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TWO-WAY INTERNET OVER iPSTAR USING ADVANCED ERROR CORRECTION AND DYNAMIC LINKS

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Abstract

Two-way Internet service over satellite for consumers has proven so far to be too expensive to attract large numbers of subscribers. One way to reduce service cost is to increase the number of subscribers per satellite transponder by using advanced error correction and dynamic links (adaptive fade compensation). Customer Premise Equipment (CPE) modems and head-end modems have been developed by Efficient Channel Coding (ECC) using higher level modulation and advanced Turbo Product Codes (TPC) that, in conjunction with dynamic links, significantly increases the number of subscribers per transponder compare to fixed links with QPSK and Reed Solomon/Convolutional concatenated codes. This increase is from one and one half to four times depending on the RF frequency and the rain attenuation region. The Dynamic Link Assignment (DLA) system (patents pending) is being used by Shin Satellite Public Company (Shin Sat) to provide commercial Internet services in Asia using their existing Ku Band satellites. In late 2003, the iPSTAR spot-beam satellite will be launched and placed into the 120 degree East longitude orbit slot. Using the DLA system the iPSTAR information capacity will be up to 40 Gbps.

Introduction

Two-way Internet over satellite for consumers is characterized by asymmetric interactive services supporting a wide-band forward link to the user with a narrow-band return link to the gateway. A recent report[1] on commercial satellite Internet systems has indicated that more Internet subscribers need to be able to be accommodated on a transponder to reduce the transmission cost, which is a major component of the overall service cost. The current service cost of $70 a month for satellite Internet in the US is just too high to attract a large number of subscribers.

Existing satellite systems normally used QPSK modulation with concatenated Convolutional and Reed-Solomon error correction codes. In addition, the RF links are run using fixed margins with the size of the margin dependent upon the maximum rain attenuation predicted for the service area. One way to increase the system data throughput is to manage each user terminal separately and have each one use as high a level modulation in combination with as high a code rate as the instantaneous link conditions allow. As link conditions fade, the modulation level and code rate is changed to maintain BER requirements. Since only a low percentage of user terminals in a beam will encounter significant rain attenuation at any time, this technique significantly increases average information throughput per unit bandwidth. ECC has developed a system using advanced error correction that efficiently implements this technique. The system was developed with Codespace and Shin Sat and will be incorporated into their iPSTAR satellite service. In this paper the technique is described and its advantages detailed.

The use of dynamic links or adaptive rain compensation has been proven for geostationary satellite systems by the ACTS program[2]. In the case of ACTS, the compensation consisted of introducing, simultaneously, a single ½ rate coding and a ½ data rate reduction for an individual user terminal when it automatically sensed a significant rain or other fade. The compensation was a one-step on/off system. The program showed that the signal to noise ratio could be reliably monitored by each user terminal with little cost impact. Switching to a new data rate or coding requires coordination (messaging) between the user terminal and the network control. For a geostationary satellite this coordination requires on the order of one second. ACTS demonstrated that the compensation could be accomplished fast enough using simple messaging with the network control before any significant additional fade occurred. The DLA system described here is a greatly improved one providing multiple step changes to both the level of the modulation and code rate. Its Turbo Product Codes also provide significant gain over the traditional codes.

It is widely accepted that Forward Error Correction (FEC) is a valuable technique to increase power and spectrum efficiency and has an important role in any satellite system. ECC has performed significant research on a class of codes that offer performance closer to Shannon's limit than traditional concatenated codes. These codes, which we call Turbo Product Codes (TPCs), involve the iterative soft decision decoding of a product code[3]. TPCs have a wide range of flexibility in code rate with significant increase in gain. For example for QPSK with a 0.793 rate code, TPCs are able to provide an additional gain of approximately 1.6 dB over that for the traditional concatenated Reed Solomon outer code with a Viterbi inner code at a BER of 10^{-7}. This result is based on data from back-to-back modem tests. ECC's efficient decoding algorithm enabled the world's first practical turbo code error correction chips and software in late 1998[4]. TPCs are used to provide all FEC in the iPSTAR physical layer.

The outline for this paper is as follows. Section 1 describes the iPSTAR system. In section 2 the system and dynamic link approach is presented. Section 3 discusses the system benefits of using dynamic links with advanced coding.

1. iPSTAR

iPSTAR, which is scheduled for launch in late 2003, will provide a last mile broadband access solution in Asia for Internet, broadcast, multicast and continuous circuit services. The geostationary satellite, which is shown in figure 1, has 114 total beams. All transponders operate in a "bent pipe" mode.

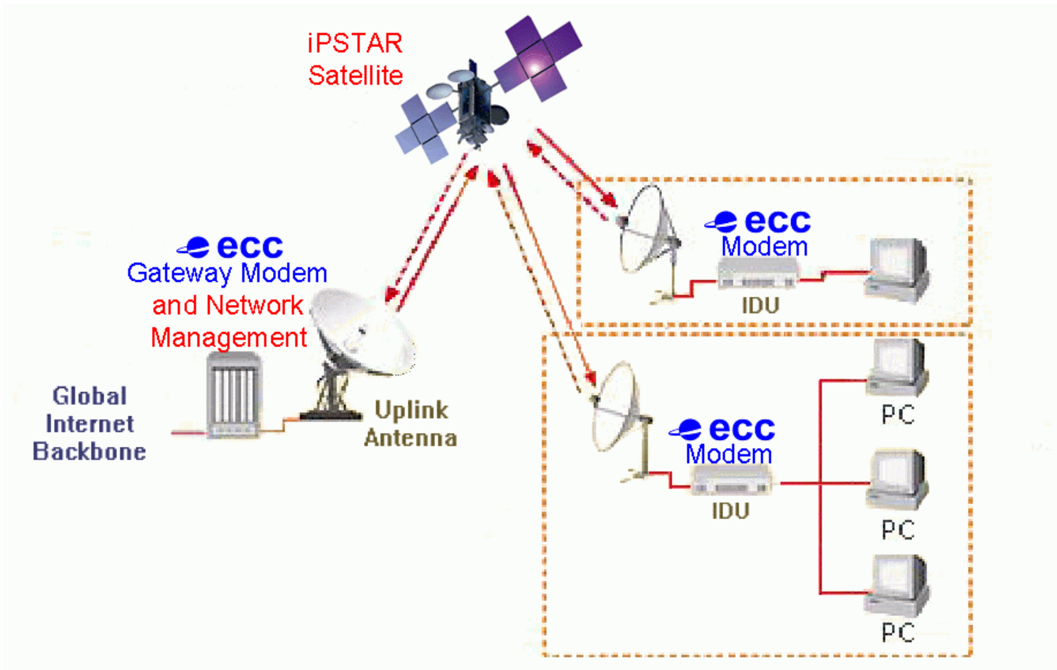

Figure 1: iPSTAR System Configuration with Bent Pipe Operation

The physical layer technology being utilized on iPSTAR plus the high degree of frequency reuse achieved from the spot beams allows it to offer far more capacity than other proposed broadband satellites, making iPSTAR extremely cost-effective. The user information throughput capacity of iPSTAR is approximately 40 Gbps, depending on link conditions and terminal antenna sizes. With the first iPSTAR satellite located at 120.0 degrees East longitude, service coverage will include India, China, East Asia, South East Asia, Australia and New Zealand. For this coverage, the iPSTAR system will provide telecommunication and multimedia services to households, businesses and private organizations.

Each user terminal operates in a "star" configuration with its assigned gateway. The user data rates available on the return link can be up to 4.1 Mbps, while on the forward link the user rates can be up to 12 Mbps. The actual data rates for each user depend on the particular service being provided, the link conditions, and antennae patterns.

Space System/Loral using their 1300-S Bus system is manufacturing the spacecraft. The transponders consist of TWTAs at either 65, 90 120 or 150 Watts. The total launch weight is 6,735 Kg and the electrical power is 14 KW at the end of its 12-year design life. It should be emphasized that the large number of transponders on iPSTAR significantly lowers the transmission costs per unit bandwidth. Although this is not discussed in detail in this paper, it is a significant factor in providing a very cost effective service.

2. System Approach

The basic architecture for the physical and network layers are described in this section.

Dynamic Link Assignment (DLA)

For dynamic links, variable modulation and TPC codes rates are utilized in an adaptive fashion. The signal to noise ratio (SNR) for the forward link is constantly monitored by each user terminal. The SNR for the return link from each user terminal is monitored by the gateway. As the SNR varies with changes in link attenuation, the modulation and/or code rate is automatically changed on both the forward and return links on an individual user terminal basis to ensure that its BER requirement is maintained.

Under clear air conditions, each terminal uses a high level modulation in conjunction with a high code rate. The maximum bits per symbol per Hz that is achievable with the present design is 3.52 using 16-ary modulation with a 0.879 rate TPC. When a particular terminal encounters rain or other degradation (link attenuation, interference, spot beam rolloff, etc.), its modulation level and code rate is reduced. The minimum bits per symbol per Hz that can be used for the current system is 0.65 using QPSK with a 0.325 rate TPC.

An approximate one dB of system margin is maintained at all times to cover the time delay associated with the terminal and gateway control loops as it relates to the fade slope of severe rain attenuation events. Under most environmental conditions, only a small percentage of terminals are encountering significant rain attenuation at any one time. As a result, the data throughput for a transponder using the DLA scheme can be approximated by the throughput when all user terminals are under clear air conditions. Large increases in data throughput per transponder can be achieved using DLA versus fixed links.

DLA also provides a significant advantage for spot beam systems. In the typical spot-beam system the satellite antenna gain from edge of coverage to beam center varies by 4 dB. As a result, the satellite EIRP varies by the same amount over the beam coverage. Dynamic links as opposed to fixed links allows each user terminal to automatically sense where it is in the spot beam and to operate at as high a modulation level and code rate as possible. This will significantly increase the transponder data throughput.

Channelization Architecture

The channelization architecture design is summarized in table 1. The forward link is composed of multiple channels each at a constant symbol rate of 3.375 Msps. Sixteen channels are multiplexed together, providing a 54 Msps band. The iPSTAR satellite uses transponders that can accommodate up to 9 of these 54 Msps bands. Since the transponders have a wide bandwidth and must accommodate multiple channels, they are operated in a linear gain regime. Each user's data is time multiplexed in a conventional fashion onto a forward link channel. Since channels within a band have a fixed frequency and time relationship, a user terminal can change modulation and coding rapidly without resynchronization. The range of selectable modulations and TPC rates are shown in table 1.

The return link is also composed of a large number of channels that are accessed using Multiple Frequency Time Division Multiple Access (MF-TDMA). The channel bandwidth, which is selectable for each user, varies between 131.84 KHz and 2.1094 MHz in powers of 2. The access can be accomplished via Aloha, Slotted Aloha or MF-TDMA schemes. Aloha is primarily for a user terminal to gain entry into the system. Slotted Aloha is used for low return channel data rate applications where real time performance is not required, e.g. web browsing. MF-TDMA is used for higher data rate packet transmissions or for continuous circuits. The modulation and TPC rates are selectable as given in table 1.

The gateway controller allocates the modulation and coding for the forward and return links based on an individual terminal's need to accommodate any link attenuation. The controller also assigns the capacity for each terminal and ensures that quality-of-service requirements are met. Once a user terminal has been accepted into the system, it is both symbol and frame synchronized, minimizing overheads for any transmissions on the forward and return links.

Table 1: Forward and Return Link Channelization Architecture

Link	Channelization	User Access	Selectable Modulation	Selectable TPC Rate	Bits Per Symbol
Forward	Sixteen 3.375 Msps channels in 54 Msps band	Time Division	QPSK, 8-ary, 16-ary	0.325 – 0.879	0.65 – 3.52
Return	MF-TDMA 131.84 KHz – 2.1094 MHz	ALOHA, Slotted ALOHA, MF-TDMA	QPSK, 8-ary	0.325 – 0.879	0.65 – 2.64

The indoor unit or set-top box will be provided with either a USB or Ethernet user interface for ease of installation. There are many possible applications for the iPSTAR system, however using the flexibility offered by the transmission system, each application might be configured with different bandwidth assignment in order to meet its requirements. iPSTAR will be serving the mass market for the Last Mile access and is particularly suitable for broadband Internet and rural telephony, which is an underserved market in Asia. However it is also capable of providing high-rate, two-way, continuous symmetric circuits that will satisfy many special needs for businesses.

Since November 2001, Shin Satellite has been running a commercial field trial using the iPSTAR system in conjunction with their existing Ku band satellites. This initial roll out has demonstrated the functionality of the DLA design and advanced error correction performance, although has not yet been extended to the full range of features in the system design (e.g. 16-ary modulation has not yet been demonstrated). The soft start over existing satellites provides for early development and field operation of the terminals to be used on iPSTAR-1 when it is launched in 2003. In addition it provides the various Service providers with an early opportunity to begin cost effective services using available capacity on conventional satellites and build a subscriber base that can be transferred to iPSTAR-1. These field operations have also provided valuable information on the performance of the equipment along with the operation of dynamic links and have thus proven out the design of the physical layer and network control.

3. Benefits of Advanced Waveforms and Dynamic Links

A quantitative assessment was performed to determine the data throughput advantage of using adaptive modulation and TPCs versus using fixed links as defined by the Digital Video Broadcasting (DVB) specification EN 300 421. In order to simplify the analysis we considered only the forward link. Similar gains can be achieved on the return link.

A link analysis was performed for the two regions shown in table 2. The user terminal location is positioned in a large rain attenuation area for the region. The amount of rain attenuation for 99.5% annual availability was determined by using the new ITU-R rain attenuation model based on the work of Dissanayake, et al[5]. When comparing results between the two regions note that the satellite – terminal configuration results in different elevation angles for both regions.

Table 2: Location for Gateway and User Terminal

Region	Gateway Location	User Terminal Location	Satellite Longitude
US	Denver, CO	Tampa, Florida	119.2W
Asia	Bangkok	Singapore	120.0E

In all cases, a 33 MHz transponder is used to transmit a single channel. A single channel mode was adopted since this is the normal mode for DVB. The same total symbol rate was assumed for each model and the BER requirement was set at 10^{-7} for this single channel, with a 0.28 roll off factor. This BER was chosen since measured modem performance was available at that value. Equivalently the symbol rate for the channel was held constant, in all cases, at 25.78 Msps.

Fixed Link

In the case of fixed links, QPSK modulation was combined with the standard DVB coding consisting of a Reed Solomon (204/188) outer code concatenated with a Viterbi convolutional inner code with constraint length K = 7. Convolutional code rates of ½, 2/3, ¾, 5/6 and 7/8 are available. The Eb/No performance used in the analysis for a BER of 10^{-7} was taken from product brochures. This modem performance included degradations that occurred under back-to-back operation (i.e. without any satellite components in the link). With the fixed link approach, the code rate used is that required to provide the required BER with the rain attenuation. This code rate is used on a continuous (fixed) basis for all user terminals whether or not the rain attenuation actually exists. A 1 dB system margin is included in order to ensure the BER. The information throughput for the entire transponder is directly determined by the code rate.

Dynamic Link

In the case of dynamic links, the full range of modulations and TPC parameters, as described in the previous section, were used in the analysis. That is the allowable modulations were QPSK, 8-ary and 16-ary, and the TPC code rates available varied over the range of 0.325 to 0.879. The Eb/No performance values utilized in this analysis are based on back-to-back modulator to demodulator measurements by ECC, i.e. the Eb/No values used in both the dynamic and fixed links were determined on a similar basis.

Broad versus Spot Beams

The comparison of fixed versus dynamic link was done for Ku and Ka frequencies. In the case of Ku, a single broad beam covering a large area such as the US was assumed. For purposes of this analysis, the EIRP was considered constant in the broad Ku beam.

In the case of Ka, a narrow spot beam was assumed where the area coverage is defined by the –4.1 dB contour. The throughput for fixed link was calculated using the EIRP value at the –4.1 dB contour. The throughput for dynamic link was determined by calculating the throughput for each 1-dB contour segment and arriving at an average throughput assuming uniform user distribution throughout the beam.

Results

Standard link analyses were performed whereby the C/No on the uplink is considerably higher than the downlink, which is a common practice for DVB operators. The same user terminal size was used in the analysis for both the fixed and dynamic links. QPSK was always used for the fixed links and the code rate was selected to provide a fixed margin equal to the rain attenuation for 99.5% availability. The selected code rate directly determines the information throughput.

Results are shown in Tables 3 and 4 for both Ku and Ka frequency bands. The information throughput for the dynamic links is based on the assumption that most terminals in a region are not encountering significant rain fade, and therefore, the throughput can be approximated by considering all terminals are in clear air conditions.

The throughput benefit of dynamic links with TPCs over fixed links using concatenated Reed Solomon with Viterbi code is considerable. For Ku-band, the benefit ratio for dynamic links varies over the two regions from 1.4 to 2.0. In the case of Ka-band, the ratio varies over the range from 1.6 to 3.5. *In addition to the 3.5 Ka-band improvement in throughput for the Asia region, the required satellite EIRP is 3 dB lower using dynamic links.* As the tables show the amount of the benefit is proportional to the magnitude of the rain attenuation at the selected availability. All of the data throughput improvements that dynamic links provides are significant since they can be achieved with only minor recurring cost impact to the user and gateway terminals.

Table 3: Fixed versus Dynamic Forward Links – Ku Band

(Downlink BER = 10^{-7}, Downlink Availability = 99.5%, 33 MHz Transponder)

User Location	User Terminal Size (M)	Satellite EIRP (dBW)	Downlink Rain Attenuation (dB)	Technique	Information Throughput (Mbps)	Benefit Ratio for Dynamic TPC
Tampa Florida	0.5	51.8	1.76	Fixed	35.63	1.43
				Dynamic	51.04	
Singapore	0.5	51.5	2.93	Fixed	31.67	2.04
				Dynamic	64.58	

Table 4: Fixed versus Dynamic Forward Links – Ka Band

(Downlink BER = 10^{-7}, Downlink Availability = 99.5%, 33 MHz Transponder)

User Location	User Terminal Size (M)	Satellite Spot Beam Center EIRP (dBW)	Downlink Rain Attenuation (dB)	Technique	Information Throughput (Mbps)	Benefit Ratio for Dynamic TPC
Tampa Florida	0.66	52.7	5.79	Fixed	23.75	2.79
		52.7		Dynamic	66.26	
Singapore	1.2	55.6	10.01	Fixed	23.75	3.54
		52.5		Dynamic	83.97	

Conclusions

A two-way satellite Internet system has been developed using advanced error correction and dynamic links, which greatly increases the data throughput per unit bandwidth. Depending upon the rain attenuation region and the RF frequency for operations, the benefit of Dynamic Links with Turbo Product Codes versus Fixed links with concatenated Reed Solomon/Viterbi code varies from one and one half to four times the information throughput. This system is currently being used by Shin Sat to provide commercial services in Asia using their existing Ku Band satellites. In late 2003, Shin will launch the spot-beam iPSTAR-1 satellite. iPSTAR-1 with its high degree of frequency reuse coupled with the advanced error correction and DLA will provide the most cost effective broadband services of any satellite system.

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