N89-27918

AERONAUTICAL MOBILE TDMA/MCTDMA SYSTEM

DR. THOMAS MAGILL, Stanford Telecommunications, Inc. United States;
WAYNE PIERZGA, ARINC, United States

STANFORD TELECOMMUNICATIONS, INC.
2421 Mission College Boulevard
Santa Clara, California 95054
United States

ABSTRACT

A multiple carrier TDMA system capable of supporting voice, stream data, and packet data traffic between aircraft and ground terminals is presented. Demand assignment permits efficient resource sharing for voice and stream data. The bandwidth efficiency of uncoded AQPSK is 1 bps/Hz. High time efficiency ($\approx 83\%$) is achieved through the use of symbol synchronous TDMA. Demodulation is achieved without loop hang-up while requiring only a 16 symbol preamble each burst. A concatenated coding system provides reliable transmission under multipath conditions.

System Overview

An aeronautical satellite system has been designed to support data and voice traffic. The high rate of the voice traffic, 8 kbits/s, has a large impact on system design. The high rate necessitates multiple L-band spot beams which are accessed by choice of carrier frequency. Owing to the limited available bandwidth and power it is mandatory to have an efficient demand assignment system. These considerations have led to a multiple beam satellite system using a very efficient demand-assigned TDMA, which is described in the remainder of this paper.

A pair of ground entry stations (GES), one acting as the net control terminal (NCT) and the other as the alternate NCT (ANCT), support as many as 240 aircraft terminals (AT) per transponder/beam. The NCT and ANCT transmit reference bursts in alternate frames. The time, frequency, and power resource management of each satellite is controlled by this redundant pair of reference stations. The NCT allocates time/frequency slots for voice traffic and stream data traffic according to service requests. Random access (slotted ALOHA) is used for datagram traffic which is restricted to specific slots assigned for these function by the NCT. Each outbound (hub to remote) transponder supports one carrier operating in a TDMA mode operating at 160 kbaud using a form of staggered QPSK modulation known as AQPSK. Owing to the limited available AT EIRP the inbound transponders support 5 32 kbaud carriers each using AQPSK with time synchronized TDMA across the five carriers. By rapid carrier hopping any AT can use any one of the 5 inbound carriers (but only one at a time). We

refer to the inbound multiple access technique as multiple carrier TDMA (MCTDMA).

Rationale for Selection of TDMA

TDMA is well suited to supporting demand assignment with relatively simple ATs. The fact that only a single carrier is present at a time at an AT means that highly efficient class-C HPAs may be employed. Furthermore the TDMA/MCTDMA system is very power and bandwidth efficient. The TDMA/ MCTDMA carriers are spaced by 320 kHz and 64 kHz, respectively, resulting in an asymptotic bandwidth efficiency of 1 bps/Hz for uncoded transmissions such as voice traffic. The AT inbound transponder backoff required to avoid genera-tion of IM crossproducts is a potential inefficiency shared with FDMA systems. FDMA systems, either SCPC or variable rate, encounter additional problems. With SCPC each new circuit requires a separate carrier. Thus, it is necessary to either: 1) operate the AT HPA at a significant backoff to avoid generation of large IM crossproducts, or 2) use multiple HPAs with a complex multiplexer. With variable rate FDMA occupied bandwidth varies with the number of circuits. Variable rate FDMA avoids the problem of multiple carriers in a common HPA but encounters a severe resource fragmentation problem. At some time a new access will require carrier reassignment to find sufficient continguous bandwidth. With FDMA, in contrast to TDMA, this reassignment temporarily interrupts service.

TDMA Architecture

Symbol synchronous TDMA (SSTDMA) [Ref. 1] was selected rather than classic burst TDMA owing to its greater efficiency. SSTDMA avoids the lengthy symbol sync acquisition process (50 to 150 symbols) by requiring symbols from all sources arrive synchronously at the satellite to within a fraction of a symbol duration. Thus, a single receiver time base is sufficient to detect data from all sources. Careful design of the network timing system achieves this goal even with highly dynamic ATs.

Bursts from GESs and ATs entering the outbound and inbound satellite transponders form TDMA frames of 40 ms duration. The beginning of an out-bound TDMA frame is defined by a reference burst which is sent by the (A) NCT. Following the reference burst are a number of traffic bursts orginating from the NCT, ANCT, and ultimately, other GES. Bursts transmitted in the inbound direc-tion are synchronized to the outbound reference burst. Transmission bursts in either direction are separated by a minimum guard time of 4 symbols. The num-ber of bursts, their duration, and their location in the TDMA frame are specified by the net Burst Time Plan. The TDMA frame duration used in the system is the same in both the outbound and inbound directions. Each of the inbound TDMA carriers is frame synchronous with its outbound TDMA carrier. Figure 1, a hypo-thetical Burst Time Plan, illustrates the relationship between the inbound frames and the outbound reference burst. The frame hierarchy includes: 1) The data frame, 2) the master frame consisting of two data frames, 3) a reporting frame

110

consisting of 512 data frames, and 4) a super frame consisting of 7500 data frames (5 minutes).
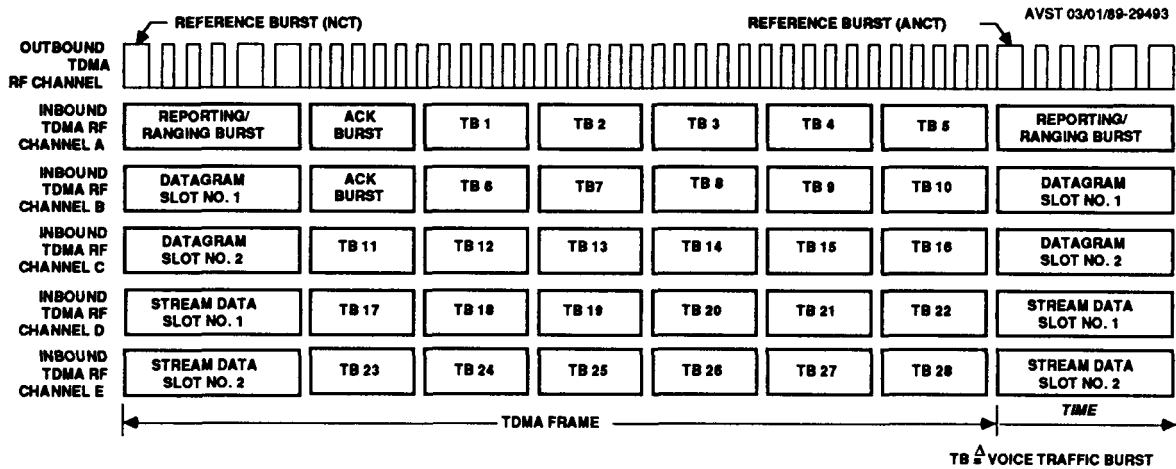

Figure 1. TDMA/MCTDMA Frame Format Example

There are 3 major burst types: 1) reference bursts, 2) reporting bursts, and 3) traffic bursts. Each burst is preceded with a 16 symbol preamble except for the reference burst which has a 112 symbol preamble. The first two types convey overhead information while the latter conveys user traffic. The reference bursts provide time and frequency references to the ATs as well as support the net control information described below. During steady-state operation each net participant transmits a reporting burst which permits the NCT to control every 20.48 s the frequency and time accuracy of that net participant even if it is not actively transmitting user traffic. There are three types of traffic bursts: 1) voice traffic, 2) stream data traffic, and datagram or packet data traffic.

Reference bursts provide a communication circuit that is used to broadcast network configuration and control information to all GESs and ATs. This circuit is referred to as the Overhead Communications Circuit (OCC). The OCC is comprised of three parts, as shown in Figure 2. One part is used to distribute network configuration information and is called the Network Control Circuit (NCC). All GESs and ATSs decode the information provided by this circuit, which contains: 1) the identity and frequency of each inbound TDMA channel associated with the spot beam, 2) the Burst Time Plan that will be used in the next Super Frame 3) the identities of all earth stations in the net, 4) the location of the satellite relative to the earth's center, and 5) the location of the NCT relative to the satellite. The above information, which defines the network, does not change rapidly with time. It is formatted into a message which is repeated several times each Super Frame (5 minutes).
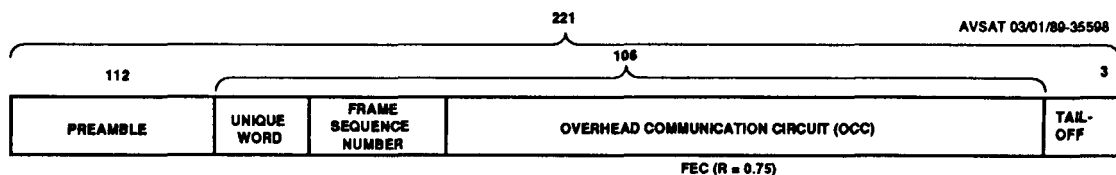

Figure 2. Reference Burst Structure

111

The OCC also contains the Communication Control Circuit (CCC) which provides: 1) the outbound TDMA frame sequence number that is used to synchronize network activities, 2) flow control parameters to manage access to inbound slotted ALOHA datagram time slots and 3) addressed Circuit/Time slot assignment information. The information provided by the CCC is updated every date frame. The OCC also contains a Terminal Control Circuit (TCC) which is used to control the following transmit parameters: 1) power, 2) frequency, 3) symbol rate, and 4) burst time. This information is formatted into addressed data packets which are sent in each date frame.

The information described above is provided both by the NCT and the ANCT. The ATs respond only to the NCT unless the OCC CRC checks indicate an NCT failure in which case the ANCT information is used and the ANCT assumes net control.

Acquisition and System Timing Control

The TDMA frame timing is established by the periodic occurrence of the reference burst . All ATs send their transmission bursts based on the time offset relative to the time of reception of the reference burst. Bursts are maintained in their assigned positions in the TDMA frame by the NCT. The NCT monitors the position of the reporting bursts and sends correction information to the source terminals and to the ANCT.

To begin net entry, a terminal first receives the outbound primary reference burst and decodes the OCC. Satellite ephemeris and the net Burst Time Plan are used to aid in the transmit phase of net entry. The terminal computes an estimate of its transmit delay using its location and the received satellite ephemeris. The station then transmits a short ranging burst in an inbound datagram time slot.   This burst is sent at time $t_o + t_c$ where t_c is the computed time offset and t_o is the reference burst reception time. The NCT measures the position of this initial ranging burst relative to the leading edge of the reference burst time slot and generates an initial delay value which, after implementation by the terminal, will cause subsequent transmissions to be aligned with the leading edge of the time slot. The initial delay value along with a permanent reporting burst time slot assignment is sent to the terminal via a message in an outbound datagram circuit; upon receiving the assignment the net entrant will commence transmitting reporting bursts.

Network Time and Frequency Control for Dynamic Aircraft

Aircraft may be traveling at velocities relative to the satellite as high as 800 nmph and may execute a 180° turn within 1 minute. Use of reporting bursts is clearly inadequate to provide the required time and frequency accuracy. Measurement of the Doppler shift on the received reference bursts is used to correct the inbound carrier frequency and symbol clock by a compensating amount. This solution appears to require a very precise and expensive aircraft frequency standard. Fortunately, the reporting bursts provide a mechanism for correcting a much less stable and more affordable standard.

Figure 3 is a conceptual block diagram of the net frequency control loop (showing only the inbound carrier correction). The inbound carrier frequency is controlled by an instantaneous correction based on the reference burst Doppler shift measured at the AT and a long-term correction measured at the NCT which accounts for the drift in the AT standard. The mechanism illustrated in Fig. 3 requires that the satellite frequency translation oscillator errors be compensated. If a common oscillator is used to generate all tranponder offset frequencies, the compensation can be accomplished as follows. The NCT receives the reference burst in its own L-band spot beam and compares the received frequency with a local standard. The difference is used to modify the uplink carrier frequencies for each transponder such that the satellite drifts are effectively compensated.
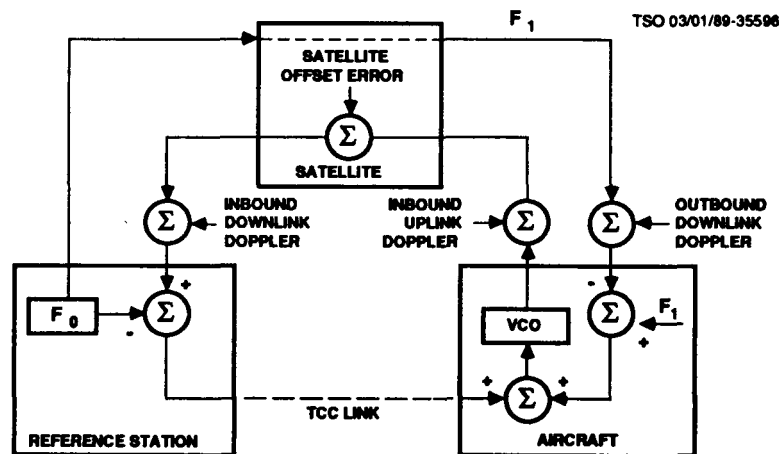

Figure 3. Conceptual Block Diagram of Network Frequency Control Loop

Modulation and Coding Formats

AQPSK, staggered QPSK with square-root raised cosine spectral shaping with 100% excess bandwidth, is used for both inbound and outbound links. AQPSK has been shown to be particularly well suited for transmission through class-C HPAs [Ref. 2] while providing very good bandwidth efficiency. Under most circumstances voice traffic is transmitted uncoded. A punctured, $R = 3/4$, $K = 7$ convolutional code is used for all data traffic including network control traffic. Datagram traffic uses only convolutional coding with a 16-bit CRC check. Stream data traffic used this convolutional code concatenated with a RS (30, 20) code based on 6-bit symbols. The RS code with its interleaver provides very low BER performance (suitable for file transfers) even in the presence of the fading and interference that is characteristic of the multipath environment.

Preamble Structure and Demodulator Type

A hybrid demodulator illustrated in block diagram form in Fig. 4 has been selected. Owing to the phase trajectories of hard-limited AQPSK and to the SNR degradation of harmonic multiplication this type of carrier recovery PLL is not employed. Rather a modified form of a remodulation or decision-directed loop is used. Potential PLL hang-up is avoided by the use of block phase estimation

113

(BPE) (Ref. 3). BPE, a feedforward technique, is used for the first 16 symbols resulting in an excellent initial phase estimate when the feedback loop is closed and the decision feedback mode commences. Thus, avoidance of PLL hang-up
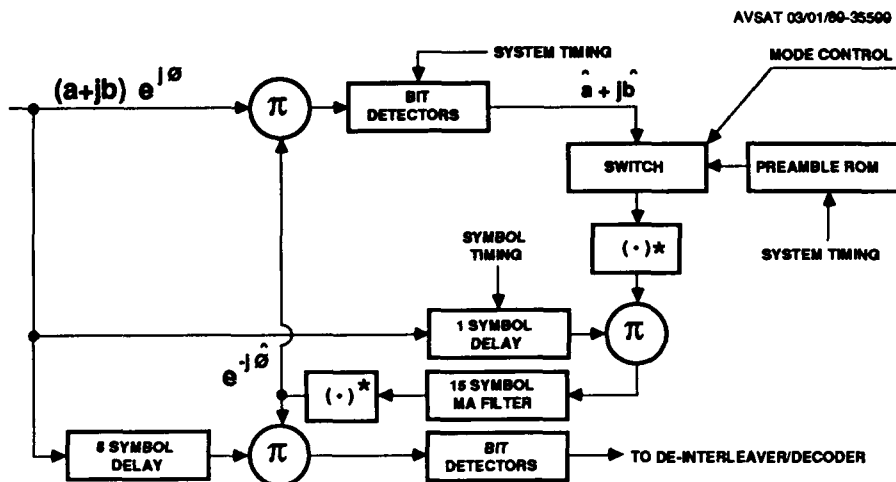

Figure 4. Block Diagram of Data Demodulator

dictates the use of a 16 symbol preamble on each burst. Use of BPE requires that the frequency error on each burst, be sufficiently small that the phase shift over the 8 symbol duration be less than 2°. Since the initial phase estimate must be made in a multipath environment it is essential to design a preamble signal which protects the phase estimate from corruption by multipath. Our preamble signal design is based on quaternary sequences and achieves a maximum sidelobe magnitude level of 2 out of 16. Computer simulations have demonstrated excellent BER performance of this demodulator operating in a severe multipath environment.

Conclusions

A highly efficient TDMA/MCTDMA system, capable of supporting voice, stream data, and datagram traffic is feasible for aeronautical service. High bandwidth efficiency is achieved with AQPSK modulation of multiple carriers. High time efficiency is achieved through the use of symbol synchronous TDMA, a unique demodulator that avoids PL hang-up, and net time and frequency control loops. Use of multiple carriers reduces aircraft EIRP requirements.

References

1. R. Huff, "Uplink Symbol-Synchronous TDMA SATCOM System Architecture" NTC Record, 1978
2. D. Magill, D. Kwan, and W. Pierzga, "Optimum Signal Waveform for Use in Aeronautical Mobile Satellite Communications, " ICCS '88 Conference Record, Singapore, November, 1988
3. I. Richer, "A Block Phase Estimator for Offset-QPSK Signaling," NTC Record, December, 1975