Communications Research Centre

CRC, DOT AND THE INTERNATIONAL AERONAUTICAL-MOBILE SATELLITE SERVICE

by

M.Moher
(Directorate of Satellite Communications)

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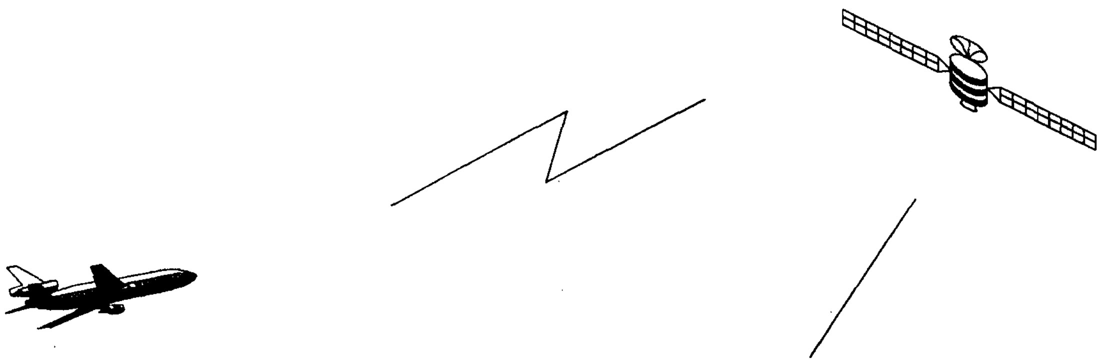

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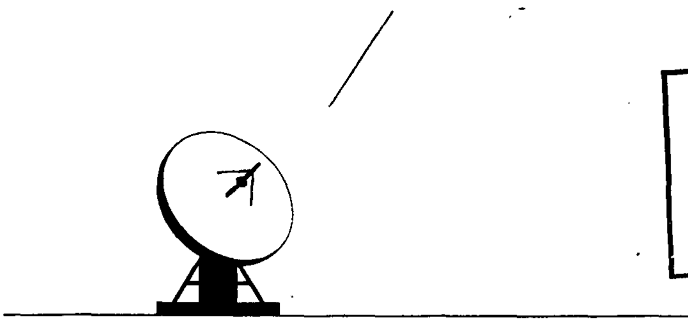

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ABSTRACT

The activities of the Communications Research Centre (CRC) and the Canadian Department of Transport (DOT) in the international aeronautical-mobile satellite service (AMSS) are summarized. It begins with a history of the major activities in the international standards process starting with ICAO Committee on Future Air Navigation Systems (FANS) in 1984, and continuing through the Airline Electronic Engineering Committee (AEEC) activities, the ICAO Aeronautical-Mobile Satellite Service Panel (AMSSP), to the ICAO Aeronautical Mobile Communications Panel (AMCP) in 1992. A parallel history of development of aeronautical satcom technology by CRC and DOT is then described, starting with the A-BPSK P-channel modem development in 1987, through industrial development and technology transfer, to its first commercial showing in an aeronautical satcom terminal in September 1992. The summary concludes with a description of the AMSS physical and link layers, and the technology developed at CRC to implement these layers.

RÉSUMÉ

Les activités du Centre de recherche sur les communications (CRC) et du Ministère des transports (MDT) reliées au service mobile aéronautique par satellite (AMSS) sont résumées. Un historique des principales activités rattachées au développement de normes internationales débute l'article. Tout d'abord, en 1984, les activités débutèrent avec le Comité spécial des futurs systèmes de navigation aérienne (FANS) de l'OACI, pour ensuite se poursuivent avec le Airline Electronic Engineering Committee (AEEC), puis le Groupe d'experts du service mobile aéronautique par satellite de l'OACI et finalement le Groupe d'experts des communications mobiles aéronautiques de l'OACI en 1992. Un historique parallèle sur le développement de technologie pour les communications par satellite entrepris au CRC et au MDT suit. En 1987, le développement de la modulation A-BPSK pour le canal-P, suivi d'un transfert de technologie à l'industrie mena à la première démonstration d'un terminal aéronautique en Septembre 1992. Le résumé conclut avec une description des couches physique et liaison de l'AMSS, et de la technologie développée au CRC pour réaliser ces couches.

1.0 HISTORY OF INTERNATIONAL ACTIVITIES

The idea of using satellite communications to improve the coverage and reliability of aeronautical communications and navigation is not new. Satellite communications for civil aviation was first demonstrated in the late 1960s. Initial CRC-DOT involvement began with the Aerosat program from 1972-1976. This was a joint Canada/U.S./Europe experimental project which overcame many of the technical hurdles, and successful flight trials were performed using an experimental satellite provided by NASA. Under this program CRC was funded by DOT to provide technical support and perform specific research and development tasks.

The Aerosat program was terminated in 1976, and there was little activity in the area of aeronautical satcom until the mid-1980s. In 1984, the International Civil Aviation Organization (ICAO) formed the committee for Future Air Navigation Systems (FANS) whose mandate was to determine the communications, navigation and surveillance requirements for civil aviation for the next twenty-five years, and to propose methods of meeting these requirements. At the same time, in the forum of the U.S.-based Airlines Electronic Engineering Committee (AEEC), interest in satellite communications for both safety and public correspondence motivated a series of meetings and the formation of a subcommittee to develop a standard for aeronautical satcom. The third major body in this development was Inmarsat whose vast experience with international maritime satellite communications led to a widening of its mandate in 1985 to include aeronautical communications.

One of the immediate (and possibly foregone) conclusions of each of these three bodies was that satellite communications would play a significant role in future aeronautical communications. There just remained the question of what form it would take. This is where CRC-DOT cooperation was rekindled. The first major question to be addressed was the multiple access technology. There were three proposals regarding this aspect: frequency division multiple access (FDMA), time division multiple access (TDMA), and code division multiple access (CDMA). An analysis and comparison of the different approaches performed by Miller Communications [1],[2],[3], directed and presented by J.Rigley (DOT) at FANS meetings in 1986/87, was instrumental in the selection of FDMA as the access strategy and the associated communications structure.

In parallel with this debate over access technology, there was considerable discussion over the modulation strategy to use with the aeronautical satcom system. A tutorial paper by J.Lodge (CRC) [4], presented to the FANS committee clarified much of the confusion associated with modulation strategies. This paper also recommended a new modulation strategy for the low bit rate service, A-BPSK, drawing on previous studies for MSAT land-mobile applications [5],[6]; and supported the Inmarsat proposal of offset QPSK for the higher data rates. This paper was later presented to the AEEC, with some supporting simulation results performed by Miller Communications [7],[8], (funded by DOT). This eventually led to the adoption of both modulation strategies recommended in [4] by all bodies concerned. It was also in the paper [4], that a novel validation technique for testing satcom terminal equipment was first proposed. This technique was investigated further by Miller Communications [9] with the support of DOT.

In the report of the FANS Committee[10], published in 1988, it was concluded that exploitation of satellite technology is the only viable solution to overcoming the shortcomings of present communications, navigation and surveillance systems, and to meeting future requirements on a global basis. This prompted ICAO to immediately form a panel of experts, the Aeronautical Mobile Satellite Services (AMSS) Panel, with the mandate of developing a Standards and Recommended Practices (SARPs) for safety-related satellite communications and answering related questions. At the first Panel meeting in November 1988, J.Rigley (DOT) was chosen as rapporteur for the working group on SARPs issues. By the second AMSS Panel meeting in April 1989, a first draft of the SARPs had been prepared through contributions from P.Platt (U.K.), M.Moher (CRC), and Inmarsat, drawing heavily on previous standards work performed by Inmarsat. The format of the SARPs paralleled the OSI model for communications with Sections 1 to 4 being the physical layer, Sections 5 and 6 being the link layer, and Section 7 being the network layer. The remaining three sections, 8, 9 and 10, covered voice communications, aircraft and ground station management. At this second panel meeting, it was recognized that Sections 1 to 4 were in a form close to being acceptable as SARPs material. However, the remaining sections covered areas which were novel to ICAO and, consequently, there was considerable discussion about what form it should take. A significant portion of the discussion was due to the compatibility requirement with the Aeronautical Telecommunications Network (ATN) concept which was being developed concurrently by another ICAO panel.

This discussion continued through a working group in Williamsburg, Virginia where the U.S. agreed to take responsibility for editorship of sections 5 through 10, and through the third AMSS Panel meeting in February, 1990. At this latter panel meeting, CRC presented a simulation of the data link protocol to the participants of the AMSS Panel and to the Air Navigation Commission of ICAO. It was not until a working group meeting in Paris in the summer of 1990, following the third Panel meeting, that a form for sections 5 through 10 was agreed upon. At this point, technical editorship of Sections 1 through 4, 5 through 7, and 8 through 10, were assigned to M.Moher (CRC), P.Platt (U.K.), and D.Cox (U.S), respectively. From the time of the Paris working group meeting[1] until the meeting at Falmouth, Massachusetts in July 1992, there was a slow but steady refinement of the SARPs, addressing the technical issues as they arose. Even Sections 1 through 4, which were considered quite mature as early as February 1989, have had many minor changes. The latter were mainly due to the continual evolution of the technology associated with the physical layer. As of the Falmouth meeting, the SARPs working group agreed that the SARPs were mature and the validation work should begin in earnest.

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[1] In mid-1991, the mandate of the AMSS Panel was expanded to include the development of VHF radio services and associated SARPs, and its name was changed to the Aeronautical Mobile Communications (AMC) Panel which held its first meeting in November 1991.

2.0 HISTORY OF CRC/DOT TECHNOLOGY DEVELOPMENT

The development of aeronautical satcom technology at CRC[2] in the post-Aerosat era began in 1987 in parallel with the participation of CRC and DOT in the FANS, AEEC, and AMSSP meetings. The project, initiated by J.Lodge and D.Boudreau (CRC), with the financial support of DOT, was the development of a low-cost low-rate P-channel (to-aircraft) A-BPSK data modem using state-of-the-art technology. The project was delayed for almost a year when D.Boudreau took educational leave, until the arrival of M.Moher in May, 1988. However, concurrent with this delay was a significant maturing of the standard, as well as significant developments in digital signal processing technology; consequently, the delay caused little harm.

Concurrent with the development of the A-BPSK modem, the federal Departments of Transport, Communications, and Supply and Services signed a development contract with Canadian Astronautics Ltd. (now known as CAL Corp.) and Skywave Electronics Ltd. in the fall of 1988 [11]. The intent of the contract was to develop a low-cost aeronautical satcom terminal aimed at the general aviation market. Under this contract CAL was to develop the RF portion of the satcom terminal including the antenna. Skywave was to provide IF hardware and the baseband signal processing using DMSK/ACSSB technology which had been transferred from CRC. Discussions (London, February, 1989) between CAL, Skywave, CRC, DOT and Inmarsat led to the decision to change the signaling strategy from DMSK to A-BPSK, consistent with the standard being developed for international civil and commercial aviation. (The A-BPSK technology was to be transferred from CRC.) This contract led to the development by CAL of several state-of-the-art components including a linear solid-state power amplifier, high performance low noise amplifier, and phased array antenna, all of which are crucial for aeronautical voice communications via satellite.

The contract decision to use A-BPSK signaling, initiated the development of the burst mode R- and T-channel (from-aircraft) modems at CRC to complement the P-channel (to-aircraft) modem which was nearing completion. This required some adaptation of the P-channel software and the development of burst acquisition software. A large part of this work was performed by F. Patenaude (CRC).

In early 1989, M.Moher initiated a project at CRC to implement, simulate and validate the datalink protocol suggested by Inmarsat for the international standard. This project was motivated by the observation at AMSSP/1 that Inmarsat was developing the datalink protocol with little outside verification and validation. The majority of the work by CRC in this area was performed by co-op students. This datalink protocol development proved useful for two reasons. Firstly, it resulted in many corrections and improvements to the standard being proposed by Inmarsat, and created a much greater degree of confidence in the resulting standard. Secondly, although the work was initially a validation effort, it also became of commercial interest with the decision to implement the AMSS signaling standard in the CAL/Skywave contract.

[2] This report does not include aeronautical satcom technology developed at CRC for domestic applications such as the Ontario Air Ambulance service.

By the end of 1989, the work being performed by CRC, CAL, and Skywave was receiving significant international interest. In particular, in November 1989, Skywave signed a contract with Inmarsat to deliver a ground data unit (GDU). The GDU comprises the baseband and IF portions of a P-channel transmit, R- and T-channel receive chains. Inmarsat would use the GDU with a special purpose interface to test and validate any aircraft earth station (AES) wishing to be accepted to their system. The GDU uses CRC modem technology and resulted in a formal technology transfer agreement in October, 1990 for the A-BPSK modem software. The delivery of this unit to Inmarsat in February, 1991, and the subsequent good performance has led to orders of thirteen of these GDUs, with more likely in the future. At the time of this writing, Skywave is also under contract with Inmarsat to deliver the ground earth station (GES) portion of the data link protocol (developed at CRC) to use in Inmarsat's test suite for additional testing and validation of aircraft earth stations.

During the execution of the CRC/DOT/DSS contract with CAL/Skywave, it became clear that there was a significant market for low-cost aeronautical satcom terminals but that the terminals would have to be compatible with the AMSS standard being accepted internationally. This compatibility requirement included both the voice channel (C-channel) as well as the signaling channels (P and R-channels). The technical knowledge acquired through this contract, together with the recognition of significant market potential led to the signing of a contract between CAL and IDB Aeronautical Communications in 1991, to provide 20 AES terminals for business class jets. To complete the terminal, CAL subcontracted Skywave Electronics to provide the baseband and IF hardware, and TRL of the U.K. to provide the C-channel modem. Skywave was also to provide the protocol and signaling software; this led to a technology transfer agreement between Skywave and CRC for the datalink protocol software in October, 1991.

The culmination of all of this technology development effort was the first showing of a terminal, completed under the CAL/IDB contract and installed on a Gulfstream IV business jet, at the National Business Aircraft Association convention in Dallas, Texas, September 1992.

3.0 AMSS PHYSICAL LAYER AND CRC TECHNOLOGY

3.1 SERVICE REQUIREMENTS

Digital communication over the aeronautical satellite channel is challenging for a number of reasons. The first is the limited signal power, which is characteristic of satellite communications. In this case however, it is not only the satellite which is the limiting factor, but the need to make AES amplifiers small, lightweight, and cool limits the transmit power of the AES. Secondly, time-varying multipath, which is characteristic of mobile communications, is a significant factor. This includes not only reflections from the ground, sea, and ice floes but also reflections and possible blockage from the aircraft itself which vary with the aircraft orientation with respect to the satellite. Thirdly, the need to make aircraft antennas small and lightweight, and yet have high gain and hemispherical coverage is a very challenging problem. Fourthly, the digital modem must be able to track and maintain performance through aircraft maneuvering.

To meet the physical communications requirements of an aeronautical mobile satellite service, the system is designed to operate four different channel types of channels, which have been given the letter designations P, R, T, and C.

The P-channel is a packet mode TDM channel used in the to-aircraft direction from the GES to the AES. The transmission is continuous from each GES and sequential packets are normally addressed to different aircraft. This is a control channel which every AES must monitor continuously.

The R-channel is a random access (slotted-Aloha) channel used in the from-aircraft direction, from the AES to the GES. This channel carries signaling information, specifically the initial signals of a transaction, and small amounts of user data (up to 33 bytes). This channel allows different AESs to access communications services quickly, but because multiple AESs may access the R-channel simultaneously, it can be unreliable.

The T-channel is a reservation TDMA channel in the from-aircraft direction, from the AES to the GES. The receiving GES reserves time slots needed for transmissions by the AESs, according to message lengths and priorities. The AES transmits messages according to priority. Once an AES has indicated its need for services over the R-channel, the use of the T-channel allows more efficient use of the available spectrum, and more reliable communications.

The C-channel is a circuit-mode single channel per carrier channel used in both directions. For safety-related applications, this channel carries voice only. It can also carry data and facsimile for commercial and public correspondence. The use of the channel is controlled by assignment and release signaling at the start and the end of each call. In a fully automated air traffic control system, the use of the C-channel for safety applications is expected to be limited to distress and non-routine situations.

Each of these channel types can be transmitted at one of several channel rates. The rate used depends on the capabilities of the AES, the GES, the spacecraft, and the requirements of the service. The core service refers to the minimum capability of an AES, which must be supported by the spacecraft and the GES. The core service is defined as the capability to continuously receive one 600/1200 bps P-channel and to transmit 600/1200 bps data using either an R or T channel. That is, the core service is strictly a packet data service, it does not include voice communications. In the interest of extending the lifetime of the avionics in the light of potential network evolution, it is recommended in the ICAO AMSS SARPs that such a core service should also be capable of supporting 2400 bps channel rates.

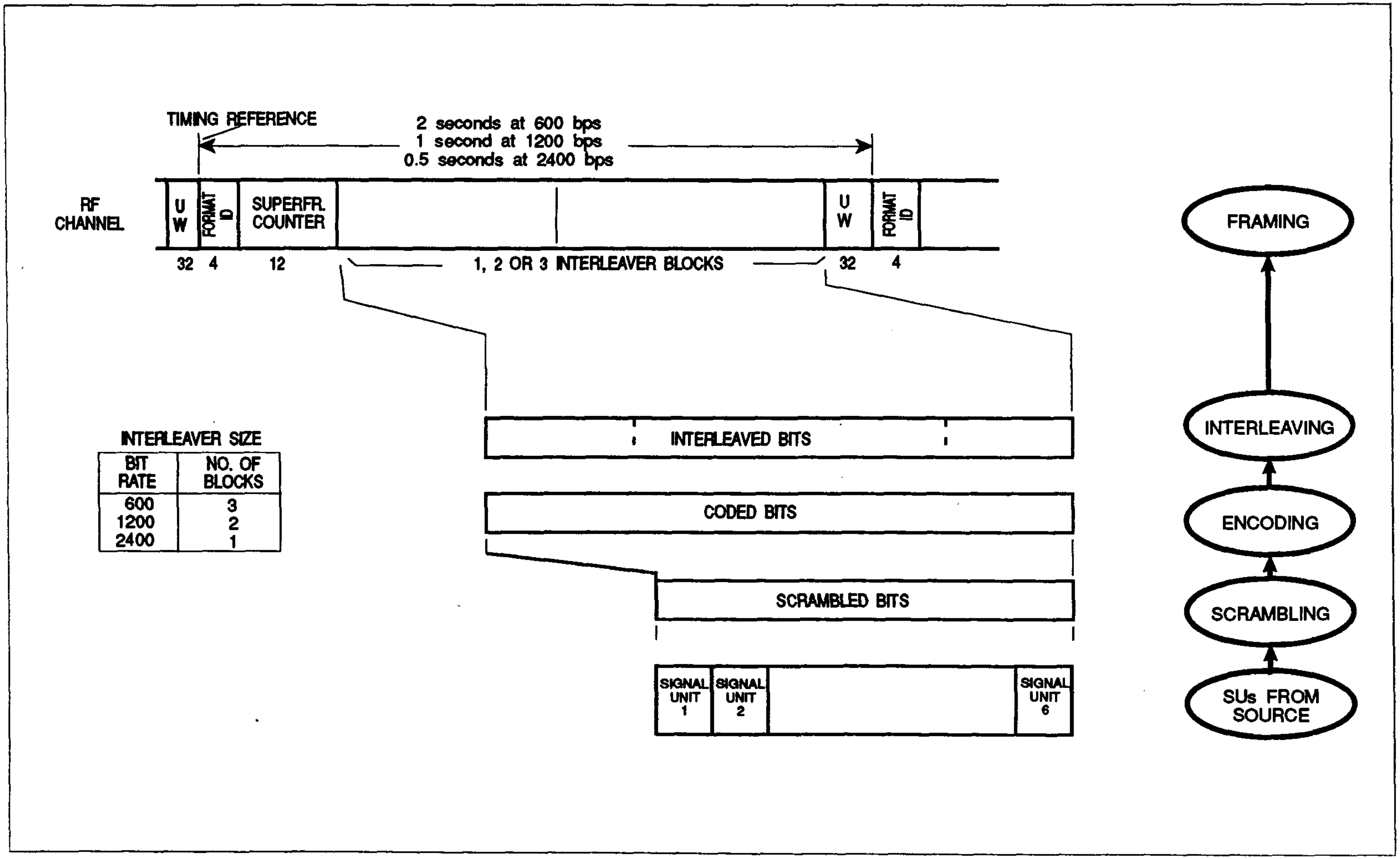
The difficulties of aeronautical satellite communications, i.e., limited power and time-varying multipath, are partially solved by the choice of modulation strategy. The modulation specified for the core service P, R and T channels is Aviation-BPSK (A-BPSK) which allows the use of efficient Class "C" amplifiers with little degradation in performance. A further solution to some of these problems is provided in the modem by using forward error correction (FEC) coding and interleaving the data to improve bit error rate performance for a given amount of transmitted power. A rate 1/2 constraint length 7 code is applied to all data, and interleaver block sizes were chosen as a compromise between spreading the time-varying affects of fading and minimizing the channel delay. The interleaver block sizes typically range from 300 milliseconds to 2 seconds depending upon the channel type.

3.2 CRC TECHNOLOGY

The objective of the CRC developmental effort was an economical implementation of the core service modem using state-of-the-art digital signal processing technology. This is a software based implementation of the modem which reduces both the size and amount of hardware required, and also provides the flexibility to adapt to a standard which was undergoing much change through the first years of implementation.

The design of the modem is centered around the Texas Instruments TMS320C25 digital signal processor which implements virtually all of the signal processing functions of the modem. This simplifies the hardware requirements of the modem and also increases its flexibility over a traditional discrete component implementation. On the transmit side this processor is used to implement the baseband functions of data scrambling, coding, interleaving, framing, and modulation. On the receive side this processor performs frequency acquisition and tracking, bit and frame synchronization, demodulation, interleaving, decoding, and descrambling. The following is a brief description of the implementation, more details are given in [12].

The modem uses Aviation Binary Phase Shift Keyed (A-BPSK) modulation with channel rates of 600 and 1200 bps. This is a form of BPSK in which bits are differentially phase-encoded where a phase shift of 90° implies a binary "1" and a phase shift of -90° implies a binary "0". The data is transmitted in frames which range from 0.5 to 2 seconds in length, as illustrated in Figure 1. The frame format for each of the three channel types is similar. Each includes a 32-bit unique word to determine the frame boundary, as well as 1, 2 or 3 interleaved blocks carrying the data. The P-channel also includes some header information with each frame for timing purposes, while the burst mode R and T channels include a preamble to assist synchronization. The modem parameters are summarized in Table 1.



BIT RATE	NO. OF BLOCKS
600	3
1200	2
2400	1

Figure 1. Frame structure and data processing stages for P-channel.

RF Interface	
- transmit: 70 MHz, 0 dBm, 50 ohms	
- receive: 70 MHz, -10 dBm, 50 ohms (nominal)	
Transmitter Specifications	
- channel rates:	600 and 1200 bps
- data scrambling:	15 stage scrambler: $1 + x + x^{15}$
- coding:	rate ½ constraint length 7 convolutional
- block interleaving:	as per [14]
- frame format:	as per [14]
- modulation:	A-BPSK as per [14]
- nominal bandwidth:	1.5 times the channel rate[3]
Receiver Specifications	
- frequency resolution:	70 MHz ± 5 MHz in 10 Hz steps
- dynamic range:	+10 dB to -20 dB relative to nominal level
- acquisition range:	±2 kHz (P-channel) ±1 kHz (R- and T-channels)
- acquisition time: (superframe lock)	10 seconds at E_s/N_0 of 4 dB (AWGN) and frequency offset of ±2 kHz (P-channel).
- performance:	1×10^{-5} bit error rate under the following conditions P-channel: E_s/N_0 of 4.0 dB (AWGN) E_s/N_0 of 7.2 dB (C/M=7 dB[4]) R- and T-channel: E_s/N_0 of 4.7 dB (AWGN) E_s/N_0 of 7.9 dB (C/M=7 dB)
- burst performance:	1×10^{-3} missed burst rate under the following conditions R- and T-channel: E_s/N_0 of 4.7 dB (AWGN) E_s/N_0 of 7.9 dB (C/M=7 dB)

Table 1. Summary of Modem Characteristics.

3.2.1 The P Channel

A block diagram of the P-channel transmitter baseband hardware is shown in Figure 2. Conceptually the hardware is quite simple with most of the intricacies of the FEC coding and modulation being performed in software by the TMS320C25. When used as a stand-alone unit the data is clocked in serially to the processor where it is processed as shown in Figure 3. This includes scrambling of the data, FEC coding, block interleaving, the addition of framing information, modulation, and pulse shaping. The output of the pulse

[3] The nominal bandwidth for the R- and T-channel will be significantly larger if used with a Class C amplifier.
[4] The fading rates are 20, 60, and 100 Hz.

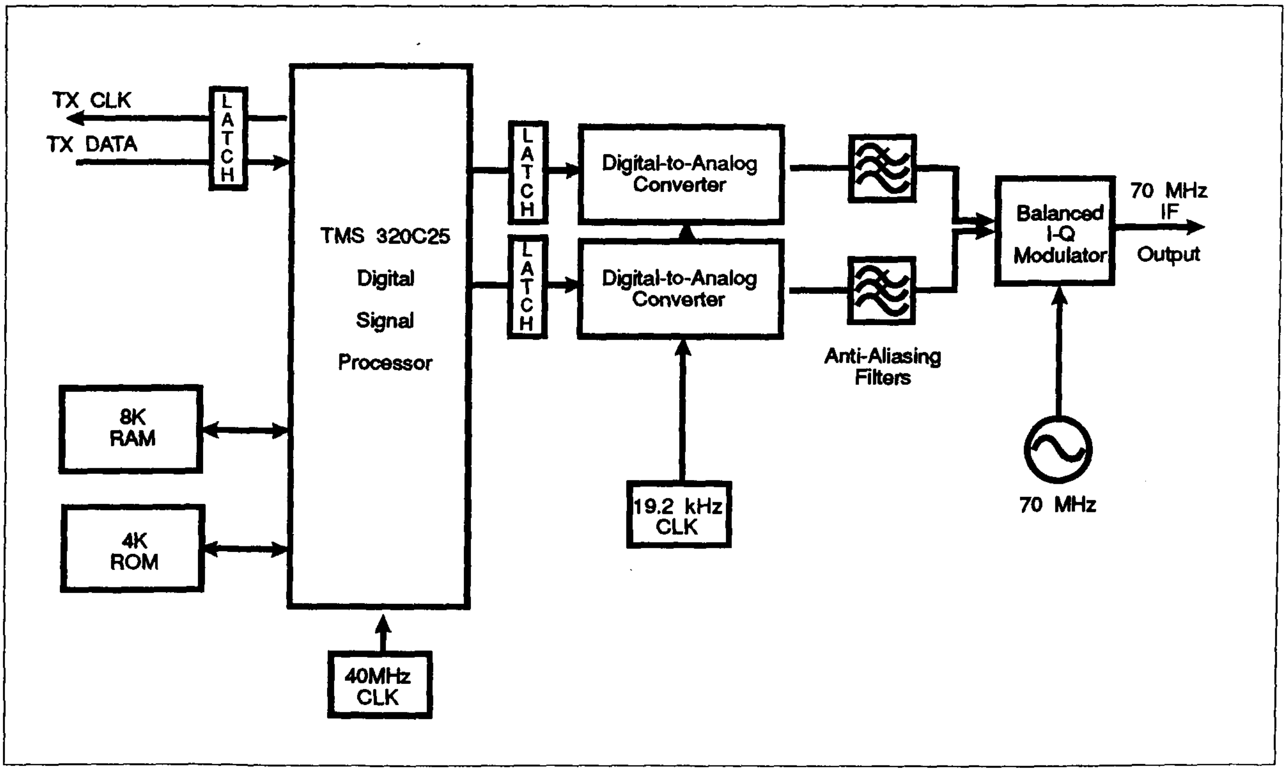


Figure 2. Block diagram of transmitter baseband hardware.

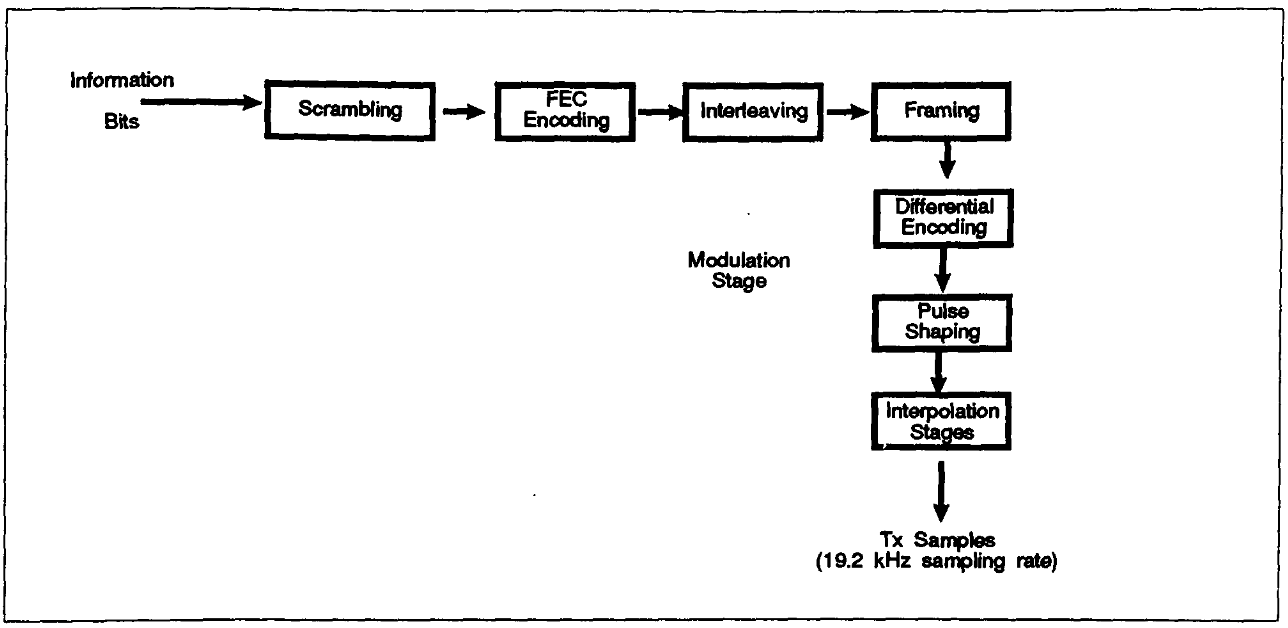


Figure 3. Block diagram of process of P-channel Transmit Data Unit.

shaping process is the complex modulated signal sampled at 19.2 kHz; the real and imaginary parts of this signal are then used to drive separate digital-to-analog converters. The output of the digital-to-analog converters is filtered before being directly modulated to an IF of 70 MHz.

The first stage of data processing within the TMS320C25 is scrambling of the data using a sequence which is initialized at the beginning of each frame. The data is then coded using a rate ½ encoder which doubles the bit rate. The coded data is then block interleaved using a 64-row n-column buffer, where the number of columns (n) per buffer depends on the channel rate. These interleaver blocks are inserted in the frame structure, three interleaver blocks per frame at 600 bps and two at 1200 bps. The resulting data stream is then modulated using the A-BPSK format.

For channel rates of 600 and 1200 bps the software is implemented on a single TMS320C25 running at 40 MHz and uses two 8-bit D/A converters. The current version of the software requires just under 2 Kword of program memory and less than 1 Kword of data memory.

A block diagram of the P-channel receive baseband hardware is shown in Figure 4. It interfaces to the RF unit at an IF frequency of 70 MHz plus or minus the channel offset. The IF signal is immediately down-converted to a low IF frequency of 4.8 kHz using a numerically-controlled oscillator which corrects for channel and Doppler frequency offsets.

The low IF signal is processed by the Texas Instruments TLC32041 Analog Interface Chip. This chip performs bandpass (anti-aliasing) filtering of the IF signal and then samples it at a rate of 19.2 kHz; these samples are passed to the TMS320 digital signal processor through the high-speed serial interface and all further processing of the received signal is done in software. In the stand-alone arrangement, the hardware communicates the detected data to the outside world over a serial interface which is synchronized to a received data clock as shown in Figure 4. For data rates of 600 and 1200 bps, a single TMS320C25 operating at 40 MHz can perform all of the operations required for data detection. It requires 3 Kword of program memory and 5 Kword of data memory.

The different stages of signal processing performed internally to the TMS320C25 are shown in Figure 5. The first stage of signal processing is a digital down-conversion of the signal to complex baseband followed by a decimation by 2. It is at this stage that the signal can follow one of two routes, either frequency acquisition or demodulation, depending upon the modem state.

In the frequency acquisition route, which is performed only for initial frequency acquisition or when frame synchronization has been lost, the down-converted and decimated samples are buffered in blocks of 256 complex samples. The samples in each of these buffers are then squared, FFTed, and a spectral average is performed over 32 such buffers. The resulting spectral average is then searched for the two spectral

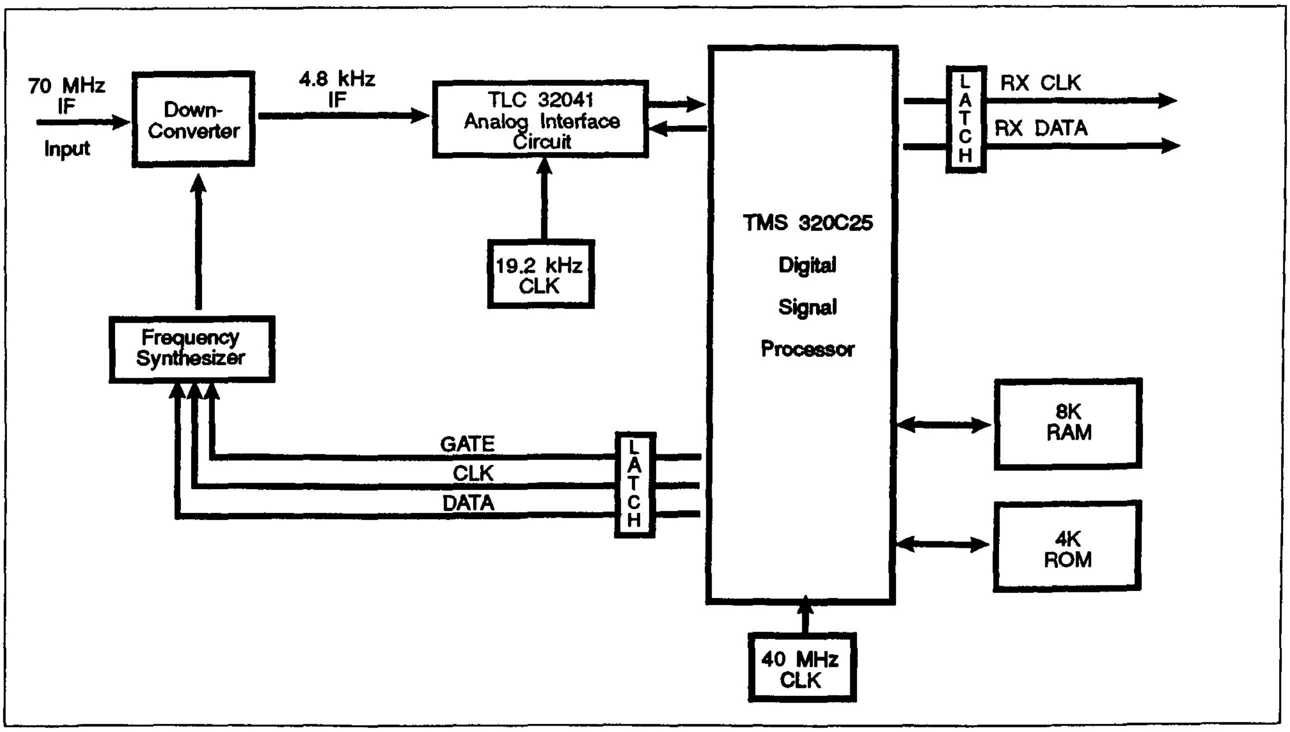


Figure 4. Block diagram of receiver baseband hardware

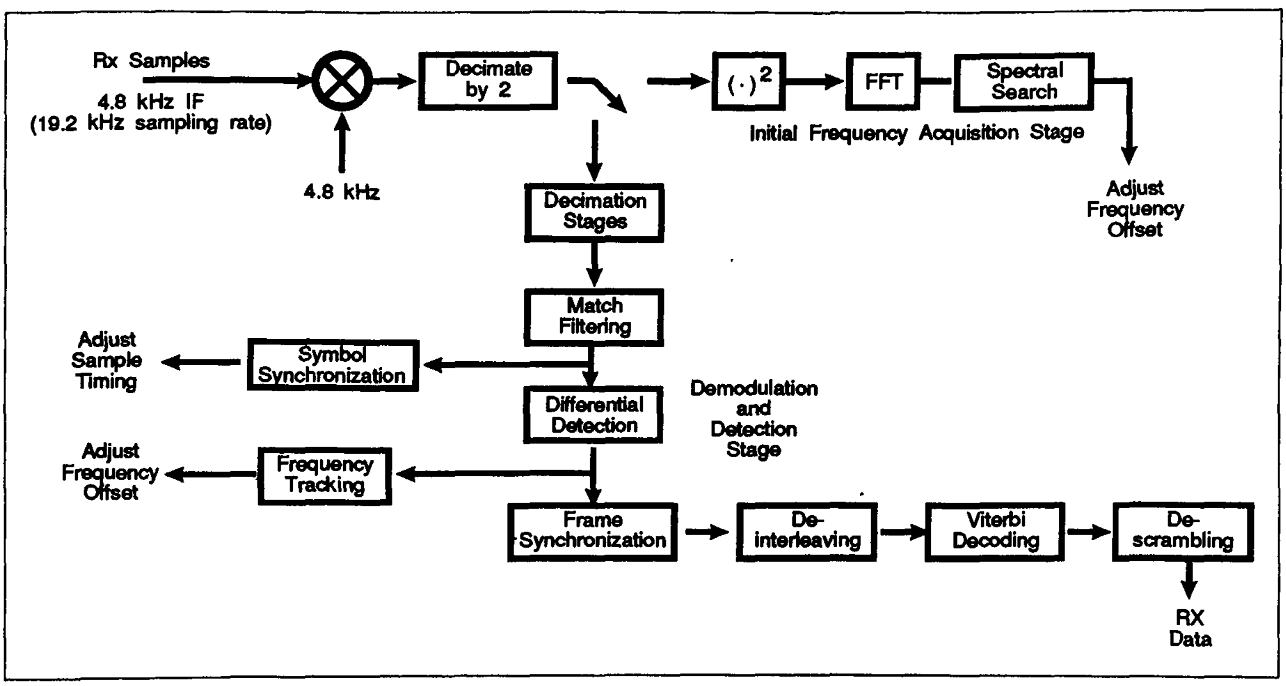


Figure 5. Block diagram of processing of P-Channel Receive Data Unit.

components which are separated by the baud rate and centered at twice the frequency offset. The resulting estimate of the frequency offset is then used to correct the numerically controlled oscillator used in the down-converter for the Doppler offset due to aircraft motion.

In the demodulation route, the sampled signal is processed by a series of decimation by 2 stages which reduce the sampling rate to 2 samples per symbol. There are three such stages at 600 bps and two stages at 1200 bps. The decimated signal is then match-filtered and the data is differentially detected. The output of the matched-filter, sampled at twice the symbol rate, is also used for both symbol synchronization and frequency tracking. The symbol synchronization algorithm estimates the timing error and uses this to adjust the sampling instant of the TLC32041. The frequency tracking algorithm estimates the frequency error and uses this to correct the frequency of the numerically-controlled oscillator. The demodulated data is correlated with the unique word which delimits each frame to obtain frame synchronization. Once frame synchronization is obtained and header information is removed, the data is buffered in blocks corresponding to the interleaver size for that data rate. These interleaver buffers are then de-interleaved, decoded using a Viterbi decoder and descrambled. The descrambled data is then output by the modem.

3.3.2 The R Channel

The baseband hardware required for the R-channel transmit data unit is the same as shown in Figure 2. However, the data are now transferred from the terminal controller in the form of Signal Units (SUs) of 19 bytes, i.e., 152 bits. Each SU is scrambled, coded and interleaved to form a block of 320 bits to be modulated and transmitted. This block is inserted in a burst frame following a burst of unmodulated carrier, a sequence of alternating bits, and a unique word. Each burst is transmitted according to the R-channel slot structure defined by the received P-channel superframe giving 8, or 16 random access slots/superframe for the R-channel data rates of 600, and 1200 bps. Because of the propagation delay due to the near-far aircraft position, each slot includes a guard time of 40 milliseconds to prevent collision of adjacent bursts. The R-channel implementation uses the same modulation parameters, signal level, and software approach described for the P-channel. The current version of the software requires under 3 Kword of program memory and under 1 Kword of data memory.

The R-channel receiver is very similar to the P-channel receiver. The only difference is that the initial frequency acquisition and bit timing acquisition must be performed at the beginning of each burst. The frequency acquisition algorithm performs both burst detection and frequency correction based on the unmodulated carrier at the beginning of each burst. After detection of a carrier signal, the receiver looks for the detection of the alternating sequence and estimation of the bit timing. Once the bit timing has been successfully acquired, the unique word detection is performed. If a given threshold is exceeded, then the receiver starts to buffer the coming samples that are eventually passed to the Viterbi decoder and the associated bit processing functions. If the threshold is not exceeded then the receiver is re-initialized and the frequency acquisition is re-started.

The current version requires about 4 Kword of program memory and about 5 Kword of data memory.

3.3.3 The T Channel

The baseband hardware required for the T-channel transmit data unit is the same as used in the P-channel unit shown in Figure 2. However, the data are now transferred from the terminal controller in the form of Signal Units (SU) of standard length (96 bits). The number of SUs in a burst varies from 1 to 32 and once a SU has been transferred to T-channel transmit modem, it is scrambled, coded and interleaved before being modulated and transmitted. The first interleaver block has a length of 320 bits and is formed out of a burst identifier (48 bits), a SU, and 16 bits of the next SU or 16 flush bits. The remaining interleaver blocks are 192 bits long. These blocks are inserted in a burst frame following a burst of unmodulated carrier, a sequence of alternating bits, and a unique word as in the R-channel. Each burst is transmitted according to the T-channel frame and slot structure defined by the received P-channel superframe. The T-channel implementation uses the same modulation parameters, signal level, and software approach described for the P-channel. The current version of the software requires approximately 4 Kword of program memory and under 5 Kword of data memory. The T-channel receiver software implementation is identical to that used by the R-channel except that it is modified to handle longer bursts, and to perform synchronization tracking over these longer bursts.

4.0 AMSS DATALINK PROTOCOL AND CRC TECHNOLOGY

4.1 FUNCTIONAL REQUIREMENTS

The functions of the datalink protocol in the AMSS system are fourfold: priority, segmentation, reliability, and link management. The priority function arises from the fact that the service must carry different kinds of data ranging from public correspondence through safety-related messages such as weather reports, up to distress/urgency messages. Because it is a low bandwidth system, it is necessary to implement a priority system to insure that the most important messages are not delayed by less important lower priority messages. This leads directly to the second function: segmentation, that is, the breaking up of long messages into small blocks of a standard size. This is necessary to insure that a long message of low priority can be interrupted transparently, to deliver a message of higher priority. In the event of link reliability problems, segmentation also allows re-transmission of only those portions of the message which were not received correctly.

The last two functions of the datalink protocol, reliability and link management, are closely related. These include the protocol functions, for acknowledgment of messages, requests for retransmissions, and also the signaling required for setting up a T or C-channel transmission.

Although more complex at the system level than the physical layer, the implementation of the protocol poses no significant technical difficulties; the main concern regarding protocols is their validation. That is, insuring that they are correct and will not fail, i.e., paralyze the network or deliver incorrect data, under expected operating conditions. See [13] and [14] for further description of the datalink protocol.

4.2 IMPLEMENTATION

At CRC, the datalink protocol was implemented in the high-level language Pascal on two IBM-compatible PCs. One of the PCs represents the GES protocol machine and the other represents the AES protocol machine. The two PCs are connected by an RS-232 interface which represents the satellite link. Artificial errors can be introduced on this link, to represent the effects of the physical transmission.

At the link level, that is, that level of the OSI model for communications corresponding to the datalink protocol, the functions of the physical layer P, R, and T channels become intertwined. For example, data messages which sent on the P-channel to an AES are acknowledged on the R-channel.

The protocol machine is implemented as a time-sharing operating system on each of the PCs. The operating system controls a number of parallel processes, and each is given a slice of the CPU time in an event-driven manner. Some of these processes represent control functions necessary for the protocol but a large portion of them represent messages that are currently active in the system, i.e., are in the process of being transmitted, waiting for acknowledgment, etc. Consequently, it is a very dynamic system with the number and type of processes depending on the incoming traffic and the channel conditions.

4.2.1 To-aircraft messages

In Figures 6 and 7 the division of the software processes between the GES and AES protocol machines is shown. To understand the implementation it is easier to consider to-aircraft messages and the associated signaling by itself. This will illustrate the relationship between the processes at the GES and the AES and the handshaking that must occur between them. The following is a brief overview of the software functions.

In OSI terminology, at the GES, a message arrives at link layer in the form of a link service data unit (LSDU) as shown in Figure 6. This LSDU is directed to the P-channel queuing unit (PQU), which assigns a P-channel transmit process (PTX) to the message. This PTX process exists until the message is successfully acknowledged or until a failure is declared. The PTX process breaks the message down into 12 byte signal units (SUs) which are then forwarded to the P-channel transmit process (PTP). The PTP buffers the SUs as they arrive from all of the PTX processes and forwards the SUs, in order of priority, for physical layer transmission.

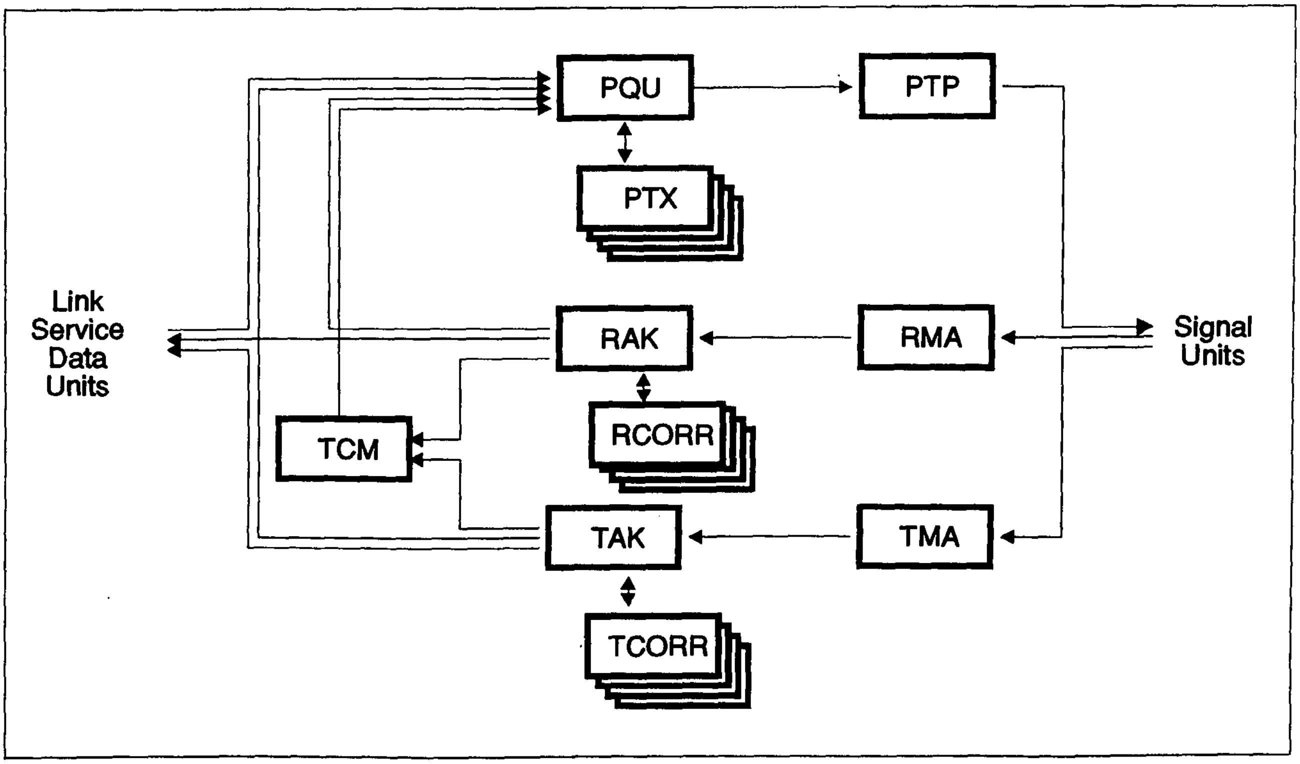


Figure 6. GES Link Layer Processes.

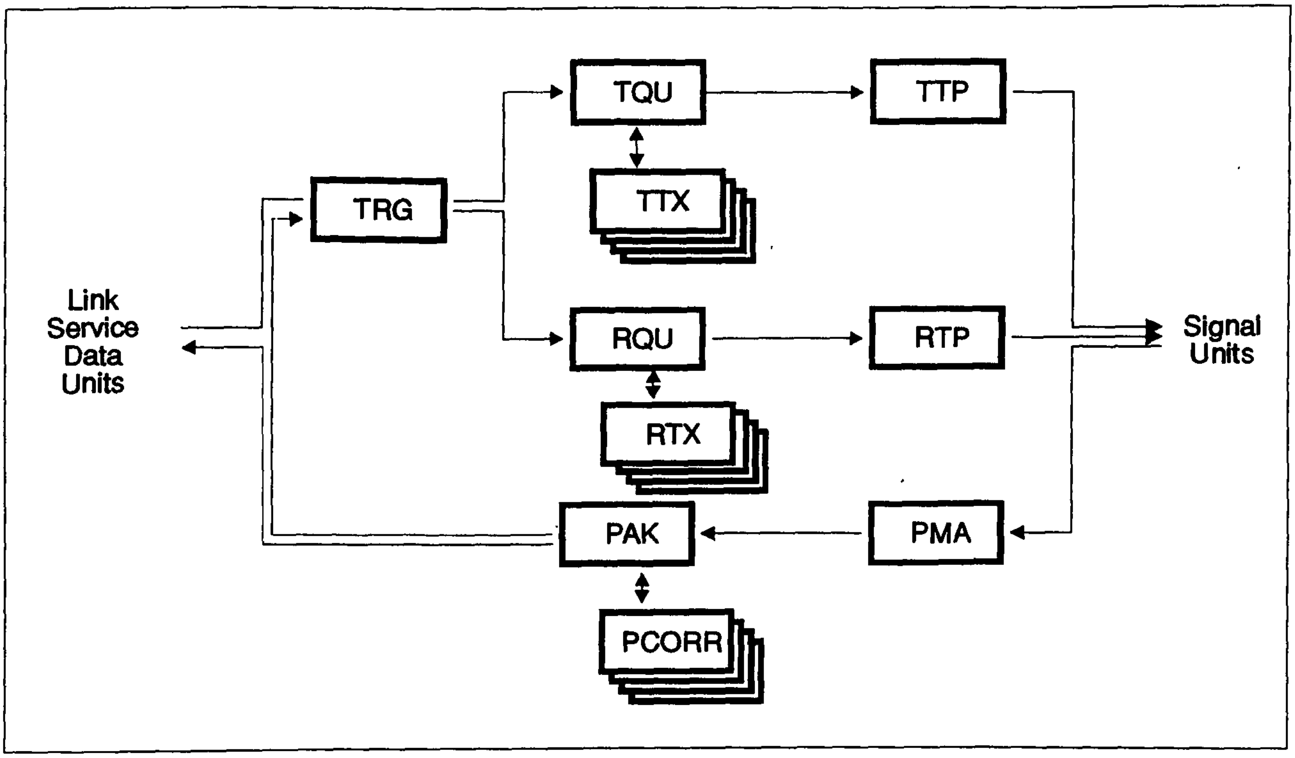


Figure 7. AES Link Layer Processes.

At the AES, the SUs received by and addressed to the AES are sorted according to the message to which they belong by the P-channel message assembler (PMA) process as shown in Figure 7. These assembled messages (possibly incomplete) are forwarded to the P-channel acknowledgment unit (PAK) which assigns a P-channel correction (PCORR) process to each message being received. The PCORR process exists until the message is received correctly or a failure is declared. If the message is received incorrectly, the PCORR process generates a request for retransmission SU which indicates which of message's SUs were received incorrectly. If the message is received correctly, PCORR generates an acknowledgment SU and then closes itself. The retransmission SU or the acknowledgment SU are forwarded to the T-channel request generator (TRG) and then to the R-channel queuing unit (RQU). From there they are forwarded to the R-channel transmit process (RTP) where they are queued, according to priority, before being forwarded to the physical layer for transmission.

At the GES, the received retransmission or acknowledgment SU is forwarded by the R-channel message assembly process (RMA) through the R-channel acknowledgment unit (RAK) to the PQU as shown in Figure 6. At the PQU, this response SU is directed to the PTX process of the corresponding message.

This completes one loop of the protocol. If there are no transmission errors, it is also the only loop made by the protocol for that particular message. If there are transmission errors, then the loop will be repeated up to five times until the message is received error free. If there are still errors after the fifth loop, a failure is declared and the next highest layer of the protocol stack, the subnetwork layer, is notified.

4.2.2 From-aircraft Messages

The from-aircraft protocol is very similar to the to-aircraft protocol, the major difference being that there are two types of channels. At the AES, incoming LSDUs from the network layer are redirected by the TRG according to length as suggested in Figure 7. All LSDUs less than 33 bytes in length are sent via the R-channel; all longer LSDUs are sent via the T-channel. Also since the R-channel is a random access channel with a significant probability of collision, the transmission strategy and retransmission strategy is somewhat modified.

4.2.3 Signaling

Signaling includes the acknowledgments and requests for retransmission SUs described above. It includes signaling via the R- and P-channel to set up a T-channel slot assignment. This reservation procedure is controlled by the T-channel manager (TCM) processor in the GES shown in Figure 6. Signaling also includes those SUs necessary to set-up and tear-down a C-channel circuit mode voice channel.

5.0 CONCLUSIONS

The ICAO Committee on Future Air Navigation Systems identified three major shortcomings with the current global air traffic management system which are [10]: i) the propagation limitations of current line-of-sight systems and reliability of other systems; ii) the difficulty to implement present communication, navigation and surveillance systems and operate them in a consistent manner in large parts of the world; and iii) the limitations of voice communications and the lack of digital from-aircraft data interchange systems to support modern automated systems in the air and on the ground. It was concluded by the committee that the exploitation of satellite technology is the only viable solution to overcoming these shortcomings and fulfilling requirements of the foreseeable future on a global basis.

These problems, which were identified on a global basis, are particularly relevant to Canada, and particularly to the Canadian Department of Transport with its responsibilities for air traffic control over Canada's North, and a large part of the North Atlantic. With increasing demands upon the air traffic control system, new solutions such as Automatic Dependent Surveillance have been proposed. However, to take full advantage of these solutions, one needs a delivery system that only satellite technology can provide.

The exploitation of satellite technology for aeronautical applications spawned a number of problems, all of which have been conquered to a large extent. The primary technical problems lie with the design of terminal equipment to satisfy weight, size, and cooling limitations imposed by the airframes. Specifically, this requires the design of high gain antennas, high power amplifiers, and very low loss modems to accomplish this in an extremely dynamic mobile environment. Economic factors also played a role in the design of the service. Partially because of the high cost of the satellite technology, the service has a number of features not previously seen in aeronautical safety communication services. These include sharing of the service between safety and public correspondence, and the use of a commercial telecommunications infrastructure. The service is also the first mobile service to be designed with the Open System Interconnect (OSI) design philosophy and to be compatible with the Aeronautical Telecommunications Network (ATN) concept. It is also the first to use digitally encoded speech.

As this report has demonstrated, CRC and DOT activities have significantly influenced standards and Canadian industrial development in the area of aeronautical satellite communications. This influence means that the international service will be compatible with DOT's air traffic control needs in the North and in the North Atlantic. This work has increased CRC's technical expertise in the area of satellite terminal development and has resulted in several publications describing the technology [15]-[23]. It is a good example of what can be accomplished with inter-departmental cooperation.

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