Ka BAND SATELLITE SYSTEM ARCHITECTURE FOR LOCAL LOOP INTERNET ACCESS

Ali E. Atia
Orbital Sciences Corporation
20301 Century Blvd.
Germantown, MD 20874

ABSTRACT

A ka-band satellite system architecture that provides wide-band local loop access to consumers and small businesses is described. It is based on the phased deployment of simple, low cost bent-pipe GEO satellites providing highly directive spot beam coverage over the continental United States. Each spot beam covers a desired service area, usually not well served by terrestrial communications systems. Internet Service Providers (ISP) use hub antennas within the spot beams to provide two-way Internet connections to the end users. The end users access the ISP hub via the GEO satellite using USAT's (Ultra-Small Antenna Terminals). The downstream data rate can be as high as 90 Mbps, and the upstream rates vary from 64 kbps to as high as 2.048 Mbps.

INTRODUCTION

The rapid increase of Internet usage and the availability of inexpensive powerful personal computers are creating large increases in data traffic in today's networks. As broadband multimedia applications evolve, traffic rates will continue to increase. While the deployment of fiber optic transmission media will enable backbone networks to accommodate this traffic, the 'local loop' will continue to be a bottleneck for communication services provided to consumers and small business.

Currently, the most common access method is telephone dial-up using phone line modems but these devices are limited to 56 kbps and don't satisfy the needs of broadband applications. New local loop solutions, both wired and wireless, are being implemented to provide higher data rates. Such technological solutions include x-digital subscriber lines, Local Multi-point Distribution Service(LMDS), fiber to the home, and cable modems/web TV. Each of these solutions has advantages and disadvantages. The ultimate factors that will determine the widespread usage of any specific technology are:

1. Economic i.e. cost of service and equipment
2. Availability of service and equipment
3. Quality of service
4. Convenience and ease of installation and use
5. Marketing of the services.

Given the magnitude of the local loop problem, it will take a generation to deploy these new systems in the United States. In addition some areas are so sparsely populated, that it may never be cost-effective to serve them using terrestrial communications. Therefore, there is a big opportunity for satellite to meet these needs. Most of the future 'wide-band' ka-band satellites are targeting large and medium size business users, involve rather complex and expensive satellites, and employ advanced technologies such as on board processing and switching, inter-satellite links, re-configurable beams, etc. While the economy of scale may eventually justify the huge investments in such systems, the reality is that the business risk and uncertainty of the market growth timing are major factors in delaying or eliminating many of these systems.

The incremental introduction of wide-band wireless local loop using proven technology, with modest capital demand and forward compatibility with potential future systems is a logical way to proceed. This paper presents technical description of the proposed ka-band satellite system architecture that provides wide-band local loop to consumers and small business type terminals. The concept underlying this architecture relies on a ka-band satellite system which provides a broadband two-way pipe to connect users with an ISP. Using this "broadband pipe", the user is able to access multimedia applications resident on Internet Web sites. A key feature of this "pipe" is that its capacity requirements are asymmetric – very high bandwidth on the forward link from the ISP to the subscriber but only modest bandwidth in the return link direction.

SYSTEM ARCHITECURE

The system is based on the phased deployment of simple bent-pipe GEO satellites where each satellite provides multiple highly directive spot beam coverage. Each spot beam covers a desired service area, usually not well served by terrestrial communications systems. As shown in Figure 1, users access the service with their dedicated Ultra-Small Antenna Terminal (USATs). The GEO satellite provides the local loop connectivity between USAT and Gateway. Each terminal will be covered by one of the satellite user spot beams labeled Spot A, B, or C in the diagram while the gateways are covered by their own dedicated spot beam. The mapping between user spot beams and gateway spot beams is fixed. To provide connectivity to the Internet, the gateway is located on or near the premises of Internet Service Providers (ISP). Then the ISP connects terrestrially to the Internet Backbone. Within each subscriber beam, the forward link operates in a broadcast mode with a data rate as high as 90 Mbps. The return link is a multiple access link and operates at data rate varying from 64 kbps to as high as 2.048 Mbps depending upon user needs. The satellites, hub stations and customer premise equipment are designed to provide quality of service similar to terrestrial systems. The designs include sufficient link margins for rain attenuation, depolarization and other impairments. The use of the bent-pipe satellites instead of satellites with on-board switching is ideally suited for Internet access because users operate as only Web clients accessing Web servers resident on the Internet. Thus, in this architectural concept:

- there is no direct Web client to Web client traffic,
- Web servers are not resident on the satellite network.

With these simple client-server traffic patterns, bent pipe satellites are best suited to meet user needs.

Figure 2 depicts representative spot beam coverage with 24 user spot beams covering the continental United States. Antenna gain contours shown in Figure 2 are 1 dB steps between –1 dB and – 6dB. This coverage is based on 0.9 degree beamwidth such that each beam covers an area approximately 300 miles diameter. Beam to beam isolation is achieved by frequency separation in the adjacent beams, for a total of 4 frequencies and spatial isolation in alternate beams. Each beam would have one forward link operating at 90 Mbps providing 2.160 Gbps system capacity on the forward link. The return link capacity would be allocated to a small number of high capacity channels (2 Mbps) or a larger number of lower capacity channels (64 kbps to 256 kbps).

The 24 user spot beam satellite would require six gateways resulting in the allocated frequencies being reused six times. Each of the gateway beams re-uses the same frequency band; therefore the gateways are geographically separated to achieve isolation. Efficient use of the frequency spectrum is an important consideration in a ka-band system design. The proposed system reuses the allocated frequency band six times and allows for an incremental increase of capacity by adding up to four satellites in one orbital slot. Each satellite requires 500 MHz of spectrum of one linear polarization, to provide the data rates described above. The first and second satellite would utilize the same 500 MHz band of 29500 to 30000 MHz and 19700 to 20200 MHz in an orthogonal polarization. Satellites three and four of a second pair, would use the 29000 to 29500 MHz and 19200 to 19700 MHz bands. Optionally, a third pair of satellites could use the 28100 to 28600 MHz and 18300 to 18800 MHz bands.

The system concept is illustrated for a CONUS satellite system having spot beams. Extension of the same concept to a larger or smaller coverage areas or numbers of beams is straightforward.

SPACE SEGMENT

The payload architecture, depicted in Figure 3, has been optimized for wideband internet access for home or small business by providing a high data rate forward link to users while providing a high G/T thereby simplifying user terminals. The 24 forward and reverse link user beams are mapped into 6 forward and reverse link gateway beams. These gateways would typically be located near regional Internet hubs. Each transponder consists of a simple, non-regenerative amplifier chain. The elimination of baseband processing, on-board switching and inter satellite links greatly simplifies and reduces the cost of the payload. In the block diagram of Figure 3, redundancy is not shown for clarity.

The forward link segment of the payload has a receive antenna for the six gateway spot beams, each 336 MHz wide and consisting of four 90 Mbps channels. A 30 / 20 GHz receiver network, with a 9 for 6 redundancy follows. Each of the 336 MHz bands are multiplexed and filtered into four 78 MHz channels for a total of 24 channels. A limiting driver amplifier and 80 watt TWTA amplify each channel. The Driver Amplifier / TWTA pairs are arranged in a 32 for 24 redundancy network. Four high gain antennas form the 24 user downlink spot beams. Forward

0-7803-6540-2/01/$10.00 (C) 2001 IEEE

link transponder characteristics are listed in Table 1.

The return link segment has similar antenna coverage. The 24 user uplink beams and 6 gateway downlink beams are congruent with their respective forward link beams. A Low Noise Amplifier network, with 32 for 24 redundancy and a six, 4 channel filter / multiplexer form six, 120 MHz channels from the 27 MHz receive bands. Each channel is downconverted to the transmit frequency band and amplified by a Driver Amplifier, pre-distortion linearizer and 80 Watt TWTA. The Driver Amplifier, Linearizer and TWTA strings are arranged in a 9 for 6 redundancy network. A six beam transmit antenna completes the link at the gateway. The return link transponder characteristics are given in Table 2.

The ka-band satellite is based on the Orbital Sciences Star2 Bus, which is a high performance, low cost satellite for geostationary missions. Table 3 lists a summary of key satellite parameters. The Star2 Bus uses a state of the art graphite and aluminum composite structure with an integrated high performance thermal cooling system. DC power is provided by a sun light regulated 48 volt power subsystem employing a six panel solar array with triple junction GaAs solar cells.

GROUND SEGMENT & USE TERMINALS

The ground segment consists of a set of gateways providing the interconnection of the satellite based local loop and the terrestrial Internet. Six gateways would be used to support the 24 spot beam configuration with frequency reuse of six. All of the gateways access the Internet via their local ISP. There is no need to support any gateway to gateway traffic for user services because of the client-software traffic patterns. However, if a gateway were managed remotely from another gateway site, then there would be network management traffic between gateways. The Internet or leased lines could be used for the transmission of this traffic.

The major functions of the gateways are:

- RF subsystem performing up/down conversion, radiation, and signal reception;
- Baseband Processing subsystem performing the modulation/demodulation, forward error correction encoding/decoding, and multiple control; Networking subsystem performing the interconnection between the satellite communications network and the terrestrial network;
- Control subsystem performing the demand assignment multiple access control and the overall network management.

High speed interconnection would be provided between the gateway and the ISP at OC3 rates (155 Mbps). Use of either ATM or IP over SONET are candidate implementations.

In addition to the Gateways, the ground system would also have TT&C systems to support the operation of the satellites.

The user terminal consists of indoor and outdoor units to provide two way connectivity to the Internet. The outdoor unit consists of a rooftop antenna, typically with 0.65 cm diameter, and the RF electronics while the indoor unit provides the modulation, coding, and multiple access functions.

CONCLUSIONS

This paper has described a ka-band system architecture to provide a wireless local loop for broadband Internet Access to consumers and small businesses. It is based on the phased deployment of simple, low cost bent-pipe satellites to meet the needs of these users in a very cost-effective manner. The technical approach described enables a more conservative business case to introduce broadband ka-band services in an unproven market.

Table 1. Forward Link Transponder Characteristics

Parameter	Value
Satellite G/T	19.75 dB/K EOC
Number of Receive Beams	6
Number of Channels per Beam	4
Bandwidth per Channel	78 MHz
Number of Transmit Beams	24
Number of Channels per Beam	1
Bandwidth per Channel	78 MHz
Total Channels	24
Beamwidth	0.9°
Frequency Reuse	6 times
Occupied Bandwidth	336 MHz
Satellite EIRP	59.2 dBW EOC
HPA	32 for 24 TWTA
RF Output Power	80 Watts Saturated
NPR	11 dBc

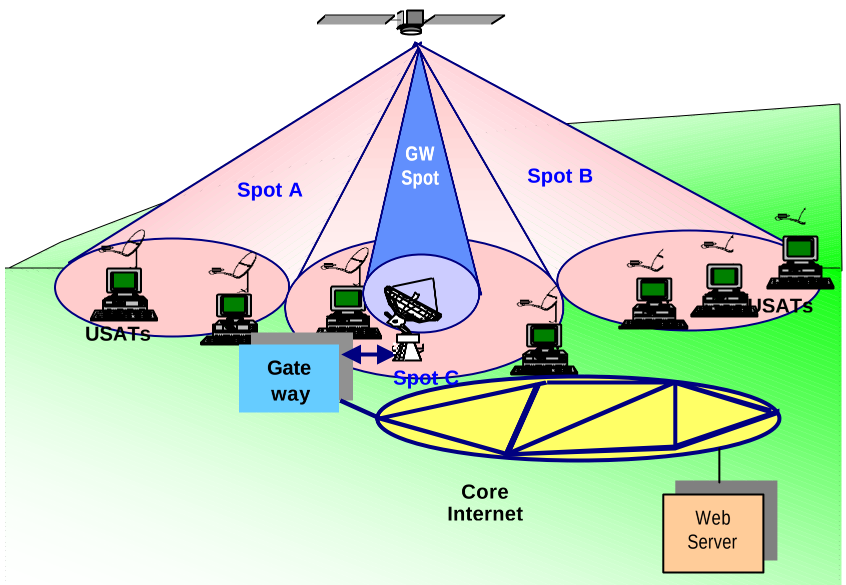

Figure 1. System Architecture

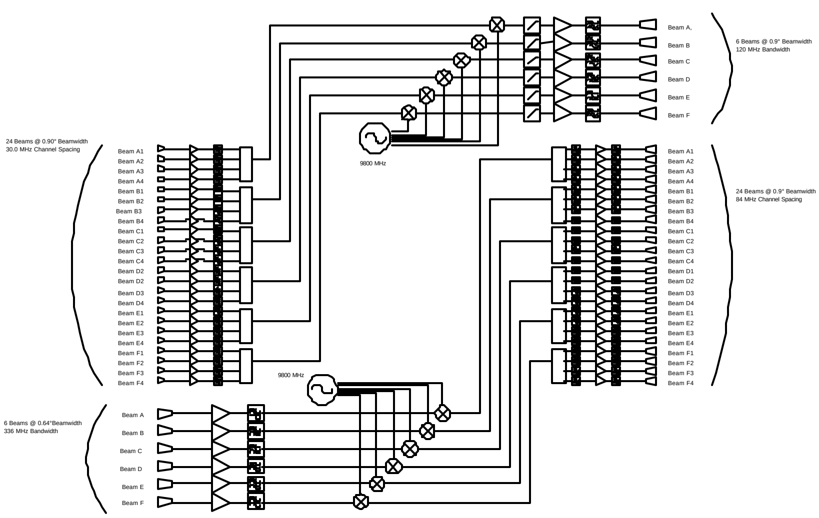

Figure 3. Payload Concept

Table 2. Return Link Transponder Characteristics

Parameter	Value
Satellite G/T	59.2 dB/K EOC
Number of Receive Beams	24
Number of Channels per Beam	1
Bandwidth per Channel	27 MHz
Number of Transmit Beams	6
Number of Channels per Beam	4
Bandwidth per Channel	27 MHz
Total Channels	24
Beamwidth	0.9°
Frequency Reuse	6 times
Occupied Bandwidth	120 MHz
Satellite EIRP	50.2 dBW EOC per Channel
HPA	9 for 6 TWTA
RF Output Power	40 Watts Linear
NPR	15 dBc

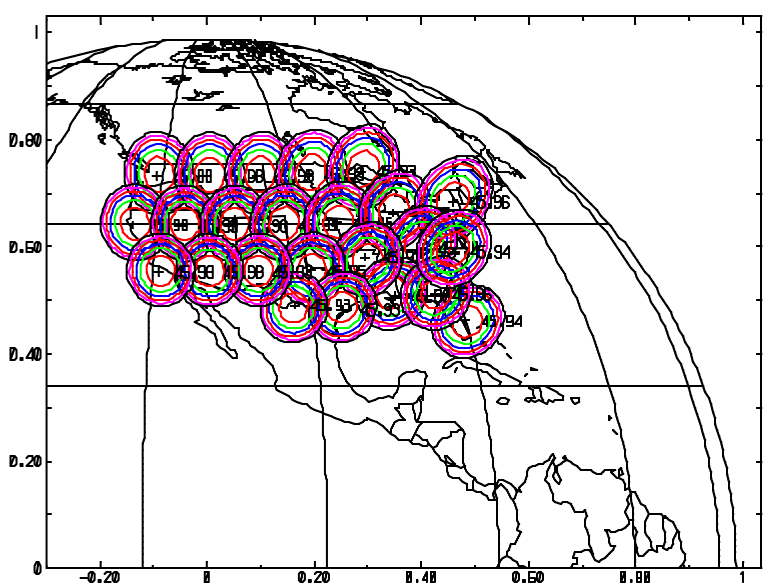

Figure 2. Beam Patterns

Table 3. Star 2 Bus Characteristics

Parameter	Value
Mass	2579 kg
Launch Mass	284 kg
Payload Mass	830 kg
Spacecraft Bus Mass	1465 kg
Propellant	
DC Power	4674 Watts
Payload	4282 Watts
Spacecraft Bus	392 Watts
Command, Telemetry & Ranging	
Launch & Initial Ops	C-Band
On-Station	Ka-Band
Ranging	4 tone
Spacecraft Pointing	0.05°
Reliability	
Design Life	15 years
Ps	0.80 at 12 years