8

VERY SMALL APERTURE

TERMINALS

1. DEFINITIONS OF VSAT

A very small aperture terminal (VSAT) is a digital satellite terminal where economy is the key word. The term very small aperture, of course, refers to the size of the terminal antenna. The diameters of VSAT parabolic antennas vary from 0.6 m (2 ft) to 2.4 m (7.8 ft), depending a great deal on the capabilities desired from the terminal. These can vary from a data connectivity (inbound) of 1200 bps up to a full DS1 or E-1.

In most cases, the definition denotes a family of modest “out terminals’’ and a comparatively large ‘‘hub’’terminal. This implies a wheel made up of a hub and spokes. In fact, most VSAT architectures can be seen as hub and spokes, the spokes being the connectivities to the VSAT outstations, most often in a star network configuration as shown in Figure 8.1. The larger hub, in theory, compensates for the smaller handicapped VSAT outstations.

With the VSAT star network, traffic can be one-way or two-way. VSAT networks have extended the definition to include mesh-connected networks with no hub, as shown in Figure 8.2. The star configuration does not lend itself well to VSAT-to-VSAT voice communication because of the added delay, whereas the mesh architecture does lend itself to voice interconnectivity among VSATs.

Some sources even call any network of small satellite terminals a VSAT network.

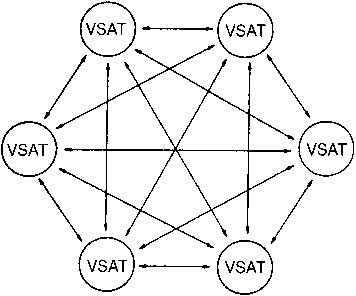
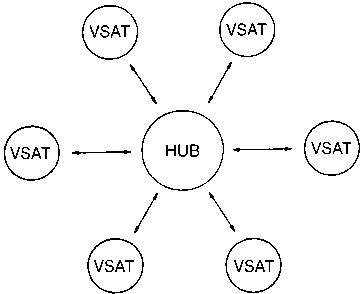
1. VSAT NETWORK APPLICATIONS

VSATs are commonly implemented in private networks. Why they are attractive depends largely on a country’s telecommunication infrastructure. In

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Figure 8.1. The conventional VSAT star network configuration.

Figure 8.2. A VSAT network based on a mesh architecture.



the United States and Canada, economy is the driving factor. Such VSAT networks bypass the local and long-distance telephone companies and ostensibly save money by doing so.

In many other countries, national governments permitting, well- engineered VSAT networks can provide sterling quality service, whereas the local telecommunication administrations cannot. There is a third category that includes countries with a poor infrastructure and where many communities are afforded no electrical communications whatsoever.

1. One-Way Applications

This application basically involves data distribution from the hub outward to VSAT receive-only terminals. These data include the following:

* Press releases, news from press agencies, or the like
* Stocks, bonds, and commodity information
* Remote loading of computer programs
* Weather information from meteorological agencies, typically to airports
* Video distribution utilizing compressed video, typically 1.544 or 2.048 Mbps

Another data application is in the direction VSAT-to-hub for data collection purposes. This application may involve remote sensors on oil pipelines, environmental monitoring, and electric power utilities remote facilities. However, with many of these applications, some form of network control is necessary making two-way communication desirable.

1. Two-Way Applications

The most widely used application of VSAT communications is for diverse types of two-way data communications. Such a network provides complete flexibility for file transfer and all types of interactive data exchanges such as inquiry/response. In most configurations, the hub is co-located with corporate headquarters. Typical two-way applications are the following:

* Point-of-sale operations
* Financial, banking, and insurance information from field branches to central headquarters
* Credit card verification
* ATM (automatic teller machine) operations
* Hotel and motel reservations and all other types of reservations
* Support for shipping and freight handling facilities
* Inventory control and cash flow
* Technical support network, manufacturer-to-manufacturer representatives
* Supervisory control and data acquisition (SCADA), pipelines, railroads
* Extension of local area networks

If sufficient capacity is built into a VSAT network, telephone connectivities are feasible from outstation to headquarters and vice versa. It is not feasible because of added delay from outstation to other outstation via the hub. It would be feasible on VSAT mesh networks. With current video compression techniques, video conferencing may also be feasible (Ref. 1).

In some emerging nations, VSAT-like networks provide rural telephone connectivity.

1. TECHNICAL DESCRIPTION OF VSAT NETWORKS AND THEIR OPERATION
2. Introduction

The most common network topology of a VSAT network is the star configuration illustrated in Figure 8.1. The hub is the centerpiece and is almost always colocated with the corporate headquarters or state capital or national capital, for that matter. The hub may have an antenna with 5-m (16-ft) to 11-m (36-ft) diameter, whereas a VSAT may have an antenna diameter in the range of 0.6 (1 ft) to 2.4 m (8 ft). The RF output at the hub will vary from 100 to 1000 W, whereas a VSAT will be in the range of 1-10 W.

To reduce space segment recurring charges, it is incumbent on the system designer to use as small a bandwidth as possible on a satellite transponder. Outbound traffic is usually carried on a TDM bit stream, 56 or 64 kbps, 128, 256, 384 kbps (etc.). Inbound traffic, depending greatly on the traffic profile, will use some type of demand assignment process or contention, polling, or other protocol with bit rates ranging from 1200 bps to 64 kbps or greater.

Definition. Inbound means traffic or circuit(s) in the direction of VSAT to hub; outbound means traffic or circuit(s) in the direction of hub to VSAT.

VSATs commonly operate in the Ku-band because of the more favorable EIRP permitted on downlinks when compared to C-band. However, this does not mean to imply that C-band operation is ruled out. Let’s examine a typical Ku-band two-way VSAT operation. Of course, excess attenuation due to rainfall must be contended with at Ku-band and can be minimal or neglected at C-band.

1. A Link Budget for a Typical VSAT Operation at Ku-Band

The model VSAT system in question is a two-way operation using Ku-band frequencies. The outbound link is 128 kbps in a TDM format employing QPSK modulation with coherent detection using rate 2 convolutional coding, K = 7 and 3-bit quantization, and Viterbi decoder. The inbound (traffic) link has a transmission rate of 32 kbps using a HDLC\*-type frame format, QPSK with similar FEC. The 128-kbps link with its rate 2 coding has a coded symbol rate of 256 symbols/s. This link requires 200-kHz RF channel; the 32-kbps information rate and 64-kbps coded symbol rate require a 50-kHz RF channel. The BER, under clear-sky conditions, is 1 X 10 9; for degraded conditions the BER may drop to 1 X 10 6. There is a 2-dB modulation implementation loss so that the Eb/N0 for clear-sky operation is 8.5 dB; for degraded operation, it is 6.7 dB for the 128-kbps outbound channel. The

HDLC = high level data link control.

inbound 32-kbps channel also requires 8.5 dB for clear-sky and 6.7 dB for degraded operation. To counter rainfall loss at Ku-band, there is a 4-dB margin or both links. The elevation angle at both the hub and outstation VSAT is 10°. The range (distance) to the satellite (from Figure 6.5) is 25,220 sm.

The outbound uplink frequency is 14,100 MHz; its equivalent downlink operates at 11,800 MHz. The inbound uplink frequency is 14,300 MHz; its equivalent downlink frequency is 12,000 MHz. The satellite transponders in question each have an EIRP of +44 dBW over a 72-MHz bandwidth, assuming full loading. Transponder/satellite G/T in either case is 0.0 dB/K.

The inbound carrier downlink has an EIRP of + 12.4 dBW; for the outbound downlink, the EIRP for the VSAT carrier is + 18.4 dBW. These EIRP values were calculated assuming a uniform power density across the entire transponder bandwidth of 72 MHz. Therefore the EIRP =+ 44 dBW - 10 log(72,000/200) = +18.4 dBW.\* The +12.4-dBW value is calculated in a similar fashion or EIRPdBW = + 44 dBW - 10 log(72,000/50).

The hub facility has the following terminal parameters: transmitter power output, 500 W or + 27 dBW; line loss, 2 dB; antenna aperture, 5 m or 16.25 ft. Its gain at 14,100 MHz is 53.5 dB and at 11,800 MHz it is 52.0 dB; Tsys = 200 K, so the hub G/T is +29.0 dB/K. The EIRP = +78.5 dBW.

Postulated parameters of the VSAT terminal to operate in this system are as follows:

G/T = ? The antenna aperture is unknown. We will assume its efficiency is 65%.

The Tsys for the receiving system consists of the sum of Tant and Tr. Tr = 100 K and Tant = 120 K. Thus Tsys = 220 K. These are typical values.

The VSAT EIRP is unknown. The transmission line losses are 1 dB; the transmitter power output is unknown (in the range of 0.5-10 watts). The downlink (outbound) link budget will determine the antenna aperture.

The free-space loss values are:

|  |  |
| --- | --- |
| (14,100 MHz) | FSLdB = 36.58 + 20 log 14,100 + 20 log 25,220  = 36.58 + 82.98 + 88.03 = 207.59 dB |
| (14,300 MHz) | FSLdB = 36.58 + 83.11 + 88.03 = 207.71 dB |
| (12,000 MHz) | FSLdB = 36.58 + 81.58 + 88.03 = 206.19 dB |
| (11,800 MHz) | FSLdB = 36.58 + 81.44 + 88.03 = 206.05 dB |

\*This is the same as dividing 25,188 watts by 360 because there are 360 200-kHz segments in 72 MHz.

|  |  |
| --- | --- |
| Outbound Link Budget | |
| Uplink | |
| EIRP hub | + 78.5 dBW |
| FSL | - 207.59 dB |
| Polarization loss | - 0.5 dB |
| Terminal pointing loss | - 0.5 dB |
| Satellite pointing loss | - 0.5 dB |
| Atmospheric loss | - 0.3 dB |
| Isotropic receive level | - 130.89 dBW |
| Satellite G/T | 0.0 dB/K |
| Sum | - 130.89 dBW/K |
| Boltzmann’s constant | -(-228.6 dBW) |
| C/N0 | 97.71 dB |
| Downlink | |
| EIRP satellite | + 18.4 dBW |
| FSL | - 206.05 dB |
| Polarization loss | - 0.5 dB |
| Satellite pointing loss | - 0.3 dB |
| Atmospheric loss | - 0.2 dB |
| Terminal pointing loss | - 0.5 dB |
| Isotropic receive level | - 189.15 dBW |
| VSAT G/T | 0.00 dB/K |
| Sum | - 189.15 dBW |
| Boltzmann’s constant | + 228.6 dBW/Hz |
| C/N0 | 39.95 dB |
| What net C/N0 is required for an Eb/N0 of 8.5 dB? | |
| N0 = -228.6 dBW + 10 log Tsys | |
| Tsys = 220 K | (given above) |

Thus

N0 = -228.6 dBW + 10log220 = -205.17 dBW

Eb must have a level 8.5 dB higher than -205.17 dBW or -196.67 dBW. The bit rate on the channel is 128 kbps; thus C = RSL = -196.67 dBW + 10 log(128 X 103) or -196.67 + 51.07 dB = -145.6 dBW.

Then the objective

C/N0((. = -145.6 dBW - (-)205.17dBW

= 59.57 dB

Neglecting satellite generated noise (IM products);

1

C/Nc,,) “ 1/(C/N„„) + 1 (C/Nw.) (6-32)

Convert decibel values to equivalent numerics.

59.57 dB = 905,733 numeric (objective value)

1. dB = 5,128,613,840 numeric (calculated uplink value)

905,733 = 1/[ 1/(5128 X 106) + 1/(C/N0(d))

C/N0( d) f 60 dB

Placing that value in the downlink budget above, we can now calculate a value of G/T for the VSAT. The calculated C/N0 was 39.45 dB; the required C/N0 is 60 dB so there is a shortfall in 20.55 dB in C/N0. Substitute 20.55 dB for the value of G/T. In other words, the G/T should be 20.55 dB/K rather than 0.00 dB/K. If we want a 4-dB margin, we would add 4 dB to this value, or the G/T would be 24.55 dB. We will use this latter value to calculate antenna aperture.

To calculate the required antenna aperture of the VSAT, we need the antenna gain by using the mathematical identity for G/T. Tsys was calculated to be 220 K.

G/T = GdB - 10 log 220 24.55 dB = GdB - 23.42 dB GdB = 47.97 dB

Antenna gain may be calculated from the formula

GdB = 20 log f MHz + 20 log Dft + 10log p - 49.92 (8.1)

where p is the antenna efficiency, in this case 0.65 (65%).

GdB = 20log Dft + 20log( 11,800 MHz) + 10log0.65 - 49.92 47.97 dB = 20log D + 81.43 - 1.87 - 49.92 20 log D = 18.33

D = 8.25 ft or 2.5 m

The next problem is to calculate the VSAT uplink transmit power. The EIRP of that uplink is based on an antenna with a 2.5-m (7.79-ft) aperture. Calculate the antenna gain at the uplink frequency of 14,300 MHz.

GdB = 20log(8.25) + 20log( 14,300) + 10log(0.65) - 49.92 (dB)

= 18.32 + 83.11 - 1.87 - 49.92 = 49.65 dB

Make a trial run with a 1-watt transmitter (0 dBW). The EIRP of the VSAT uplink is then = 0 - 1 dB + 49.65 dBW = +48.65 dBW. Now run the inbound link budget.

Uplink

EIRP VSAT hub FSL (14,300 MHz) Polarization loss

**+ 48.65 dBW -207.71 dB - 0.5 dB**

**-0.5 dB -0.5 dB - 0.4 dB - 159.96 dBW 00.0 dB/K -159.96 dBW/K -(-228.6 dBW/Hz)**

Satellite pointing loss Terminal pointing loss Atmospheric loss Isotropic receive level Satellite G/T Sum

Boltzmann’s constant (-)

Calculate the numeric equivalents of each C/N0 value.

|  |  |
| --- | --- |
| C/N0 | 68.63 dB |
| ownlink |  |
| EIRP satellite | +12.4 dBW |
| FSL (12,000 MHz) | -206.19 dB |
| Polarization loss | -0.5 dB |
| Satellite pointing loss | - 0.5 dB |
| Terminal pointing loss | - 0.5 dB |
| Atmospheric loss | - 0.3 dB |
| Isotropic receive level | - 195.59 dBW |
| Hub **G/T** | + 29.0 dB/K |
| Sum | - 166.59 dBW |
| Boltzmann’s constant (-) | -(-228.6 dB/Hz) |
| C/N0 | 62.01 dB |

68.63 dB has a numeric value of 7,309,840.4

1. dB has a numeric value of 1,588,547

Calculate C/N0( t

C/N0( t) = 61.11 dB

N0 = -228.6 dBW/K + 10log(200) K = -205.59 dBW/Hz

C/N0( t) = CdBW - N0 (C = RSL)

61.11 dB = RSLdBW - ( -205.59 dBW/Hz)

-205.59 dBW + 61.11 dB = RSL RSL = -144.48 dBW Eb = -144.48 dBW - 10log(32 X 103)

= -144.51 dBW - 45.05 dB = -189.53 dBW

Eb/N0 = -189.53 - ( -205.39 dBW/Hz) (calculated)

= 16.06 dB

Eb/N0 (required) = 8.5 dB Margin = 7.56 dB

The VSAT transmitter power of 1 watt is sufficient. It will be noted that the C/N0 on the inbound uplink is more than sufficient (i.e., 68 dB); it is the companion downlink that controls the total C/N0 value (only 62 dB) (Ref. 2).

1. Summary of VSAT RF Characteristics

VSAT operation commonly uses either 6/4-GHz band (C-band) or 14/12- GHz band (Ku-band).[[1]](#footnote-1) As operational frequencies increase, receiver noise performance degrades. At C-band we can expect a LNA with 50-K noise temperature; at Ku-band, 100 K. Antenna noise temperature (Tant) at C-band (5° elevation angle) is 100 K and at Ku-band (10° elevation angle) it is 106 K. Thus typical Tsys for C-band VSAT operation is 150 K and for Ku-band it is 206 K. Line losses for both bands are taken at 1.5 dB for this particular model. In the case of Ku-band, the LNA is placed as close as practical to the feed to reduce line losses.

We now construct Table 8.1, which will give typical G/T values for several discrete antenna diameters for both C-band and Ku-band operation. The table is based on the Tsys figures given above. The antenna gains are based on 65% aperture efficiency (^). Formula (2.27c) was used to calculate parabolic antenna gains.

1. ACCESS TECHNIQUES

The most common VSAT architecture is the interactive network based on star topology (hub and spokes, Figure 8.1). Reference 3 describes a VSAT network with as many as 16,000 outstations. The author is familiar with

TABLE 8.1 Typical VSAT G/T Valuesa

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Antenna  Aperture | Gain,  C-Band | G/T,  C-Band | Gain,  Ku-Band | G/T,  Ku-Band |
| 0.5 m (1.625 ft) | 23.46 dB | +1.7 dB/K | 33 dB | + 9.86 dB/K |
| 0.75 m (2.44 ft) | 27.0 dB | + 5.23 dB/K | 36.53 dB | +13.39 dB/K |
| 1.0m (3.25 ft) | 29.49 dB | +7.73 dB/K | 39.03 dB | +15.89 dB/K |
| 1.5 m (4.875 ft) | 33.01 dB | + 11.24 dB/K | 42.55 dB | +19.41 dB/K |
| 2.0 m (6.5 ft) | 35.51 dB | + 13.75 dB/K | 45.05 dB | +21.91 dB/K |
| 2.5 m (8.125 ft) | 37.45 dB | + 15.69 dB/K | 47.0 dB | +23.86 dB/K |
| 3.0 m (9.75 ft) | 39.03 dB | + 17.54 dB/K | 48.57 dB | +25.43 dB/K |

aThe reference frequencies used for antenna gain calculations are 4000 (C-band) and 12,000 MHz (Ku-band). The table includes 1-dB line loss for both bands.

networks with up to 2500 outstations interoperating with one hub. There are many access techniques, and the type selected will be fairly heavily driven by the traffic profile. The access technique will often determine the efficiency of usage of the space segment. For example, a completely assigned FDMA regime would prove to be very ineffective use of transponder bandwidth if there were hundreds of outstations, each interchanging short, interactive messages with the hub with a medium to low activity factor.

In selecting the type of channel assignment technique for a VSAT network, the following factors should be considered:

* Statistical properties of the traffic
* Permissible delay in transmission, including channel setup and propagation delay
* Efficiency of channel sharing, throughput performance
* Complexity, equipment, and implementation cost
* Operations and maintenance

For example, for credit card verifications and transactions, delay is probably the most important factor, throughput much less so. Whereas with file transfer and batch transactions, throughput is more important than delay (comparatively).

We will discuss three categories of access: random access, demand assigned, and fixed assigned. Here, of course, we refer to inbound channels. Outbound service is assumed to be a TDM bit stream and is discussed in Section 8.4.5.

1. Random Access
2. Pure Aloha[[2]](#footnote-2). Random access schemes lend themselves well to short and bursty traffic. In this case, the inbound channel is shared by several or many VSATs. This is really a contention scheme. When a VSAT has traffic, it bursts the traffic on the inbound channel, taking a chance that another VSAT is not transmitting at the same time. If there is a collision—in other words, another VSAT is transmitting traffic at the same time—the traffic is corrupted, and both VSATs must try again. Each VSAT has a random backoff algorithm. In theory, the backoff time will be different for each terminal, and the second attempt will be successful. A VSAT knows if an attempt is successful because it will receive an acknowledgment from its associated hub on the TDM outbound channel.

This scheme works out well when traffic volume is small. Delay is normally short because most transmissions only require one exchange with the hub.

As traffic volume picks up, the system becomes more and more unwieldy. The point where this occurs, according to Ref. 4, is when throughput approaches 25-30%.f As we increase loading above the 30% value for throughput, the probability of collision increases, as do transaction delays. When the traffic volume exceeds a further limiting value (some argue 50%), the system will tend to “crash,” meaning that throughput begins to approach zero because of nearly continuous collisions, backoffs, and reattempts. Flow control mechanisms can help prevent this from happening.

The type of access described here is called pure Aloha. The principal advantage of pure Aloha is its simplicity. There is no time synchronization required, and the hub and VSATs do not need precise timing control (Refs. 3 - 6).

1. Slotted Aloha. Slotted Aloha is more complex than pure Aloha in that it requires time synchronization among VSATs. In this case users can transmit only in discrete timeslots. With such a scheme, two (or more) users can collide with each other only if they start transmitting exactly at the same time. One disadvantage of slotted Aloha is the wasted periods of time when a message or packet does not use up the total timeslot allowed. Slotted Aloha has about twice the efficiency of pure Aloha or about 34% throughput versus 18% for pure Aloha. These percentage values are points where throughput begins to level off or decrease because collisions begin to increase (Refs. 3 and 7).
2. Selective Reject (SREJ) Aloha. With SREJ Aloha, messages or packets are broken down into subpackets. These subpackets have fixed length and can be received independently. Each subpacket has its own acquisition preamble and header. Generally, there is no total collision. Some subpackets may collide, but not whole messages; some of the message or main packet gets through successfully. In SREJ Aloha, only the subpackets that are corrupted are retransmitted. This reduces retransmission because the only retransmission required is a smaller subpacket, not the whole message. SREJ Aloha does not need time synchronization for messages or subpackets. It can achieve higher throughput than pure Aloha and is well suited for variable-length messages (Refs. 3 and 4).
3. R-Aloha or Aloha with Capacity Reservation. This is still another version of Aloha. It is useful when there are a few high-traffic-intensity users and other low-intensity, sporadic users. The high-intensity users have reserved slots and the remainder of the slots are for low-intensity users. This latter group operates on a contention basis similar to pure Aloha. There are many variants of this reservation system (Ref. 6).

One efficient derivative is called slot reservation or demand assignment TDMA (DA/TDMA). When a VSAT has data packets to be transmitted, a request is sent to the hub, which then replies with TDMA slot assignments. The request specifies the length and number of data packets to be sent. Upon receipt of the slot assignment, the VSAT transmits the data packets in the assigned slots without any risk of collision because the hub informs all participating VSATs that particular slots have been reserved. Although requiring more response time since a delay time of two satellite round trips is spent before the actual packets are transmitted, the reservation mode is very effective for the case of longer messages. It is pointed out that this reservation scheme is different from conventional demand assignment multiple access (DAMA) schemes in that the reservations are made on a packet-bypacket (or for a group of packets) basis and not for a continuous channel.

The reservation request can be made on a dedicated request channel or on a traffic channel, which operates on a random access (pure Aloha) scheme. Of course, there is the added overhead for reservation requests. Figure 8.3 is a conceptual drawing of reservation mode transmission. Figure

1. compares throughput versus delay performance for three Aloha access schemes (Ref. 3).
2. Demand-Assigned Multiple Access

DAMA is a satellite access method based on the concept of a pool of traffic channels that can be assigned on demand. When a VSAT user has traffic, the hub is petitioned for a channel. If a channel is available, the hub assigns the channel to the VSAT, which then proceeds to transmit its traffic. When the traffic transaction is completed, the channel is turned back into the pool of available channels.

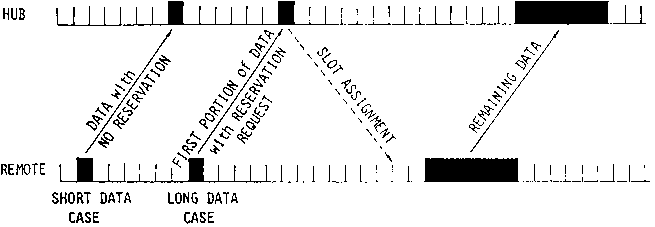


Figure 8.3. Reservation mode transmission.

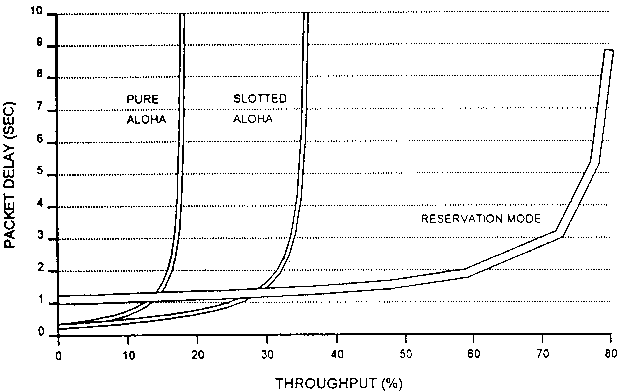


Figure 8.4. Throughput versus delay performance of some Aloha schemes. (From ITU-R Supplement 3 to Handbook of Satellite Communications; Ref. 3.)

These assigned channels can be on a FDMA basis or on a TDMA basis. In other words, the pool of channels may consist of a group of frequency slots or a group of timeslots. If the frequency domain is employed, it is called FDMA/SCPC, where SCPC stands for single channel per carrier. DAMA VSAT systems are attractive for voice operation in mesh networks or for voice connectivities of VSAT to hub. Of course, they are also useful when there is intense data traffic that is more or less continuous (Refs. 3 and 6).

1. Fixed-Assigned FDMA

When a nearly continuous traffic flow is expected from a VSAT to a hub, SCPC operation may be an attractive alternative. In this case, each VSAT is assigned a frequency slot on a full period basis. The bandwidth of the slot

TABLE 8.2 Comparison of Multiple-Access Techniques—Inbound

|  |  |  |  |
| --- | --- | --- | --- |
| Multiple-Access  Technique | Maximum Throughput | Practical Message Delay | Suitable Application |
| Random access | | | |
| Pure Aloha | 18.4% | < 0.5 s | Interactive data |
| Slotted Aloha | 36.8% | < 0.5 s | Interactive data |
| SREJ Aloha | 20-30% | < 0.5 s | Interactive data |
| Slot reservation | 60-90% | < 2 s | Batch data |
| Demand assigned | | | |
| FDMA, TDMA | High | 0.25 s | Batch data, voice |
| Fixed assigned | | | |
| FDMA, TDMA | High | 0.25 s | Multiplexed data, voice |

Source: Table 3.1.1, ITU-R Supplement No. 3 to Handbook on Satellite Communication (Ref. 3).

should be sufficient to accommodate the traffic flow. Another alternative is TDMA, where a timeslot is assigned full period for the connectivity.

1. Summary

Table 8.2 presents a comparison of the several access techniques covered in Section 8.4. The choice of which technique to adopt depends on the traffic and delay requirements of the proposed VSAT system. System complexity may also be an issue: complexity not only can be costly but may also impact reliability.

1. Outbound TDM Channel

Besides a vehicle for outbound traffic, the outbound TDM channel may have other functions. Among these functions are the following:

* Provide timing to slave VSAT clocks, typically for slotted Aloha
* Channel assignment, typically for DAMA schemes, reservation Aloha
* Acknowledgment of incoming packets
* Other control functions

The TDM channel sends a continuous series of frames where data packets are inserted in the frame’s information or data field. In many cases, as we pointed out earlier, the frames are formatted following the HDLC[[3]](#footnote-3) link layer protocol (see Ref. 8 and Chapter 5). The HDLC control field often is modified to carry out VSAT control functions; the acknowledgment technique can also be patterned after HDLC. If there is no outbound message traffic to be sent, the info field can be filled with null data or supervisory

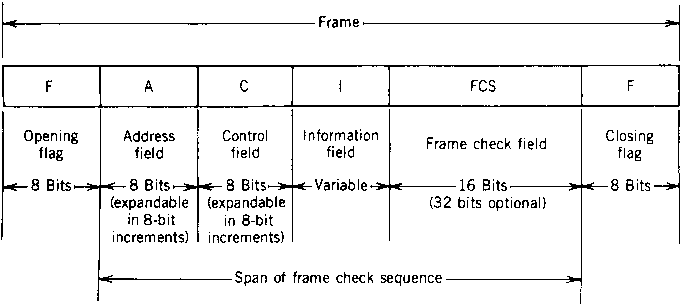


Figure 8.5. The HDLC frame format. It should be noted that there are three types of HDLC frames: information, supervisory, and unnumbered. In the latter two frame types there is no information field, and the other variant is the control field.

frames can be sent. In some implementations, a frame timing and control field, including preamble and unique word (UW), are used.

A typical HDLC frame is shown in Figure 8.5, unmodified. It should be pointed out that the address field must have sufficient length to accommodate addresses for all VSATs in the system as well as group and broadcast addresses. In some systems, an OSI layer 3 (the network layer) can be employed. Often this is based on ITU-T Rec. X.25 (see Ref. 3).

1. A MODEST VSAT NETWORK IN SUPPORT OF SHORT TRANSACTION COMMUNICATIONS

In this exercise, we are called upon to design a modest transaction-type VSAT network where minimal delay and cost are overriding requirements. The system will operate at Ku-band. The network is to support a chain of 50 discount department stores. The hub is located at the company headquarters. The inbound transaction messages are based on a HDLC frame 40 octets long, including overhead. The inbound transmission rate is 9600 bps with a convolutional code rate f, K = 7, 3-bit soft decision receiver with Viterbi decoding providing a coding gain of 5.3 dB (see Figure 4.19 and Table 4.7). The outbound TDM stream is 19.2 kbps with similar coding. QPSK modulation is used in both cases.

Each store can have as many as 16 checkout counters in operation at one time, and the worst case is a transaction per minute for each checkout station. Credit card verification and the actual charge transaction are carried out in one HDLC frame. Thus the worst-case frame rate for a store is 16 frames a minute at 40 X 8 or 320 bits per frame. A transaction duration, then, is 320/9600 second or 33 ms. The time on-line per store is 0.528 second per 60 seconds (i.e., 16 X 33 ms). Assuming all 50 stores have such a traffic profile, we then would have 50 X 0.528 for worst-case, peak-hour traffic intensity. This would be 26.4 seconds per minute. This value is well in excess of the 18% allowed under pure Aloha.

Three possibilities arise. (1) Use slotted Aloha with the increased cost and complexity involved. (2) Have three inbound channels, dividing the traffic up to place ourselves inside the 18% requirement of pure Aloha. Thus, on each channel, there would only be the traffic from 17 stores or 9.061 seconds per minute or around 15%. (3) Use a higher inbound bit rate, for example, 32 kbps. The decision is made by trading off recurring space segment charges based on bandwidth versus first cost of the complexity of slotted Aloha.

Slotted Aloha is selected. The outbound TDM bit stream has sufficient capacity at 19.2 kbps because the traffic predominantly is VSAT-to-hub or inbound.

Bandwidths are calculated using 1.5 Nyquist cosine rolloff. The symbol rate is twice the bit rate (2 rate coding). Thus the inbound channel is calculated at 10 X 2 X 1.5 or 30 kHz and the outbound channel is calculated at 20 X 2 X 1.5 or 60 kHz; both use coherent QPSK modulation.

The satellite spot beam used for the system has a +45-dBW EIRP spread uniformly over 72-MHz transponder bandwidth. The EIRP of the outbound satellite downlink carrier is +14.21 dBW. The inbound downlink carrier has + 11.18-dBW EIRP. The BER, both inbound and outbound, for clear-key conditions, is 1 X 10 9; based on QPSK modulation with coherent detection and FEC coding, the required Eb/N0 is 8.5 dB, including 2-dB modulation implementation loss. (Note: There is a 5.3-dB coding gain discussed above.) As 5-dB rainfall and interference margin is required.

Elevation angle in both cases is 20°. Range to the geostationary satellite is 21,201 nm or 24,397 sm.

Frequency assignments versus functions and equivalent free-space losses are shown in Table 8.3.

For inbound uplink, the VSAT transmitter power output is assumed to be 1 watt (0 dBW). In the case of the outbound uplink (i.e., at the hub) transmitter power output is assumed also to be 1 watt. Satellite G/T in both cases is +1 dB/K.

TABLE 8.3 Frequency Assignments and Free-Space Losses

|  |  |  |
| --- | --- | --- |
| Function | Frequency | Free-Space Loss |
| Inbound uplink | 14,400 MHz | 207.50 dB |
| Inbound downlink | 12,100 MHz | 205.98 dB |
| Outbound uplink | 14,100 MHz | 207.31 dB |
| Outbound downlink | 11,800 MHz | 205.77 dB |

Inbound Uplink

Transmitter output Transmission line loss Antenna gain (p = 0.65, 6.5 ft) EIRP

**0 dBW -1.0 dB + 47.64 dB + 46.64 dBW -207.50 dB**

* **0.5 dB 0.0 dB**
* **0.5 dB -0.3 dB**
* **162.16 dBW + 1.0 dB/K**
* **161.16 dBW (-228.6 dBW/Hz)**

**67.44 dB**

**+ 11.18 dBW -205.98 dB**

* **0.5 dB 0.0 dB**
* **0.5 dB**
* **0.3 dB**
* **196.1 dBW**

**+ 25.84 dB/K**

* **170.26 dBW/Hz (-228.6 dBW/Hz)**

**58.34 dB**

Free-space loss Polarization loss

Satellite pointing loss (off contour) Terminal pointing loss Atmospheric loss Isotropic receive level Satellite G/T Sum

Boltzmann’s constant C/N0

Inbound Downlink

Satellite EIRP Free-space loss Polarization loss

Satellite pointing loss (off contour) Terminal pointing loss (hub) Atmospheric loss Isotropic receive level Terminal G/T (hub, 10 ft)

Sum

Boltzmann’s constant C/No

The objective C/N0(t) is calculated as follows, based on an Eb/N0 of 8.5 dB. The Tsys at the hub is 200 K. Thus N0 = -228.6 dBW + 10log200 = - 205.59 dBW. Eb must be 8.5 dB above this level or - 197.09 dBW. C = RSL = -197.09 dBW + 10 log 9600 = -157.24 dBW. Or the objective C/N0( t) for the inbound links should be

C/N0(t) = -157.24 dBW - ( -205.59 dBW) = 48.35 dB

To this C/N0 value we add the required 5-dB rainfall and interference margin for a total of 53.35 dB.

Using equation (6.32), we next calculate the net C/N0(t). Calculate the numeric equivalents of each C/N0 value:

Uplink: 67.4 dB = 5,495,408.7 Downlink: 58.34 dB = 682,338.7 C/N0(t) = 57.83 dB

The next step is to calculate the outbound link budgets.

Outbound Uplink

Transmit power (1 W) Transmission line loss Antenna gain (hub, 10.0 ft)

**0 dBW -2.0 dB + 51.19 dB + 49.19 dBW -207.31 dB**

* **0.5 dB 0.0**
* **0.5 dB**
* **0.5 dB**
* **159.62 dBW + 1.0 dB/K**

**-158.62 dBW (-228.6 dBW) 69.98 dB**

**+ 14.21 dBW**

* **205.77 dB**
* **0.5 dB 0.0**
* **0.5 dB**
* **0.3 dB**
* **192.86 dBW + 21.91 dB/K**
* **170.95 dBW (-228.6 dBW/Hz)**

**57.65 dB**

EIRP hub Free-space loss Polarization loss

Satellite pointing loss (off contour)

Terminal pointing loss

Atmospheric loss

Isotropic receive level

Satellite G/T

Sum

Boltzmann’s constant C/N0

Outbound Downlink

Satellite EIRP Free-space loss Polarization loss

Satellite pointing loss (off contour) Terminal pointing loss Atmospheric loss Isotropic receive level Terminal G/T (hub, 6.5 ft)

Sum

Boltzmann’s constant C/No

The objective C/N0 for the outbound links is calculated as follows. The desired Eb/N0 is 8.5 dB. Tsys of the VSAT receiving system is 206 K; thus N0 for that system is -228.6 + 10 log 206 = -205.46 dBW. Eb must be 8.5 dB higher in level or -205.46 dBW + 8.5 dB = -196.96 dBW. C = RSL = -196.96 dBW + 10log(19.2 X 103) = -154.12 dBW. The objective value for C/N0(t) is -154.12 dBW - (-205.46 dBW) = 51.33 dB. To this value we must add 5 dB of rainfall and interference margin for the final objective value of 56.33 dB.

Now we calculate the outbound C/N0( t) from the link budgets. First we must derive the numeric equivalents of the uplink and downlink C/N0 decibel values:

Uplink: 69.98 dB = 9,954,054 Downlink: 57.65 dB = 582,105 C/N0(t) = 57.40 dB

This last value is just inside the objective value of 56.33 dB. It will be noted that the hub is comparatively small; thus it probably will not require any form of automatic tracking. The inbound uplink appears overdimensioned, but the G/T of the companion downlink to the VSAT dictates an antenna diameter that the VSAT uplink must use. Likewise, the outbound uplink appears overdimensioned, but the inbound downlink requires a G/T value that needs a 10-ft antenna. It would be advisable to equip the outbound uplink with a 10-watt HPA and use the decreased output power (i.e., 1 watt). This would provide an additional 10 dB of margin on that uplink.

Any further reduction in link parameters would degrade performance below that specified at the outset.

1. INTERFERENCE ISSUES WITH VSATs

VSATs by definition have small antennas. As a result, they have comparatively wide beamwidths. For aperture antennas, beamwidth is related to gain. Jasik and Johnson (Ref. 9) provide the following relationship for estimating beamwidth:

BW3-dB = 70° (X/D) (8.2)

where X is the wavelength and D is the diameter of the antenna. Both D and X must be expressed in the same units.

If we use the downlink Ku-band frequency of 12,000 MHz, its equivalent wavelength is 0.025 m. If we use a 1-m dish, the beamwidth will be 1.75°. This gives rise to one interference problem in installations with such small antennas. Satellites in geostationary orbit are now placed 2° apart. A beamwidth of 1.75° with a VSAT antenna pointed to one satellite will be prone to interference on the downlink from a neighboring satellite, just 2° away in the orbital equatorial plane.

For the 12-GHz frequency (i.e., X = 0.025 m), we develop Table 8.4 for various diameters of parabolic dish antennas that may be employed in a VSAT installation. The table is based on formula (8.2).

TABLE 8.4 Antenna Beamwidths for Various Diameter Dishes

|  |  |  |
| --- | --- | --- |
| Antenna Diameter (m) | Antenna Diameter (ft) | Beamwidth (°) |
| 0.5 | 1.625 | 3.5 |
| 0.75 | 2.44 | 2.33 |
| 1.0 | 3.25 | 1.75 |
| 1.5 | 4.875 | 1.166 |
| 2.0 | 6.5 | 0.875 |
| 2.5 | 8.125 | 0.70 |
| 5.0 | 9.75 | 0.35 |

TABLE 8.5 Examples of Single Entry Interference Protection Ratios for Typical Satellite Carrier Services

|  |  |  |
| --- | --- | --- |
| Fixed Satellite Service Carrier Type | | Single Entry Interference Protection ratioa |
| A | Frequency modulated television (FM/TV) |  |
|  | Studio quality | C/I = 28 dB |
|  | Good quality | C/I = 22 dB |
| B | Digital data channels |  |
|  | Wideband, full transponder bandwidth | Eb/Ic = 25 dB |
|  | Narrowband, SCPC, T1 (1.544 Mbps) | Eb/I0 = 20 dB |
|  | Narrowband, SCPC (56 kbps) | Eb/Ic = 20 dB |
| C | Spread spectrum channels | Eb/Io = 20 dB |
| D | Frequency modulated SCPC, | 1000 picowatts maximum in worst |
|  | voice interference contribution | baseband channel |
| E | Frequency modulated SCPC, audio program | C/I = 24 dB |

aEb/I0 refers to the ratio of signal energy per bit per hertz of interference; C/I refers to the ratio of carrier power to interference power.

Source: Table 3.5.1, ITU-R Supplement 3 to Handbook on Satellite Communications (Ref. 3).

From the table we see that the larger the antenna, the narrower the beamwidth and the less the possibility of overlap from one satellite to an adjacent satellite in the geostationary orbit.

The ITU-R organization has established some interference guidelines among various telecommunication services offered by satellite relay. These guidelines are summarized in Table 8.5 based on carrier-to-interference ratios (C/I). For digital systems it is more convenient to use Eb/I0 or energy per bit to interference spectral density ratio. The C/I and Eb/I0 values in the table apply to the combined uplink and downlink values of the link budget process. Ku-band antenna discrimination values in decibels are given in Figure 8.6.

In a homogeneous arrangement of adjacent satellite systems providing narrowband digital services in which carrier power flux densities are approximately the same (Figure 8.6 and Table 8.4), to obtain a single entry C/I ratio (or antenna discrimination value) of about 20 dB, the VSAT antenna diameter must exceed 1.2 m for satellite separations of 2° or about 0.8 m for satellite separations of 3°. In this example it is assumed that the VSAT system employs a star network with a hub station of at least 4 m in diameter so that the hub-to-satellite link has at least 30 dB of antenna discrimination and contributes less than 0.5 dB to the overall link C/I. On the other hand, if the system is composed of VSATs only (typically with a mesh network, Figure 8.2), and neither uplink nor downlink is controlling with regard to interference, then the antenna sizes must be larger than the VSATs given in the above example. In this case, if the antennas are of the same size, the antenna discrimination value needed will more likely be on the order of 23

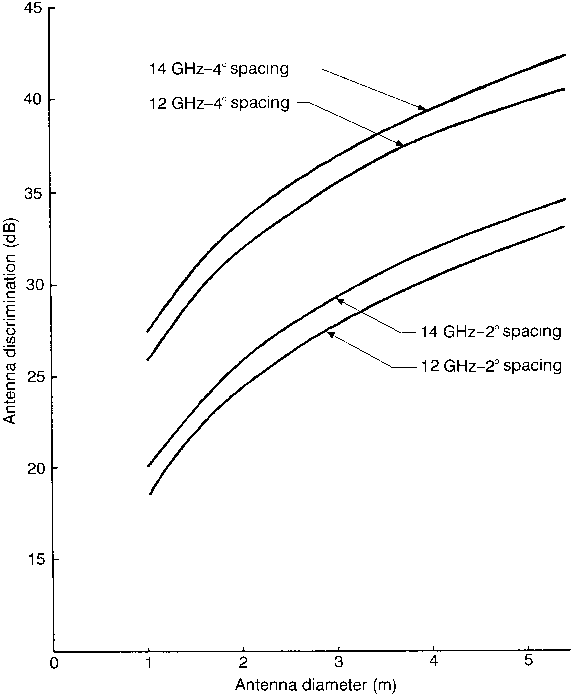


Figure 8.6. Parabolic antenna discrimination at the 14/11-12 GHz band for 2° and 4° satellite orbit spacing. (From Figure 3.5.1, ITU-R Supplement 3 to Handbook on Satellite Communications ; Ref. 3.)

dB. From Figure 8.6, this results in an antenna diameter requirement of 1.7 m at 2° of satellite spacing or 1.1 m at 3° of satellite spacing.

Besides antenna discrimination, interference from adjacent satellite emissions can be reduced by:

* Using channelization plans in which carrier center frequencies in adjacent satellite systems are offset from each other
* Employing cross-polarization techniques
* Using FEC techniques that can reduce receiver sensitivity to interference

Unfortunately, VSAT systems often are bunched together, because many VSAT applications are found in urban areas. Thus many interference scenarios are set up such as:

* VSAT-to-VSAT
* VSAT-to-large earth station (and vice versa)
* Line-of-sight microwave-to-VSAT and vice versa

1. EXCESS ATTENUATION DUE TO RAINFALL

As a general rule, we have said that radio systems operating above 10 GHz must take into account excess attenuation due to rainfall and, during rain events, due to an increase in sky noise. Thus the popular Ku-band must take into account rainfall, whereas, in general, in C-band, rainfall attenuation can be neglected. These topics are dealt with in detail in Chapter 9.

PROBLEMS AND EXERCISES

1. What is the most common type of VSAT network? What other (synonymous) name is used to describe such a network?
2. For common VSAT operation, where is a common (and desirable) place to locate the hub?
3. Give an overriding reason why a hub facility is so much larger than each VSAT it serves.
4. If a VSAT network is to provide voice operation among VSATs, what type of architecture is advisable to use? Why?
5. For typical hub-and-spoke VSAT networks, there is one-way operation and two-way operation. Give at least three applications of one-way application, and give at least five applications for two-way operation VSAT networks.
6. In the case of conventional VSAT networks, the outbound link is nearly always in what type of format?
7. Name at least four possible access methods applicable to the inbound link.
8. Conventional VSATs often have a transmitter with output power in the range (watts or dBW) of what values? What is the range of values for antenna sizes?
9. What factors and parameters basically determine the size of a VSAT terminal?
10. Size a hub and its related VSATs for transmit power, receiver LNA, and antenna apertures for hub and VSAT. Use EIRP and G/T in the analysis. Outbound transmission rate is 56 kbps TDM; inbound bursty at 9600 bps. Apply reasonable BER values. Select the modulation type and FEC coding, if deemed advantageous (argue these advantages or disadvantages). Select the inbound access mode. Assign transponder bandwidth. Operate at Ku-band.
11. Why is Ku-band often more desirable than C-band operation for VSATs? What is the principal disadvantage of Ku-band when compared to C-band?
12. Why can we eliminate increased free-space loss as a factor in question 11? Think! (Clue: Increasing frequency affects more than free-space loss.)
13. What is the principal driver in the selection of the inbound access technique? Name two other driving factors in that selection.
14. Describe how pure Aloha operates. When does it become unwieldy and why?
15. Compare pure Aloha to slotted Aloha.
16. Describe how demand assignment TDMA works.
17. What might be a typical data link layer protocol for an outbound channel?
18. What is a principal drawback of VSAT systems considering their small antennas?
19. List three interference scenarios for VSATs operating in urban areas.
20. In large VSAT networks, why must we reduce the cost (in any way possible) of VSATs without unreasonably sacrificing performance of the VSAT network (and possibly spend more on the hub)?

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1. There is nascent VSAT activity in Ka-band (30/20-GHz band) with the advent of the NASA ACTS. Surely other satellites will follow, and in time there will be equal or greater VSAT activity in the Ka-band. [↑](#footnote-ref-1)
2. Aloha derives from Hawaii. The University of Hawaii developed a random access technique for a digital data radio system connecting island campuses.

   fThe ITU (Ref. 3) places this point at an 18% throughput value. As further traffic is encountered, actual throughput drops. [↑](#footnote-ref-2)
3. HDLC = high-level data link control, a link layer protocol developed by the ISO. ADCCP, LAPB, and LAPD are direct derivatives of HDLC. [↑](#footnote-ref-3)