PERFORMANCE ANALYSIS OF A MULTIPLE-ACCESS PROTOCOL FOR VSAT NETWORKS

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ABSTRACT

In this paper we analyze a model of the performance of a media access control protocol for VSAT networks. This protocol is a mixture of several multiple-access techniques employed to provide different kind of services. The model is solved numerically to obtain performance measures of interest to the network designer.

1. INTRODUCTION

In the recent years, there has been a growing interest in the design and analysis of access protocols suitable to be employed in VSAT technology based networks [1], [2], [4], [6]. VSAT networks have proved to be an economical and technical alternative for the deployment of wide area data networks. They usually operate in the Ku-band and require 1.2 to 1.8 m diameter antennas. Communications paths form a star connectivity and transmission rates varies from 56 to 256 Kbps from VSAT to hub, and from 512 Kbps to 21 Mbps from hub to VSAT. In this kind of networks it is mandatory to keep the terminal complexity as low as possible. Random access protocols are very adequate for the traffic scenario that characterizes VSAT applications [3], i.e., a large number of bursty terminal with low data rate. They also fulfill the simplicity requirements for keeping the terminal cost as low as possible. However, some services that can be provided by VSAT networks, such as voice, have low delay and high bandwidth requirements. In order to accomplish them, some synchronization procedures must be performed and some kind of circuit connection be allowed. New sophisticated access methods have been proposed in the literature, such us SREJ-ALOHA [8], RAN [7] and others.

In this paper we analyze the performance of an access protocol with circuit allocation capabilities, and develop an stochastic model that would be useful to evaluate the impact that the establishment of circuits has on other kind of connections, such as DAMA packet connections.

2. PROTOCOL DEFINITION

The protocol we are going to analyze implements the Media Access Control sublayer functions of the Data Link Control Layer. We don not consider the interaction with upper layers, such as the LLC sublayer.

It can be described as a mixture of slotted ALOHA and DAMA TDMA protocol with packet and circuit connections. The channel is divided in frames. Each frame is composed of slots (an integer number of bytes) for reservation and slots for data. Data slots can be accessed randomly or reserving them in the reservation slots. Reserved slots are of two different kinds: for circuit connections and for packet connections. In a circuit connection, a number of slots are allocated for a channel in all the subsequent frames, until a dislocation petition is processed. Packet connection corresponds to the usual DAMA TDMA connection, where space is reserved in a packet by packet basis. Circuit connections are thought for services like voice or long data files transfer, either delay sensitive or with high bandwidth requirements. Packet connections are convenient for short data transfer. Random access is convenient for data transmissions when the traffic is low and bursty. In these circumstances, it produces a lower delay than DAMA packet connections and implies a lower processing complexity. The portion of frame for random access and for reserved slots is fixed for each network configuration. Reservations are met on a first-come first-served basis.

In order to maximize the throughput of the network and given the relative low bit rate, it is convenient to keep the number of reservation slots as low as possible. It is not feasible in a VSAT network to have a reservation slot for each terminal station. A more realistic approach is to think that it is possible to make only one reservation per frame, perhaps more depending on the bit rate. So, procedures to keep the reservation traffic as low as possible and guarantee stability are necessary, such as to attach the petition for space for a new packet to the one being sent, or to let the allocation/disallocation petitions of circuit connections be processed only once per a number of frames. The contention scheme for the reservation is slotted ALOHA. All these particularities are taken into account in the proposed stochastic model of the protocol.

In the following points, we analyze this protocol considering that there is space in the frame for only one reservation.

3. ANALYTICAL MODELING

The analysis of the proposed scheme will be divided into three parts:
- The acquisition of the slots for reservation for the traffic.
- The actual acquisition and usage of the data slots.
- The acquisition and usage of the random access slots.

3.1. RESERVATION ACCESS

In this paragraph we analyze the acquisition process assuming that it can be performed only one reservation per frame.

Every time that a user wants to perform one of the following actions:
- to reserve space for a circuit connection
- to reserve space for a packet connection
- to free a circuit connection
it sends a request packet in the first reservation space available.

We will assume that time between consecutive petitions follows the exponential distribution. The mean reservation traffic rate can be calculated as:
\[
\lambda = (\sum 2 \cdot \lambda c + \mu b \cdot \lambda b) \cdot T
\]

where \( \lambda c \) and \( \lambda b \) are the new connections petitions rate of each of the network terminals, \( \mu b \) is the mean number of packets transmitted in each packet connection and \( T \) is the frame duration. \( \lambda c \) is multiplied by 2 because each circuit connection implies a disconnection. A higher throughput in the reservation channel is got adding the new packet request to the data packet. Then

\[
\lambda = (\sum 2 \cdot \lambda c + \lambda b) \cdot T
\]

As usual, the behaviour of the slotted ALOHA is modeled as a discrete time Markov chain [9]. We will assume that there are \( N \) stations in the network, that generate a common Poissonian traffic of rate \( \lambda N \). Of these \( N \) stations, \( n \) are backlogged, i.e., they are waiting for retransmitting a collided packet. We will suppose that each backlogged or systemtransmits a collided packet in the next slot with probability \( p_r \). So, the number of slots between the moment that an station is aware that a collision has taken place and the collided packet is retransmitted is a geometric random variable of value \( i \) with probability \( p_r \). \((1-p_r)\)\(^i\).

The probability that an unbacklogged station transmit a packet in a slot is given by:

\[
p_e = 1 - e^{-\lambda N/N}
\]

Let \( Q_e(1,n) \) be the probability that \( i \) unbacklogged stations transmit a packet and \( Q_r(1,n) \) the probability that \( i \) backlogged stations retransmit a packet, they will be given by the following expressions:

\[
Q_e(1,n) = \left( \frac{n}{N} \right) \cdot (1 - p_e)^{N-n} \cdot p_e^j
\]

\[
Q_r(1,n) = \left( \frac{n}{N} \right) \cdot (1 - p_e)^n \cdot p_e^j
\]

We will define the state of the system as the number \( n \) of backlogged packets waiting for being transmitted. From one slot to the next, the value of the state changes by the number of new arrivals transmitted by unbacklogged stations less one if a packet is transmitted successfully. A packet is transmitted successfully if only one new arrival and no backlogged packet, or no new arrival and one backlogged packet, is transmitted. So, the transition probability of the chain is given by:

\[
P_{nn+1} = Q_e(1,n) \]

\[
2s_i s(N-n)
\]

\[
Q_e(1,n) 
\]

\[
Q_e(1,n) - (1 - Q_r(0,n))
\]

\[
Q_e(1,n) \cdot Q_r(0,n)
\]

\[
Q_r(1,n) - (1 - Q_r(1,n))
\]

\[
Q_r(0,n) - Q_r(1,n)
\]

The steady state probability vector will be given by the solution of the system \( \pi = \pi P \)

Once determined the matrix \( P \), it is easy to calculate the mean number of backlogged packets (by over-relaxation or by geometric methods) as:

\[
\bar{n} = \sum_{i=0}^{N} i \cdot \pi_i
\]

The probability that a packet is transmitted successfully is given by:

\[
P_{\text{succ}} = Q_e(1,\bar{n}) \cdot Q_r(0,\bar{n}) + Q_r(0,\bar{n}) \cdot Q_r(1,\bar{n})
\]

Developing this expression, we have:

\[
P_{\text{succ}} = \left( \frac{(N-\bar{n}) \cdot p_e + \bar{n} \cdot p_r}{1 - p_e} \right) \cdot (1 - p_e)^\bar{n} \cdot (1 - p_r)^\bar{n}
\]

Employing the approximation:

\[
(1 - x)^y = e^{-xy}
\]

for small \( x \), we obtain:

\[
P_{\text{succ}} = G(\bar{n}) \cdot e^{-G(\bar{n})}
\]

where:

\[
G(\bar{n}) = (N-\bar{n}) \cdot p_e + \bar{n} \cdot p_r
\]

### 3.2. DATA TRANSMISSION

The part of the channel employed for the transmission of the data traffic previously reserved has been modeled by means of a finite state Markov chain. The time unit is the frame and the state of the system is the pair of the number of circuit and packet messages that are currently being transmitted. The possibility of employing the frame as the time unit, given that each new packet connection petition requires a round trip plus processing time in order to be allocated, is based in the application of the Poisson processes property known as PASTA (Poisson Arrivals See Time Averages) [10], and its extensions, ASTA and EPESTA [11] [12]. Messages are divided in bursts of an integer number of slots. Circuit and packet bursts may have different size.

The first problem to solve is of combinatorial nature: to determine the possible states and transitions between states. Given an state, not all the transitions are possible. So, we have grouped them in eight sets in order to calculate the transition probability matrix.

The maximum number of possible states will be \( N \cdot N \cdot m = N \cdot m^2 \). Where \( m \) is the space for reserved data transmission in the frame and \( x \) is the burst size. But only the states that accomplish \((i,j) \neq (i',j') \neq (i',j'') \) will be possible. If \((i',j') \neq (i',j'') \) does not satisfy this condition.

\[
P((i,j),\omega((i',j'))) = 0
\]

In order to simplify the notation, we will define the following probabilities:

\[
P(P) = P_{\text{succ}} \cdot e^{-\lambda T}
\]

\[
P(nP) = 1 - P_{\text{succ}} \cdot e^{-\lambda T}
\]

\[
P(C) = \frac{1}{N} \cdot P_{\text{succ}} \cdot \lambda T \cdot e^{-\lambda T}
\]

\[
P(\bar{n}C) = 1 - \frac{1}{N} \cdot P_{\text{succ}} \cdot \lambda T \cdot e^{-\lambda T}
\]

\[
P((i-x,i,P)) = \text{Probability that } x \text{ terminals have not a new packet to transmit the next frame} = \]

\[
\left( \frac{i}{i-x} \right) \cdot (1 - e^{-\mu T}) \cdot (1 - e^{-\mu T}) \cdot e^{-\mu T} (i-1) \]

\[
P((i-1,i,P)) = (1 - e^{-\mu T})
\]

\[
\Phi(i,j) = 1 \text{ st } (i,j) \in \text{(Possible states)} \equiv Q
\]

\[
\Phi(0,i,j) = 0 \text{ st } (i,j) \notin \text{(Possible states)} \equiv Q
\]

\[
P(1,j,C) = \text{The same for circuit connections} =
\]

\[
\frac{1}{N} \cdot P_{\text{succ}} \cdot (1 - e^{-\mu T})
\]

\[
P(0,j,C) = 1 - \frac{1}{N} \cdot P_{\text{succ}} \cdot (1 - e^{-\mu T})
\]

Where \( P_{\text{succ}} \) is the no-collision probability in the reservation channel, \( \eta \) is the number of frames between the processing of two circuit petitions, \( 1/\mu_c \) and \( 1/\mu_p \) are the mean (exponentially distributed) duration time per connection.

The entries of the transition matrix are calculated as is indicated below:

**GROUP 1**

Transitions from state \((0,0)\).
\[ P((0,0) \rightarrow (1,0)) = P(P) \cdot P(nC) \]
\[ P((0,0) \rightarrow (0,1)) = P(nP) \cdot P(C) \]
\[ P((0,0) \rightarrow (0,0)) = P(nP) \cdot P(nC) \]
\[ P((0,0) \rightarrow (1,1)) \equiv P(P) \cdot P(C) \]

**GROUP 2**

From \((i,0) \rightarrow (i+1,0) \in \Omega.\]
\[ P((i,0) \rightarrow (x,0)) \equiv P(nC) \cdot [P((i-x,1,P) \cdot PnP) + P((i-x+1,1,P) \cdot P(P))] \]
\[ P((i,0) \rightarrow (0,0)) \equiv P(nC) \cdot P(O,1,P) + P(P) \cdot P(1,1,P) \]
\[ P((i,0) \rightarrow (1,0)) \equiv P(nC) \cdot P(O,1,P) + P(P) \cdot P(1,1,P) \]
\[ P((i,0) \rightarrow (0,1)) \equiv P(nC) \cdot P(O,1,P) + P(P) \cdot P(1,1,P) \]
\[ P((i,0) \rightarrow (1,1)) \equiv P(nC) \cdot P(O,1,P) + P(P) \cdot P(1,1,P) \]

\[ P((i,0) \rightarrow (x,0)) \equiv P(nC) \cdot [P((i-x,1,P) \cdot P(nP) + P((i-x+1,1,P) \cdot P(P))] \]
\[ P((i,0) \rightarrow (0,0)) \equiv P(nC) \cdot P(O,1,P) + P(P) \cdot P(1,1,P) \]
\[ P((i,0) \rightarrow (1,0)) \equiv P(nC) \cdot P(O,1,P) + P(P) \cdot P(1,1,P) \]
\[ P((i,0) \rightarrow (0,1)) \equiv P(nC) \cdot P(O,1,P) + P(P) \cdot P(1,1,P) \]
\[ P((i,0) \rightarrow (1,1)) \equiv P(nC) \cdot P(O,1,P) + P(P) \cdot P(1,1,P) \]

**GROUP 3**

From \((i,0).\]
\[ P((i,0) \rightarrow (x,0)) \equiv P((0,i) \rightarrow (i-1,x,P) = P(nC) \cdot [P((i-x,1,i,P) \cdot P(nP) + P((i-x+1,1,i,P) \cdot P(P))] \]
\[ P((i,0) \rightarrow (0,0)) \equiv P((0,i) \rightarrow (1,1,i,P) \cdot P(nP) + P((1,i) \rightarrow (1,i,P) \cdot P(P))] \]
\[ P((i,0) \rightarrow (1,0)) \equiv P((0,i) \rightarrow (1,1,i,P) \cdot P(nP) + P((1,i) \rightarrow (1,i,P) \cdot P(P))] \]
\[ P((i,0) \rightarrow (0,1)) \equiv P((0,i) \rightarrow (1,1,i,P) \cdot P(nP) + P((1,i) \rightarrow (1,i,P) \cdot P(P))] \]
\[ P((i,0) \rightarrow (1,1)) \equiv P((0,i) \rightarrow (1,1,i,P) \cdot P(nP) + P((1,i) \rightarrow (1,i,P) \cdot P(P))] \]

**GROUP 4**

From \((j,0) \forall j \in [1, j-1].\]
\[ P((0,j) \rightarrow (1,j)) \equiv P((0,j) \rightarrow (0,j) \cdot P(1,1,j,C) \cdot P(nC) + P((1,j) \rightarrow (1,j) \cdot P(1,1,j,C) \cdot P(nC) \]
\[ P((0,j) \rightarrow (1,j+1)) \equiv P((0,j) \rightarrow (1,j) \cdot P(0,1,j,C) \cdot P(nC) + P((1,j+1) \rightarrow (1,j+1) \cdot P(1,1,j+1,C) \cdot P(nC) \]
\[ P((0,j) \rightarrow (0,j-1)) \equiv P((0,j) \rightarrow (0,j) \cdot P(1,1,j-1,C) \cdot P(nC) + P((1,j-1) \rightarrow (1,j-1) \cdot P(1,1,j-1,C) \cdot P(nC) \]
\[ P((0,j) \rightarrow (0,j)) \equiv P((0,j) \rightarrow (0,j) \cdot P(1,1,j,C) \cdot P(nC) + P((1,j) \rightarrow (1,j) \cdot P(1,1,j,C) \cdot P(nC) \]

**GROUP 5**

From \((i,j), \text{ such that } i \in [1, i-1]\)
\[ j \in [1, j-1].\]
\[ P((i,j) \rightarrow (x,j)) \equiv P((0,j) \rightarrow (1,j) \cdot P(0,1,j,C) \cdot P(nC) \]
\[ P((i,j) \rightarrow (0,j)) \equiv P((0,j) \rightarrow (1,j) \cdot P(0,1,j,C) \cdot P(nC) + P((1,j) \rightarrow (1,j) \cdot P(1,1,j,C) \cdot P(nC) \]
\[ P((i,j) \rightarrow (0,j+1)) \equiv P((0,j) \rightarrow (1,j) \cdot P(0,1,j,C) \cdot P(nC) + P((1,j+1) \rightarrow (1,j+1) \cdot P(1,1,j+1,C) \cdot P(nC) \]
\[ P((i,j) \rightarrow (0,j-1)) \equiv P((0,j) \rightarrow (1,j) \cdot P(0,1,j,C) \cdot P(nC) + P((1,j-1) \rightarrow (1,j-1) \cdot P(1,1,j-1,C) \cdot P(nC) \]
\[ P((i,j) \rightarrow (1,j+1)) \equiv P((0,j) \rightarrow (1,j) \cdot P(0,1,j,C) \cdot P(nC) + P((1,j+1) \rightarrow (1,j+1) \cdot P(1,1,j+1,C) \cdot P(nC) \]
\[ P((i,j) \rightarrow (1,j-1)) \equiv P((0,j) \rightarrow (1,j) \cdot P(0,1,j,C) \cdot P(nC) + P((1,j-1) \rightarrow (1,j-1) \cdot P(1,1,j-1,C) \cdot P(nC) \]
\[ P((i,j) \rightarrow (1,j)) \equiv P((0,j) \rightarrow (1,j) \cdot P(0,1,j,C) \cdot P(nC) + P((1,j) \rightarrow (1,j) \cdot P(1,1,j,C) \cdot P(nC) \]

\[ \text{where } jal \text{ is such that:} \]
\[ (j \in [1, j-1])\cdot x = 1, x \geq d \, / \, ja1 = 0 \]

\[ 0 < x < 1 \]
This model is thought to be employed in order to estimate some interesting parameters that characterize the behavior of the network, such as:
- Blocking Probability,
- Throughput, defined as
- Packet arrival rate \( x \) (1 - Blocking Probability)
- Response time, defined as
- Delay

\[ E(\text{Sent Packets - Acknowledged Packets})/\text{Throughput} \]

for given traffic and configuration conditions.

A packet is said to be blocked when it is not possible to send it because there is not space available in the transmission channel. For circuit traffic, the sum of all \( w \) associated to an state \((i,j)\) such that:

\[(i+1)\cdot x + j \cdot x > d\]

is the blocking probability. In the way for packet traffic.

Taking into account the error probability of the link, the probability of losing a packet \( P_L \) is given by the expression:

\[ P_L = P_s + P_x + P_s \cdot P_x \]

where \( P_s \) is the probability of losing a packet due to error introduced by the link.

If all lost packets are retransmitted, the packet arrival rate is modified as:

\[ \lambda' = \lambda/(1-P_L) \]

The delay introduced can be estimated as:

\[ D_m = D_m + T_{R} \cdot P_L/(1-P_L) \]

where \( D_m \) is the delay introduced by the transmissions, \( D_m \) is the delay due to transmission y \( T_m \) is the mean retransmission time. \( T_m \) is a function of the backoff algorithm selected, and usually it is a function of \( \lambda' \).

5. Numerical Results

A simulation model has been developed in order to estimate the accuracy of the analytical model. A 56 kbps satellite channel was considered, with 50 slots frames and 6 bytes slots. Bursts duration was 20 slots for circuit connections and 10 slots for packet connections. It was possible to process only one reservation petition per frame and it was not provided capacity for random access. The results obtained are reflected in the figure.
REFERENCES


