ONBOARD PROCESSING FOR COMMUNICATIONS SATELLITES

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ABSTRACT

Future satellite networks may include satellites that provide multiple uplink and downlink coverage antenna beams together with signal processing subsystems. Where the number of earth terminals is large and the traffic is diffuse, efficient methods for routing signals need to be developed. This paper addresses the switching and routing processes for both long term connections (stream traffic) and short messages (burst traffic). Onboard routing appears most efficient for burst traffic where as stream traffic is best handled by means of a ground based traffic controller. An integrated control system concept is suggested together with access and multiplex formats to accommodate mixed traffic.

INTRODUCTION

The projected demand for new services, e.g., electronic mail, video conferencing, and facsimile transmission, plus increased volume of diversified traffic dictate a need for improved efficient and cost-effective communication techniques. A leading candidate for satisfying this need is a network utilizing communication satellites with multiple beam antennas, efficient multiple access schemes, and integrated switching and routing algorithms.

The use of onboard processing in communication satellites as a means of increasing throughput efficiency has been under study for several years. Several levels of processing are possible.

RF PROCESSING

RF processing consists of a microwave switching matrix and its control circuitry. This device dynamically varies the interconnectivity between multiple receive and transmit satellite antenna beams. This type of processing is being used in the Advanced WESTAR and will also be used in the INTELSAT VI.
BIT STREAM PROCESSING

A bit-stream processor demodulates the received signals, performs the switching at baseband, and modulates the transmitted carrier. Bit-stream processing isolates the uplink from the downlink so that they can be separately optimized and independently operated. Of particular significance is the isolation of uplink noise and interference from the downlink, which leads to improved end-to-end bit-error-rate performance.

FULL BASEBAND PROCESSOR

The full baseband processor performs additional functions such as decoding, network control, signal routing, and reformatting the data for retransmission. With this capability, the onboard processor can become an integral part of the network control system. The salutary effect of the onboard net control on network architecture and protocol can be significant, and it could lead to substantial improvements in throughput efficiency and delay but could incur increased satellite complexity and reduced reliability.

Very recently, work on multiple beam satellite systems with onboard processing, storage, and switching is receiving considerable attention. In order to provide full area coverage, fixed spot beams have been used in conjunction with scanning spot beams in the systems defined by Reudink et al (1). Various onboard processing techniques and related issues regarding implementation of multibeam communication satellites that would service a wide range of users in the 1990’s have been discussed by Ruddy and White (2). An extension of this study considered fixed beams to cover major metropolitan areas, and scanning beams that periodically cover the remainder of the United States (3). Frequency-division multiple access (FDMA) and time-division multiplex (TDM) are employed on the uplinks and downlinks, respectively. User signals are regenerated and packets are reformatted on board. Link establishment and packet routing protocols are defined.

DeRosa, Weiner, and Ozarow (4) analyzed a slotted ALOHA system applied to a communication satellite with a multiple uplink and single downlink. It was shown that the use of processing in the satellite increased the throughput. Eaves (5) extended these results to the multiple downlink case showing further increase in throughput. Ivan Kadar (6) proposed a system utilizing slotted ALOHA/FDMA uplinks in each beam, satellite-switched time-division multiple access (SSTDMA) downlinks in each beam, and throughput-delay analysis was performed.

Irwin Jacobs et al (7) have discussed various aspects of a general purpose packet satellite network to handle integrated data and conference speech services and proposed a priority-oriented demand assignment (PODA) algorithm for a nonprocessing satellite system. Davies, Chethik, and Pennick (8) have investigated a processing satellite system with
multiple beam antenna concepts for packet communications and conducted performance-
cost tradeoffs. This study has concluded that the reservation system is more cost effective
than the random access system. A single microprocessor based packet switch for use on
board a satellite has been designed by M. Arozullah et al (9) and the performance
evaluation of the switch was also reported. The throughput-delay performance of various
multiple access schemes for a packet switched time-division multiple access (TDMA)
system using satellite-switched multiple beams and a varying degree of onboard processing
have been performed by T.E. Stern et al (10). In all these systems, multiple access issues,
-system concepts, and throughput-delay performance analyses have been considered, but
the traffic control for a multibeam processing satellite system is not fully addressed.

In this paper the issue of what network control functions should be placed in a satellite
(rather than on the ground) is addressed with estimates of advantages and disadvantages.
This evaluation is performed on the basis of throughput capacity, delay, and satellite
complexity. Other criteria, such as network survivability in a military environment, are not
considered.

SYSTEM MODEL

Figure 1 shows the satellite communication network under consideration. The satellite has
several antenna beams, each isolated from the others, and many earth terminals in each
beam. The antenna beams may exist simultaneously as a multiple beam antenna (MBA), or
in a time sequence (beam hopping), or both.

The basic network control functions may be defined as follows:

a) **Uplink entry.** The method for many earth terminals in one beam accessing a single
   uplink at the same time.

b) **Satellite routing.** The method for connecting the uplink to the desired downlink(s).

c) **Downlink multiplexing.** The method for combining multiple downlink circuit messages
   or multidestination signals in a single beam.

Two types of traffic may exist in this network:

a) **Stream traffic.** Continuous signals such as voice, video, and certain types of computer
data. (Stream traffic might also be constructed by concentrating a large number of burst-
type traffic at one node.)
b) *Burst (packet) traffic*. Interrupted traffic between interactive computer terminals, word processors, and the like.

Stream traffic is characterized by message durations in excess of several seconds, (generally several minutes), while burst traffic message durations are generally less than one millisecond. While it is possible to dedicate separate networks for each type of traffic (i.e., INTELSAT for stream traffic, ARPANET for burst traffic), many communications networks and even individual subscribers require both. A single system approach to these network requirements may be most cost effective. Burst traffic does not efficiently utilize circuits set up for stream traffic, whereas the total throughput of burst-only traffic may be too low to justify the expense of a separate satellite network. This paper considers approaches designed to handle both in a single system.

**TRAFFIC CONTROL TECHNIQUES**

Traffic control may be implemented by a wide variety of techniques. For communication satellite networks, these techniques may be classified in several categories as shown in Table 1. The simplest approach consists of dedicated circuits between users. This technique is most suitable for high capacity trunks between major traffic nodes, but it becomes quite inefficient when applied to a large number of small capacity users, each using the circuit only a small percentage of the time.

At the other extreme the random access technique (ALOHA), used primarily for burst traffic, is bandwidth inefficient and also incurs unacceptably long delays as traffic load increases.

Therefore, various methods of demand assignment multiple access (DAMA) have been developed that rapidly assign circuits to users as required. This assignment is performed by a central controller (with the exception of reservation techniques, which are discussed later). The central controller is generally accessed by the user through an orderwire circuit. Since this orderwire circuit is also shared by many users, an orderwire access technique is also required. This may consist of random, polled, reservation, or dedicated circuit techniques. Table II lists the principal characteristics of the orderwire access control schemes.

**Traffic Control Protocol for Stream Traffic**

For single channel per carrier (SCPC) stream traffic, the user initiates a sequence of communications with the net controller in the form of request and control signals that pass through the satellite between users and controller by separate orderwire links. The controller accepts the transmit user request, establishes the connection with the designated
receive user, and assigns the satellite circuit (antenna beam, frequency, and time slot) to both users. The circuit remains busy until one of the users requests termination of the connections again via the orderwire.

Note that in most satellite networks the central controller is located at an earth station. The question may be asked, “Is there any advantage in placing the central controller on the satellite?” The extra propagation time introduced by the earth bound satellite-controller link is only a fraction of a second, which is small compared to a voice circuit connection duration. Thus for stream traffic, there is no advantage and the onboard controller adds complexity to the satellite.

The required capacity of the satellite-controller link to the earth bound controller is small as shown in the following example.

Suppose for each circuit request the user transmits

a) user identification
b) destination identification
c) message type (data rate)

The controller would respond by controlling the satellite to set

a) data rate of demod, remod (if variable)
b) forward error correction, in or out
c) receiver-to-transmitter routing (interconnect)
d) frequency or time-slot assignment
e) scan beam pointing angle (if scanning beam used)
f) user terminal transmit power level (if variable)

Each circuit request or controller response could be handled by eight 8-bit words including data required for synchronization, and other overhead. A total of 128 bits per circuit request and controller response is thus required in each direction (up and down). Assuming an average message duration of 3 minutes and a peak satellite throughput of approximately 25,000 voice circuits, one can expect about 140 requests per second. The central control-satellite link must therefore handle an average rate of approximately 18 kb/s, which is small compared to the traffic throughput.

**Traffic Control for Burst Traffic**

The technique described above for stream traffic control is unsuitable for burst or packet traffic. The message duration is generally one or several packets, each of which may be on
the order of $10^3$ or $10^4$ bits. Assuming a transmission burst rate of approximately 50 Mb/s for the uplink, the burst duration is on the order of $10^{-3}$ seconds. The ground controller concept described for stream traffic would require at least 1/4 second more than an onboard controller to set up the circuit for each packet. Thus the satellite or the earth terminal would have to retain in its memory all packets awaiting routing instructions from the ground controller. Assuming a total packet network throughput of about 1 Gb/s, a storage capability of approximately $2.5 \times 10^8$ bits would be required. On the other hand, the onboard routing technique would require substantially less hardware. An example of the onboard routing system is shown in Figure 2. This system, a form of the Roberts’ reservation technique (Ref. 11), is based on the use of each satellite antenna beam coverage zone to indicate to all users in that zone which time slots in a TDMA frame are available for packet transmission. The uplink orderwire channel, which is used as a reservation channel, operates on a contention basis in which each user monitors the satellite retransmission of his random-access reservation message to determine if he has successfully reserved the slot (8). If a collision in the orderwire uplink occurred, then the sender must reattempt the reservation. Since contention only occurs in the reservation process, no data packet acknowledgments are required. This is in contrast to more conventional random access packet architectures where end-to-end acknowledgments are required (9).

The earth terminal memory requirements become even worse if end-to-end acknowledgment is contemplated. It is assumed that the basic uplink and downlink transmission provides adequately small bit-error-rate for the packet network, and that the major concern is on access contention. Thus no end-to-end acknowledgment would be required under this assumption.

Several other efficient protocols can be defined by using a decentralized control approach. Each terminal within a zone reports to the onboard controller indicating the number of packets and priority information of the intended packet transmission. The onboard controller looking at this information broadcasts the traffic lists and reservation lists. Each terminal listening to the downlink starts transmitting in accordance with the controller commands.

Packet routing is performed by decoding the destination address of the packet header on board the satellite and using this information to route the packet onto the designated downlink. Here the packet is placed into a buffer where it awaits its turn for transmission from the satellite. A previous study (8) has shown that the probability of buffer overflow can be kept very low with moderately sized buffers provided that the average throughput rate does not approach the full downlink capacity.
The receiving user terminal continuously monitors the downlink signal. When it receives a packet with its own address code, the packet is stored, formatted, and suitably relayed over its terrestrial network to its ultimate destination.

**INTEGRATED CONTROL FOR STREAM AND BURST TRAFFIC**

The results of the previous discussion indicate that onboard traffic control is worthwhile for burst traffic but not for stream traffic. An integrated system to handle both types of traffic would employ both types of controllers as shown in Figure 3. The network synchronization and orderwire (including the satellite-ground controller link) functions are integrated with the traffic data in a TDM format as shown in Figure 4. The uplinks consist of TDMA bursts from individual user terminals.

The traffic data are either stream traffic TDMA bursts or packets. The allocation of time slots between these types and within the basic frame structure is arbitrary and can be under control of the ground controller.

If one service type becomes saturated, capacity may be transferred from the other service under ground controller command, thereby keeping the satellite capacity efficiently utilized.

Thus the advantage of reduced delay for packet transmission is maintained while the principal switching control functions are kept on the ground.

**IMPLEMENTATION ISSUES**

The concepts described previously are logical extensions of TDMA and SSTDMA to be used in the near term in systems such as satellite business systems (SBS) and Advanced WESTAR. The additional subsystems to be added to the SSTDMA satellite for onboard bit stream processing and traffic control include the following:

a) *Demodulators.* TDMA rapid synchronizing demodulators for uplink TDMA and reservation packet demodulation. Demodulators can include forward error correction decoders and random access demodulators with reservation packet contention detectors and successful packet detectors.

b) *Data Buffers.* Packet memories to facilitate onboard routing and transmit time-division multiplexing.
c) **Controllers.** Computation processes to process packet addresses and otherwise manage demodulator and data buffer resources. Controller also reports state of the network (e.g., load on packet net) to both the subscribers and the ground controller.

d) **Modulators.** Facilitate the transmission of the downlink beams. Can include forward error correction subsystems.

**CONCLUSION**

Onboard processing in communication satellites represents a number of functions such as demodulation and remodulation, switching, routing, and error control. With this capability, the onboard processor can become an integral part of the network control system. The principal issue of control partitioning between an onboard controller and a ground based controller has been addressed. For stream traffic a call establishment protocol using an orderwire channel to an earth bound controller and for burst traffic a reservation based packet transmission protocol with an onboard net controller are defined. Initial throughput-delay analysis results indicate that there is no advantage for a stream traffic controller on the satellite. On the other hand, onboard control with efficient routing protocols is found to reduce the delay to burst traffic by approximately 1/4 second, which is significant for interactive data traffic and may have major cost impact. (The later protocol assumes no end-to-end acknowledgment.)

An integrated system to handle both stream and burst traffic is discussed. The integrated system configuration employs controllers both on the satellite and on the ground. The network synchronization and orderwire functions are integrated with the traffic data in a TDM format. The uplink consists of TDMA bursts from individual user terminals. Some of the extensions of this work will include throughput-delay analysis of the integrated control protocols and performance-cost tradeoffs.

**REFERENCES**


Table 1. Traffic Control Techniques

<table>
<thead>
<tr>
<th>Antenna Coverage</th>
<th>Access Control</th>
<th>Uplink Multiple Access</th>
<th>Satellite Routing</th>
<th>Downlink Multiplexing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single beam</td>
<td>Fixed assigned</td>
<td>FDMA</td>
<td>Frequency channelization &amp; translation</td>
<td>Frequency channelization &amp; multiplexing at RF</td>
</tr>
<tr>
<td>Multiple continuous beams</td>
<td>Channel switched central control</td>
<td>TDMA</td>
<td>Onboard TDMA demodulation and buffering</td>
<td>Time multiplexing at RF</td>
</tr>
<tr>
<td>Single beam hopping</td>
<td>Channel switched regional control</td>
<td>Contention</td>
<td>Packet demodulation address decoding and buffering</td>
<td>Serialize buffer synchronize and modulator</td>
</tr>
<tr>
<td>Multiple beam hopping</td>
<td>Channel switched Demand assigned</td>
<td></td>
<td>Fast channel switching at baseband</td>
<td>digital baseband onto single carrier</td>
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<td></td>
<td>Satellite control</td>
<td></td>
<td>Slow channel switching at RF</td>
<td>Parallel modulator into multicarrier FDMA</td>
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<tr>
<td></td>
<td>Message switched Demand assigned</td>
<td></td>
<td>Fast channel switching at RF</td>
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<td></td>
<td>Satellite control</td>
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<td></td>
<td>Message switched central control</td>
<td>Fast channel switching at RF</td>
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<tr>
<td></td>
<td>Random access</td>
<td>Slow channel switching at RF</td>
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<tr>
<td></td>
<td></td>
<td>Fast channel switching at RF</td>
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# Table II. Orderwire Access Control Characteristics

<table>
<thead>
<tr>
<th>Scheme</th>
<th>Utilization/Delay</th>
<th>Overhead</th>
<th>Collisions</th>
<th>Traffic</th>
<th>Satellite Complexity</th>
<th>Terminal Complexity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dedicated:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FDMA</td>
<td>Excellent for stream traffic</td>
<td>No</td>
<td>No</td>
<td>Stream</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>TDMA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Random:</td>
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<tr>
<td>ALOHA</td>
<td>Excellent for low burst traffic</td>
<td>Packet header</td>
<td>Yes</td>
<td>Burst</td>
<td>High</td>
<td>Simple but large EIRP</td>
</tr>
<tr>
<td>Pure/slotted capture</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Reservation</td>
<td>Better for medium burst traffic</td>
<td>Reservation overhead</td>
<td>No (Some in reservation - ALOHA)</td>
<td>Medium burst traffic</td>
<td>Higher</td>
<td>Moderate low EIRP</td>
</tr>
<tr>
<td>Polling</td>
<td>Better for long message</td>
<td>Polling packet</td>
<td>No</td>
<td>Stream</td>
<td>High</td>
<td>High</td>
</tr>
</tbody>
</table>
Figure 1. Processing Functions in Communication Satellite Network

Figure 2. Packet Transmission Protocol
Figure 3. Processing Satellite System Control

Figure 4. Traffic (TDMA - Stream or Packet-Bursts) - Downlink Data Format