TECHNICAL RESEARCH REPORT

Review of the VSAT ACTS Experiments at the Center for Satellite & Hybrid Communication Networks

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CSHCN T.R. 96-4
(ISR T.R. 96-22)

REVIEW OF THE VSAT ACTS EXPERIMENTS AT THE CENTER FOR SATELLITE & HYBRID COMMUNICATION NETWORKS

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Abstract

This paper describes experiments conducted over ACTS and the associated T1 VSAT terminal. The experiments were motivated by the commercial potential of low-cost receive-only satellite terminals that can operate in a hybrid network environment, and by the desire to demonstrate frame relay technology over satellite networks. A custom unit termed Frame Relay Access Switch (FRACS) was developed by COMSAT Laboratories for these experiments; the preparation and conduct of these experiments involved a total of twenty people from the University of Maryland, the University of Colorado, and COMSAT Laboratories, from late 1992 through 1995.

INTRODUCTION

In many communication applications there is a need to transmit much information primarily in one direction between two points and much less information in the opposite direction. This is typically the case in file transfer and database services. While a two-way satellite channel may be used for such asymmetric applications, it is also possible to support them by means of a combination of a one-way satellite channel for the bulk information transfer and a parallel terrestrial channel for the low-bandwidth portion of the application traffic. In such a hybrid network–with parallel satellite and terrestrial channels–the satellite terminal need not have transmit capability, and thus it can be a much less expensive receive-only terminal. In addition to a cost savings, it is possible that improvement in network performance may also be achieved since the terrestrially-carried traffic does not suffer the high propagation delay incurred through satellite links.

These advantages of hybrid networks, coupled with the availability of low-cost, receive-only satellite terminals, suggest commercial potential for hybrid networks. To develop this potential, the CSHCN proposed in 1992 a series of experiments in hybrid interconnection of local area networks (LANs). The scope of the experiments was later expanded to include other facets of hybrid networking, and three experiments were ultimately devised. The first one examined dynamic allocation of satellite bandwidth in response to variations in the amount of traffic to be sent through the satellite. The second experiment investigated error-control schemes for use in both point-to-point and point-to-multipoint hybrid networks. Finally, the third experiment considered using a hybrid network architecture for remote multimedia database access and also compared the performance of some networking protocols in local area network interconnection.

EXPERIMENT 1: DYNAMIC BANDWIDTH ALLOCATION

The purpose of the first experiment was to find effective methods to rapidly adapt the link bandwidth to fluctuating traffic levels, both for data traffic and for mixed-media traffic such as packetized voice and data. This adjustment of bandwidth was accomplished using a feature of the ACTS system, the ability to establish circuits of different bandwidths, in multiples of 64 kbit/s channels. The rationale behind the experiment is to request, and use, the minimum necessary amount of bandwidth that will permit achievement of satisfactory performance levels, and release it when not needed. Since the performance criteria are several and antagonistic to each other, there is a need for fine-tuned trade-offs amongst them.

Data Traffic

In the data-traffic portion of the experiment, the data was generated according to a 3-state Markov-modulated Poisson process (MMPP) model (Fisher and Meier-Hellstern 1993). The MMPP source was chosen because it is better suited for modeling LAN traffic than a simple Poisson source since it has the ability to model the time variation of the traffic arrival rate. An MMPP is a Poisson process whose instantaneous rate varies according to a m-state Markov chain. For this experiment, m was chosen to be three.

Two bandwidth control algorithms were investigated: a rate-based algorithm implemented by the FRACS and a threshold-based algorithm executed by our software. Both algorithms were evaluated on the basis of per-packet average end-to-end delay, number of packets lost due to buffer overflows, and the average number of satellite channels used, where a channel represented a 64 kbit/s circuit. Depending on the relative importance of these parameters a suitable cost function can be devised that also includes the cost of the bandwidth used.

Rate-Based Algorithm

The FRACS's rate-based algorithm determined the amount of bandwidth required by measuring the arrival rate of the incoming traffic. This traffic rate was measured over 100 ms intervals and was compared with the allocated rate for the outgoing traffic. Whenever the rate of the incoming traffic exceeded the allocated bandwidth, more bandwidth was requested (in 64 kbit/s chunks). Slightly below the allocated bandwidth was a "release" bandwidth. When the rate of the incoming traffic dropped below the "release" rate, bandwidth was released.

Threshold -Based Algorithm

We also proposed and tested a sophisticated threshold-based algorithm to compare with the FRACS's crude rate-based algorithm. The threshold idea was motivated by theoretical analysis of the slow server problem, where for exponential servers an optimal policy was found to be of a threshold type (Lin and Kumar 1984, Walrand 1984, Rubinovitch 1985, Viniotis 1985). In this algorithm, the amount of bandwidth required was determined by measuring the amount of data queued for transmission. Whenever the queue size exceeded a specified fraction of the maximum buffer size, an additional 64 kbit/s channel was requested from the ACTS system. Slightly below each such "request" threshold was a "release" threshold, and a channel was released whenever the queue size fell below the release threshold. Tests were done to find the optimal difference between pairs of request and release thresholds, and also between pairs of thresholds. The "hysteresis" between up-crossing and down-crossing thresholds was motivated by the need to smoothen the effect of short-term traffic fluctuations.

Mixed-Media Traffic

In the mixed-media portion of the experiment, the traffic consisted of voice and data packets. The data packets were generated using an MMPP source as in the data-traffic portion of the experiment. The voice calls arrived according to a Poisson model, and the call durations were exponentially distributed and independent.

The bandwidth allocation algorithm for mixed-media traffic used two-dimensional "threshold" structures, known as switch functions. The state of the system, i.e. the number of voice calls in progress and the number of data packets in the transmit-buffer, can be represented by a point in the abstract decision space of data buffer occupancy and amount of bandwidth used for voice calls. Thus, a state (i, j) indicates that there are i voice calls in progress and j packets of data traffic in the queue. The object is to decide what to do when a new voice-call request arrives. The options are to reject it, admit it, or admit it at a "compressed", reduced-bandwidth (and reduced-quality) level. As the acceptance of a new voice call may result in reducing the available bandwidth for data-service excessively, a decision must also be made whether to request more bandwidth. The purpose of the algorithm is to minimize the cost function $E(D) + \alpha P_B$ where $E(D)$ is the average delay for data packets, P_B is the voice-call blocking probability, and α is a coefficient that reflects the desired relative weighting of the two cost criteria. Under a number of conditions, the optimal call admission policies have been shown to take the form of a set of switching curves in this abstract space (Viniotis and Ephremides 1988). The switch functions consist of different threshold values in both dimensions, of i (the data queue size) and of j (the number of on-going calls). To the left and below a switch-curve, an arriving call is accepted, while to the right and above that curve that call is rejected. In addition, based on the same philosophy we introduce additional switch function curves that govern additional bandwidth request and release. A separate threshold on the voice-call blocking rate is also enforced at all times. If blocking a call leads to a higher than acceptable blocking rate, additional bandwidth is requested and the call is accepted no matter where the instantaneous state lied in the decision space.

This algorithm was evaluated on the basis of per-packet average end-to-end delay, number of packets lost due to buffer overflows, average number of satellite channels used, voice call blocking frequency, and the voice call quality (degree of compression). Depending on the relative importance of these parameters, a suitable cost function can be devised that must include the cost of the bandwidth used. For example, the user may wish to assign more weight to voice call blocking probability and to end-to-end packet delays than to voice quality and average number of satellite channels used, and so on.

EXPERIMENT 2: ERROR CONTROL SCHEMES FOR SATELLITE AND HYBRID NETWORKS

Our experiments were motivated by the commercial potential of hybrid networks. Information transferred using a hybrid network must be protected against errors just as in a satellite network. However, the availability in a hybrid network of a terrestrial link with less propagation delay than the satellite channel presents additional problems as well as possibilities for error control, particularly in the case of automatic-repeat-request (ARQ) schemes. The second experiment explored such possibilities. Furthermore, a satellite is an excellent means for point-to-multipoint communication. Hence this experiment also investigated ARQ error control schemes for multicast communication in hybrid networks.

This experiment was additionally motivated by the possibility of improving throughput by sending ARQ acknowledgments terrestrially instead of by satellite, thus avoiding the satellite propagation delay for the acknowledgments. Throughput might be increased yet more by retransmitting packets (as may be necessary) terrestrially instead of by satellite. Calculations showed that judiciously using the hybrid configuration could indeed increase the throughput in some cases, sometimes significantly.

Data was sent from one station to another via satellite. Before transmission, an error control protocol was applied by the transmitter to protect the data as it traveled through the satellite channel. Since the ACTS channel, when used with a T1 VSAT, typically exhibits a bit error rate of 10^{-7} or less, it was necessary to inject artificially-produced noise in order to study error control schemes. An independent, identically-distributed model of bit inversion was used for the artificial noise. After corruption by artificial noise, the receiver applied the error control protocol to correct any errors which may have developed in the data. The data was then stored for later comparison with the original data to determine a residual bit error rate.

Both forward error correction (FEC) and ARQ error control schemes were investigated. For all the error control methods tested, a continuous source of traffic was used. The FRACS was used as an interface between workstations and VSATs. The Internet and a 14.4 kbit/s telephone modem connection were each employed as the terrestrial link for hybrid operation. The parameters of interest were throughput, end-to-end delay, and the residual error rate of the data received. Not only were the results from FEC testing compared with each other, as were the point-to-point ARQ results, but the results of these two parts were compared as well.

Forward Error Correction

The forward error correction (FEC) codes selected were the BCH (15, 7) and the Golay (23, 12) code since they are simple to implement and have rates of about one-half, as it had originally been hoped to compare the performance of these with the rate one-half code used by ACTS to combat rain fading. (It was later determined we could not test ACTS's coding since we cannot control the errors produced in the channel, nor even detect the occurrence of these errors, since the coding itself corrects them.) A third code, the BCH (15, 11) code, was later added to provide a broader set of FEC choices. For comparison purposes, plain uncoded text was sent as well. (The Reed-Solomon (127, 123) and (127, 121) codes constructed over $GF(2^7)$ had originally also been included to protect against expected burst errors, but were abandoned when the actual non-bursty error behavior of the ACTS channel was learned from another experimenter.)

As the encoder and decoder software developed for this work would not support real-time operation for the desired ACTS channel bit rate (128 kbit/s), encoding and decoding were conducted offline. The encoded data were sent from via satellite, corrupted with i.i.d. noise and stored. Later, the data were decoded and the resulting information was compared bit-by-bit to the original data.

Automatic-Repeat-Request

Both go-back-N and selective-repeat ARQ protocols were tested in satellite-only and hybrid configurations. The go-back-N and selective-repeat protocols tested followed the logic of the REJ protocol and SREJ protocol with multiselective reject option, respectively (ISO Standard 4335 and ISO Proposed Draft Standard 7776). The parameters of the protocols were modified for our satellite experimentation, and some parts not integral to error control, such as call setup and termination, were not included in the software implementation since they were accomplished by other means.

In the go-back-N scheme, the transmitter sent packets continuously to the receiver, which returned an acknowledgment for each valid packet received. If a packet required retransmission, the receiver discarded all subsequently-received packets until the required packet was received. In the selective-repeat scheme, the receiver could, to a limited extent, accept packets out of order, and so could specify to the transmitter a list of packets still required.

The system used for ARQ operated as follows. A set of data packets were produced continuously and sent over the satellite. Each packet comprised 126 bytes of data, a 2-byte sequence number, and a 2-byte cyclic redundancy check (CRC-CCITT). Upon receipt, they were corrupted with artificial noise. After checking for errors, the receiver would generate an acknowledgment according to the ARQ protocol and send this reply to the transmitter. Testing was conducted with the acknowledgments carried over ACTS or terrestrially via either Internet or via the public switched telephone network. For cases in which acknowledgments were carried terrestrially, retransmitted packets were sent either over satellite or over the same terrestrial link (in the opposite direction). Retransmitted packets were always carried via satellite if the acknowledgments were so carried.

The throughput, total transmission time, and residual error rate were the primary parameters of interest in ARQ experimentation. The number of packets sent, received, and received in error on each link were also recorded.

EXPERIMENT 3: REMOTE DATABASE ACCESS AND INTERNETWORKING PROTOCOL COMPARISON

In the third experiment, the hybrid network mechanism of data access was demonstrated and evaluated against the use of solely satellite connection or solely Internet connection. Two internetworking protocols were applied in the satellite link, namely CCITT's standard X.25 protocol and the frame relay protocol. The logic and the performance of these protocols were studied and compared. We focused on the data link layer functionalities since this is where the key differences of those two protocols reside. In addition, we studied the commonly used transport layer protocol, TCP, over the satellite link; in the process, a problem of using TCP was identified, and a solution was provided, which was to use an extended version of TCP (Jacobson and Dorman 1992). Finally, and most importantly, two emulated LANs were interconnected by the satellite link, and a comparison of the performance of X.25 and frame relay used for their interconnection is being carried out as the culmination of the objectives of this experiment.

This portion of the experiment has not yet been completed.

CONCLUSION

As of this writing, it is clear that the experiments have not yet been completed, largely due to uncontrollable factors. The ACTS VSAT suffered several problems, including incorrect installation, cable breakage, two complete failures of its transmit power amplifier and partial failures of its control computer. The weather in Colorado prevented experimentation several times by disrupting the optical link. Conducting experiments with equipment 1500 miles away has presented its own challenges, including operating computers through the unpredictable Internet. Despite these difficulties, work continues in earnest. We expect to follow up and present the complete and detailed results of these experiments at several upcoming forums in the near future.

Acknowledgements

This work would not have been possible without the kind and helpful support, including the loan of the T1 VSAT, of ACTS program personnel at the NASA Lewis Research Center. Further, the authors were only part of a larger team which designed, implemented and conducted the experiments. This team included: Dr. Apostolos Traganitis of the University of Crete, Greece; Timothy Kirkwood of the CSHCN; Yannis Konstantopoulos of MCI; Dr. Anil Agarwal, Moorthy Hariharan and Anita Fitzwater of COMSAT Laboratories; Dr. Stanley Bush, Fan Huang, Gil Weiss, Neill Cameron, Wenjin Yang and David Bailey of the University of Colorado at Boulder; Marjorie Weibul of NTIA; and Ruplu Bhattacharya, Samardh Kumar and Anastassios Michail of the University of Maryland.

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