effectively combined. The benefits of this are twofold. First is the classical diversity advantage; that is, not only is the mean received power increased but the fluctuations around the mean are decreased. But even more important is that the ability to receive simultaneously on different satellites provides robustness of signal reception in the presence of blockage by obstructions. This is illustrated in figure 11. When one satellite is blocked, the forward link signals on that satellite can be directed off to another unoccluded satellite while the finger assigned to the blocked satellite will continue to search for the return of the blocked satellite. The angular separation of satellites that can be seen by a given user terminal is usually large which fosters the robustness of the multiple satellite use. The diversity advantage in the reverse direction is analogous. The user terminals naturally create intentional diversity paths since their near-omnidirectional antennas transmit to multiple beams/satellites. Note that such multiple path transmissions do not require additional transmit power at the user terminal. The gateway combines the signal energies from all the beams/satellites that pick up the user terminal's transmission with adequate strength to be useful.

4.1. Soft handoff

Another innovation made possible by the use of Rake receiver is the "make-before-break" soft handoff in CDMA [18]. In IS-95, when a user terminal is in an intermediate area between two cells or two sectors of a cell, it can receive from and transmit to both cells/sectors simultaneously (intentional diversity). In the forward direction, the user terminal receiver is able to put one or more fingers on each base station's transmission and reap substantial diversity benefits from Rake combining before demodulation. A similar advantage is obtained in the reverse direction as well. When two sectors receiving the user terminal's transmission are combined by the Rake receiver in the same base station, the situation is quite analogous. However, when two different base stations receive from the same user terminal, the situation is somewhat different. In this case the signals are individually demodulated in each base station, and both demodulated digital streams are passed on to the mobile switching center (MSC). At the MSC, the better stream (i.e., the one with lower frame error rate) can be selected. This is switch diversity rather than signal
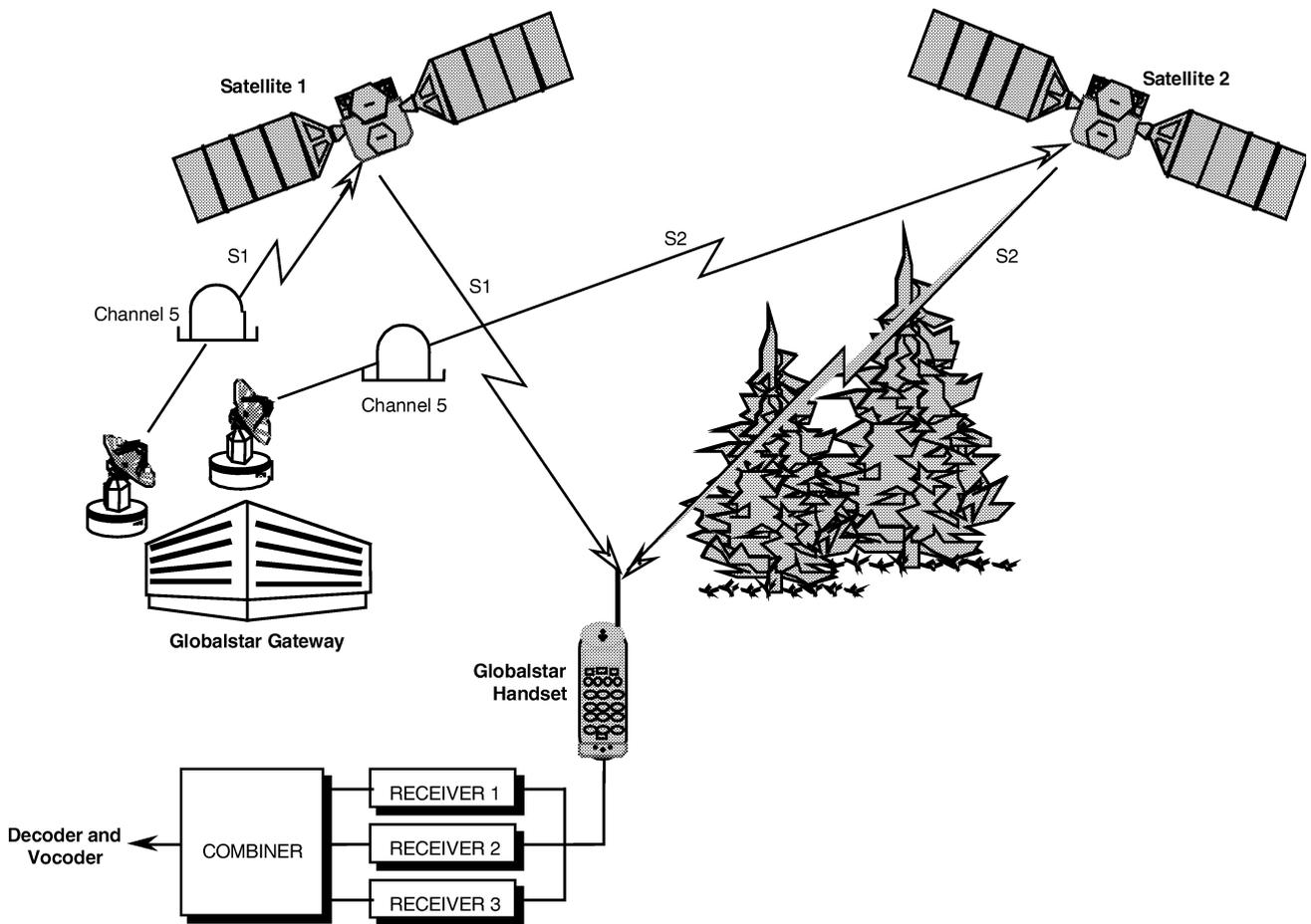
Figure 11. Diversity through multiple satellite operation.

combining diversity. Relative to the above handoff scenarios in cellular, it should be remarked that in Globalstar there is no need for switch diversity, since all demodulators are in the gateway and all beams terminate at the gateway. In other words, in Globalstar diversity combining always occurs before demodulation.

The net result of the above is that, in cellular, operating with one base station (or one sector) is the "normal operation", and operation with multiple base stations or sectors is something that is done in a "handoff mode" when moving from one sector to another. In Globalstar, on the other hand, it is "normal" to operate through more than one satellite and the user terminal can virtually spend all its time in that mode. Let us now consider how handoff is performed in Globalstar.

Unlike in cellular where handoffs occur mainly due to user's motion, in Globalstar handoffs occur even when the user is static because of the relative satellite motion. There are two types of handoffs on the forward link; handoff in idle mode and handoff in traffic mode. In idle mode, the user terminal continuously measures the received strength of a set of pilots (periodically provided by the gateway through the paging channel), and autonomously hands off to the beam with the strongest pilot. Handoff may occur from one satellite to another or from one beam to another

beam on the same satellite. Satellite diversity is not provided in idle mode. In traffic mode, once a traffic channel is established on a beam, the user terminal is periodically provided a list of beams/satellites that are currently in use by the gateway. The user terminal measures the strength of the corresponding pilots and periodically reports a set of those pilots and their strengths to the gateway. Based on these pilot strength reports, the gateway decides whether a handoff has to occur or not and advises the user terminal accordingly. In the process, the gateway always gives preference to provide intentional dual satellite diversity. The gateway also uses suitable threshold hysteresis mechanisms so that it picks up or drops a diversity satellite beam only when it becomes sufficiently strong or weak, respectively. This mechanism avoids possible ping-pong effect (repeatedly picking up and dropping the same diversity satellite beam over short time intervals) due to cyclic variations in signal strength caused by specular reflections.

On the reverse link traffic channel, handoffs occur by way of gateway autonomously measuring and picking only the strongest signals through different beams/satellites as candidates for Rake combining. There is neither Rake combining nor reverse link handoffs during access channel packets transmision.

5. Power control

In terrestrial cellular systems, the propagation delays are small and this permits rapid and accurate closed-loop power control on the reverse link transmission [3]. In IS-95, a power control bit is punctured into the traffic frame once every 1.25 ms giving a power control update rate of 800 Hz. By contrast, in Globalstar the minimum propagation delay between the user terminal and the gateway (via the satellite) is 9.4 ms at 90 degrees satellite elevation, and it can be as high as 23.4 ms when the elevation is 10 degrees. With delays of that order, one cannot have effective closed-loop power control to compensate for the rapid signal variations due to multipath [3]. However, the fact that the multipath fading in Globalstar is Rician distributed renders the power control less critical. Consequently, in Globalstar closed-loop power control is applied at a slower rate of 50 Hz (i.e., one power control bit every 20 ms frame) on both forward and reverse links. As in cellular, each power control bit instructs the transmitter to increase or decrease the transmit power in fixed steps. On the other hand, signal variations due to shadowing and distance losses are slow and a simple open-loop power control strategy which does not need power control command feed back can effectively compensate those variations [4]. Thus a combination of open-loop (referred to as the outer loop) and closed-loop (referred to as the inner loop) strategies provide effective power control in Globalstar.

On both forward and reverse links the inner and outer loops function as follows. The frame energy E_c/I_t (energy per chip divided by the total noise density where total noise include both thermal noise and interference) is measured every frame. This measured frame energy is used to compare against a target value to determine whether to ask for an increase or decrease in transmit power. The power control bit decision algorithm also takes into account the round trip delay and the most recent power control bits that have been transmitted. This is because it will take a number of frames delay before the receiver can see any effect from previous power control bits. If the power control bits were toggled up and down without taking this effect into account it could result in oscillatory response of the loop. The target E_c/I_t value for the inner loop is set and controlled by the outer loop. The outer loop sets this target to the proper value by observing the frame error rate in the recent past. Its goal is to adjust the target value so that the frame error rate is neither too good nor too bad. The elements of an outer loop are present in IS-95 cellular, too, but the importance of outer loop is much more important in Globalstar than in cellular because of the large variation in path loss as a function of satellite elevation in Globalstar. Also, readers familiar with IS-95 will note that in IS-95 the open loop power control is based on signal strength measurement on the opposite link. Such a procedure is reasonable in cellular because the frequency separation between the forward and reverse links is small, such that the slowly varying losses are very much correlated on

both links. However, in Globastar the user terminal transmit frequency is about two thirds of the receive frequency (L-band versus S-band) which does not result in high correlation between both links. Hence, open loop control based on frame error measurement is used in Globalstar.

User terminal speed has an impact on the target E_c/I_t value. When the user is standing still, the multipath fade rate is very small and the inner loop can effectively remove the slow fades. In this case, the proper target value would be low and close to the value corresponding to an AWGN channel. When the user is moving in a car, the fade rate gets large so that the inner loop cannot keep up with the fading fluctuations. Depending on the vehicle speed, the multipath fade remains constant over a frame interval or not. The highest target value is needed at some intermediate speed where the inner loop is ineffective and the fade is not rapid enough to harness the benefit of interleaving and coding within a frame.

In summary, the inner loop asks for more or less transmit power in accordance with trying to get the received signal level close to a target value, while at the same time the outer loop at a slower rate readjusts the target value based on the measured frame errors. Incidentally, the outer loop does not work symmetrically on target increases and decreases. To ensure that users get satisfactory service, the outer loop is relatively quick to adjust targets up to improve frame error rate but rather slow to decrease targets.

6. Other differences and similarities

In this section we highlight some of the other differences and similarities between IS-95 and Globalstar.

6.1. Lower effective data rate

Satellite power is a precious commodity. Because the average satellite power used for a call is proportional to the average data rate, one of the earliest decisions made in the Globalstar program was to reduce the effective average data rate of a call. This has been accomplished via three mechanisms. First, the vocoder output rate has been reduced with virtually no noticeable decrease in speech quality compared to the IS-95 vocoder. Second, all other things being equal, the fact that power control has to puncture only one bit per frame (i.e., 50 Hz) rather than 16 bits per frame (i.e., 800 Hz) in IS-95 allows the same quality of reception for a lower power in Globalstar. And finally, lower data rates are added to the rate set for use when little or no data need be sent.

6.2. Continuous reverse link transmission

This again was one of the earliest decisions taken in the Globalstar program. In IS-95, the forward direction uses continuous transmission. That is, as the data rate is stepped down from 9600 bps to 4800 to 2400, etc., the signal is simply transmitted with successively half the power

at each step (i.e., the E_b/N_0 stays the same). But in the reverse direction the transmission is always at the peak rate and power but intermittant so that for 4800 bps transmission occurs half the time and for 2400 bps transmission occurs for one quarter of the time, and so on. The transmission periods are randomized. The problem with this approach for Globalstar is that sometimes the user terminal may not have sufficient peak power to transmit at 9600 bps. We want to be able to go to a mode where if the user terminal has a power that is less than that is needed for 9600 bps but still is more than half that power, then it can transmit at 4800 bps with slight degradation in the speech quality. Similar argument applies for available power just adequate for 2400 bps. Hence the reverse link transmission in Globalstar has been changed to a continuous mode transmission.

6.3. Pilot, Paging and Sync Channels

The Pilot, Paging and Sync Channels in Globalstar play analogous roles to their use in IS-95. But Globalstar offers the possibility of reducing the power of the pilot (continuing the theme of conserving precious satellite power). This is compensated for by filtering with a considerably narrower filter for pilot tracking at the user terminal. In IS-95, because of the Rayleigh fading environment, use of narrow band filtering is not effective to track the large phase fluctuations of the Rayleigh process. In other words, narrower filter would result in large phase error between the received pilot and the user terminal generated reference. With the Rician fading environment of Globalstar, phase fluctuations in the received pilot are much more contained and pilot tracking is better. However, low value of pilot strengths could cause problems in pilot acquisition in Globalstar. To overcome this problem, an innovative pilot acquisition technique that harnesses the power in the Paging and Sync Channels is employed in Globalstar user terminals.

6.4. Access Channel preamble

The access packets sent on the Access Channel consist of a preamble at the beginning of the packet in order to enable the gateway to search, acquire, and track the packet transmission with adequate frequency and time accuracy so that the following message payload in the packet can be demodulated. The preamble has to be long enough for the gateway to search the entire search space defined by the maximum time and frequency uncertainties involved due to propagation delays and Doppler effects [2]. Contrary to terrestrial systems, the time and frequency uncertainties in Globalstar are quite high. The maximum time uncertainty is calculated as the difference between the earliest and the latest packet arriving times with respect to the system time frame boundaries at the satellite. The earliest and the latest packet arriving times correspond, respectively, to the minimum and maximum user terminal-to-satellite delay (which, in turn, correspond to 90 and 10 degrees elevations, respectively). The maximum time uncertainty for Globalstar

is calculated to be about 14 ms. The maximum frequency uncertainty, on the other hand, is given by the maximum Doppler and the maximum uncertainty in the frequency of the user terminal's local oscillator. In Globalstar, the worst case Doppler which occurs at 10 degrees elevation is about ± 18 ppm. At 1.6265 GHz transmit frequency (maximum L-band frequency), this corresponds to a frequency uncertainty of about ± 30 KHz due to Doppler alone. All these represent a substantially large number of time and frequency hypotheses to be searched in the access channel acquisition. Consequently, the access channel preamble is required to be much longer in Globalstar than in IS-95.

6.5. Protocol stack for data services

In terrestrial CDMA, asynchronous data and Fax services are supported. The IS-99 standard [17] defines these data services using IS-95 CDMA standard as the underlying physical layer. IS-99 uses a Transport Control Protocol/Radio Link Protocol (TCP/RLP) protocol stack at the user terminal and the base station to support reliable data transfer. TCP is tuned to perform well in wireline networks where the channel error rates are low and congestion is the primary cause of packet loss. However, when used over wireless channels which are characterized by high frame error rates, the performance of TCP is severely affected. In order to reduce the frame error rate seen by the TCP layer, a Radio Link Protocol (RLP) is introduced at the link layer, i.e., above the physical layer and below the TCP layer. In IS-99, the RLP performs a partial link layer recovery through a limited number of RLP frame retransmissions in case of frame error. In the event of RLP failure due to excessive frame errors, control is passed on to the TCP layer which is ultimately responsible for providing complete error recovery over the air. Asynchronous data and Fax services are supported in Globalstar using a protocol stack very similar to the IS-99 stack.

7. Conclusions

We described the forward link and reverse link signal design in Globalstar and discussed some of the changes that were made to IS-95 for Globalstar operation along with the reasons for those changes. The underlying philosophy remains the same and the family resemblance between the two systems is clear. The differences are sufficiently small that user terminals that are dual mode Globalstar/IS-95 will be able to share much common circuitry with resultant size and cost reduction.

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