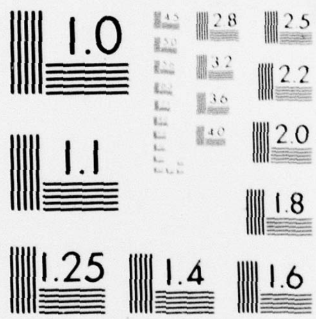
AD-A053 902 MASSACHUSETTS INST OF TECH LEXINGTON LINCOLN LAB F/G 17/2
PACKET SWITCHING IN A PROCESSING SATELLITE.(U)
AUG 77 J K DEROSA, L H OZAROW F19628-76-C-0002
UNCLASSIFIED JA-4774 ESD-TR-78-44 NL

1 OF 1
AD
A053902

END
DATE
FILMED
6-78
DDC




MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

# Packet Switching in a Processing Satellite

JOSEPH K. DEROSA AND LAWRENCE H. OZAROW

**Abstract—This brief note represents a simple but significant change in the thinking that is applied to satellite packet switching. It demonstrates that in a processing satellite there is no fundamental limitation to the efficiency and throughput of packet switching systems. With a minimal impact on spacecraft weight and power, throughput is increased by providing more capacity on the uplink than on the downlink. Efficiency is increased because the power-intensive downlink is more fully utilized. A slotted ALOHA example is given to show how the performance can be made to go from that of conventional slotted ALOHA to that of a TDM system. Several possible variations and far-reaching implications are indicated.**

Manuscript received August 3, 1977. This work was supported by the Defense Communications Agency.

The authors are with M.I.T. Lincoln Laboratory, Lexington, MA 02173.

## I. Introduction

It is well-known that the maximum throughput of a satellite channel using packet switching is much less than one packet per time slot [1], [2]. For slotted ALOHA it is 0.37 packets per time slot. The efficient utilization of the satellite resources is usually assumed to be limited by this throughput, and therefore the terms efficiency and throughput are often used interchangeably.

However, in a processing satellite additional uplink demodulators can be furnished at a modest cost in spacecraft weight and power. The primary cost is in providing the power amplifier for the downlink broadcast. Thus efficient utilization of the spacecraft resources requires efficient utilization of the downlink.

This brief note demonstrates that in a processing satellite there is no fundamental limitation to the efficiency and throughput of packet switching systems. In fact in a slotted ALOHA configuration they can be made to exceed the throughput obtained with a simple repeating satellite by a significant amount.

## II. Results of Analysis

Consider a processing satellite with $n$ FDMA uplinks and one downlink. The satellite time is partitioned into time slots of duration $T$ seconds with all packet transmissions synchronized to lie within a time slot at the satellite. A user may transmit a packet in any one of $n$ uplink channels chosen at random. The successful transmission of a user's packet in a time slot requires that

1) there is no contention on the chosen uplink, and
2) the satellite processor allocates the downlink slot to this packet (instead of one of the other successful packets).

If the packet is successful, the user receives an automatic acknowledgment after a round-trip transmission delay of $R$ time slots.

In the event of an unsuccessful transmission, the user again chooses an uplink channel at random and retransmits the packet in one of the next $K$ time slots, also chosen at random. Thus there are $nK$ cells to choose from, and the probability of repeated contentions is decreased (see Fig. 1).

The total traffic in any time slot is assumed to be Poisson[1] with a mean of $G$ packets/slot (or $G_n = G/n$ packets/cell). The average number of successful transmissions per slot is then given by

$$S = Gq \tag{1}$$

where $q = \Pr$ {a given packet is successful on uplink and downlink}. Note that $q$ can be expressed as

$$q = q_u q_d \tag{2}$$

where $q_u \triangleq \Pr$ {the given packet successfully enters the uplink cell} and $q_d \triangleq \Pr$ {packet enters downlink/successfully enters uplink cell}. Since the traffic in an uplink cell is Poisson with intensity $G/n$ per cell, the

[1] It can be shown that this assumption is true in the limit as $nK \to \infty$ when the new traffic generation is Poisson.

0018-9219/78/0100-0100$00.75 © 1978 IEEE

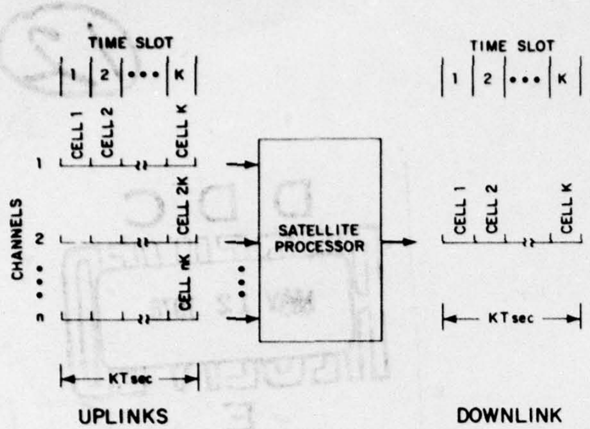



**Fig. 1. Packet switching in a processing satellite.**

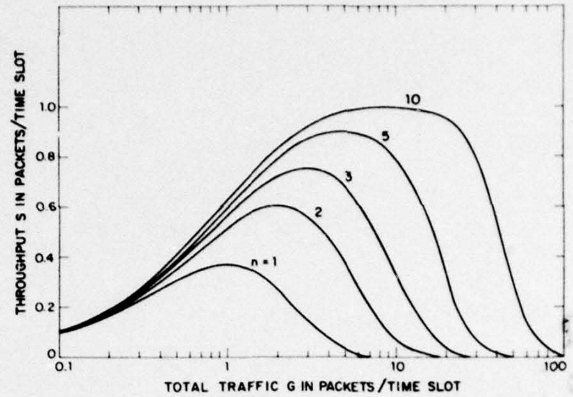



**Fig. 2. Throughput for slotted ALOHA in a processing satellite with n uplinks and one downlink.**

residual traffic is still Poisson, and $q_u$ = Pr {no other tries in cell}

$$q_u = e^{-G/n} \tag{3}$$

The probability that there are exactly $j$ other successes in the remaining $n - 1$ cells of the chosen time slot is given by a binomial probability law

$$P_j = \binom{n-1}{j} p_s^j (1 - p_s)^{n-1-j} \tag{4}$$

where $p_s \triangleq$ Pr {a success in a cell} = Pr {one Poisson arrival in a cell}

$$p_s = \frac{G}{n} e^{-G/n} \tag{5}$$

If the successful uplink packet being considered and the $j$ other successful packets have an equal chance of getting into the downlink slot, then

$$q_d = \sum_{j=0}^{n-1} \frac{1}{j+1} P_j. \tag{6}$$

Substituting (4) and (5) into (6) gives

$$q_d = \frac{1}{np_s} [1 - (1 - p_s)^n] = \frac{e^{G/n}}{G} \left[1 - \left(1 - \frac{G}{n} e^{-G/n}\right)^n\right] \tag{7}$$

Substituting (2), (3), and (7) into (1) gives the throughput per time slot

$$S = 1 - (1 - p_s)^n = 1 - \left(1 - \frac{G}{n} e^{-G/n}\right)^n \tag{8}$$

This is shown in Fig. 2.

The maximum value of $S$ occurs when $G = n$ and is given by

$$S_{max} = 1 - \left(1 - \frac{1}{e}\right)^n \tag{9}$$

Note that when $n = 1$, the slotted ALOHA throughput is $Ge^{-G}$ and the processing satellite acts identically to a repeater satellite [1], [2]. When there is a large number of uplinks (i.e., $n \to \infty$), the throughput approaches one packet per slot, and the downlink utilization approaches 100 percent (as in TDM). From a practical viewpoint, $n$ need not be very large before substantial gains in throughput are obtained. Fig. 1 shows that for $n > 3$, 75-percent throughput can be achieved, and for $n = 10$ nearly 100-percent efficiency is achieved.

The average delay (in number of time slots) from the transmission of a packet to the successful reception is given by

$$D = \sum_{r=0}^{\infty} \left[(R + 1) + r\left(\frac{K-1}{2} + R + 1\right)\right] Q_r$$

$$= (R + 1) + \bar{r}\left(\frac{K-1}{2} + R + 1\right) \tag{10}$$

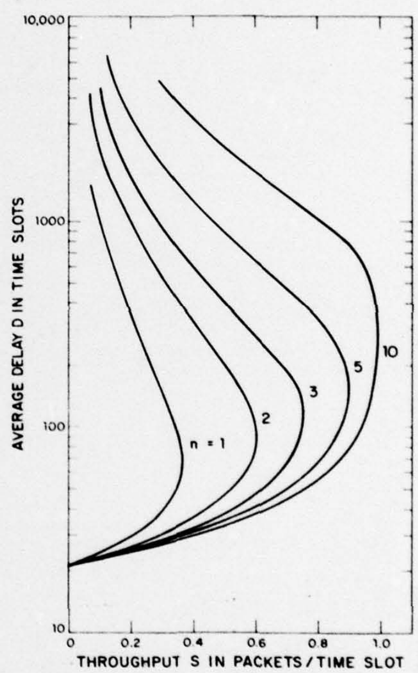



**Fig. 3. Average delay for slotted ALOHA in a processing satellite with n uplinks and one downlink.**

where $Q_r$ = Pr {successful transmission after $r$ retries} and $\bar{r}$ = average number of retries. (Recall that $R$ = round trip delay and the retry can go into any one of the next $K$ slots.) Under the assumption that the probability of success is the same on any try,[2] $r$ has a geometric distribution, i.e., $Q_r = q(1 - q)^r$ and $\bar{r} = (1 - q)/q$. A graph of $D$ versus $S$ with $R = 20$, $K = 15$ is shown in Fig. 3 for various $n$. In addition to the increased throughput at larger $n$, there is a lower average delay and more margin against saturation at any allowable operating point.

## III. Conclusions

In this correspondence it has been shown that the throughput, and efficiency, of a satellite packet switching system are substantially increased with a processing satellite. Efficiencies of close to 100 percent can be achieved at the expense of modest increases in processing

[2] This is reasonable for $K$ sufficiently large. See [2] and [3].

capability and hence spacecraft weight and power. Detailed consideration of delay, stability, and more exact modeling of the packet arrival process do not affect the fundamental nature of this result.

Several generalizations of this result become immediately obvious.

1) When the uplink is not power limited, increased capacity can be provided by using a higher burst rate on the uplink (i.e., more slots per frame on the uplink than the downlink).

2) Performance can be enhanced by providing a packet queue on the satellite at a cost of some prime power for random access memory. The additional waiting time in queue would be offset by the decrease in number of retries.

3) The satellite processor can be used to dynamically allocate circuits. Therefore, a packet switched network could ride "piggyback" on a circuit-switched (demand-assigned) network by using the presently unassigned satellite circuits.

Detailed performance and design tradeoffs associated with packet switching in a processing satellite will follow this expository note.

### References


[1] N. Abramson, "Packet switching with satellites," in *Proc. National Computer Conf.*, pp. 695–702, June 1973.

[2] L. Kleinrock and S. Lam, "Packet-switching in a slotted satellite channel," in *Proc. National Computer Conf.*, pp. 703–710, June 1973.

[3] L. G. Roberts, "Optimal retransmission delay for ALOHA system," ARPANET Satellite System Note 9, NIC #11291, July 3, 1972.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

## REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: ESD-TR-78-44
2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle): Packet Switching in a Processing Satellite.
5. TYPE OF REPORT & PERIOD COVERED: Journal Article
6. PERFORMING ORG. REPORT NUMBER: JA-4774
7. AUTHOR(s): DeRosa, Joseph K. Ozarow, Lawrence H.

   Joseph K./DeRosa, Lawrence H./Ozarow
8. CONTRACT OR GRANT NUMBER(s): F19628-76-C-0002
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Lincoln Laboratory, M.I.T. P.O. Box 73 Lexington, MA 02173
10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 33126K
11. CONTROLLING OFFICE NAME AND ADDRESS: Defense Communications Agency 8th St. & South Court House Rd. Arlington, VA 20390
12. REPORT DATE: 3 Aug[redacted]977
13. NUMBER OF PAGES: 3
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): Electronic Systems Division Hanscom Air Force Base Bedford, MA 01730
15. SECURITY CLASS. (of this report): UNCLASSIFIED

15a. DECLASSIFICATION DOWNGRADING SCHEDULE: n/a

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Proceedings of the IEEE, Vol. 66, No. 1, January 1978

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Packet switching Processing satellite Slotted ALOHA

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This brief note represents a simple but significant change in the thinking that is applied to satellite packet switching. It demonstrates that in a processing satellite there is no fundamental limitation to the efficiency and throughput of packet switching systems. With a minimal impact on spacecraft weight and power, throughput is increased by providing more capacity on the uplink than on the downlink. Efficiency is increased because the power-intensive downlink is more fully utilized. A slotted ALOHA example is given to show how the performance can be made to go from that of conventional slotted ALOHA to that of a TDM system. Several possible variations and far-reaching implications are indicated.

DD FORM 1473 1 JAN 73 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

207 650