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SIMULATION ANALYSIS OF DEMAND ASSIGNED MULTIPLE ACCESS (DAMA) ALGORITHMS USED IN SATELLITE COMMUNICATIONS SYSTEMS

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ABSTRACT

A discrete event simulation model has been constructed for use in analyzing DAMA algorithms applied to satellite communications systems. The paper is divided into 4 parts: Introduction, description of problem, description of model, and simulation results. A discussion of DAMA, Time Division Multiple Access (TDMA) and the use of Burst Time Plans (BTPs) is followed by a high-level comparison of circuit connectivity within the INTELSAT VI and Advanced Communications Technology (ACTS) satellites. The simulation model's structure is described along with simulation results.

1. INTRODUCTION

The work herein was performed at COMSAT Laboratories in Clarksburg, Md. At the time, both authors were members of the ACTS Master Control Station (MCS) development team. Views and opinions expressed are solely the authors'.

The search for efficient DAMA algorithms for satellite communications networks becomes increasingly important as we enter the age of the "switchboard in the sky".

1.1 Definitions

A network which provides *Demand Assigned* conectivity establishes circuits between the caller and the called when the need arises. This is in contrast to the *Fixed* mode of providing connections. Caller A could only talk to Called B, but that circuit was always available.

Multiple Access refers to that property of networks which allows any node (port, element, user) to be connected to any other node.

Therefore, a communications network which provides *DAMA* allows any user to be call any other user on demand.

DAMA algorithms are logical methods of efficiently allocating limited network resources (frequencies, time-slices, bandwidth, etc.) to achieve high system utilization and low call-blocking rates.

System utilization and call-blocking rates tend to be factors traded off agains each other. This is due to the computations necessary to efficiently determine resource allocation. For example, a DAMA-based network controller may become so busy determining how to best implement the most recent connection request that it blocks incoming requests.

1.2 Time Division Multiple Access

A typical network of earth stations connected via satellite is shown in figure 1. (adapted from Spilker (1977)). Each ground terminal within the network transmits a burst of RF energy at its own pre-determined time.There are 4 ground terminals: **A**, **B**, **C** and **D**. The bursts are controlled by a system-wide master clock, and are usually separated by a small "guard time" to prevent overlap.

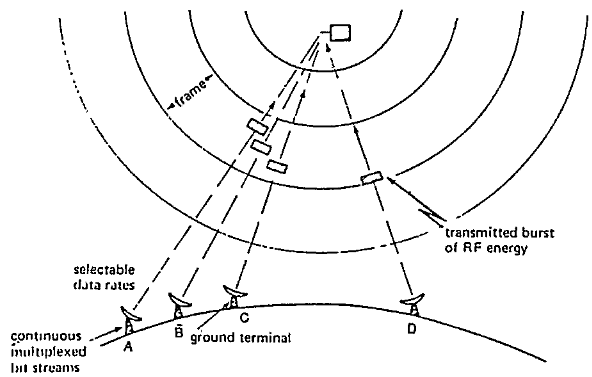

FIGURE 1: TYPICAL TDMA CONFIGURATION

A frame is typically 1 millisecond (ms) in duration. To reduce system overhead, many network designs have frames grouped into "superframes", which are in the neighborhood of 75 ms. Refer to Figure 2 for a hierarchical decomposition of the frame format for a typical TDMA system.

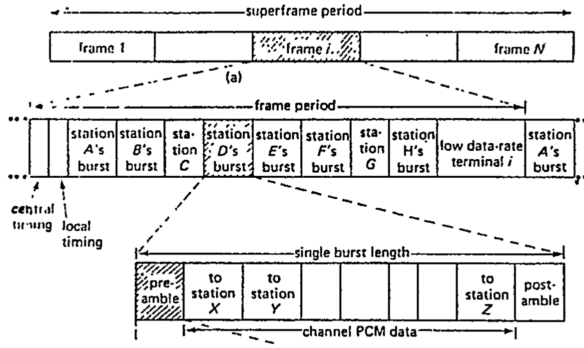

FIGURE 2: FORMAT STRUCTURE OF TYPICAL TDMA SYSTEM

At the highest level, a superframe consists of N one-millisecond frames. Each frame, in turn, consists of bursts from individual traffic stations. [The terms "ground terminal" and "traffic station" are used synonymously.]

Each burst is composed of PCM (pulse code modulated) data which are the actual voice/data circuits (channels). This example shows calls originating from traffic station **D** and destined to stations **X**, **Y** and **Z**.

The pre- and post- ambles contain overhead such as capacity requests, guard time, and timing/status information.

1.3. Burst Time Plan (BTP)

The BTP is a list of all active circuits and their associated time slots. A copy is kept in each traffic station. The ACTS network has a copy kept within the satellite as well.

Some networks (e.g., INTELSAT VI) have BTPs generated off-line using a mainframe computer. Network parameters such as number of circuits per traffic station, transmit and receive frequencies, transponder assignments are inputs to the BTP generator program. This is described in King (1982). The resulting BTP is then sent to each remote traffic station, and on a given command, all nodes switch to the new BTP. New BTPs are generated typically every few days.

Other networks, (e.g., ACTS) have BTPs generated and maintained in real-time by an on-line MCS (Master Control Station). Each remote traffic station is instructed by the MCS as to the start slot and length of its burst. Inbound orderwires containing requests for circuit connection/disconnection, equipment status, etc., are processed by the MCS. A new BTP may be generated once every few seconds, depending on system load and traffic patterns.

In both types of networks, foreground and background memories allow traffic stations to have their BTPs updated while not interfering with current network activity.

1.4 Updating the Burst Time Plan

Refer to figure 3 for this discussion. Terminal **A** has all its allocated slots busy with traffic, whereas Terminal **D** has 6 free slots.

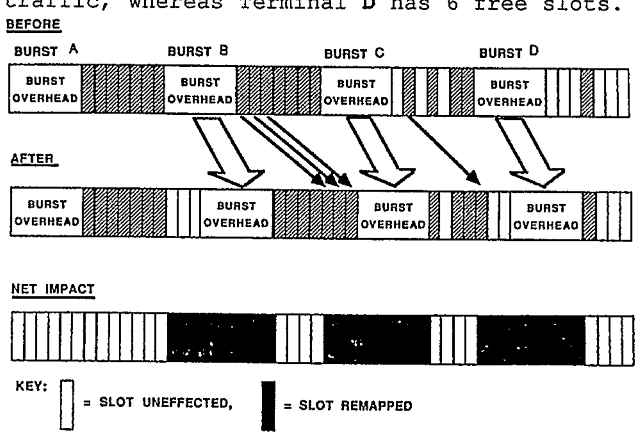

FIGURE 3: BURST MOVEMENT WITHIN TDMA SYSTEM

Should Terminal **A** require more capacity, it would be desirable to "borrow" free slots from neighboring Terminal **D**. If this were not possible, the attempted calls at **A** would be blocked.

To accomplish this "borrowing transaction", all traffic terminals that burst between **A** and **D** are affected. That is, since **A's** burst has expanded and **D's** has shrunk, all terminals in between must be shifted over.

The net impact is shown at the bottom of the figure: 24 slots have to be remapped.

2. PROBLEM DESCRIPTION

The main purpose of the simulation was to investigate factors which would affect updating the BTP in real-time. Such factors could include:

- o System load
- o Slot assignment technique
- o Switchover-to-new-BTP time
- o Slot Condensing Time
- o Burst Qualifier Thresholds

Before describing details of the above factors, it is worthwhile to analyze from end-to-end each step required to setup a call connection.

2.1 Call Processing Procedure

As stated earlier (section 1.3), that the ACTS system design requires copies of BTPs to be maintained in both the earth stations' and the satellite's memories. When a connectivity change occurred, all background memories would be updated by the MCS. At a coordinated moment, all nodes would switchover to what was the background. At that point, a new set of connections was in place.

Figure 4 is a simple example of a call being made from terminal 2 to terminal 1. Eight possible sources of delay are shown from left to right.

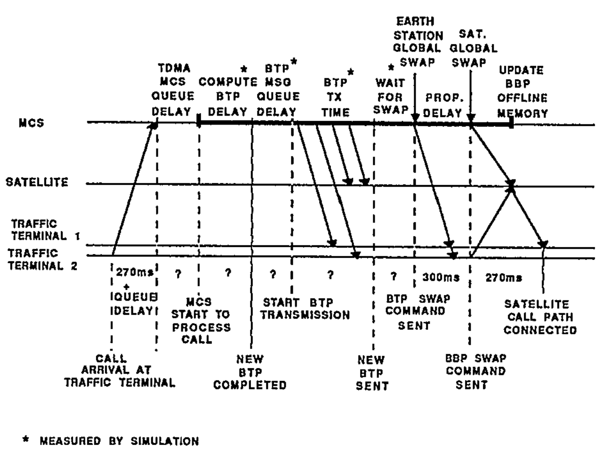

FIGURE 4: CALL SETUP PROCESSING TIME

Delay 1:
First the user at terminal 2 picks up the phone (goes off-hook). This causes the traffic terminal to send out a request for connection to the MCS via outbound orderwire.

Delay 2:
A delay occurs when the request arrives at the MCS's earth station, gets decoded and formatted with all the other requests, and eventually is received by the MCS.

Delay 3:
The MCS computes a new BTP.

Delay 4:
The commands for reformatting the earth station and satellite BTP wait for their turn to be transmitted.

Delay 5:
The commands are sent. (The length of transmission will depend on the number of slot-moving commands required.)

Delay 6:
After all BTP reformatting commands are sent, we must wait for the next SWAP (background and foreground memories) command from the MCS to the network of earth stations. [SWAP is sometimes referred to as GLOBAL SWITCHOVER or ARM]

Delay 7:
Transmission of the BTP SWAP takes 300 ms.

Delay 8:
As far as the traffic terminals are concerned, the connection is already made and #2 is sending information to #1. The MCS must also send the SWAP command to the satellite just prior to this so the connection can be established at the satellite.

Three of these delays (1, 7 and 8) are known. The simulation model was designed to investigate the unknown delays, and determine the end-to-end setup time.

We now discuss each factor which might cause further delays.

2.2 System Load

Perhaps the most significant factor affecting the BTP update process is system load. This determines

a) the total number of slots used

b) rate of calls coming into the system

c) traffic pattern. Calls may come evenly or unevely distributed over the network.

2.3 Slot assignment technique

In what manner should slots be assigned to calls? There are several options:

a) assign slots from center of burst and work outwards to edges.

b) assign slots from either right or left and work toward opposite side

c) assign slots randomly within burst

These options are similar to Memory Management schemes used by computer operating systems.

2.4 Switchover-to-new-BTP time

Two options are available here:

a) periodic (send every x seconds)
b) based on system load. The send swap command more often when system gets busy.

2.5 Slot condensing time

Similar to "garbage collection" in operating systems, this refers to periodically coalescing disperse slots within a burst. Having all free slots contiguous would reduce the amount of re-shuffling when an adjacent burst needed to "borrow".

2.6 Burst Qualifier Thresholds

There are several criteria that should be considered before the MCS borrows slots from a neighboring burst:

a) The number of free slots that must be available before any are borrowed. If set too high, the number of qualified bursts would decrease and the call might be blocked. If set too low, terminals could "nibble" away at their neighbor's capacity until none were left for the neighbor.

b) The minimum number of slots to borrow at a time. An optimal value would decrease the remapping and burst movement by borrowing >1 at a time. If set too high, performance would degrade due to the necessity of having to return slots to the "borrowee" burst.

c) The maximum percentage of free slots to borrow would determine how much capacity could be taken from a terminal on a given transaction. If set too high, borrowee terminals would soon have all their free slots taken away.

2.7 Two examples of satellites using DAMA

Intelsat VI IOR (Indian Ocean Region). Was launched in 1986 by Arianspace. It has three large hemispheric beams which provide a total of 33,600 channels. Full connectivity is available between all traffic stations. Changes to connectivity are implemented by updating the BTPs in the order of every other day.

ACTS. The ACTS satellite is currently scheduled for a 1990 Space Shuttle launch. This is a one year slip from original plan due to the Challenger accident. GE-Astro Division (formerly RCA) is systems integrator and will provide the spacecraft bus. TRW and Motorola are responsible for the spacecraft's payload. It consists of the Multibeam-antennae Communications Package (MCP) and Base Band Processor (BBP). COMSAT is providing the ground segment. This includes all equipment from the earth station antenna to the telephone equipment interface. The Master Control Station sets up all calls on an as-needed basis in real-time.

ACTS contains East and West Scan Beams. It "scans" by using an array of multiple feed horns in the satellite antennae and time-sequencing the moment any given "spot" illuminated in a pattern determined by the BBP.

3.0 THE SIMULATION MODEL

The simulation model was written in the C programming language to run under the VAX VMS operating system. Figure 5 shows the simulation model consisting of two layers: the Network Operating System (NOS) and the Application System.

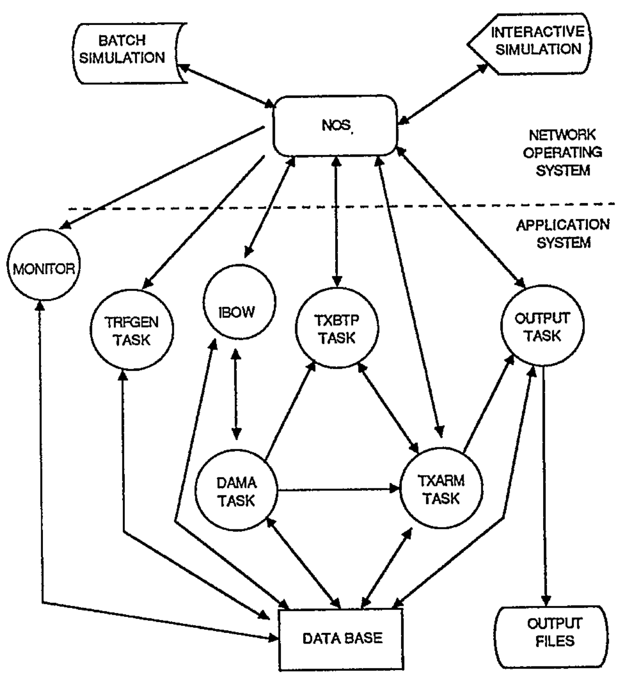

FIGURE 5: DAMA SIMULATION MODEL

NOS is a generic package of C routines and data structures similar to a multi-tasking operating system. It contains a scheduler, semaphores, event flags, a priority scheme, queue handlers and routines for setting/resetting timers.

Tasks are scheduled and will continue to execute until:

a) It needs to wait for another event to occur.

b) It suspends itself and sets a timer to simulate a delay.

In both cases its state becomes BLOCKED and it is placed on the READY queue.

Valid states for tasks are : RUNNING, BLOCKED and READY. READY indicates that whatever was causing it to be BLOCKED no longer is true.

The following list provides an example of the generic NOS routines available to be called by applications tasks:

1. DELAY (delay-time, timer-id) : a timer request is inserted in the delay queue. When the delay-time has expired, the calling task is rescheduled and the related event flat is set to signal the calling task.

2. CANCEL_TIMER (timer-id) : The specified timer is removed from the delay queue.

3. TEST-RESET-TIME-FLAG (timer-id) : the status of the event flag for a specified timer is returned and the event flag is reset.

The application tasks shown in figure 5 correspond nearly one-to-one with the delay points with a questionmark shown in figure 4.

applic. task name	delay point(s)
ibow	call arriving at terminal. transmission and queue delays
dama	computing btp
txbtp	btp msg queue delay btp tx delay
txarm	waiting for swap commands (earth station and satellite)

Two of the application tasks (monitor and output task) maintain statistics and output results.

trfgen is the traffic generator responsible for introducing calls into the simulation.

3.1 Input to Model

To run NOS, several questions must be answered before the simulation begins. A database is initialized with this information and the simulation is run accordingly.

The following list parameters are initialized:

length of simulation
call generation rate
slot allocation technique
name of output file
trace on/off
 trace calls
 trace time to compute BTP

display port status
switch-to-new-BTP period
number of trunks at each terminal
number of available slots
slot condensing period
min. number of slots to take
min. number available
max. number of slots to take (%)
How often to monitor statistics
traffic pattern

3.2 Output from Model

Immediately after initialization, all parameters are echoed back as shown in Figure 6.

```
/*******************************************/
/*                                         */
/*  CALL PROCESSING SIMULATION RESULT      */
/*                                         */
/*******************************************/

Simulation Parameters:
 call arriving rate:               200 (ms/call)
 simulation period:                70 (minutes)
 LBR DAMA Algorithm-id:            2
 Numbers of Traffic Stations:      20 (stations)
 Numbers of trunks:                140 (trunks/Station)
 ARM timing:                       400 (ms)
 UPLINK slot:                      1656 (110MBPS-Word)
 LEAST_BORROWING slots:            1 (slots)
 MAX_BORROWING_PERCENTAGE:         50 (percent)
 LENDER_QUALIFIER:                 1 (slots)
 Circuit arriving period:          RANDOM
```

FIGURE 6: INPUT PARAMETERS

When the simulation has ended, (in this case 70 minutes) several reports are generated. One is the call processing statistics shown in figure 7.

```
/****************************************************/
/*                                                  */
/*          CALL PROCESSING STATISTIC               */
/*                                                  */
/****************************************************/

total simulation seconds =3600
########################################

 total call setup   = 9068 (calls)
 total call release = 9059 (calls)
 total call blocked = 0 (calls)

########################################
Total queuing time in Traffic Station        =506442.00 (ms)
Total IBOW to MCS delay time                 =5628540.00 (ms)
Total request queue waiting time             =2401.00 (ms)
Total new BTP computing time                 =29366.00 (ms)
Total waiting time in the transmission queue =5526975.00 (ms)
Total new BTP transmission time              =146988.00 (ms)

Average queuing time in Traffic Station        =  27.94 (ms)/per call
Average IBOW to MCS delay time                 = 310.51 (ms)/per call
Average request queue waiting time             =   0.13 (ms)/per call
Average new BTP computing time                 =   1.62 (ms)/per call
Average waiting time in the transmission queue = 304.90 (ms)/per call
Average new BTP transmission time              =   8.11 (ms)/per call
 ARM propagation delay time                    = 300    (ms)/per call

 Average call delay                            = 953.21 (ms)/per call
```

FIGURE 7: CALL PROCESSING STATISTICS

Note that the time spent computing BTPs is almost insignificant when compared to the total end-to-end call setup time.

4. SIMULATION RESULTS

Several experiments were conducted to establish the credibility of the model. Each input parameter was varied over a wide range of values while holding the remaining parameters constant.

All results showed that transmission time and orderwire queueing delays accounted for the vast majority of the call setup time. Computing new BTPs never exceeded 2% of total setup time.

One group of experiments increased load while holding other parameters constant. Figure 8 shows the call setup time increasing almost linearly as a function of load. Figure 9 shows utilization rapidly increasing to a point, but when saturation occurs utilization goes down. At that point blocking goes up (see Figure 10).

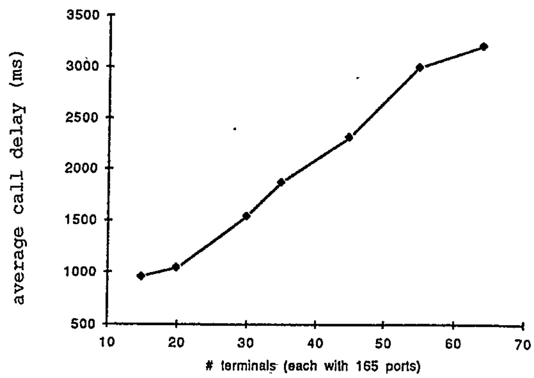

FIGURE 8: CALL DELAY vs. LOAD

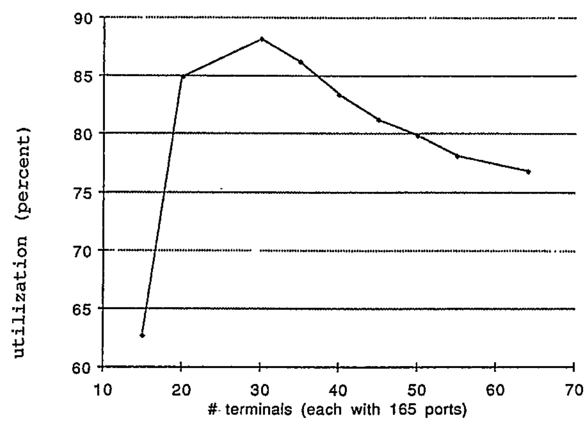

FIGURE 9: UTILIZATION vs. LOAD

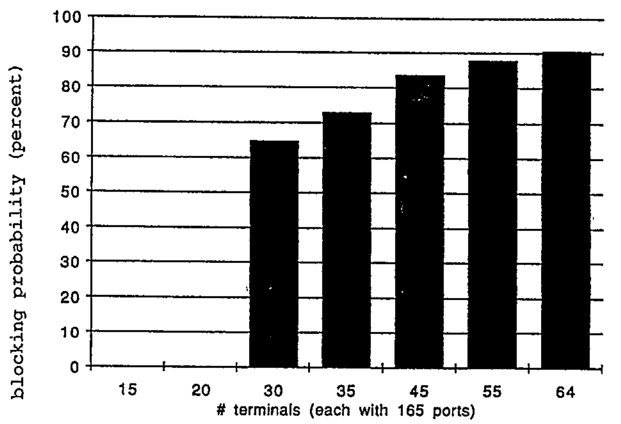

FIGURE 10: BLOCKING PROBABILITY vs. LOAD

Another group of experiments was conducted at a very high load, with DAMA-related factors being varied one-at-a-time. No significant improvements in system utilization or call blocking were observed.

For instance, by varying the minimum number of slots to lend, figures 11, 12 and 13 show a variation of <7% in any of the measured quanities. This was not surprising when one considers how small a portion of the total call setup time is affected by the DAMA-related factors.

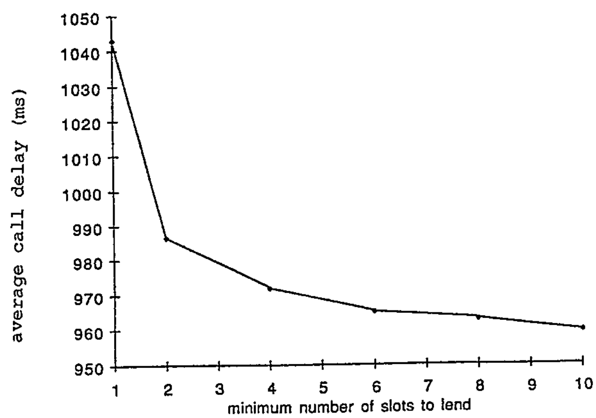

FIGURE 11: CALL DELAY vs. MIN. SLOTS

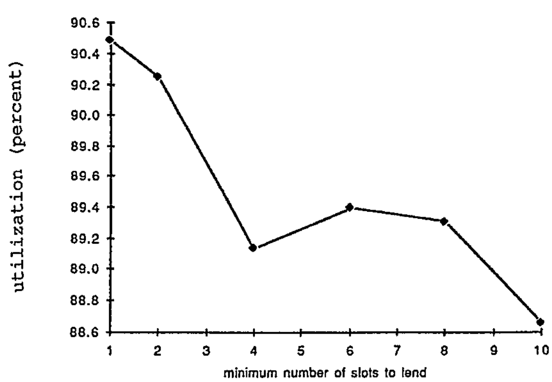

FIGURE 12: UTILIZATION vs. MIN. SLOTS

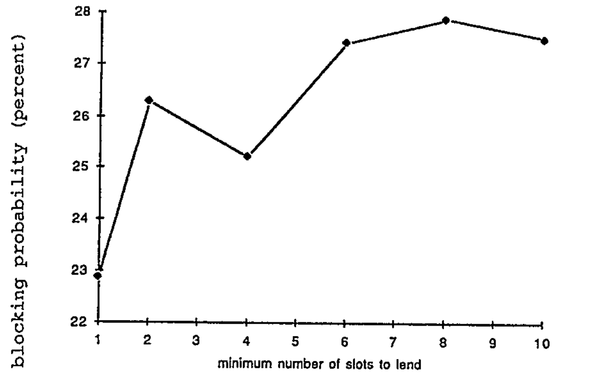

FIGURE 13: BLOCKING PROB. vs. MIN. SLOTS

5. SUMMARY AND CONCLUSION

Analysis of factors affecting a DAMA-based satellite communications system was conducted using a simulation model. Results indicate overall system performance with respect to call setup time, system utilization and call blocking is determined overwhelmingly by

a) system load
b) 22,300 miles between earth and satellite.

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BIOGRAPHIES

Howard S. Tsai received an M.S. in Computer Engineering from Case Western Reserve in 1983. His current interests include simulation, communication, articial intelligence, parallel processing and distributed systems.

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