# Blocking and Clipping Estimations for TDM in Satellite Communication Technology

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***Abstract*** *– Satellite communications is currently playing a major role towards the implementation of a global communication infrastructure, especially in the explosive growth of wireless technology. This paper presents the analysis and simulation of blocking and clipping probabilities for time-division multiplexing (TDM) in satellite communication technology. Specifically, we illustrate the evaluation of multiplexing systems in which the number of input sources is greater than the number of available channels. For the case of the blocking situation in synchronous TDM, we investigate the blocking probability and the average number of busy channels that can be delivered. For the case of clipping in statistical TDM, we examine the clipping probability and the expected number of busy channels that can be delivered. We compare the blocking and clipping proabilities for fixed number of sources and different number of channels. We also compare the expected number of busy available channel for synchronous TDM and the average number of busy channel for statistical TDM methods for fixed number of sources and different number of channels.*

***Key words*** – Time-division multiplexing (TDM), blocking and clipping probabilities, satellite communication system

## I. INTRODUCTION

Satellite communications was first deployed in the 1960s for military applications. Satellites have played an important role in both domestic and international communications networks since the launch of the first commercial communication satellite by NASA in 1965. They have brought voice, video, and data communications to areas of the world that are not accessible with terrestrial lines. By extending communications to the remotest parts of the world, virtually everyone can be part of the global economy.

Satellite communications is not a replacement of the existing terrestrial systems but rather an extension of wireless system. However, satellite communication has the following merits over terrestrial communications [1]:

- *Coverage*: Satellites can cover a much large geographical area that the traditional ground-based system. They have the unique ability to cover the globe
- *High bandwidth*: A Ka-band (27-40 GHz) can deliver throughput of gigabits per second rate
- *Low cost*: A satellite communications system is relatively inexpensive because there are no cable-laying costs and one satellite covers a large area.
- *Wireless communication*: Users can enjoy untethered mobile communication anywhere within the satellite coverage area.
- *Simple topology*: Satellite networks have simpler topology which results in more manageable network performance.
- *Broadcast/multicast*: Satellites are naturally attractive for broadcast/multicast applications.

- *Maintenance*: A typical satellite is designed to be unattended, requiring only minimal attention by customer personnel.
- *Immunity*: A satellite system will not suffer from disasters such as floods, hurricanes, fire, and earthquakes and will therefore be available as an emergency service should terrestrial services be knocked out.

A satellite band is divided into a number of separated portions: one for earth-to-space links (the uplink) and one for space-to-earth links (the downlink). Separate frequencies are assigned for sending to the satellite (the uplink) and receiving from the satellite (the downlink). Table 1 provides the general frequency assignments for uplink and downlink satellite frequencies. We notice from the table that the uplink frequency bands are slightly higher than the corresponding downlink frequency band. This is to take advantage of the fact that it is easier to generate RF power within a ground station than it is onboard a satellite. In order to direct the uplink transmission to a specific satellite, the uplink radio beams are highly focused. In the same way, the downlink transmission is focused on a particular *footprint* or area of coverage.

**Table 1 Typical uplink and downlink satellite frequencies**

| Uplink frequencies (GHz) | Downlink frequencies (GHz) |
|---|---|
| 5.925-6.425 | 3.700-4.200 |
| 7.900-8.400 | 7.250-12.20 |
| 14.00-14.50 | 11.70-12.20 |
| 27.50-30.0 | 17.70-20.20 |

Multiple access Technologies allow different users to utilize satellite's resources of power and bandwidth without interfering with each other. Satellite communication systems use different types of multiple access technology including frequency division multiple access (FDMA), time division multiple access (TDMA), and code division multiple access (CDMA). The access technology can vary between the uplink and downlink channel.

The ability of multiple earth stations or users to access the same channel is known as FDMA. In FDMA, each user signal is assigned a specific frequency channel. One disadvantage of FDMA is that once a frequency is assigned to a user, the frequency cannot be adjusted easily or rapidly to other users when it is idle. The potential for interference from adjacent channels is another major shortcoming.

In TDMA, each user signal is allotted a time slot. A time slot is allocated for each periodic transmission from the sender to a receiver. The entire bandwidth (frequency) is available during the time slot. This access scheme provides priority to users with more traffic to transmit by assigning those users more time slots than it assigns to low-priority users. Satellite providers will extend the capability and will employ multiple frequencies (MF-TDMA). If there are N frequencies, each offering M Mbps of bandwidth, then the total available bandwidth during a time slot is NxM Mbps. Although FDMA techniques are more commonly employed in satellite communications systems, TDMA techniques are more complex and are increasingly becoming the de facto standard.

In CDMA, users occupy the same bandwidth but use spread spectrum signals with orthogonal signaling codes. This technique increases the channel bandwidth of the signal and makes it less vulnerable to interference. CDMA operates in three modes: direct sequence (DS), frequency hopping (FH), and time hopping (TH).

In recent years, significant effort has been made toward evaluating blocking probabilities experienced by customers contending for a commonly shared resource. By definition, the blocking probability is the probability that a connection service request is denied due to insufficient network resources. Proportional differentiation models have been proposed as effective methods for scalable differentiation services provision into optical Wavelength Division Multiplexing (WDM) networks with blocking probability to various traffic classes [2-4].

Once a channel is assigned to a given talkspurt, the channel is held till the spurt ends. The occurrence of freeze-out typically causes the initial part of a talkspurt to be clipped. If a talkspurt sees no channel available upon its arrival, the initial portion of the talkspurt will be clipped until a newly freed channel can be assigned. Clipping probability is used in measuring video quality [5-7].

In this work, we will illustrate the multiplexing models used in satellite communication systems especially TDM, focusing on synchronous TDM and statistical TDM methods.

## II. MULTIPLEXING MODELS AND RESULTS

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 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, FDMA, 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 [8-11]. Blocking and statistical probabilities are applied for TDM multiplexing as in [12-21]. In this paper we will analyze and simulate the blocking and statistical probabilities of TDM applied to satellite communications systems.

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 TDM system is a high-speed data stream scheme which acts at layer 1 (physical layer) of Open Systems Interconnections (OSI) model and at the layer 4 (network interface) of Transmission Control Protocol over Internet Protocol (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 source $s$ 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).

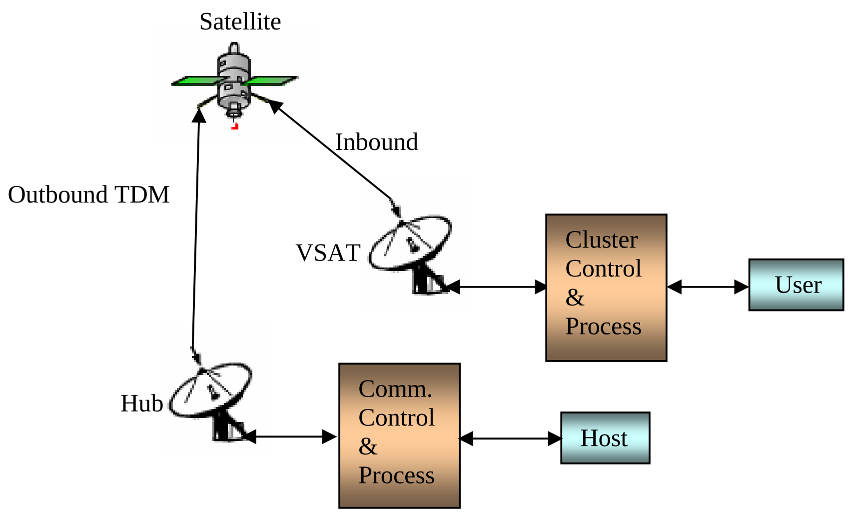


**Fig. 1 Satellite communication System with TDM.**

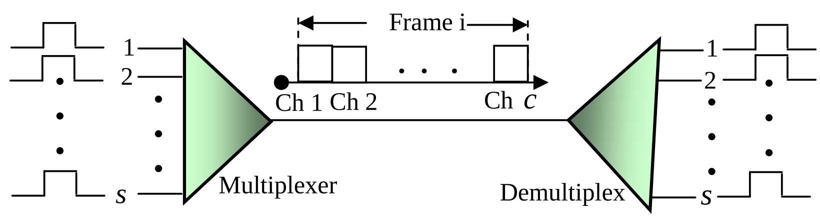


**Fig. 2 A Time-division multiplexer (TDM) with $s$ inputs and $c$ channels.**

### *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 Quality of Service (QoS) of synchronous TDM is based 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 source 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. Let us assume that values of $t_a$ and $t_d$ are random and exponentially distributed. (This assumption is based on experience). 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, $\rho$, can be obtained by $\rho = \dfrac{t_a}{t_a + t_d}$.

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:

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

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 $c = 8$). The blocking probability clearly rises with the increased utilization, $\rho$, for all three cases; and also it is higher when a fewer number of channels, $c$, is available.

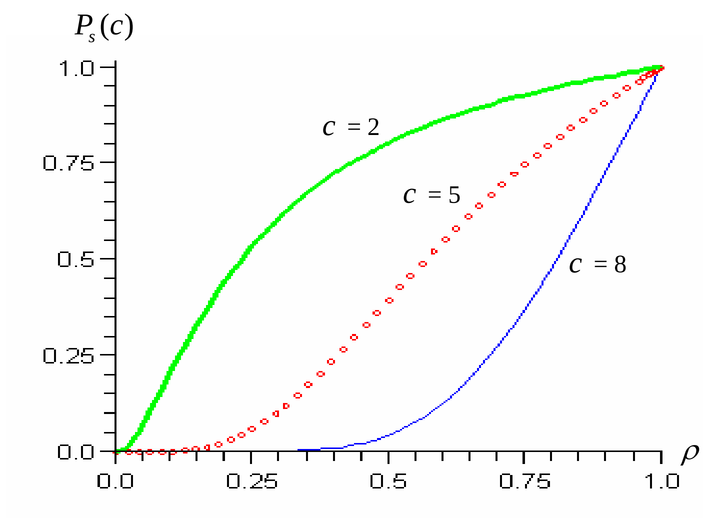


**Fig. 3 Comparison of blocking probability, $P_s(c)$ vs. probability of active input source, $\rho$, with $0 \le \rho \le 1$, for s =10, $c$ = 2, 5, and 8.**

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 varies in its maximum values based on the interval of utilization.

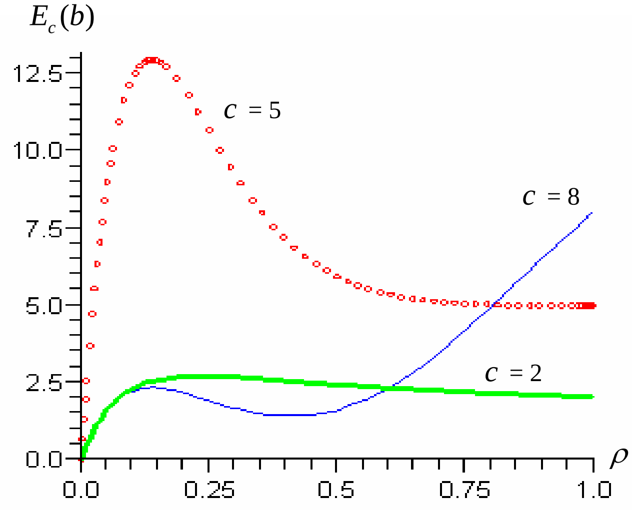


**Fig. 4 Comparison on expected numbers of busy available channels, $E_c(b)$, vs. probability of active input source, $\rho$, where $0 \le \rho \le 1$, for $s = 10$, $c$ = 2, 5, and 8.**

## *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 guarantee QoS, because of 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 react 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.

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 $c$ =8 ). The clipping probability of 2 channels has the highest clipping probability compared to 5 and 8 channels.

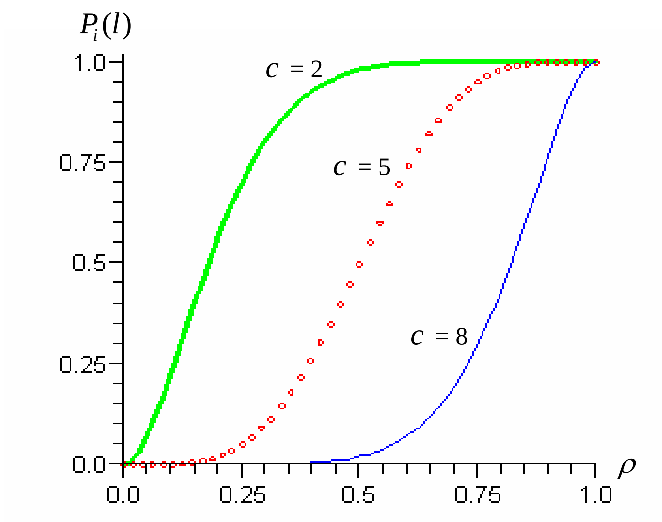


**Fig. 5 Comparison of clipping probability, $P_i(l)$, vs. probability of active input source, $\rho$, where $0 \le \rho \le 1$, for $s$ =10, $c$ = 2, 5 and 8.**

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

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

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 $c$ = 8). 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.

The average number of busy channels, $A_c(b)$, is:

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

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

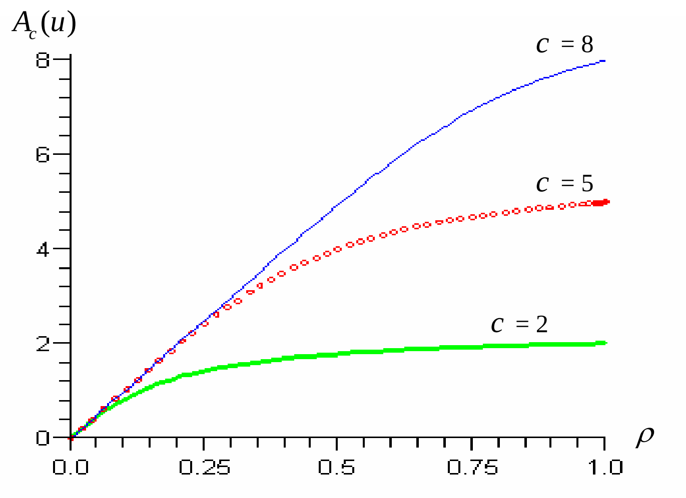


**Fig. 6 Comparison of average number of used channels, $A_c(u)$, vs. probability of active input source, $\rho$, where $0 \le \rho \le 1$, for $s$ =10, $c$ = 2, 5, and 8.**

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 all cases is almost the same up to $\rho$ = 0.25, but it differs for $\rho$ > 0.25.

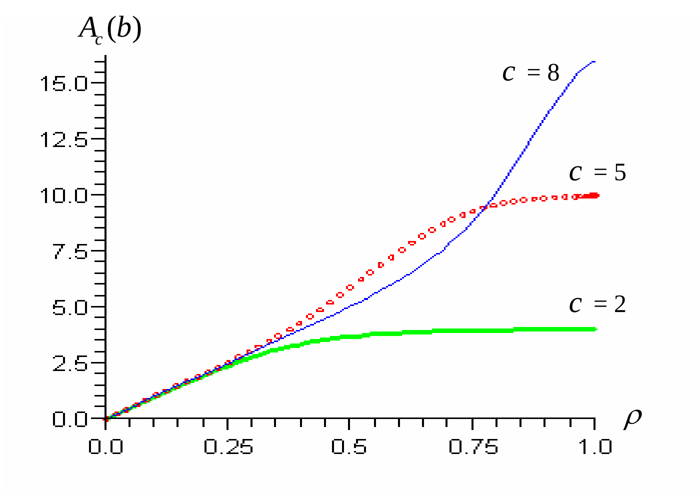


**Fig. 7 Comparison of average number of busy channels, $A_c(b)$, vs. probability of active input source, $\rho$, where $0 \le \rho \le 1$, for $s$ =10, $c$ = 2, 5, and 8.**

Figures 8 through 10 show the comparison between blocking and clipping proabilities for fixed number of sources ($s$ =10) and different number of channels ($c$ = 2, $c$ = 5, and $c$ = 8 respectively). We observe that the blocking probability is greater than the clipping probability for 2 and 5, but it varies at channel 8.

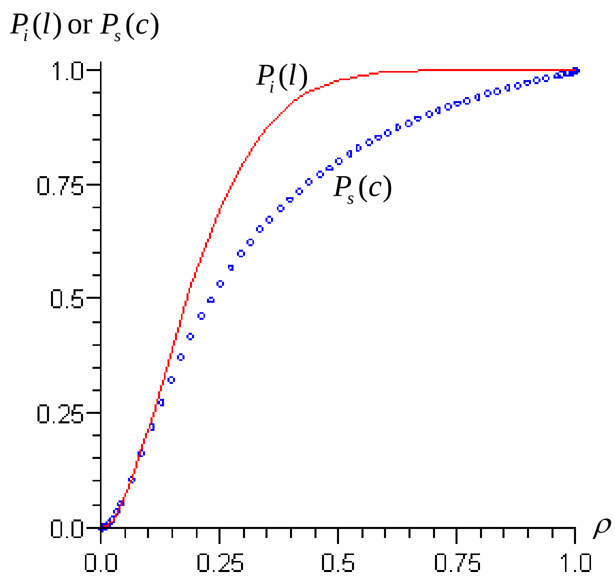


**Fig. 8 Comparison of blocking probability, $P_s(c)$, and clipping probability, $P_i(l)$, vs. probability of active input source, $\rho$, with $0 \le \rho \le 1$, for s =10, $c$ = 2.**

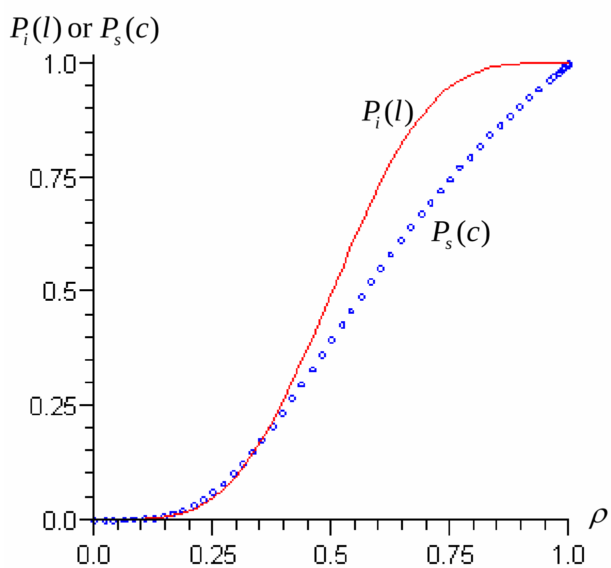


**Fig. 9 Comparison of blocking probability, $P_s(c)$, and clipping probability, $P_i(l)$, vs. probability of active input source, $\rho$, with $0 \le \rho \le 1$, for s =10, $c$ = 5.**

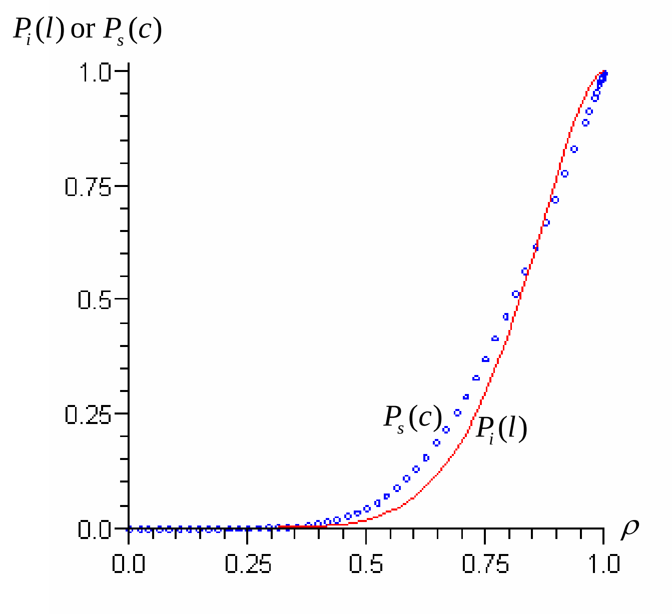


**Fig. 10 Comparison of blocking probability, $P_s(c)$, and clipping probability, $P_i(l)$, vs. probability of active input source, $\rho$, with $0 \le \rho \le 1$, for s =10, $c$ = 8.**

Figures 11 through 13 show the expected number of busy available channel for synchronous TDM and the average number of busy channel for statistical TDM methods for fixed number of sources ($s$ =10) and different number of channels ($c = 2$, $c = 5$, and $c$ = 8 respectively). We observe that the average number of channels and the expected number of busy available channel varies in the different utilization numbers.

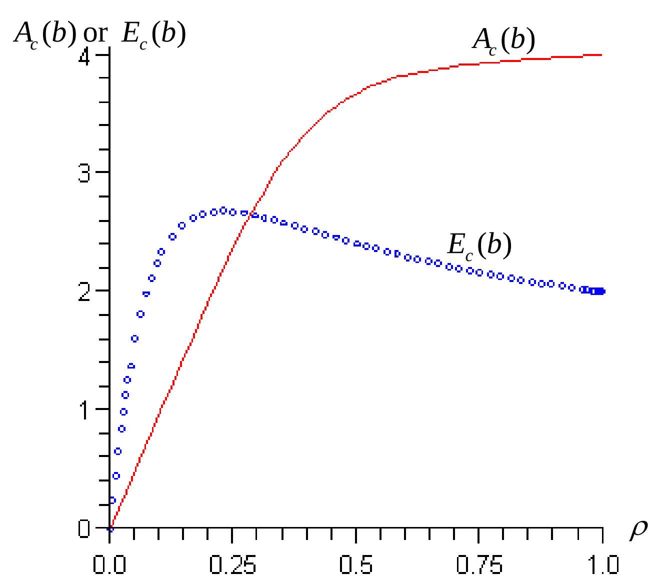


**Fig. 11 Comparison of expected number of busy available channels, $E_c(b)$, and average number of busy channels, $A_c(b)$, vs. probability of active input source, $\rho$, where $0 \le \rho \le 1$, for $s = 10$, $c$ = 2.**

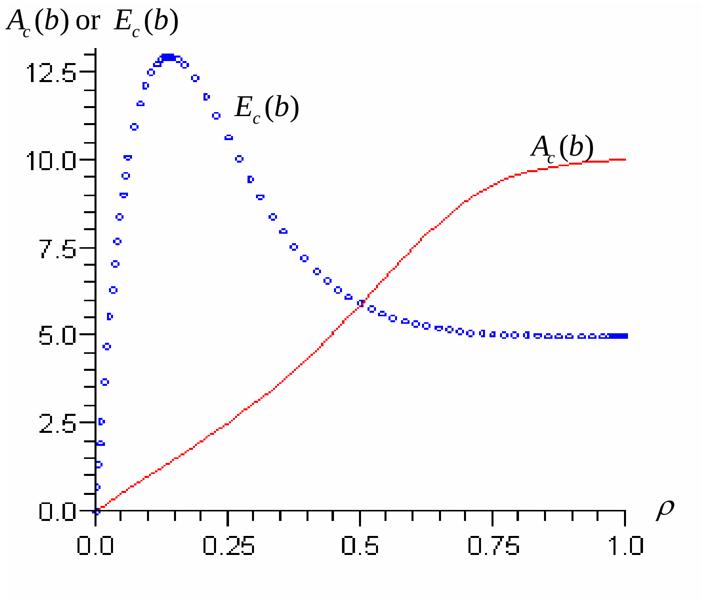


**Fig. 12 Comparison of expected number of busy available channels,** $E_c(b)$**, and average number of busy channels,** $A_c(b)$**, vs. probability of active input source,** $\rho$**, where** $0 \le \rho \le 1$**, for** $s = 10$**,** $c$ **= 5.**

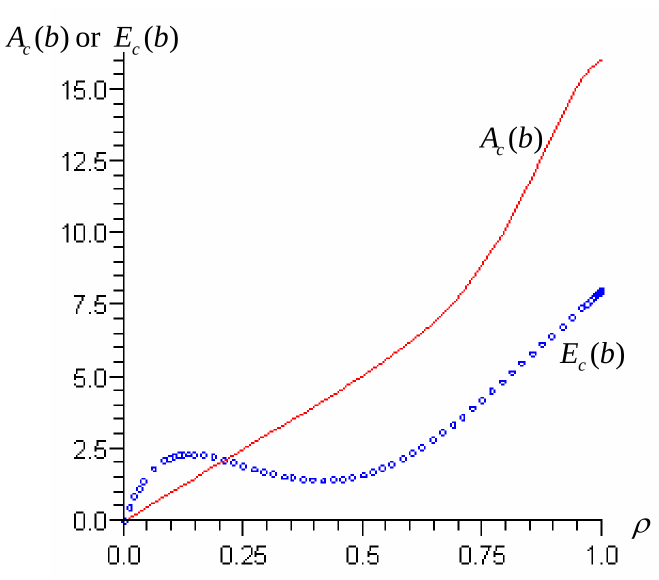


**Fig. 13 Comparison of expected number of busy available channels,** $E_c(b)$**, and average number of busy channels,** $A_c(b)$**, vs. probability of active input source,** $\rho$**, where** $0 \le \rho \le 1$**, for** $s = 10$**,** $c$ **= 8.**

## III. CONCLUSION

This paper presented the analysis of Time Division Multiplexing (TDM) applied to satellite communications systems when input sources are greater than available channels. The analysis of blocking and clipping probabilities for TDMs was successfully achieved and results of the analysis were generated. For blocking cases in synchronous TDMs, we illustrated the blocking probability and the average number of busy channels that could be delivered. For the clipping in statistical TDM, we examined the clipping probability and the expected number of busy channels. We compared the blocking and clipping proabilities for fixed number of sources and different number of channels. We also compared the expected number of busy available channel for synchronous TDM and the average number of busy channel for statistical TDM methods for fixed number of sources and different number of channels.

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