The Multimedia Migration: Transponder Versus Processing Payload VSAT Networks

Daniel Azaren, William Courtney, Joseph Freitag,
Peter Hadinger, Douglas Shannon, Terrence Smigla,
and Eric Wiswell
TRW Space & Electronics Group
Redondo Beach, California 90278 USA
(310) 812-2371
joe.freitag@trw.com

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Daniel Azaren, William Courtney, Joseph Freitag, Peter Hadinger,
Douglas Shannon, Terrence Smigla, and Eric Wiswell
TRW Space & Electronics Group, One Space Park, Redondo Beach, CA 90278
Email: **joe.freitag@trw.com**, *Voice: +1.310.812.2371, Fax: +1.310.812.8307*

1. SUMMARY

A previously published TRW paper [1] has demonstrated that multi-beam processing payloads offer significant business advantages to top-level network service providers (NSPs). From a network service provider perspective, the increase in effective satellite capacity and billable bits is a key differentiator of processing payloads relative to traditional transponder payloads. The success of any business relies on its ability to attract customers. For NSPs using processing payloads to be successful, users (i.e. network managers) must be convinced that implementing their networks through a processing payload system offers an advantage over transponder-based systems. It is therefore worthwhile to explore processing payloads from a user perspective.

With their flexibility, increased capacity, and performance benefits, processing payloads will open the door for many exciting new broadband multimedia applications. Skeptics may argue that it is risky to base a business case on the availability of new applications. Will there be user demand for processing payload systems when they are deployed? To answer this question, it is important to remember that there is a profitable, vibrant, and growing VSAT market present today. What is sometimes understated is that processing payloads are not only an enabler for future applications, but they offer distinct advantages for existing VSAT applications.

This paper compares the user costs of a typical VSAT network using existing transponder technology to the same network implemented using TRW's Gen*Star processing payload technology. Unlike proposed future applications for which no quantitative data exists, the properties of existing VSAT networks are well known and can be easily evaluated. The results demonstrate that processing payloads represent a superior solution for both today’s VSAT networks and for the more sophisticated applications and network topologies inevitable in the future.

2. REVIEW OF VSAT NETWORKS

VSAT networks are characterized by small interactive stations with antennas typically less than 2 m in diameter. With approximately 500,000 interactive sites operating world wide, VSAT networks have become an accepted and growing means for meeting corporate communications needs. Key advantages driving this growth are:

- VSAT services are available nearly everywhere in the world
- Rapid deployment
- Sites easily added or removed from a VSAT network
- Costs often much lower than terrestrial alternatives for equivalent data rates and geographic distribution of sites
- Connection costs are distance-insensitive
- Highest level of service availability among all communication alternatives (typically > 99.9%)

2.1 VSAT APPLICATIONS

Interactive VSAT networks have penetrated a wide cross-section of business, government, and scientific applications. Initially, corporate users found VSAT networks to be financially attractive relative to leased lines from the telephone companies. Large VSAT networks are now employed by corporations to provide better data collection and information dissemination to geographically dispersed facilities. Figure 1 lists several important industries that use VSAT networks and the services they provide. In general, these applications involve many geographically distributed terminals. Although some networks provide voice communications, most VSAT networks provide data services that are somewhat less sensitive to transmission delay.

Figure 1. VSAT Applications

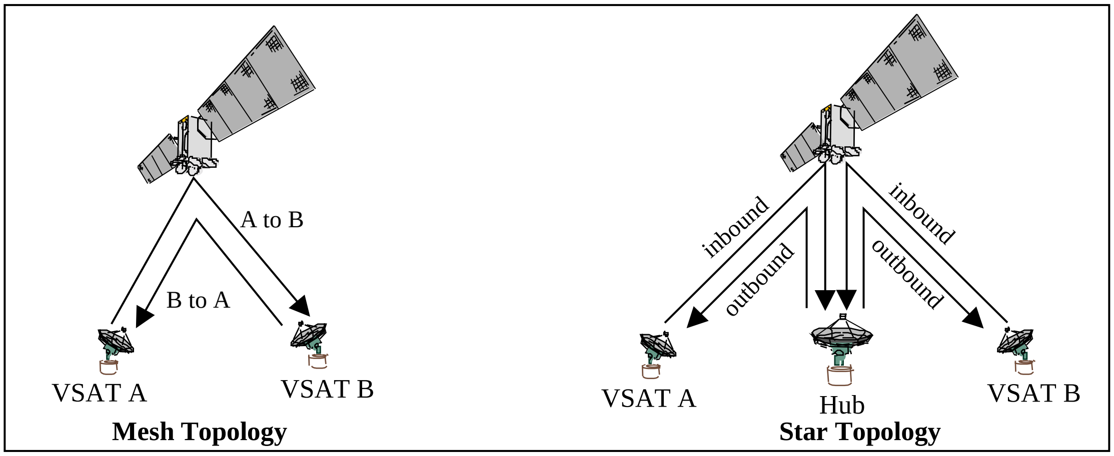
Industry	Services	
Banking	• Automatic teller machines • Transaction support, database access	• File/software updates • Branch bank automation • Teller services
Retail	• Credit authorization • Point of sale • Pricing updates	• Inventory control • Video promotions • Frequent buyer programs
Transportation	• Inventory control • Fleet management • Shipment tracking	• Order entry • Credit authorization
Financial Services	• Brokerage service • Electronic payment transactions	• On-line trading • File/software updates, data base access
Energy	• Pipeline monitoring • Power line monitoring	• Communication to drilling sites
Miscellaneous	• Internet access • Corporate email	• LAN internetworking • Distance learning

2.2 TECHNICAL CHARACTERISTICS OF VSAT NEWORKS

Three key elements that define a VSAT network architecture are the network topology, data rates supported, and multi-user access scheme. The two basic network topologies for VSAT networks are star and mesh (Figure 2). In the mesh topology, VSAT terminals communicate to each other using direct paths through the satellite, and thus VSAT-to-VSAT transmissions require only one satellite hop. In the star topology, all VSAT communications go through a hub. VSAT A transmits to VSAT B via an “inbound link” to the hub, where it is retransmitted on an “outbound link” to VSAT B. VSAT-to-VSAT communications thus involve two satellite hops in the star configuration. If there is little VSAT-to-VSAT communication, the star topology is particularly effective; for example, if a hub is co-located with a corporate headquarters and nearly all VSAT communications are to and from the headquarters.

Transmit and receive data rates for VSAT sites are limited by the antenna size and the capability of the transmit amplifier. In transponder-based star networks, the hub antenna size and transmit amplifier power can usually be made large enough that the link between the VSAT and the satellite dominates performance. Consequently, higher transmit and receive data rates are generally available in star networks than in mesh networks where both the uplink and downlink are limited by VSAT performance. Data rates vary with terminal size, but typical VSATs have transmit information rates between 64 and 512 kbps and receive information rates between 64 and 6000 kbps.

Figure 2. VSAT Network Topologies



The VSAT sites in a network must share the total satellite bandwidth and power resources available to it. The total resources may be divided by frequency, time, spread-spectrum multiple access codes, or combinations thereof, and the segments assigned to the multiple sites. Such assignments may be defined permanently (fixed assignment), or the assignments may be dynamic based on the traffic (demand assignment). Figure 3 compares fixed assignment and demand assignment.

Figure 3. Fixed Assignment Versus Demand Assignment

Access	Advantages	Disadvantages
Fixed Assignment	• Simple Implementation • Lower delay in connection setup • No blockage if VSAT site stays within its allocated capacity	• Inefficient bandwidth utilization • Fewer terminals can be supported by network with a given bandwidth
Demand Assignment	• Active terminals may take advantage of unused bandwidth • Less bandwidth required for network, particularly for bursty traffic • Network with a given bandwidth can support more terminals	• More complex network protocols • Longer connection setup delay • Non-zero blockage probability

3. VSAT NETWORK ANALYSIS

The following analysis compares the costs of operating a VSAT network using transponder versus processing payload implementations. The analysis uses a specific real-life example network, whose key network parameters are described. This is followed by a detailed analysis of the costs for transponder and processing payload implementations. Although the reference network serves as the analysis baseline, its sensitivity to key network parameters such as capacity and connectivity is also explored. In evaluating the processing payload case, TRW's Gen*Star architecture described in [1] is used as the reference payload.

3.1 REFERENCE NETWORK PARAMETERS

The reference network was based on a published RFP [2] for a VSAT network to service Barclay's Bank in Europe. This example was chosen because it provided a concise traffic model, summary cost data was available, and it was an application representative of typical VSAT networks. In addition, since it was an application well suited to a transponder-based star network, it provided a challenge to processing payload implementations.

Servicing approximately 230 geographically distributed sites in Europe, the network is used for a proprietary banking application in which local offices retrieve customer account information from a central data center. Key network requirements are summarized in Figure 4.

Figure 4. Reference Network Requirements

Network Parameter	Requirement
Application	Banking
Number of VSAT sites	230
Contract duration	5 years
Daily transactions	306,000 both inbound and outbound
Daily throughput	44 Mbytes inbound and 73 Mbytes outbound
Peak transaction rate	110,000 transactions per hour
Peak throughput	16 Mbytes/hour inbound and 26 Mbytes/hour outbound
Average transaction size	150 bytes inbound and 250 bytes outbound
Guaranteed network response time	2.5 seconds

3.1.1 Network Throughput Analysis

Several of the key costs in a VSAT network are a function of the throughput required to support the network. The throughput must be sufficient to support the network under peak traffic conditions. Here the decision to employ a fixed assignment or demand assignment access scheme can have an extremely large impact on overall network cost. In a fixed assignment scheme the total throughput required is the number of sites times the peak throughput required per site. Clearly, if the ratio of peak-to-average throughput required by a terminal is high, provisioning the network to accommodate all terminals simultaneously in their peak condition is wasteful and expensive. For our reference network, the traffic is quite bursty and the delay constraints are not too demanding. Thus it is a natural choice for a demand assignment scheme.

An analysis to determine the throughput requirements of the reference network with a demand assignment scheme was performed using the traffic parameters in Figure 4. The key performance metric was the guaranteed (99.5% of the time) maximum response time of 2.5 sec. The response time begins when the remote VSAT wants to send a request and ends when the hub's reply reaches the remote, but does not include time that the hub spends processing the remote's request and preparing its reply. Since the throughput analysis is dependent on the functional operation of the network, the following operational concept was assumed:

1. A remote VSAT with a transaction to be processed requests bandwidth by transmitting a bandwidth request message
2. The demand-assigned-multiple-access (DAMA) process receives the remote's request for bandwidth and prepares a bandwidth assignment message that is sent to the remote. Assignments are made in first-come first-served order for all requests made in this step and in step 7.
3. The remote receives the bandwidth assignment message, waits for the assigned bandwidth to become available, then sends the transaction request message to the hub
4. The hub receives and processes the transaction request and transmits a reply
5. The remote receives the transaction reply (this is the end of the network response interval)
6. The remote requests bandwidth for its confirmation message
7. The DAMA process receives the request for bandwidth and prepares a bandwidth assignment message which is sent to the remote
8. The remote receives the bandwidth assignment, waits for the assignment to occur, then sends its confirmation message to the hub

Using this model of the functional flow combined with the traffic model parameters described above, the required network throughput was computed. For a DAMA algorithm resident at the hub (or network operations center for the processing payload), the 2.5 second network response time was satisfied 99.5% of the time with a total network data rate of 260 kbps. This includes forward and return traffic as well as framing and signaling overhead. If the DAMA algorithm is resident on the satellite payload (available only in the processing payload option) the total network data rate is slightly lower at 255 kbps. Had a fixed assignment access scheme been used, 5 to 10 times more throughput would have been required to support the network.

Transponder Throughput Implications. For the transponder-based network, a fixed amount of transponder bandwidth is leased to support the required network throughput. The total network throughput can be translated to transmission bandwidth by applying modulation, forward error correction coding, and guard band assumptions. In typical transponder networks, these data rates are in the border region between BPSK and QPSK modulation. We optimistically assume QPSK is used. Including guard bands, spectral efficiency is assumed to be 1 bps/Hz. Rate ½ FEC coding is also typical for transponder-based VSAT networks. Therefore, the total bandwidth required for the transponder network is (260 kbps)x(2 code bits/info bit)/(1 bps/Hz) = 520 kHz.

Processing Payload Throughput Implications. For the processing payload network, required network throughput is not accommodated by leasing a fixed amount of transmission bandwidth. Some of the flexible ways in which processing payload throughput may be procured are discussed in Section 3.2.4.

3.2 COST ANALYSIS

VSAT network cost is the total of costs for terminal equipment and maintenance, network infrastructure (e.g., hubs and leased lines), satellite usage, and licenses. Commonly, the total is used to derive a cost-per-VSAT-site-per-month. In the following sections, the primary cost components are calculated for transponder and processing payload implementations of the reference network.

3.2.1 VSAT Terminal Costs

VSAT earth station costs represent a large portion of the overall network cost. Earth station costs include both the purchase of the equipment and substantial installation and maintenance costs. Terminal costs are also a function of the data rates and availability required for a given application. As discussed above, the data rates required for both transmit and receive information are about 150 kbps. Such rates can be supported with relatively small terminals.

Transponder Terminal Costs. Historically, equipment costs for transponder-based terminals that support these data rates have been approximately $10,000 per site [3]. In recent years, costs have been reduced to approximately $3500-$8000 [2]. Installation costs are about $1,000 per site and yearly maintenance costs are roughly 10% of the equipment cost. For the purpose of this analysis, we assume prices will continue to drop. We optimistically assume that by the time processing systems are available transponder-based VSAT equipment will cost approximately $3000.

Processing Payload Terminal Costs. Most of the proposed processing payload systems will support several classes of terminals. TRW’s Gen*Star system accommodates three classes of terminals (see Figure 5). The class Z terminal exceeds the requirements reference network and provides substantial growth capability for increased capacity.

Figure 5. Gen*Star Terminal Classes

Parameter	Class Z Terminal	Class Y Terminal	Class X Terminal
Antenna diameter	< 100 cm	100 cm	180 cm
Uplink information rates	16 kbps to 1 Mbps	16 kbps to 5 Mbps	16 kbps to 25 Mbps
Downlink information rate	120 Mbps	120 Mbps	120 Mbps
Uplink access	FDM/TDMA	FDM/TDMA	FDM/TDMA
Downllink access	TDM	TDM	TDM

Target prices for the class Z terminals are considerably less than existing transponder terminals designed to support the same data rates. The primary reason for the lower cost is a different business paradigm. The processing payload systems are designed to support far greater numbers of interactive users. With this increased revenue-generating capacity, the satellite network operators are highly motivated to maintain as large of a user population as satellite capacity permits. Consequently, processing payload system developers have identified user terminal costs as a key issue. Given that all terminals for a processing payload system will share a common standard and a single satellite may be capable of supporting over one million users, the production quantities of processing payload terminals should be much greater than existing transponder-based terminal equipment. In addition, processing payload system developers have established strategic partnerships with terminal manufacturers and are actively pursuing aggressive price targets. The price target for class Z type terminals is approximately $1000. As with the transponder terminal, a $1000 per site installation fee is assumed as well as a 10% annual maintenance fee. Not only is this price substantially less than transponder-based equipment, but the processing payload terminal provides extensive data rate growth capability. A summary of terminal related costs for transponder and processing payload networks is provided in Figure 6.

Figure 6. Terminal Cost Summary

Terminal Cost Item	Transponder Network	Processing Payload Network
Terminal equipment	$3000/site	$1000/site
Installation	$1000/site	$1000/site
Maintenance (10% of equipment $)	$300/site/year x 5 years	$100/site/year x 5 years
Total per site (5 years)	$5,500	$2,500
Total for 230 sites	$1,265,000	$575,000

3.2.2 Infrastructure Costs

Since all VSAT communication in the reference network is to and from the central data center, a star network is the logical topology. With a star topology, the hub costs must be included in the overall network costs.

Transponder Infrastructure Costs. For the transponder-based implementation, the two basic hub options are: (1) a dedicated user-owned and operated hub, and (2) a shared leased hub. A dedicated hub gives the customer full control of the network. Furthermore, the hub can be co-located with the central data center, eliminating the need for leased terrestrial lines between the two. While the dedicated hub provides the highest degree of control and flexibility, it also requires the highest capital expenditure. A mini-hub with a 2-3 m antenna capable of supporting up to about 400 VSAT sites typically costs approximately $120,000 [3]. Larger hubs that service 1000 VSAT sites can cost over $1,000,000. In addition to the one-time purchase and installation, recurring operation and maintenance are estimated at approximately $380,000 per year.

Shared leased hubs offer a more attractive cost scenario, particularly for smaller networks. In [3] the yearly lease for a hub supporting 1.25 MHz to the network is approximately $48,000. Since lease costs scale fairly linearly with bandwidth, the 520 kHz of bandwidth needed by the reference network would cost approximately $20,000 per year. Although the costs are considerably lower than the dedicated hub, there are some disadvantages. Any future expansion of the network would require additional hub capacity to be available. Since the shared hub is not co-located with the central data center, a leased terrestrial line is needed to provide this connectivity. The RFP indicated such leased terrestrial lines would need to be at least 256 kbps. The exact cost of the leased line depends on the specific countries hosting the data center and the hub as well as the distance between the two. In [3], a leased line for a typical European system is estimated to cost $20,000 per year.

Processing Payload Infrastructure Costs. The inherent flexibility of processing payloads provides unique possibilities for a hub. In a transponder-based star network, the hub handles connection requests and overall resource management. In TRW's Gen*Star architecture, these functions are performed for the entire satellite network of users by a single Network Operations Center (NOC). The cost for such services is built into the satellite usage fees (to be discussed later). Therefore, this hub is simply a terminal capable of adequate data rates to service all of the remote sites. Such a terminal can easily be located at the central data center, thus eliminating the cost of leased terrestrial lines. Since the hub is basically a terminal without much of the required functionality of transponder-based hubs, operation and maintenance costs are more consistent with those of remote terminals. Furthermore, the required transmit and receive information rate for the hub in our reference network is only about 150 kbps. This is easily accommodated by a class Z Gen*Star terminal described above.

Figure 7 is a summary of infrastructure costs for transponder and processing payload implementations of the reference network.

Figure 7. Comparison of Infrastructure Costs

Parameter	Dedicated Hub Transponder Network	Shared Hub Transponder Network	Processing Payload Network
Hub Equipment	$120,000	N/A	$3,000 + $1,000
Hub Operation & Maintenance	$380,000 x 5 years	N/A	$300 x 5 years
Hub Lease	N/A	$20,000 x 5 years	N/A
Terrestrial Leased Line	N/A	$20,000 x 5 years	N/A
Total (5 years)	$2,020,000	$200,000	$5,500

3.2.3 License Costs

License fees can also be a non-trivial component to the total VSAT network cost. Fees vary substantially between countries, ranging from about $10 to $2000 per site per year. Since these fees are independent of whether the network is transponder-based or processing payload-based, they are not a differentiator. The RFP summary [2] recommended an average monthly fee of $40 per site as a guideline.

3.2.4 Satellite Usage Costs

The last component of total VSAT network costs is satellite usage.

Transponder Satellite Usage Costs. For typical transponder networks, a fixed amount of bandwidth is leased to support the entire network. Leased transponder rates are a function of location and the quantity of bandwidth to be leased. Wholesale rates for 36 MHz Ku-band transponders range from $1.7M to $2.3M per year, with the cheapest rates in Asia and the highest in Europe. Rates per unit of bandwidth increase if only a fraction the transponder is required. A rate of approximately $190k/MHz/year is used as a typical fractional transponder lease rate [3]. At this rate, the 520 kHz of bandwidth required for the reference network would cost approximately $100K per year.

Processing Payload Satellite Usage Costs. For processing payload networks, there are a number of scenarios available for satellite usage fees. Three examples are:

- A fixed amount of bandwidth is partitioned off and managed exclusively by the VSAT network (similar to transponder network)
- The network is billed only for bandwidth used (similar to ATM switched virtual circuit networks)
- A flat monthly rate per terminal is charged for unlimited use at set peak rates (similar to ADSL networks)

Each of these scenarios is a viable approach with unique advantages; the best choice depends on the needs of the network. The second and third approaches are more cost-effective as they take greater advantage of the unique properties of the processing payload. Some of the key features of processing payloads that promote lower usage fees are:

- Multi-beam frequency re-use increases satellite raw capacity
- Statistical multiplexing allows traffic with varying degrees of burstiness to be handled more efficiently, increasing the effective satellite throughput
- On-board processing allows empty uplink time slots to be discarded, increasing the efficiency of downlink transmission
- Ability to dynamically reallocate unused bandwidth allows for lower cost to each customer
- Uplink and downlink bandwidth can be provisioned asymmetrically to take advantage of traffic statistics
- On-board demodulation improves link performance and yields higher bandwidth efficiency

In [1], a representative Gen*Star multi-beam processing payload was described with approximately 7 Gbps of raw capacity. We will use this as our reference processing payload capacity. Referring to our network throughput analysis in Section 3.1.1, the 260 kbps of required network throughput represents 0.0037% of the satellite's total 7 Gbps of raw capacity. In comparison, the transponder implementation required 520 kHz out of the satellite's total 1 GHz (typical dual polarization license bandwidth) of billable resources (i.e. 0.052%). The ratio of required-to-available satellite resources is thus a factor of 14 higher for the transponder implementation. In actuality this factor is probably much higher, since the resources required for the processing payload can easily be resold during periods of the day when the network is not fully utilizing them. Processing payloads do carry a higher price tag than transponder payloads. Conservatively, the space segment and corresponding ground support equipment costs for a processing payload are roughly twice those of a transponder. This cost includes additional functionality of the network operations center which provides resource management and access control for the entire satellite. Combining the utilization factor and cost factors, it is reasonable that satellite usage costs for the processing payload will be approximately 1/7 those of the transponder.

3.2.5 Transponder Versus Processing Payload Cost Totals

Figure 8 is a summary of total costs for transponder and processing payload implementations of the reference VSAT network.

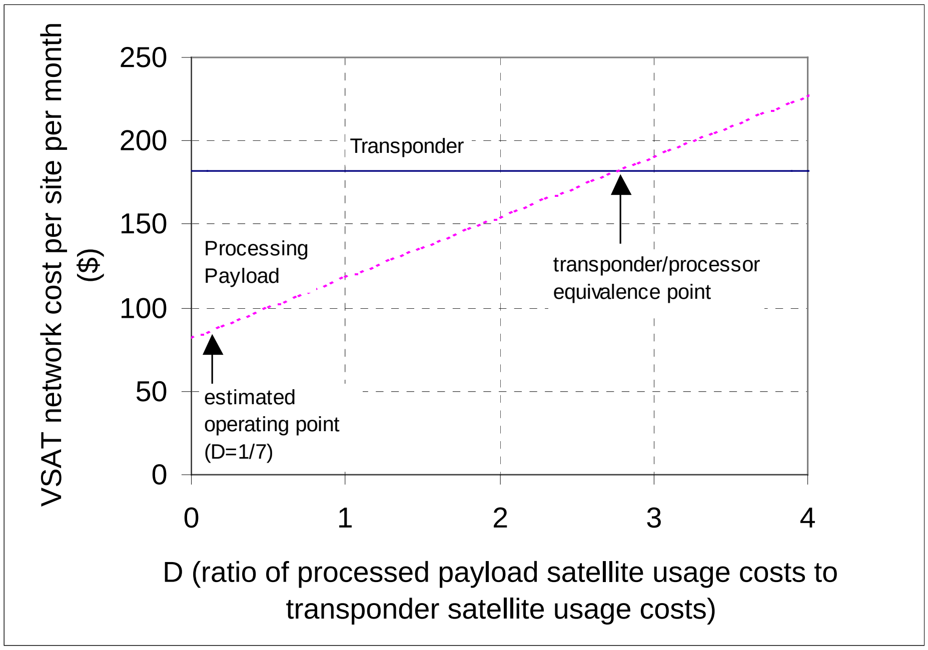
As a validity check, the transponder-based costs computed here were compared to the response bids from the reference network RFP [2]. The bids ranged from \$3,000,000 to \$7,500,000 (average was \$4,900,000) and did not include license fees or terrestrial leased line fees, which account for \$652,000 of the total in Figure 8. Therefore, the transponder network values computed here are lower than the actual bids that were submitted primarily due to our aggressive, forward-looking assumption on transponder-based terminal costs. Even with these very optimistic assumptions for transponder-based networks, the processed payload implementation still resulted in a cost reduction of over 50%.

Figure 8. Reference Network Cost Totals

Cost Category	Transponder Network Cost ($)	Processing Payload Network Cost ($)
Terminal Equipment & Maintenance	1,265,000	575,000
Infrastructure Costs (5 years)	200,000	5,500
License (5 years)	552,000	552,000
Satellite Usage (5 years)	500,000	500,000 x 1/7
Total (5 years)	2,517,000	1,204,000
Total per site per month (230 sites)	182	87

The most uncertain cost in the analysis is the satellite usage cost for the processing payload implementation. Figure 9 illustrates the sensitivity of this parameter by plotting total processing payload costs as a function of the ratio of (satellite usage costs for the processing payload)/(satellite usage costs for a transponder). This ratio is referred to as “D.” Even though D was estimated to be approximately 1/7, the processing payload network implementation actually results in lower overall costs as long as D is less than approximately 2.75. This demonstrates that there is a wide “win-win” service pricing range where satellite operators and middle level network service providers can realize greater revenues while still providing a lower cost solution to users than existing transponder networks.

Figure 9. Network Costs Versus D



3.2.6 Transponder Versus Processing Payload Cost Sensitivities

The traffic model assumptions for the reference network were very favorable to a transponder-based implementation. Even with these assumptions, the processing payload implementation was considerably less expensive than the transponder implementation. This section explores the impact of changing some of these assumptions.

First, consider the possibility that the type of network traffic has changed over time and now the majority of traffic is VSAT-to-VSAT instead of VSAT-to-data center. Since all communications must still go through the hub in the transponder implementation the network bandwidth required by the satellite and the hub will increase significantly. Depending on the amount of VSAT-to-VSAT traffic, this could mean as much as 100% increase in required bandwidth. For this example, we will assume a 75% increase in bandwidth for both the satellite and the hub. Hub costs thus increase from $100,000 to $175,000 and satellite usage costs increase from $500,000 to $875,000. Conversely, TRW's Gen*Star processing payload implementation requires *no* additional bandwidth to provide VSAT-to-VSAT traffic.

In addition, let us revisit the assumption that D = 1/7 (satellite usage costs for processing payloads are 1/7 satellite usage costs for transponders). This was based on a percentage of satellite resource utilization under peak conditions. One of the major advantages of the processing payload is its ability to dynamically reallocate bandwidth based on instantaneous demand. If the resource demand of our reference network drops from its peak throughout the day, those resources can be resold to other networks. Therefore, the network can be billed on its statistical usage over the day rather than its peak needs. It is quite likely that D could go from 1/7 to 1/14 based on this capability. Further, since the processing payload implementation did not require additional bandwidth to provide VSAT-to-VSAT traffic, this factor should be applied to the original transponder bandwidth costs prior to the increase for VSAT-to-VSAT traffic.

Using these updated assumptions, Figure 10 shows that total network costs for the processing payload implementation are less than 40% of the transponder implementation.

Figure 10. Transponder Versus Processing Payload Network Costs (Example 2)

Cost Category	Transponder Network Cost ($)	Processing Payload Network Cost ($)
Terminal Equipment & Maintenance	1,265,000	575,000
Infrastructure Costs (5 years)	275,000	5,500
License (5 years)	552,000	552,000
Satellite Usage (5 years)	875,000	500,000 x 1/14
Total (5 years)	2,967,000	1,168,000
Total per site per month (230 sites)	215	85

4. CONCLUSIONS

Processing payload systems are in development now and will soon be part of the satellite communications landscape. Using very conservative assumptions and an example that did not take full advantage of processing capabilities, the analysis provided in this paper shows that processing payload networks can revolutionize the VSAT market. VSAT service providers who recognize the tremendous potential of these systems will be able to offer a dramatically lower-priced solution to their customers while realizing even greater profits than were possible with transponder based networks. In addition, processing payloads easily adapt to changing traffic needs of the network. The ability to provide full mesh connectivity, dynamic resource allocation, and statistical multiplexing of diverse traffic results in lower costs for existing VSAT networks and an easy migration path for these networks to expand their capacity, connectivity, and range of applications.

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