TECHNICAL RESEARCH REPORT

Hybrid Internet Access

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HYBRID INTERNET ACCESS

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Abstract

Access to the Internet is either too slow (dial-up SLIP) or too expensive (switched 56 kbps, frame relay) for the home user or small enterprise. The Center for Satellite and Hybrid Communication Networks and Hughes Network Systems have collaborated using systems integration principles to develop a prototype of a low-cost hybrid (dial-up and satellite) network terminal which can deliver data from the Internet to the user at rates up to 160 kbps. An asymmetric TCP/IP connection is used breaking the network link into two physical channels: a terrestrial dial-up for carrying data from the terminal into the Internet and a receive-only satellite link carrying IP packets from the Internet to the user. With a goal of supporting bandwidth hungry Internet applications such as Mosaic, Gopher, and FTP, this system has been designed to support any Intel 80386/486 PC, any commercial TCP/IP package, any unmodified host on the Internet, and any of the routers, etc., within the Internet. The design exploits the following three observations: 1) satellites are able to offer high bandwidth connections to a large geographical area, 2) a receive-only VSAT is cheap to manufacture and easier to install than one which can also transmit, and 3) most computer users, especially those in a home environment, will want to consume much more information than they generate. IP encapsulation, or tunneling, issued to manipulate the TCP/IP protocols to route packets asymmetrically.

INTRODUCTION

A wireless broadcast mode of communications offers extraordinary efficiencies as compared to wireline communications even where the wireline service employs sophisticated packet switching techniques such as X.25 or ATM. Traditional radio and TV broadcasting has exploited the efficiencies of the broadcast mode for years using terrestrial RF (radio frequency). Satellites are now being designed to offer TV and radio broadcasts from the vantage of geosynchronous orbit in space. The system described here expands the scope of the evolution from terrestrial to satellite broadcast beyond radio and TV to data services delivered to the personal computer. The numerous online data services such as America Online, Compuserve and Prodigy which have come into existence in recent years will benefit from this enhancement to satellite-based broadcasting.

The enabling technology required to realize the advantages of satellite broadcast communications for the PC market is the PCRO, a low-cost, receive-only terminal for the personal computer. The technology developed will allow for the future development of an additional enhancement: the combination of the PCRO with a TVRO. The intent is to realize additional economies for the consumer who would be able to use the same satellite dish to receive both television programming and PC data.

The objectives of this joint effort between the University of Maryland at College Park and Hughes Network Systems is to develop inexpensive hybrid (satellite and terrestrial) terminals that can provide a variety of services to the user and to foster hybrid communications as the most promising path to the National Information Infrastructure. As the most direct demonstration of these capabilities we are developing a variety of services that can extend Internet services through satellite broadcasting, while at the same time providing the end user with a higher quality service.

Indeed Internet access is either too slow (SLIP dial-up) or too expensive (switched 56 kbs/s, frame relay) for individual users or small enterprises. Our solution is what we have called "Hybrid Internet Access". Using hybrid networking, the hybrid terminal will merge two connections, a bidirectional terrestrial link using a modem and a receive-only satellite link, so that the TCP/IP software above the device driver sees one "virtual" device. This design exploits three concepts: 1) satellites are able to offer high bandwidth connections to a large geographical area, 2) a receive-only VSAT is cheap to manufacture and easier to install than one which can also transmit, and 3) most computer users, especially those in a home environment, will want to consume much more data than they will generate ("asymmetric" computer use).

Internet applications have been chosen as a user requirement for this design because there exists a vast number of enormous databases available on the Internet, much of it accessible by using applications such as file transfer (FTP), Internet News, Gopher, Archie, WAIS, or Mosaic. We again note the asymmetric bandwidth requirements for all these applications. The Internet is the closest existing prototype of the National Information Infrastructure and if this hybrid, asymmetric link design has performance and cost advantages over other methods of accessing information on the Internet, then it may be instrumental in demonstrating satellites' significance in the development of the NII.

The goal of our proposed designs and products is to enable a variety of hybrid Internet services which work with: any 80386/486 PC, any Windows TCP/IP, any dial-up SLIP provider, any host on the Internet, any of the routers etc. within the Internet.

TECHNICAL APPROACH AND DESIGN

The development plan incorporates the maximum use of COTS products and technologies to reduce development time and end-product cost. To this end, both HNS and the Center for Satellite and Hybrid Communication Networks (CSHCN) are providing products for inclusion in different phases of the project. Additionally, off-the-self commercial software will be sought to provide programming solutions wherever possible. Still, there is significant work required to synthesize the elements and to provide high performance services.

The Basic Hybrid Internet Access

Students and faculty from the University of Maryland collaborated with engineers from Hughes Network Systems to create a prototype system that was demonstrated to offer up to 300kbps receivable data (peak rate) and 160kbps average rate. The user terminal in the system used a Hughes device known as a BIC or DirecPC card to interface the computer with a 0.6 meter antenna (of the receive only VSAT). A product line will be introduced by HNS at the COMDEX Trade Show in November of 1994.

The key problem we solved in the work completed to date was how to force routing of packets on the Internet without requiring special modifications to the user application or the destination machine the user was trying to reach. Solving this problem meant manipulating the two primary Internet packet protocols: Transport Control Protocol (TCP) and Internet Protocol (IP) to affect the routing we wanted. TCP/IP is a connectionless protocol where each packet is addressed with its destination and the network finds the best path each time a packet is sent into the system. Address Resolution Protocol (ARP) is used to locate machines on a local network once a packet has arrived at the gateway between the destination machine and the Internet. A typical client-server exchange includes the client creating a request packet which includes the server's IP address (the destination) and the client's own IP address (the source). Once the server has received the request and generated a reply, it merely swaps the two addresses from the request header and sends out the reply to the client. We provide here a brief summary of the basic system design.

Careful consideration of the potential user markets generated several requirements for the system:

- The system must provide significantly less delay responding to requests for large data files experienced using a modem.
- The system must work with any 386/486 33MHz machine.
- The system must work with any commercial TCP/IP package.
- The system must work with any commercial SLIP service provider.
- The system must be able to access any Internet host.
- The system must support Internet initiated connections.

Satisfying the user requirements while minimizing user cost and development time has justified the design of the different subsystems within this system. Our solution is described in Figure 1. In Figure 1 we describe the general process of how a request from the user terminal is carried through the Internet and to a machine running a host application and how that machine's response is carried back to the user. The various subsystems are introduced here. The user terminal is given two IP addresses. One IP address corresponds to the SLIP interface and would by typically be assigned by the SLIP service provider. The other IP address corresponds to the satellite interface and

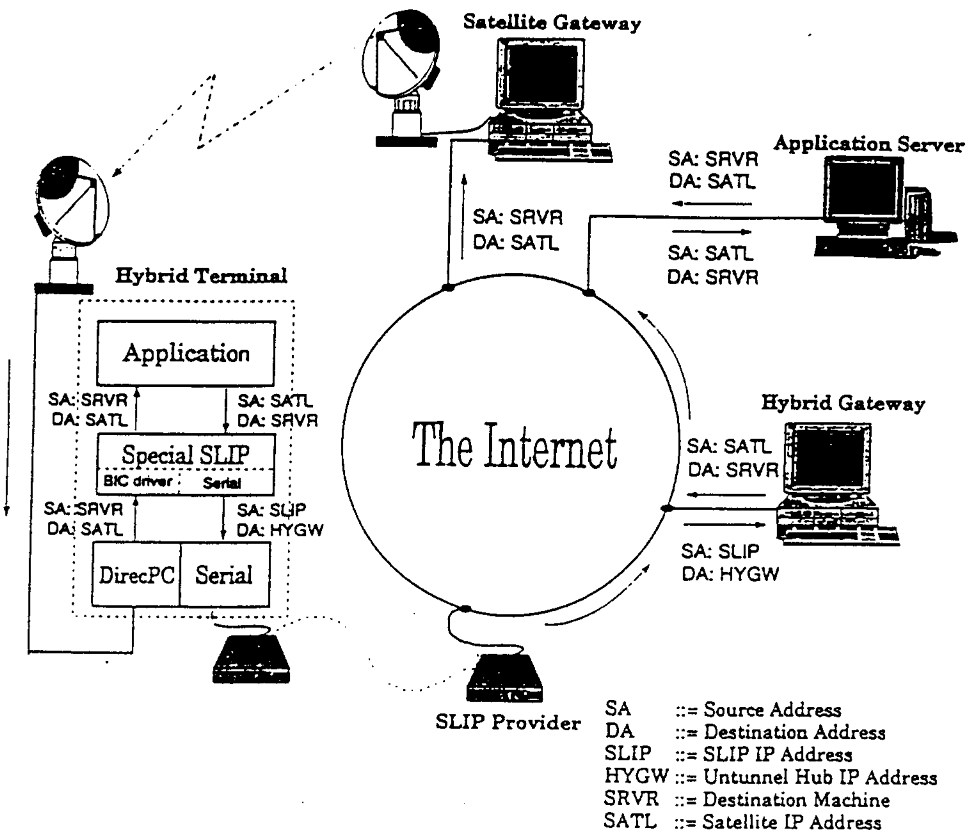

FIGURE 1. Path Traveled by a Tunneled Packet generated by the Hybrid Terminal.

would be assigned by the hybrid service provider. These IP addresses correspond to completely different networks. We note that the SLIP service does not need to know anything about the satellite IP address or even whether the user is using the hybrid service. If a host somewhere in the Internet is trying to deliver a packet to the satellite IP address by using the Internet routing scheme of routers, gateways, and ARPs, the *only* way that packet can reach the satellite IP interface is to traverse the satellite by being routed to the satellite gateway.

When requesting a data transfer, say using FTP, the user sends a request to a remote machine that is running FTP server software. This software receives file transfer requests and responds to them in the appropriate fashion. If a hybrid terminal user wanted to receive a file from a machine running FTP server (we'll call it the Application Server), every packet from the user terminal would take the following path:

1) Within the User Terminal, Hybrid Host, the FTP client software generates a request and passes it to the TCP/IP module. TCP/IP would place the request first in a TCP packet then in an IP packet which would then be passed to the Special SLIP driver software. This request would have a source IP address corresponding to the satellite interface and the destination IP address of the Application Server.

2) In the Special SLIP, the IP packet is encapsulated, or tunneled, inside of another IP packet and sent over the modem connection to the SLIP server host. The encapsulation amounts to adding a new IP header in front of the original one with a source address corresponding to the SLIP interface and a destination address corresponding to the machine we are calling Hybrid Gateway.

3) The SLIP server receives the IP packet, analyzes the tunneling header and, thinking it is destined for the Hybrid Gateway, uses standard Internet routing to send the packet to Hybrid Gateway.

4) When the Hybrid Gateway receives the packet it strips off the tunneling header, revealing the true header with the Application Server as the destination. The packet is then sent back out into the Internet.

5) Internet routing takes the packet to the Application Server which replies with the requested file and addresses the reply to the request's source IP address, i.e. the IP address of the User Terminal's satellite interface.

6) In order to find the user terminal's satellite interface, the Internet routing protocol will send the packet to the subnet containing a router/gateway connected to Hybrid Gateway. When that router/gateway sends out an ARP for any user terminals' satellite IP address the Hybrid Gateway responds and says "send it to me."

7) Once the Hybrid Gateway receives the reply packet, it encapsulates it in a special packet format that is used over the satellite link and uses the satellite IP address to uniquely identify the satellite packet's destination. Then the Hybrid Gateway sends the packet over ethernet to the Satellite Gateway.

8) The Satellite Gateway broadcasts over the satellite link any packets it receives from the Hybrid Gateway.

9) The driver in the Hybrid Host that services the DirecPC card scans all packets broadcast over the satellite looking for the satellite IP address in the header. Once it identifies one, it captures it, strips off the satellite header revealing the reply IP packet, and sends it to the Special SLIP driver.

10) The special SLIP driver calls the TCP/IP package notifying it that it has received an IP packet and passes up the reply, completing the transaction.

The User Terminal has required the most development. Device driver software has been developed that will appear to an off-the-shelf TCP/IP package that the computer is connected to an ethernet card when it is actually connected to a satellite dish and a modem. At the same time it must appear to the SLIP Server that the computer has a single IP address assigned by the SLIP provider, and force the Internet to route IP packet replies to a different IP address than the requests originated from. For this last task the Hybrid Gateway is needed also. In the hybrid configuration the interface between TCP/IP and the driver doesn't change. It can't if we are going to support the user requirement of being able to use an off-the-shelf package without modification. However, instead of communicating with a single physical network, the driver for the hybrid terminal, which we are calling Special SLIP, communicates with two physical networks as shown in the diagram of Figure 2.

One of the most innovative concepts incorporated in this design is the tunneling of IP packets to fool the Internet routing scheme. The reason for tunneling is this: the user terminal has two IP addresses associated with it—one for the SLIP interface which is assigned by the SLIP provider, a commercial service the developers have no control over, and the other corresponding to the satellite interface, assigned by HNS and essentially an extension of the uplink network. The way to get the Internet to route packets to the satellite interface when the request came from the SLIP interface is to set the source IP address in the request packet to be the satellite IP address. That way, when the Application Server forms its reply to the request, it addresses the reply to the source address, i.e. the satellite IP address.

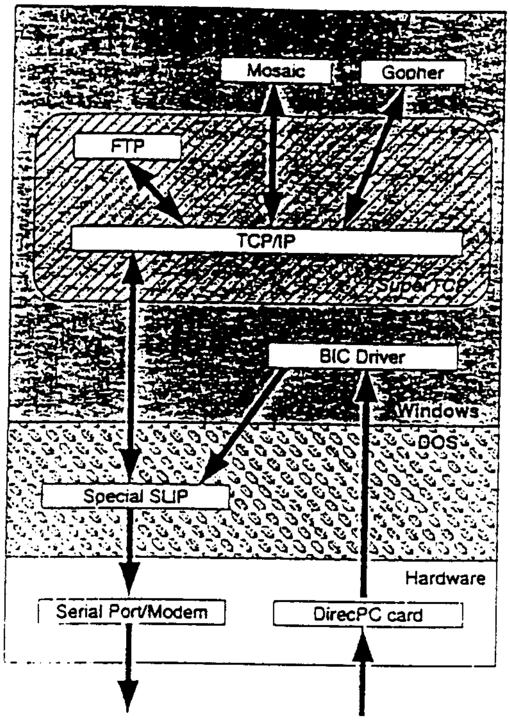

FIGURE 2. The data paths within the User Terminal take data in off the DirecPC card and send data out to the modem.

IP encapsulation or tunneling is used to bypass the address checking that may occur in the SLIP server. In tunneling, every IP packet passed to the Special SLIP driver by the TCP/IP package has the satellite IP as its source address and some Application Server as its destination address and is encapsulated in *another* IP packet which has SLIP IP as its source address and Hybrid Gateway as its destination address. The "encapsulation" really just amounts to adding a new header in front of the true one. The effect of the new header is to route every packet to the Hybrid Gateway. At the Hybrid Gateway, the tunneling header is removed and the packet is sent back out into the Internet to be rerouted to its proper destination.

Performance Improvements for the Hybrid Internet Access.

Current and future efforts are focused on systematic procedures to improve the performance of the hybrid Internet access developed to date. There are several items proposed which we will describe now. The system is capable in its current state of producing over 300kbps per terminal. With the modifications suggested, we hope that the 1Mbps barrier will be broken and true ethernet bandwidths will be available to the home user. This is sure to change the nature of computing for the general population. A growing number of Americans have computers in their homes and the utility and importance of the National Information Infrastructure will have a direct correlation to the average Americans ability to satisfactorily navigate the "net."

We have demonstrated that the hybrid network configuration can be used to access the Internet. We have also demonstrated that by using the hybrid configuration, the total throughput can be dramatically increased from approximately 14kbps to 300 kbps. The next step is to fine tune our design. The TCP/IP suite of protocols was designed primarily for symmetric data links. TCP/IP, when used in a hybrid configuration as in this project, could cause many side effects which would reduced the system performance. To optimize the system performance, an innovative idea called "TCP Spoofing" is introduced.

The Internet TCP transport protocol provides reliable connection. It ensures that the data arrives correctly and in sequence. TCP accomplishes this by sending an acknowledgment message to the sender for every segment of the data messages. The sender keeps limited number of unacknowledged data in buffers. The amount of which is limited by the window size. Maximum achievable throughput is window-size/RTT (Round-Trip-Time). Typically, the window-size of most TCP connections is merely 4K or 8K, where the maximum is 64K. Because the satellite has large bandwidth-delay product, maximizing the window-size for the Internet TCP connection would help increase the throughput at the receiver end further.

The delay in the satellite path (about 500ms) is another important factor that prevents the system from optimum performance. The sender on the Internet would send out a set of packets over the Internet backbone and wait for more than 500ms for the acknowledgment to come back before starting the transmission of the second set of data. To overcome this, acknowledgments could be sent from the hybrid gateway on behalf of the receivers. This way, the sender would keep on sending information to the hybrid gateway until all the buffers are filled up. The hybrid gateway would relay the data over the space link to the receiver at its own time. The ACKs from the receivers would be used by the hybrid gateway to empty out the buffers from data received by the receivers.

Packet losses also decrease the performance significantly; this is because the data in the space link on its way to the receiver cannot be used until the receiver receives the retransmission of the lost packet. Since the receiver machine has a limited number of buffers, most of the data in the space link will be discarded. Also, for TCP/IP, when a packet is lost, the receiver will reduce its advertised window size. Depending on the RTT, the time for the receiver's window size to reach maximum again could be significantly large.

Spoofing tries to minimize these effects, and optimize the performance. The idea is to put a large manageable buffer pool in the intermediate point between the terrestrial network and the satellite link. Because incoming and outgoing traffic for the hybrid terminals must go through the hybrid gateway, spoofing is done in the hybrid gateway. A software component called the TCP spoofer runs on top of the IP network layer at the hybrid gateway(HGW). The spoofer tries to fool the TCP protocol by intercepting packets sent from an internet host (IH) to a hybrid host (HH), and sending back fake acknowledgments to the IH before the data even reaches the HH. The spoofer also increases the default window size to 64KB. Clearly, to guarantee reliable communication the spoofer queues up the data in its buffers, freeing it up only upon receiving the actual acknowledgment from the HH. Since we keep a large amount of buffer space at the HGW which translates to a large window size the net result is that the maximum achievable throughput is much higher now. Development of the TCP spoofer has been completed and is currently under testing.

Another idea for optimizing the performance is to selectively drop unnecessary acknowledgments at the receiver's end. At the receiver's end, large amounts of data from the satellite link must be acknowledged. This process would generate many ACKs and fill up the small serial transmit buffer with ACKs very fast, causing congestion. One solution is to selectively drop ACKs. This can be done because of the cumulative nature of the TCP acknowledgment scheme. Older pure (no data) ACKs can be dropped and be substituted by a more recent one. This strategy will help reduce the outgoing traffic on the low bandwidth terrestrial modem link.

Acknowledgments

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