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ABSTRACT

In September 1993, NASA launched its long-awaited Advanced Communication Technology (ACTS) satellite. ACTS is a $500 million experimental all-digital spacecraft hosting a number of first-time technologies: on-board processing and switching, high-powered electronically hopping spot beams, adaptive rain-fade compensation and opening of the Ka frequency band. Among the earliest of the tests on the new satellite was a NASA sponsored project conducted by Ohio University and its commercial partner, The Huntington National Bank. HNB is a $17 billion regional bank with 338 offices in fourteen states. Transactions on HNB's data networks currently travel on terrestrial T-1 lines. The Ohio University/HNB tests were initiated to determine the capability of the satellite for service restoral in the case of a failure in one of the Bank's terrestrial links. The ACTS Disaster Recovery Project was designed to test the Bank's ability to by-pass such problems on the ground by switching to a space path. The goal was to make the switch-over with the briefest interruption of service, with minimal loss of transmitted data, within acceptable cost and with sustained security.

INTRODUCTION

The tests conducted by Ohio University in conjunction with the Ohio-based Huntington National Bank were welcomed by NASA. The project represented a research collaboration between a respected university, with experience in design of experiments in data systems management, and a regional bank which currently uses terrestrial T1 networks to move its financial data around.

The problem is one of practical importance. In the banking business, as in other time-sensitive information businesses, when a vital communications link goes down without a way to bypass the problem, such companies can go out of business in a matter of days.

While The Huntington Bank holds contracts with professional disaster recovery vendors, and maintains extensive terrestrial backup facilities, it was open to looking at the space-path as a future alternative.

The Project was specifically designed to help the Bank anticipate and prepare for the event of a natural or other disaster, such as a fire in a telephone switching center, an act of sabotage **--** any event that would interrupt the Bank's financial data flow. The experiment was to test the capability of ACTS to recover the Bank's lost communications path. The question to be answered was the extent to which the Bank data could be quickly and effectively rerouted, using space to bypass transmission problems on the ground, in an acceptable time-frame, with a minimum of lost data and at an acceptable cost.

In the remainder of this paper, we briefly discuss the history of NASA's communication satellites, and the ACTS system in particular. We also outline the available terrestrial options for providing backup and redundancy. We then describe the experimental procedures used and the results obtained during the project.

DATA COMMUNICATIONS VIA SATELLITE

SYNCOM II, launched by NASA in 1963, was the first successful synchronous orbit satellite. This satellite opened a whole new era of communications using space. Exactly 30 years and two months later, with both the C- and Ku- frequency bands becoming crowded, NASA launched its experimental Advanced Communications Technology satellite. According to NASA, ACTS is a 21st-century space technology prototype that will permit the satellite industry to rise above this frequency saturation and meet the growing need for wider, more flexible bandwidth by moving into the virtually untapped Ka-band (30/20 GHZ).

In making ACTS available as a testbed, NASA is hoping to demonstrate the means to make more efficient use of orbit and spectrum resources, and to work with the private and public sectors (corporations, universities and government agencies) in developing new forms of communication and data transfer. Immodestly, NASA says it has designed a satellite that is compatible with projected U.S. communications requirements of the next thirty years, and ensures U.S. preeminence in global satellite communications technologies and services. [4]

The specific technologies being tested by the ACTS project include onboard digital processing, storage and switching using multiple, hopping spot beams that can be redirected at will. These space segment technologies permit the use of very small and ultra small aperture (VSAT/USAT) ground terminals, as well as the high-data-rate terminals providing bandwidth needed for supercomputing and interactive multimedia. Among these advanced capabilities are wide geographical area coverage, demand-assigned multiple access, full mesh interconnectivity, and service flexibility by integrating data, voice, and video operations at variable throughput rates. The key technologies incorporated into ACTS are[1] :

Multiple Beam Antennas:
• to produce high-powered spot beams enabling communication with small, low-cost ground terminals;
• to permit reuse of the frequency spectrum;
• to average out geographically non-uniform traffic demands by adaptive beam hopping and adapting dwell time to traffic demand requests;

Onboard Processing:
• to improve link performance by demodulation and remodulation onboard the spacecraft;

Onboard Switching:
• to switch individual telephone circuits on the spacecraft. This capability, provided by the ACTS baseband processor (a digital cross-connect system operating on 64kbps channels) enables the satellite to communicate efficiently with thousands of terminals located directly on customers' premises;

Ka-band Technology:
• to open up a new portion of the RF spectrum for United States communications satellite use.

TERRESTRIAL DATA COMMUNICATIONS

Many of today's data networks are built around the T1 facilities offered by all major carriers. The T1 is a synchronous, bit-oriented, transmission facility operating at 1.544Mbps (Million bits per second). Each T1 facility in the US typically consists of two "access" circuits and one "inter-office" channel. The access circuit is provided by a local exchange carrier; it connects the user premise to the switching office of the long-distance (inter-LATA) carriers, for example AT&T, MCI, Sprint, or others. The interoffice channel carries the circuit from the originating to the terminating long-distance carrier switch.

To protect against even a short outage of one of the T1 facilities, redundant circuits are used. The most common solution is one in which the company insures that there are at least two paths between any two points in the network, <u>and</u> that no circuit is more than 50% occupied (so that it can carry the traffic of another path during a failure). In the worst case, this approach doubles the cost of the network. Another approach is the use of on-demand ("switched") services, i.e. circuits which are activated and paid for only when needed.

Terrestrial on-demand T1 service has been available for years. AT&T offers ACCUNET™ Reserve T1 (used by The Huntington National Bank). Sprint's service is called SDS (Switched Data Service), and MCI provides VPDS (Virtual Private Data Services). All of these terrestrial services have a similar structure.

Users must subscribe to an access circuit as described above.. Access circuits must be paid for on a monthly basis, even if they are idle much of the time. Traditionally, to activate the AT&T ACCUNET Reserve circuit, users must call a service entry operator who records the requests and performs the circuit setup. A typical circuit setup time has been in the 30 minute range. Newer services from all major carriers allow users to access the IXC network with a dial-up terminal entering the request electronically. Some of these services can activate the circuit within a few seconds.

It should be noted that the access circuits used for both regular and on-demand T1 are often supplied by the same carrier, unless special provisions are made (often at additional cost). Unless care is taken to "diversify" the access circuits, all paths, including the on-demand one, could fail simultaneously. An on-demand satellite link with on-premise VSAT earth terminals does not use terrestrial access circuits, and may therefore present an attractive alternative to redundant terrestrial facilities.

DISASTER RECOVERY TESTS

In order to achieve all objectives stated earlier, without causing potential disruptions of the bank's production network, tests were divided into three phases[3] :

Phase I: Off-Network Testing: ACTS earth stations were positioned at Ohio University in Athens and at Huntington's Data Center in Columbus. Multiplexers were configured in point-to-point mode and satellite connections were established between the two sites. The Columbus site transmitted test data, while measurements and analyses were performed in Athens.

Phase II: On-Network Checkout: The Athens-based VSAT earth station was dismantled and transported to Huntington's Regional Processing Center in Parma, Ohio, near Cleveland. During this phase of the experiment, the ACTS satellite was brought on-line into the financial network. Circuit quality and effective throughput measurements at both the T-1 level and the imbedded protocol level were made, still using test data. Phase I and Phase II tests were designed to demonstrate interoperability of the ACTS system with data communication protocols, front-end processors and monitoring equipment.

An additional test of the ACTS system was performed during a scheduled disaster recovery trial. During the trial, a failure of the Bank's primary data center was simulated; all data communications were re-directed to a backup data center. Since the network did not serve normal user applications during this test, it was possible to simulate a partial network failure which forced the T1 communications equipment to automatically switch a number of data circuits to the satellite link. This was the exact scenario to be verified in this trial.

Phase III: Production Tests: The ACTS connection was established as an operational circuit in the production network, monitored by the HNB network control center 24 hours a day under varying weather conditions. During this time, selected circuits in the production network were re-routed to the satellite link. The designated circuits primarily supported Bank branch terminals. These interactive applications (such as account information retrieval by tellers) require good response time performance and are therefore good test cases. In addition, some Automatic Teller Machine traffic was routed over the satellite.

The 26-week test was designed to determine suitability of ACTS for disaster recovery from both technical and operational points of view. Results show some noteworthy differences.

TECHNICAL RESULTS

The first and simpler task was to establish that the ACTS system did indeed provide a T1 circuit that is fully compatible with the terrestrial network and with off-the-shelf T1 connectivity products, such as CSUs and multiplexers. In the Ohio tests, no fundamental incompatibilities were found, and there was no need to make any satellite-specific adjustments in the multiplexers. In this context, the following observations can be made:

1. The ACTS system is designed to deliver a bit error rate performance of $1x10^{-7}$ or better, which means that on average an error will occur less than once in every 10 million bits sent. By comparison, the worst case bit error rate permitted in the terrestrial network is $1x10^{-6}$, or one in one million errors. Without invoking its special built-in "compensation" mechanisms, ACTS performed well beyond the desired specifications during periods of clear weather.

Cloud cover and fog had little effect on the system performance. Error rates remained within acceptable limits during periods of light rain, or light to moderate snow. We found that moderate to heavy rain or snow degraded the signal to the point where we were required to invoke the rain fade compensation mechanisms built into the ACTS system.

2. The on-board processor in the ACTS spacecraft includes a "rain fade compensation" mode. When this mode is invoked, both the spacecraft and the T1 VSAT earth station take steps to not only locate but also "repair" errors that occur during the transmission. This error correction capability is "paid for" by quadrupling the bandwidth required to send the T1 data stream. This sudden high-bandwidth demand could cause problems with ACTS satellite services as a result of more limited digital throughput.

The rain fade compensation worked very well, allowing error-free operations in cases where the non-compensated error performance was as poor as 1 error in 1000 bits sent. We did observe a limit to the compensation algorithm; during a severe weather event with ground-level thunderstorms and ice formation at higher altitude, the connection between the earth station and the satellite was lost completely for a period of 45 minutes.

3. The performance of typical data communication sessions between IBM mainframes and IBM user terminals, over the satellite link, was also studied. The methods used for data communications (called "protocols") in primarily terrestrial networks do not normally make allowances for the larger transmission delays inherent in satellite communications. Any satellite delay will normally be added to the time a user must wait for the answer to a query entered at the terminal (the "response time"). With existing protocols, the effect of the delay is multiplied. While a detailed analysis of the measurements is still underway, it can be concluded that the minimum increase in response time (on a very lightly used circuit) will be about 1.1 sec. [2]

4. A slow "jitter" is characteristic of the data transmissions of satellite-based T1 systems, due to a gradual change in the phase of the T1 signal as the satellite moves relative to the surface of the earth. For that reason, multiplexers contain "satellite buffers" to absorb this jitter. The Ohio researchers found that these buffers are not required with the ACTS system. This result is not surprising since the T1 signal in the ACTS system is regenerated at each earth station as well as the satellite. Buffers built into the earth stations protect against the slow slippage caused by the fact that the earth stations and the satellite may be using different "clocks," or timing sources, for the T1 signal.

The buffers were fully capable of absorbing the satellite jitter and normal clock slippage. As is often the case when connecting T1 circuits from multiple vendors, the researchers did come across situations where the clocking, or frequency, of the T1 signals in the overall network varied substantially. While the buffers in the earth stations did provide protection against these clock differences, some problems were encountered.

When a clocking buffer becomes unable to compensate for the frequency variations, it must "reset" by dropping some of the bits stored in the buffer. The "reset" operation in the ACTS earth stations, produced such a severe error event that the attached multiplexers judged the satellite circuit to be out-of-service. In many cases it took the multiplexers 20 minutes or more to "qualify" the circuit as again being operational.

RELIABILITY

The second goal of the Ohio tests was to determine whether the ACTS system could be integrated into a terrestrial-based operations environment as a disaster recovery option. In this regard, the researchers were able to gain some insight into the issue of reliability of service. They also were able to draw some conclusions regarding the way in which the ACTS system will need to be managed within the overall network environment of the user company.

Clearly, the reliability and availability of on-demand circuits used for disaster recovery must be high. During a network or data center failure, it is crucial that the stand-by circuits used for backup be activated quickly and predictably. Even very mature terrestrial on-demand services like AT&T's ACCUNET™ RESERVE T1 are continually modified and upgraded to meet customer demands for reliability.

The ACTS system is not designed as a production environment, therefore it does not permit direct measurement of operational reliability and availability performance. However, a qualitative analysis of system failure points is possible. The disaster recovery trial pointed to a number of issues which must be addressed in future production systems.

<u>Earth Station Signal Interfaces</u>: Due to the satellite's on-board processing capability, the earth stations require more "intelligence" than

comparable commercial VSAT installations. ACTS accomplishes this with the combination of a general purpose microcomputer and several special purpose digital signal processors. The failure rates of these components was higher than expected; the general purpose computer failed twice during the six months trial. This points to a need to design a more rugged implementation of these functions, as well as a need for extensive, automatic internal diagnostics and failure alarms.

Earth Station RF Equipment: The ACTS system is one of the first to utilize the Ka (20-30 GHz) band. The RF components in the ACTS VSAT earth stations are a mixture of proven Ku (12-17 GHz) band components and those newly designed for the Ka band. In order to provide the signal margins required for the data rates used by ACTS (27.5 Mbps to 110 Mbps bursts), all components are operated very close to their design limits. The resulting failure rates of the RF equipment were high. Future implementation should either raise the design specifications for the most critical parts (operating a little further away from the design limits), or provide redundant components to improve system availability.

In addition, the RF cabling design proved to be less than ideal for a VSAT application. The RF signals are carried from the transmit/receive dish to the processing equipment over semi-rigid heliax cabling. During the trial, cable failures occurred during normal operation and maintenance procedures. Since one attraction of a VSAT system is mobility, the cabling needs to be changed to a less vulnerable type.

Rain Fade: It is possible for extreme weather conditions to make transmissions to and from the VSAT earth station impossible. Even less extreme weather conditions can prevent the initial startup (or “acquisition”) of a VSAT station. Thus, it appears that the initial data exchange between the Master Control Station (at the NASA Lewis Research Center in Cleveland, Ohio) and the VSAT terminal is more easily disrupted than communications after a successful startup.

Severe weather has even been observed to “shut down” transmissions between the satellite and the much larger fixed dish at the ACTS Master Control facility. Weather events with this severity tend to last only a short time, and may pose an acceptable risk. This inherent limit on system availability needs to be taken into account during the design of any disaster recovery plan.

Master Control Station: While all user data travels directly from VSAT to VSAT in the ACTS system, command and control information is continually exchanged between every VSAT and the ACTS Master Control Station. If a VSAT loses its link to the MCS, it shuts itself down to prevent interference with other stations. This makes the MCS a single point of failure. A minimum of two geographically diverse master stations will be required in an implementation of high-reliability production systems.

OPERATIONAL RESULTS

From an operational perspective, the Ohio team found the ACTS system to be very similar to terrestrial on-demand T1 services. Network management techniques developed for such T1 circuits (which are not operational for the majority of the time) will work for the ACTS system. In general, the ACTS T1 circuit has a much shorter start-up time than typical terrestrial on-demand services. In fact, with a proper software interface, the initiation of the ACTS T1 circuit could be fully automated under the control of a T1 network management system.

The ACTS system assigns capacity on an on-demand basis. It is therefore possible for a bandwidth request from a user to be “blocked,” that is, the request will fail due to a lack of available capacity. This is exactly the same behavior exhibited by the terrestrial on-demand T1 networks. However, due to the smaller satellite capacity (compared to the terrestrial networks), the effect will be more noticeable and will require close management by the service provider.

CONCLUSIONS

The Disaster Recovery Project was completed in June 1994. The data produced from these tests are of interest not only to data managers but to those with interest in emerging satellite technologies.

With the exception of a few human interface problems, the new satellite appears to be performing to expectation. Although the ACTS system was not designed as a production environment, it is clear that network management techniques developed for on-demand T1 services work as well on the space path. Interoperability of the ACTS system with data communication protocols, front-end processors and monitoring equipment was demonstrated in these tests. While a few problem isolation techniques had to be adapted to the specific earth station design, the ACTS system performs much more like a terrestrial system than the currently available commercial satellite services.

It is noteworthy that the ACTS T1 circuit has a shorter start-up time than typical terrestrial on-demand services. The authors conclude that, with a proper software interface, the initiation of the ACTS T1 circuit can be fully automated under control of a T1 network management system. This is good news for disaster recovery managers.

The issue of rain fading had been raised from the beginning of the ACTS project. While rain fade is a minor problem in the C band, and a manageable one at Ku band frequencies, the Ka band is thought to be severely affected by this degradation of signal strength. These concerns are well founded. The ACTS design, however, does provide a good initial set of tools to attempt to manage this problem. The next generation of Ka band systems can build upon this technology to further improve their performance under rain fade conditions.

A FINAL NOTE

Although not an essential or necessary part of the experiment, the opportunity arose to conduct videoconferencing tests via ACTS connecting the Columbus and Cleveland data centers. A 384 Kbps circuit was set up using one quarter of the T1 circuit established over ACTS. Two video codecs from ABL of Mentor, Ohio, were connected over this circuit. The connection was established without difficulty. The quality of the audio and video was comparable to that of terrestrial connections. As expected, the satellite signal delay roughly doubles the compression delay present in every video codec designed for speeds at T1 or below.

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