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OPTIMIZING SATELLITE COMMUNICATIONS ACCESS WITH SIMULATION

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ABSTRACT

Most communications systems in use today employ some type of transmission medium-sharing among users. A major motivation for such sharing is the cost savings realized from minimizing transmission equipment outlays. Medium-sharing also can be a necessity, as in the case of wireless communications such as cellular telephone, packet radio, and satellite links. One such medium-sharing technique being applied to satellite communication channels is demand assigned multiple access (DAMA). Discrete-event modeling and simulation are the ideal means for selecting the control schemes and decision logic to make the evolving DAMA protocol as efficient as possible. This paper examines the benefits, objectives, and key aspects of 25-kHz DAMA simulation model development. Representative results from this ongoing effort are also presented.

1 INTRODUCTION

The DoD and other government agencies have a limited pool of frequency channels available for ultrahigh frequency (UHF) satellite communications (SATCOM). In the face of increasing demand for this constrained resource, the Navy commenced transition (circa 1985) of its existing 25-kHz UHF SATCOM channel user networks to the DAMA protocol, in order to increase the channel utilization efficiency. The DAMA protocol provides the means for multiple communications networks to concurrently share a communications channel previously available only to a single network at a time. 25-kHz DAMA achieves a 2- to 22-fold capacity increase via time-division multiplexing; the periodic communications time frame used is partitioned into time slots, through which network traffic is burst at higher transmission rates to compensate for the compacted access period. Figure 1 depicts a UHF DAMA SATCOM network.

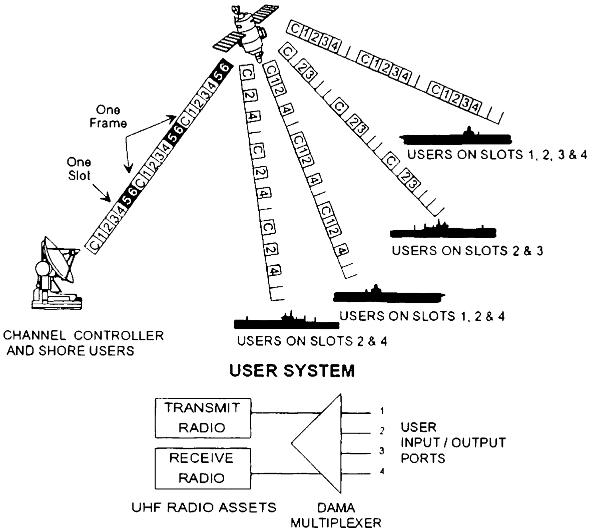

Figure 1: UHF DAMA SATCOM Network

The initial deployment of 25-kHz DAMA, known as distributed control (DC) mode DAMA, has increased channel capacity successfully, yet lacks true demand assignment and automation provisions. DC mode DAMA, in effect, pre-assigns networks to time slots, regardless of whether a network's usage of the slot is continuous or intermittent. This has led to the next stage in DAMA's evolution, the Semi-Automatic Controller (SAC), to become operational in 1995.

The SAC allows more efficient use of the channel's time slots by making automated connection setup and tear-down possible. The increased utilization of a special slot in the DAMA frame - the return orderwire - achieves this capability. Users (i.e., aboard ships, submarines, and aircraft) desiring short-term access to SATCOM resources issue a slot request within the return orderwire slot to a central channel controller that manages SATCOM asset allocation. The channel controller arbitrates these requests and issues its allocation decisions on its own orderwire slot to the user community. The SAC, however, is a transitional stage to the ultimate objective - the fully automated or automatic control (AC) mode DAMA - to commence implementation in 1996. AC mode DAMA will enable the control system to make more complex allocation decisions based on the governing operational requirements and to adapt quickly within a very dynamic communications environment.

2 MOTIVATION FOR MODELING

The primary purpose for modeling 25-kHz DAMA is to provide a flexible "test bed" by which protocol performance can be gauged in a very economical and timely manner. Traditional analytical methods can be used to predict DC mode DAMA behavior, but quickly become intractable when applied to the SAC and AC mode DAMA. Simulation is the best tool for examining these modes.

The exact role simulation serves for the SAC and AC mode DAMA differs in the timing between modeling and system development. The SAC model was developed after system design but before system deployment. Its primary value lies in the ability to expose areas of unsatisfactory or suboptimal performance by creating stressful or atypical traffic loads which are difficult to replicate in the real system. A secondary value of this model is that it implements a major subset of the AC mode orderwire protocol, and thus forms an ideal baseline for the AC mode models. The potential for near-term validation of the SAC model lends credibility to the AC mode models that are constructed from it.

AC mode DAMA, however, is presently in the "concept of operations" development stage. Models of this mode can facilitate informed design trade-offs prior to system development. The main value of the AC mode models is in assessing the effectiveness of different allocation algorithms and control schemes relative to one another. These models can be a useful design tool for optimizing the system with respect to the performance requirements, physical constraints, implementation methods, and traffic scenarios.

3 MODELING AND SIMULATION OBJECTIVES

The main objective of this simulation project is to obtain reliable steady-state estimates of the following critical performance measures: (1) throughput, (2) connection setup time, and (3) return orderwire contention. Throughput is defined here as the number of successfully completed SATCOM resource allocations divided by the number of resource requests issued over a period of time. Connection setup time is defined here as the time elapsed between a user's creation of a SATCOM access request message and the receipt of a valid resource allocation message at the requesting user's terminal. Return orderwire contention refers to the probability that two or more user terminals will transmit SATCOM access requests (or other messages) in the same return orderwire time slot.

Another objective is to develop flexible system models. The modeling tool used, BONeS® Designer™ from Cadence Design Systems, Inc., provides the necessary framework. The request traffic generator module developed for these models is highly adaptable. Unlimited traffic scenarios can be created with variable request type distributions, request precedence distributions, request interarrival rates, connection periods, two-party/conference call mixes, fixed/demand assignment mixes, and user terminal configurations. Moreover, the decision logic of the channel controller is decomposed into independent modules whose functionality can be easily modified by interchanging the *C* code for that module.

4 KEY MODEL FEATURES

DAMA is a type of medium access protocol; it operates at the Data-Link Layer of the International Organization for Standardization (ISO) Open Systems Interconnection (OSI) Reference Model. DAMA's role is to arbitrate access, and thereby prevent mutual interference, on the SATCOM link. The orderwire exchange between subscriber terminals and the channel controller is the fundamental means of exercising this control, and thus is the defining element for model abstraction. This section highlights some of the more intriguing aspects of modeling this process.

Deviations from the ideal operation, as well as lessons learned from DC mode DAMA usage, are worthy factors whose inclusion can increase model utility and credibility. One realistic factor incorporated within the models is the occurrence of random bit errors on the SATCOM link. This is modeled as a symmetric channel where errors are drawn from a binary distribution. Bit errors result from various degrading forces along the signal path, but the net result is a definite bit error rate (BER). If the BER exceeds a certain level, the transmitted information is unrecoverable and must be sent again. Such retransmissions create a ripple effect that can degrade system performance. Orderwire traffic in the models is exposed to a selectable BER. Another factor incorporated within the models is the reaction of users to service delays. Resource request queuing at the channel controller can occur due to appropriate slots being busy or the preemption of active connections. User balking is modeled with a variate corresponding to time waited after notification of queuing before the resource request is retracted.

Decision logic that reacts and adjusts to the dynamic traffic loading in order to meet performance objectives is another important aspect of the models. This logic is in the form of algorithms for frame format change decisions, preemption decisions, queue disciplines, ordering of slot allocations, and return orderwire contention limiting. There are a multitude of possible algorithms and combinations of algorithms for implementing the decision logic. For example, choice of the DAMA frame format used has a great impact on system performance. There are 1,696 unique frame formats, each with different quantities of the 24 slot types (each slot type is a unique combination of user port rate, burst rate, and forward error correction coding rate). Changing the frame format during operation can provide the correct slot types as they are needed, but there are many elements that can be considered for this decision. These elements include the precedence and type of active connections that will be disrupted, the pending request, and the requests currently queued. The 25-kHz DAMA models expedite the experimentation necessary to solve this and many other optimization problems.

5 SIMULATION RESULTS

Single 25-kHz channel models of the SAC and AC mode DAMA have been developed to date, and are yielding useful results. Two findings were selected for inclusion here to illustrate how simulation is providing the utility described in Section 2 and fulfilling the objectives set forth in Section 3. The associated poster session will have a more complete exposition of the simulation results.

The primary potential bottleneck of the 25-kHz DAMA protocol is the return orderwire time slot, since all requests for communications access must be transmitted to the channel controller during this brief, open access period. This slot abides by the Slotted ALOHA protocol, a random access technique by which the transmitting terminals are only cognizant of their own access attempts. As a result, two or more terminals can select the same return orderwire slot for their access request, creating a collision situation (i.e., contention) for which at most one transmission will be correctly received. The usual recourse for the unsuccessful terminals is to retry after a random backoff (waiting) period. Increasing contention on this slot can thus considerably lengthen the connection setup time required. Moreover, an extreme level of contention that is left unchecked may completely block DAMA SATCOM resource access.

Since return orderwire contention can have such a critical impact on both the SAC and AC mode DAMA performance, it has been the primary focus of investigation thus far. One of the most valuable results obtained by simulation is insight into the complex interaction of the various contributing factors that determine the level of contention. The offered traffic load on the return orderwire slot consists not only of the initial transmissions of access requests, but also includes corresponding responses tied to the outcome of the received requests (e.g., connection complete indication, connection cancellation request, or acknowledgement of a denied connection request) and retransmissions. Certain messages that are ancillary to the access request process (e.g., terminal status reports) are also transmitted on the return orderwire slot, but are not considered significant contributors to contention due to their relative infrequency. Another key factor is the "capture effect" observed in 25-kHz DAMA operation, which can reduce contention via the channel controller correctly receiving the strongest transmission in a collision situation. The resulting intricate combination of these and other pertinent elements forms a nonlinear contention function which is best determined by simulation.

Figure 2 shows the essential relationship between the contention level (i.e., the probability of a collision on the return orderwire slot) and the mean interarrival time between access requests. An approximation of this relationship as determined by analysis is included with the simulation results, serving as an independent corroboration. The two curves are in close agreement for mean access request interarrival times exceeding 15 seconds, below which the contention underestimation of the analytically derived expression becomes apparent.

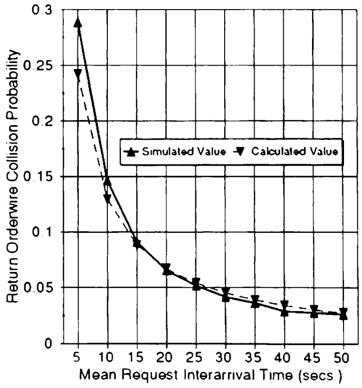

Figure 2: Contention Level Determined by Simulation and Analysis (P{collision} $\cong 1 - e^{-1.3866\lambda}$, where $1/\lambda$ = Mean Request Interarrival Time)

Figure 2 is very instructive in that it delineates the region of instability inherent to the Slotted ALOHA protocol. For traffic loading corresponding to a mean access request interarrival time of 20 seconds or greater, the number of retransmissions occurring is small and the resulting impact on performance is not significant. As the mean time between access requests drops below 20 seconds, the level of return orderwire contention increases rapidly. It is in this region that the protocol throughput can saturate and connection setup times can grow without bound. An appropriate feedback control mechanism is required which can recognize when the system is bordering on instability and swiftly act to decrease contention on the return orderwire slot. Simulation is being used to examine the trade-offs of various contention-limiting methods for 25-kHz DAMA application.

An indication of the potential for using the developed models to conduct useful design trade-off analyses is shown in Figure 3. The throughput performance of the SAC and AC mode DAMA systems is directly compared using an identical environment for each simulation (i.e., the same applied traffic characteristics, connection durations, network configuration and topology, channel error characteristics, and simulated 24-hour period).

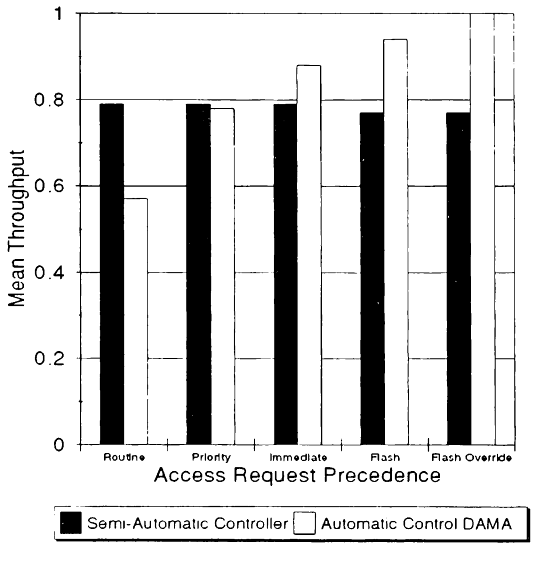

Figure 3: Throughput Versus Request Precedence for the SAC and AC Mode 25-kHz DAMA (request precedence increases rightward on the x-axis)

Figure 3 displays how the differences between the two systems produce distinct throughput performance. Mean throughput is approximately equal across precedence for the SAC, because this system processes access requests without regard to precedence. Mean throughput increases with precedence for AC mode DAMA, since it favors access requests of increasing precedence by enabling active connection preemption and frame format changes, and by implementing a more complex channel controller queue discipline. Access requests with a precedence greater than "Priority" show a definite throughput improvement for AC mode over the SAC. The reduced throughput of "Routine" precedence requests for AC mode DAMA points out the trade-off for this improvement.

One-to-one performance comparisons of the SAC and AC mode DAMA systems such as in this throughput example are important in providing justification for AC mode DAMA development and implementation. Simulation also will be invaluable in assessing the relative merits of the various prospective AC mode DAMA implementations to be examined.

6 CONCLUDING DISCUSSION

The DAMA waveform description contained in MIL-STD-188-183, and its implementation technology, are constantly being refined. Potential refinements include more capable user terminals, higher speed user slots, and additional frame formats. Such refinements should be easily accommodated in the models. Moreover, once the objectives and system configuration for AC mode are firm, its single channel model can be more fully exploited and the path will be paved for multi-channel AC mode DAMA modeling.

REFERENCES

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AUTHOR BIOGRAPHY

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