Analysis of Blocking and Clipping for TDM in Satellite Communication Systems

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***Abstract* – This paper presents the analysis of *time-division multiplexing* (TDM) applied to satellite communication systems. We evaluate multiplexing systems in which the number of input sources is greater than the number of available channels. We present analysis and simulation of blocking and clipping probabilities for TDM technology. For the blocking situation in synchronous TDM, we investigate the blocking probability and the average number of busy channels that can be delivered. For the clipping in statistical TDM, we examine the clipping probability and the expected number of busy channels that can be delivered.**

***Keywords* – Time-division multiplexing (TDM), Satellite communications, Blocking and clipping probabilities.**

I. INTRODUCTION

The technology of satellite communications can support fixed and wireless data, voice, and video communications, the Internet connections, and enterprise networking. Satellite communication successfully uses continuously transmitted signal of Time-Division Multiplexing (TDM) as in the outbound (downlink) for an improvement of transmission quality instead of Orthogonal Frequency Division Multiplexing (OFDM), because of the linearity requirement on the power amplifier. TDMs are used in satellite networks for maximum transmission capacity of a high bandwidth line. Multiplexing allows many communication sources to transmit data over a single physical line.

With a typical time-division multiplexing, users take turns in a predefined fashion, each one periodically getting the entire bandwidth for a portion of the total scanning time. Given *n* inputs, time is divided into frames, and each frame is further subdivided into time slots, or channels. Each channel is allocated to one input. This type of multiplexing can be used only for digital data. Packets arrive on *c* lines, and the multiplexer scans them, forming a frame with *c* channels on its outgoing link. In practice, packet size is variable. Thus, to multiplex variable-sized packets, additional hardware is needed for efficient scanning and synchronization. TDM can be either *synchronous* or *statistical* and it has been used with other techniques as solution for satellite communications networks such as TDMA (Time division Multiple access), FDMA (Frequency division Multiple access), and PAMA (Pre-Assigned Multiple Access). There are a number of multiplexing methods used in satellite communication systems. One of the commonly used methods used in such systems is the TDM technology as in [1- 4]. Blocking and statistical probabilities are applied for TDM multiplexing as in [5-14]. In this paper we will analysis and simulate the blocking and statistical probabilities of TDM applied to satellite communications systems.

II. MULTIPLEXING MODELS AND RESULTS

Figure 1 shows a satellite communication system using TDM technology in interactive and sending/receiving different applications based on the importance of response time. The TDM used in the outbound link between the source (sender or host) and the user (receiver). A time-division multiplexing (TDM) system is a high-speed data stream scheme which acts at layer 1 (physical layer) of OSI model and at the layer 4 (network interface) of TCP/IP model. In TDMs Technology, users take turns in a predefined way, each one periodically getting the entire bandwidth for a portion of the total scanning time. The input sources, s, is divided into frames, and each frame is subdivided into time slots (channels), c, where each channel is allocated to one input as in Fig. 2. Packets arrive on s lines, and the multiplexer scans them, forming a frame with c channels on its outgoing link. There are two different types of TDMs to deal with the different ways in which channels of frames use could be allocated, Synchronous and statistical (asynchronous).

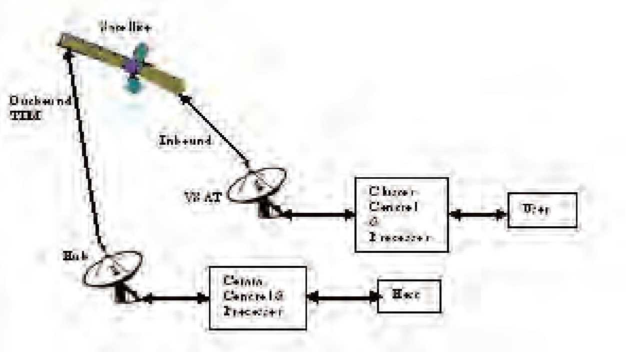

Fig. 1 Satellite communication System with TDM

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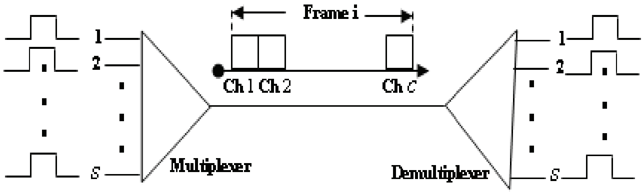

Fig. 2 A Time-division multiplexer (TDM) with s inputs and c channels

A. Synchronous TDM

In synchronous TDM, a frame is divided in a fixed–sized channels and channels are allocated to input sources in a fixed way. The QoS of synchronous TDM is base on how its transmission system is set up. For example, the multiplexer is inefficient when the number of users is greater than the available channels. This is true since the multiplexer scans all input sources lines without exceptions and the scanning time for each input source line (each connected to a user) is reallocated; as well as this time for a particular input source line is not altered by the system control. The scanner should stay on that input source line, whether or not there is data for scanning within that time slot. A synchronous TDM can also be programmed to produce same-sized frames, the lack of data in any channel potentially creates changes to average bit rate on the ongoing link.

To analyze a synchronous multiplexer, let t_a and t_d be the mean time for active input source and the mean time for idle input source respectively. Assuming that values of t_a and t_d are random and exponentially distributed. Also, consider a TDM with number of requesting input sources, s, is greater than available channels, c, where $s > c$, the TDM will react by blocking. The unassigned input sources are not transmitted and therefore remain inactive. The probability that an input source is active, ρ, can be obtained by $\rho = \frac{t_a}{t_a + t_d}$.

Let $P_s(j)$ be the probability of j different inputs out of s are active

$$P_s(j) = \binom{s}{j} \rho^j (1-\rho)^{s-j}, \qquad (1)$$

where $1 \le j \le s$. We know that $\sum_{j=0}^{c} p_s(j)$ can never be equal to 1 and in fact we must have $\sum_{j=0}^{s} p_s(j) = 1$. This can lead to normalization of $P_s(j)$ over c available channels. Thus, probability of j different output of c available channels $P_c(j)$ is given by

$$P_c(j) = \frac{\binom{s}{j}\left(\frac{\rho}{1-\rho}\right)^j}{\sum_{i=0}^{c}\binom{s}{i}\left(\frac{\rho}{1-\rho}\right)^i}, \qquad (2)$$

where $0 \le j \le c$ and $0 \le i \le c$. The blocking probability $P_s(c)$ can be obtained when $j = c$.

$$P_s(c) = \frac{\binom{s}{c}\left(\frac{t_a}{t_d}\right)^c}{\sum_{i=0}^{c}\binom{s}{i}\left(\frac{t_a}{t_d}\right)^i}, \qquad (3)$$

where in general $0 \le i \le c$.

Figure 3 shows the blocking probability for the fixed number of sources (s =10) and different numbers of channels ($c = 2$, $c = 5$, and $c = 10$). The blocking probability clearly rises with the increased utilization, ρ, for all three cases; and also it is higher when a fewer number of channels, c, is available.

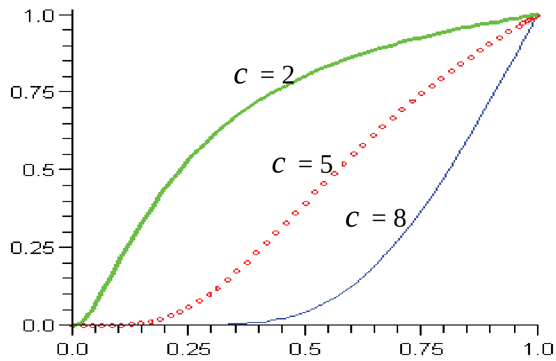

Fig. 3 Comparison of blocking probability, $P_s(c)$ vs. probability of active input source, ρ, with $0 \le \rho \le 1$, for s =10, c = 2, 5, and 8.

Then, we can calculate the expected number of busy channels for the multiplexer, $E_c(b)$, by

$$E_c(b) = \frac{\sum_{j=1}^{c} j\binom{s}{j}\left(\frac{t_a}{t_d}\right)^j}{\sum_{i=0}^{c}\binom{s}{i}\left(\frac{t_a}{t_d}\right)^i}, \qquad (4)$$

where $1 \le j \le c$, $0 \le i \le c$ and $\left(\frac{\rho}{1-\rho}\right) = \left(\frac{t_a}{t_d}\right)$.

Figure 4 shows the expected number of busy (unavailable) channels for fixed number of sources ($s = 10$) with different numbers of channels (*C=2*, *C=5*, and *C=8*). The expected number of busy channels of for *C=5* is higher than the one for *C=2* channels and lower than *C=8.*

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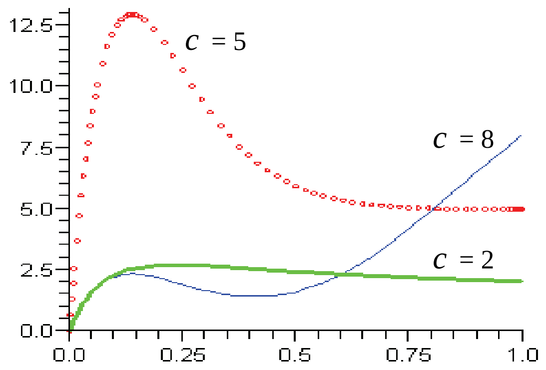

Fig. 4 Comparison of expected number of busy available channels, $E_c(b)$, vs. probability of active input source, ρ, where $0 \le \rho \le 1$ for $s = 10$, c = 2, 5, and 8

B. Statistical TDM

Statistical TDM method has high efficiency because a frame's time slots are dynamically allocated, based on demand and it removes all the empty slots on a frame. But, it is difficult to give a grantee QoS, because the requirement that additional overhead be attached to each outgoing channel. This additional data is needed because each channel must carry information about which input source line it belongs to. The frame length is available not only because of different channel sizes but also because of the possible absence of some channels.

We consider that t_a and t_d as random and exponentially distributed. Also, consider a TDM with number of requesting input sources, s, is greater than available channels, c, where $s > c$, the TDM will reacts by clipping; the unassigned input sources are partially transmitted.

If more than c inputs channels are active, we can dynamically choose c out of s active sources and temporarily block other sources. In this temporariy blocking, the source is forced to clip or lose data for a short period of time, where the amount of data lost depends on t_a, t_d, s, and c, but the source may return to a scanning scenario if a channel becomes free. This method maximizes the use of the common transmission line and offers a method of using the multiplexer bandwidth in silence mode.

The clipping probability, $P_i(l)$, or the probability that an idle source finds at least c channels busy at the time it becomes active, can be calculated by considering all s sources minus 1 (the examining source)

$$P_i(l) = \sum_{i=c}^{s-1} \binom{s-1}{i} \rho^i (1-\rho)^{s-1-i}, \qquad (5)$$

where $c \le i \le s-1$.

Figure 5 shows the clipping probability for fixed number of sources (s =10) and different number of channels (c = 2, c = 5, and c = 10). The clipping probability of 5 channels has the highest clipping probability compared to 2 and 8 channels.

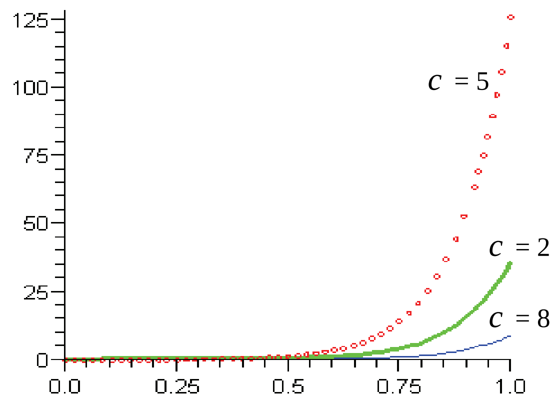

Fig. 5 Comparison of clipping probability, $P_i(l)$, vs. probability of active input source, ρ, where $0 \le \rho \le 1$, for s =10, c = 2, 5 and 8

Clearly, the average number of used channels, $A_c(u)$, is given by

$$A_c(u) = \frac{\sum_{j=1}^{c} j \binom{s}{j} \left(\frac{t_a}{t_d}\right)^j}{\sum_{i=0}^{c} \binom{s}{i} \left(\frac{t_a}{t_d}\right)^i}, \qquad (6)$$

where $0 \le i \le c$, and $1 \le j \le c$. Figure 6 shows the average number of used channels for fixed number of sources (s =10) and different number of channels (c = 2, c = 5, and c = 10). The average number of used channels of 8 channels has the highest average number of used channels compared to the ones for 2 and 5 channels.

Thus, the average number of busy channels, $A_c(b)$, is expressed by

$$A_c(b) = \frac{\sum_{j=1}^{c} j \binom{s}{j} \left(\frac{t_a}{t_d}\right)^j}{\sum_{i=0}^{c} \binom{s}{i} \left(\frac{t_a}{t_d}\right)^i} + c \sum_{j=c+1}^{s} \binom{s}{j} \rho^j (1-\rho)^{s-j}, \qquad (7)$$

where $0 \le i \le c, 1 \le j \le c$, and $c+1 \le j \le s$.

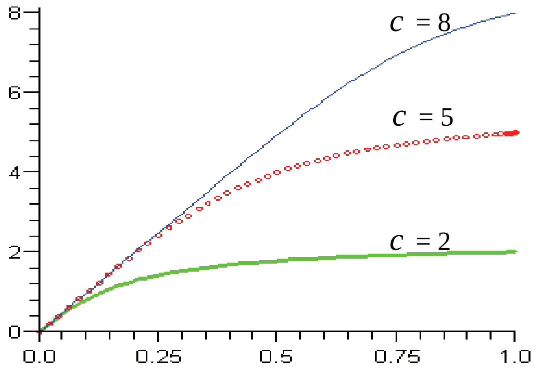

Fig. 6 Comparison of average number of used channels, $A_c(u)$,vs. probability of active input source, ρ , where $0 \le \rho \le 1$, for s =10, c = 2, 5, and 8

Figure 7 shows the average number of busy channels for fixed number of sources (s =10) and different numbers of channels (c = 2, c = 5, and c = 8). The average number of busy channels for c = 8 has the highest value compared to the ones for 2 and 5 channels.

III. CONCLUSION

This paper presented the analysis of Time Division Multiplexing (TDM) applied to satellite communications system when input sources are greater than available channels. The analysis and simulation of blocking and clipping for TDM was successfully investigated. For the blocking in synchronous TDM, we investigated the blocking probability and its average number of busy channels that could be delivered. For the Clipping in statistical TDM, we examined the clipping probability and its expected number of busy channels that could be delivered.

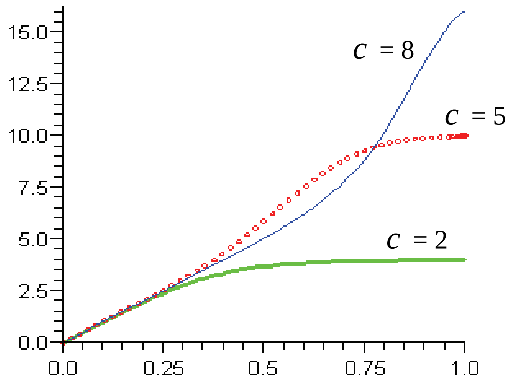

Fig. 7 Comparison of average number of busy channels, $A_c(b)$, vs. probability of active input source, ρ , where $0 \le \rho \le 1$, for s =10, c = 2, 5, and 8.

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