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Abstract

A version of the Interface Message Processor (IMP) is being developed which permits efficient use of satellite circuits within the ARPA Network.

1. INTRODUCTION

The ARPA Network [1] is a collection of nodes (called Interface Message Processors or IMPs [2,3]) connected together by leased communication circuits for the purpose of providing communication among independent computer systems (Hosts) attached to the IMPs. A Host passes data to its IMP in the form of a message, an addressed sequence of bits up to about 8000 bits long which the IMP breaks into addressed packets about 1000 bits long. These packets are forwarded from IMP to IMP across the network until they reach the IMP to which the destination Host is attached. As the packets are passed from IMP to IMP, a copy of each packet is held by an IMP until the packet has been sent to the next IMP and an acknowledgment has been returned by that IMP. At the destination IMP, the packets are reassembled into the original message which is then passed to the destination Host.

The communication circuits connecting the IMPs have typically been 50Kbs ground links, although 9.6Kbs and 230.4Kbs links are also in use. In the past year, two satellite links have been added to the network, one a 50Kbs link from California to Hawaii and the other a 9.6Kbs link from Washington, D.C. to Norway. In both cases these satellite links are conventional point-to-point links.

The likely introduction of further satellite links into the ARPA Network as it expands overseas, and the coming possibility of domestic satellite communication, have led to the development of a new variant of the IMP technology called the Satellite IMP. The Satellite IMP permits several network nodes to share a single satellite channel, enabling the nodes to statistically average their total load (at the satellite) rather than requiring each node-pair to average their traffic independently [4]. The manner in which the Satellite IMP provides such channel sharing is based on the concept of packet broadcast as first used in the ALOHA System [5] and since then considerably refined and developed [4,6,7,8,9,10,11].

2. THEORY BEHIND THE SATELLITE IMP

When using a packet broadcast protocol, all nodes sharing the channel transmit discrete packets of data on the same transmission frequency. All nodes sharing the channel also receive on the same receive frequency, picking out packets addressed to themselves and discarding packets addressed to others.

The original ALOHA or "random" ALOHA system [5] permits nodes to transmit their packets in a completely uncoordinated way. Thus, there is a substantial possibility of transmission conflict (and consequent destruction of the conflicting packets) with a frequent need for retransmission of packets. The retransmissions must somehow be randomized to avoid repeated conflict. As shown in [5], a channel operating in

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such a manner has an effective throughput capacity of 18%. Since [5], Abramson and Gaarder have studied the effects of multiple packet sizes on a random ALOHA channel [11].

Roberts, in [11], pointed out that if an ALOHA channel were divided into slots (each able to hold a packet) and if the nodes modified their behavior to transmit packets so that the leading edge of the packet always coincides with the leading edge of a slot, even though the nodes remain free to transmit into a slot without regard for the transmission of other nodes, the effective channel capacity is doubled (to 36%). A channel operated in this manner is called a "slotted ALOHA" channel.

There have been a number of interesting areas of study of random and slotted ALOHA, among them: the use of FM capture to reduce the effects of transmission conflicts, strategies for randomizing retransmissions of packets in response to transmission conflicts, channel stability, the effects of different nodal transmission rates on increasing effective channel capacity, and effective channel delay. Abramson, Kleinrock, Lam, Lu, Metcalfe, Rettberg, and Roberts have been active in these studies [6,8,9,10,11].

Several novel (i.e., not conventional round-robin TDMA) schemes have been studied which use implicit or explicit reservation of slots by nodes for the purpose of minimizing transmission conflicts and thereby increasing channel throughput (hopefully without unduly increasing delay). Particularly active in this area have been Binder, Crowther, Kanehira, Rettberg, and Roberts [4,7,11].

3. THE SATELLITE IMP

The Satellite IMP represents a practical application of the large body of theoretical knowledge about the operation of packet broadcast channels that has developed since [5]. The Satellite IMP is a conventional IMP with several additions and modifications both in hardware and software.

3.1 HARDWARE

The first hardware addition is of memory sufficient to buffer all the transmitted packets which can be awaiting acknowledgment simultaneously. Buffer space is necessary for some 32 packets assuming a 50Kbs channel and a one quarter-second propagation up to the synchronous satellite and back down. That is, 32 packets can be sent out before the acknowledgment returns for the first. The next hardware addition is a mechanism for signaling the satellite radio transmitter when to turn the radio carrier on and off as packets are transmitted; this is necessary because if two satellite ground stations have their radio transmitter carriers on simultaneously, they jam each other. The third addition is time-keeping hardware necessary for the Satellite IMPs to accomplish accurate slotting. This hardware notes the arrival time of the leading edge of a packet (slot) and makes this time available to the program when the program fields the received packet interrupt and updates the program's estimate of the slot positions. This hardware also allows the program to accurately specify transmission of a packet at a specified time in the future.

One hardware modification was necessary for construction of the Satellite IMP. The IMP modem interface normally uses a unique character sequence to denote the end of a packet, thus requiring an escape character with escape character doubling for data transparency. Escape character doubling, however, can result in the length of a packet being temporarily increased while traversing the satellite, thus overflowing a slot. The IMP modem interface, therefore, had to be modified to use a word count to specify packet length.

3.2 SOFTWARE

A number of software changes and additions are necessary to convert the normal IMP into a Satellite IMP.

We have implemented a slotting algorithm which operates as follows: each Satellite IMP tracks the location of the leading edges of all packets transmitted by other Satellite IMPs and averages them with exponential weighting to determine the average slot position, which is used as the standard.

We have added a mechanism for randomizing retransmissions. Whenever there is a packet for retransmission, we simply transmit into a slot or not, with a constant probability for each slot. This is very simple to implement and nearly equivalent in effect to the harder-to-implement retransmission scheme analyzed extensively by Kleinrock and Lam [8,9,11].

The IMP had to be modified to process routing data coming from several different sources over a single channel. Each IMP can only be allowed to send routing data over the satellite channel once each routing period even though an IMP normally sends routing to *each* of its neighbors each routing period. When the IMP decides to route a packet out the satellite circuit, it must declare which Satellite IMP at the other end of the circuit is to receive and forward the packet to its destination.

Neighboring IMPs normally exchange a pair of messages at least once each routing period to determine whether the IMP at the other end of the circuit (or the line between them) is alive. Over the broadcast satellite circuit, rather than pairwise exchange of these messages, each Satellite IMP broadcasts a message stating which of the other IMPs it has heard from (and it thus considers alive) since the last period.

The inter-IMP acknowledgment protocol normally allows only eight packets to be outstanding, awaiting acknowledgment, at a time. The satellite channel required expansion to thirty-two packets outstanding at a time. To simplify and optimize the inter-IMP acknowledgment scheme between Satellite IMPs, packets are acknowledged by the slot in which the packet arrived rather than independently for each source IMP.

Neighboring IMPs normally calculate the unused capacity and the delay over the circuit between them. This information is important to the IMPs' routing computation and the propagation of routing information across the network. The satellite version of the IMP will eventually have to take into account that the delay over the broadcast satellite channel is statistical rather than fixed and that the excess capacity may have different characteristics over the broadcast satellite channel. The statistical nature of the delay over the satellite channel will undoubtedly have important consequences for network-wide timing.

Finally, use of a slotted channel requires modification to the IMP program reloading mechanism. Previously, IMPs reloaded by requesting and receiving a complete core image in a single transmission from an adjacent IMP. This technique had to be modified to send the core image one packet at a time (interestingly, packet reloading is also necessary to facilitate introduction of the new type of IMP [12, 13] into the network).

3.3 CHARACTERISTICS

The Satellite IMP as presently constructed includes all the features of a normal IMP including the ability to have Host connections. The Satellite IMP can have multiple ground circuits (fewer than five) to the terrestrial network, but only one packet broadcast satellite circuit. The Satellite IMP presently under construction will allow a satellite channel to be shared with only a small number of other Satellite IMPs. While the initial machine will undoubtedly be used with a 50Kbs satellite channel, it has the capacity to handle a channel on the order of 200Kbs.

In fact, early calculations suggest that Satellite IMP performance will have an upper bound of

$$7C/n + C \leq 1200 \text{ Kbs}$$

where n is the number of Satellite IMPs sharing the channel and C is the effective channel capacity. As with the IMP system, the Satellite IMP system will ultimately have some capability for taking statistics for the purpose of understanding the performance and behavior of the Satellite IMP and broadcast channel.

4. COMPARISON WITH THE MENEHUNE

In the relatively self-contained ALOHA System [5], the Menehune plays a role similar to that to be played by the Satellite IMP in the larger context of the ARPA Network. Therefore, we will briefly compare the Menehune with the Satellite IMP:

- The ALOHA System is a star system with the Menehune in the center surrounded by terminals. Thus the Menehune does not have to deal with routing, as the Satellite IMP does in the store-and-forward ARPA Network.

- In the ALOHA System, only traffic from the terminal to the Menehune is sent using random ALOHA; traffic from the Menehune to the terminals is scheduled (that is, the Menehune transmits in turn to each terminal for which it has a packet). As the transmissions in the two directions are on separate frequencies, there can be no conflict between them. Between Satellite IMPs, transmissions in both directions are broadcast and can conflict with each other. In some sense this halves the capacity of the channel the Satellite IMP has to work with as compared with the channel the Menehune has to work with; in another sense this increases the channel capacity as it theoretically allows better statistical sharing of the two directions of the channel.

- The Menehune uses conventional ground radio communication which has none of the large delays inherent in a satellite system. Thus, channel functions requiring close timing must be done with greater accuracy by the Satellite IMP than they need to be done by Menehune as the delay penalty for unnecessary packet retransmission is much greater for the Satellite IMP.

- The ALOHA System assumes packets are sent from the terminals to the Menehune at normal human typing rates. This rate is low compared to the computer-to-computer communications which the Satellite IMPs must permit. Thus, the Menehune is optimized to handle hundreds of terminals while the Satellite IMP is being optimized to handle tens of nodes.

5. STATUS REPORT AND FUTURE DEVELOPMENTS

We have implemented one version of the Satellite IMP which follows a random ALOHA protocol between a pair of nodes (two nodes are sufficient to test a broadcast protocol). By the time this paper is given we should have completed another version of the Satellite IMP which follows a slotted ALOHA protocol among more than two nodes. A version of the Satellite IMP following a conventional round-robin TDMA protocol would be very simple to implement, and we may experiment with this at some time in the future. Also, we will undoubtedly experiment with some novel reservation protocol(s), of which [4] and [7] have been given the most analysis to date.

As yet no Satellite IMP has been installed in the ARPA Network, mainly because of difficulty in choosing appropriate sites and obtaining approval to carry out an experiment in packet broadcast communications. ARPA is negotiating with the satellite carriers to obtain such approval, and we hope to install the first two Satellite IMPs in the first half of 1974.

Once the first two Satellite IMPs are installed, we expect to construct several additional units, since to realize the advantages of a broadcast channel, sharing among at least three nodes is necessary. It may also be desirable to try a packet broadcast experiment over more than one satellite.

Early next year we will also begin the development of another version of the Satellite IMP, this time based on newly developing IMP technology [12,13]. We intend that this new Satellite IMP will have several advantages over the present machine, among them better reliability, multiple satellite channels, higher bandwidth (1.5Mbs) satellite channels, and many more nodes sharing a single channel.

A small field test of packet broadcast technology is imminent. We expect this field test to be successful and to show the way to ARPA and others for expanded packet broadcast operations. The marriage of satellite communications to packet broadcast communications in the Satellite IMP may well be an important step in a revolution in data communications technology.

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