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*Research Article*

# TCP-Call Admission Control Interaction in Multiplatform Space Architectures

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The implementation of efficient call admission control (CAC) algorithms is useful to prevent congestion and guarantee target quality of service (QoS). When TCP protocol is adopted, some inefficiencies can arise due to the peculiar evolution of the congestion window. The development of cross-layer techniques can greatly help to improve efficiency and flexibility for wireless networks. In this frame, the present paper addresses the introduction of TCP feedback into the CAC procedures in different nonterrestrial wireless architectures. CAC performance improvement is shown for different space-based architectures, including both satellites and high altitude platform (HAP) systems.



## 1. INTRODUCTION

The development of network architectures including the space segment (GEO satellites) aims to provide telecommunication services in wide geographical areas. The space segment can complement or even replace the terrestrial infrastructure wherever the latter either fails or is not cost effective. As a matter of fact, along with the evolution of new technological solutions, such as high altitude platforms (HAPs) [1], next generation networks are envisioned as the integration of several different subsystems, unconditionally interoperating among one another [2]. Various architectures including combinations of GEO and HAPs are under continuous study so as to take advantage of each segment's most favorable features in terms of coverage area, easy and quick deployment, robustness to failure and to disaster occurrence, and so forth.

On the other hand, some of the protocols and techniques supporting the communication through this heterogeneous wireless environment could be inadequate, since they are specifically designed for wired networks. Nevertheless, these protocols and techniques are worth being utilized due to their many desirable characteristics and to the fact that the wireless path is usually only a segment of the whole route between the sender and the receiver.

One of these protocols is TCP [3, 4], which is the predominant protocol at the transport layer when dealing with the very popular Internet-based applications. It presents several impairments when it is implemented in wireless environments [5, 6]. In brief, TCP, originally designed to work well over wired congested network, considers all losses as an explicit indication of network congestion [7]. Therefore, TCP control rate leads to unnecessary rate reductions and then to severe performance degradation without taking into account error-prone wireless links. Communication involving long-delay segments (i.e., geostationary satellites), emphasizes such an impairment slowing down the reversion to the previous transmission rate.

In addition, the presence of asymmetric links may slow down the acknowledgement flow causing problems in the forward channel as well, since TCP misinterprets the overall RTT increase as a congestion notification in the data direction.

In parallel, CAC has evolved into one of the most significant bandwidth management tools in the case of both wired and wireless networks. However, the efficiency of the CAC process is highly dependent on the accuracy of the available info concerning the transmission rate of the serviced connections, not only at the time instant that the CAC algorithm is executed but also for the whole duration of these connections. In particular, the CAC algorithm must be able to make a safe prediction regarding the availability of resources in the long term in order to decide if a new connection can be admitted into the system [8, 9].

In this frame, the present paper investigates the possibility of introducing an interaction between TCP and CAC in several nonterrestrial wireless architectures, in order to improve CAC efficiency by taking TCP dynamics into account. More specifically, the exploitation of TCP feedback as input for the CAC algorithm at regular time intervals has proved to be of primary importance for maximizing the utilization of the network resources [10]. However, as the TCP performance is rather dependent on the characteristics of the communication path, the implementation of the CAC-TCP interaction on different system architectures will introduce meaningful improvements in all the architectures showing such characteristics, demonstrating a more general importance of the concept. Additionally, so far, limited work can be found in the literature on this topic.

The paper is organized as follows: Section 2 provides a brief analysis of the TCP driven CAC concept, while Section 3 includes an overview of possible architectures. Section 4 presents a description of the reference architectures and the simulation scenario, along with results comparing the efficiency of the proposed algorithm in the several space architectures. Finally, Section 5 summarizes the conclusions.

## 2. THE CONCEPT OF A TCP-BASED CAC

TCP is a transport layer protocol based on sending data packets upon reception of acknowledgement of previously sent packets, thus guaranteeing high reliability. When the network is characterized by significant round trip time (RTT), as in the case a satellite path is included, this process can significantly slow down data transfer.

TCP can exploit congestion control either through an ACK counting mechanism (the actions on the sliding window are just based on the number of received ACKs) [3] or through the byte-counting scheme (the actions on the sliding window are based on the actual number of bytes acknowledged) [11].

When the communication path is not error-free (usual in wireless networks) TCP misinterprets the data loss due to the harsh wireless reception conditions as congestion occurrence. As a consequence, for every packet loss, TCP reduces the actual transmission rate, limiting the bandwidth utilization of the connection far below its nominal value.

This inefficiency is meaningful in wireless networks since the radio resource is usually scarce and expensive. Particularly in GEO satellite, the large footprints limit the implementation of frequency reuse, thus reducing system capacity. Therefore, achieving maximum utilization of the available bandwidth must be the primary goal of every network configuration.

On the other hand, CAC is implemented by the network manager as a preventive congestion control scheme. CAC algorithms decide upon the admittance/rejection of new connections based on the network conditions (traffic load, link capacity, buffer size, etc.) as well as the traffic characteristics and the QoS objectives of both the candidate and the already active users. In this framework, the aim of CAC is twofold: (i) to guarantee that the QoS requirements of all the admitted users are met, and (ii) maximize revenue from the network's perspective, that is, optimize the utilization of the available resources [8]. However, achieving these objectives is rather difficult, since CAC is inherently an "in advance" procedure and no traffic model can offer a priori a completely accurate prediction, in particular considering the heterogeneity of multimedia telecommunication traffic sources. Therefore, real-time measurements of each connection's load and conditions are considered essential for the CAC's effectiveness [9].

CAC functionality is based on the concept that the used bandwidth plus the bandwidth of the upcoming user should be lower or equal to the total capacity. As a matter of fact the following condition must be always respected:

$$\sum_{i=1}^{N} B_i + B_f \leq c. \tag{1}$$

Since always $B_j$_TCP_datarate $\leq$ $B_j$_nominal_datarate, the exploitation of the TCP feedback leads to a decrease in the system overall blocking probability. Moreover, the bandwidth assigned to each connection is equal to the real data rate of the connection monitored via the TCP performance. Therefore, having maximized the average number of the users simultaneously active in the network and having minimized the over-assignment of resources, the throughput of the network, defined as the percentage of the aggregate capacity that is actually occupied by the set of active connections, is radically improved.

In this frame, the possibility to get feedback information about TCP congestion window actual evolution would be of primary importance in order to efficiently drive CAC scheme. In fact, since the CAC algorithm, by taking into account the actual amount of capacity necessary to exploit all the TCP connections, could prevent the over provision of bandwidth to the aforementioned connections, a better utilization of the network resources would be achieved. In this way, the admission/rejection of the new user would be based on the actual occupancy of the channel by the active users at the time instant of a new user arrival, computed according to the TCP congestion window state of the connections instead of their nominal data rate. The above scheme is depicted in the flow chart of Figure 1.

## 3. SUITABLE ARCHITECTURES FOR CAC-TCP INTERACTION

The potential improvement introduced by the implementation of the integrated CAC-TCP scheme is addressed in various nonterrestrial wireless architectures, where either the high propagation delay and/or the occurrence of transmission errors negatively impact TCP performance by leading to an unjustified decrease of the transmission data rate.

In particular, four different architectures are introduced and described, focusing on the potential drawbacks concerning optimal TCP working.

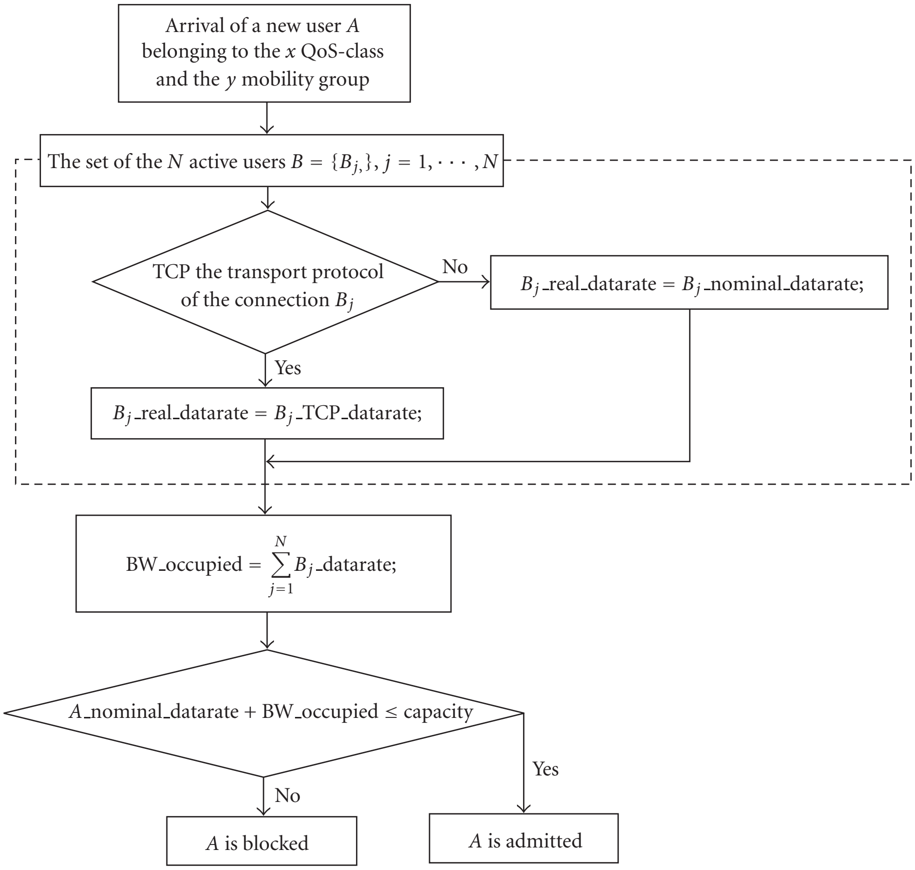


FIGURE 1: Cross-layer CAC-TCP flow chart.

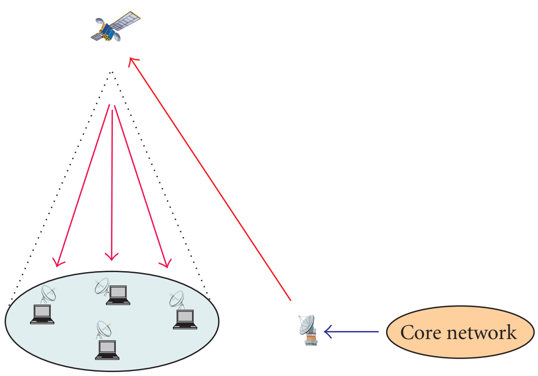


FIGURE 2: Stand-alone GEO satellite.

### *3.1. Stand-alone GEO satellite*

A system architecture based on a stand alone GEO satellite (Figure 2) implies a rather challenging environment for TCP performance. Such an architecture presents a *long propagation path* (in average about 80 000 km end to end) along with *transmission errors* quantified in terms of BER (depending on propagation channel conditions) and link unavailability, particularly meaningful in case of use of high frequencies and/or terminal mobility.

The large latency-bandwidth product could cause two harmful effects:

(i) the pipe size, indicating the amount on unacknowledged data that can be "in-flight" in a given instant, could exceed the buffer limits in the existing implementations resulting in a suboptimal maximum throughput;

(ii) the high latency entails a considerable time interval to open the TCP sliding window, when a new connection starts (slow-start algorithm). Similarly, in the case of losses, the reaction of TCP is very slow, increasing the time needed to return to high transmission rates.

### *3.2. Stand-alone HAP*

HAPS are characterized by the utilization of a platform located in the stratosphere (about 20 km from ground), allowing very fast deployment, low cost, less critical communication parameters, flexible architecture but limited coverage (Figure 3). The proximity of the HAP to the ground minimizes the propagation delay, being distances comparable to the ones in terrestrial wireless systems [1, 12].

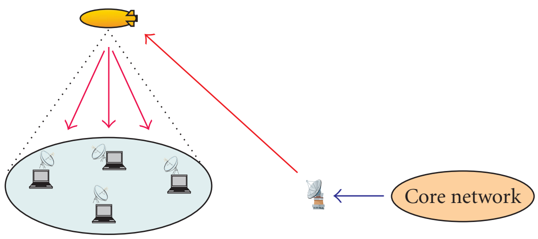


Figure 3: Stand-alone HAP.

Nevertheless, since HAP systems work also in millimeter-wave bands (47/48 GHz), in that case rain attenuation and scattering constitute a severe constraint in achieving good TCP performance. Some studies indicate a two-state (good-bad) Markov model as a suitable error model [13]. Therefore, the packet-error rate (PER) experienced by the TCP can be approximated by the probability of the bad channel conditions.

Depending on the PER value, TCP congestion window continuously stops its growth resulting in "fast retransmit and fast recovery" (FR-FR) or even timeout expirations, when due to the loss of a large burst of segments, sender does not receive any feedback (i.e., duplicate ACKs). In the latter case, TCP remains in an idle state for several seconds and resets its window to one segment.

### 3.3. Integrated GEO satellite—HAP

In order to allow HAPS users to communicate with remote locations, a link between the HAPS and the satellite can be envisaged, as depicted in Figure 4.

Being the GEO-HAP segment outside the atmosphere and in line-of-sight (LoS) conditions, errors are due to free space losses and thermal noise and quantified in terms of BER. On the contrary, the PER of the overall link is predominately defined by the HAP-ground segment, where significant transmission errors can occur depending on the utilized frequency and on eventual ground terminal mobility. Thus, from the PER point of view an integrated GEO-HAP architectures is equivalent to the stand-alone HAP case. Moreover, the use of GEO satellite as an intermediate node introduces long RTT, adding the drawbacks in the TCP dynamics detected in the stand-alone GEO satellite scenario.

### 3.4. HAP constellation

Finally, we consider the architecture of Figure 5, where the coverage area is served by a constellation of HAPs; inter-HAP links are also set up [14]. If the data is forwarded to the destination HAP via one (or more) of its neighboring HAPs, although the propagation delay is kept low, the end-to-end reception conditions could possibly become harsher, due to the imperfections of the inter-HAP links. The aforementioned imperfections could be mostly due to the stabilization problems of the platforms, which would result in corresponding pointing difficulties regarding the optical links that are envisioned for such an inter-HAP communication.

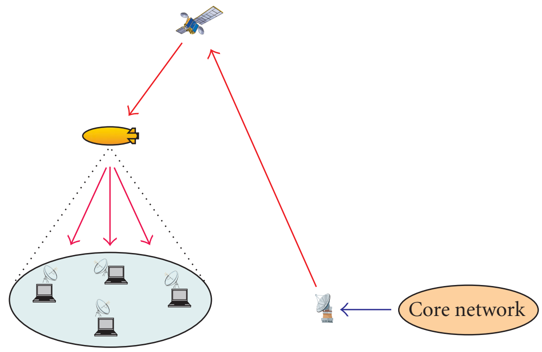


Figure 4: Integrated GEO satellite—HAP.

Then, in this scenario, TCP performance suffers mainly from the problems arisen in the stand-alone HAP architecture.

## 4. EVALUATION OF THE CAC-TCP INTERACTION IN SPACE ARCHITECTURES

### 4.1. Reference architectures

Summarizing, TCP performance over radio links, including one or more space systems, relies primarily on two factors:

(1) the delay imposed by the space segment (RTT),
(2) the reception error probability of the wireless space-user channel (PER).

The adopted TCP scheme, based on ACK counting, leads to same efficiency as achievable when using the byte-counting algorithm [11], because all the correctly delivered TCP packets are considered immediately acknowledged by the corresponding ACK (ACK are not delayed).

Thus, in order to evaluate the efficiency as well as the necessity of a TCP driven CAC scheme, only three different network architectures, based on the boundary conditions in terms of RTT and PER (or both), are selected to be simulated in the present paper. They are stand-alone GEO (Figure 2), stand-alone HAP (Figure 3), and integrated GEO satellite-HAP (Figure 4). In the following, the most meaningful implemented features concerning the selected architectures, are described. In all the three architectures losses affect both ACK and TCP packet flows (ACK losses have a slight impact on the overall performance due to the cumulative nature of ACKs [4]).

#### Stand-alone GEO architecture

Data originating from the core network are forwarded via a gateway toward the GEO satellite, which transparently redirects the stream (bent-pipe satellite) to the end users. Users are considered to be fixed and equipped with VSATs appropriately mounted so as to guarantee line-of-sight (LoS) condition for the satellite-user link. Therefore, since the signal-to-noise ratio (SNR) is not only maximized but also relatively invariant due to the absence of mobility, low PER value can

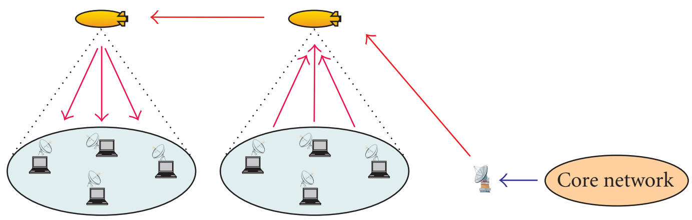


Figure 5: HAP constellation.

be assumed. Moreover, the gateway-satellite link is typically dimensioned to be error free.

*Stand-alone HAPS*

In comparison with the previous architecture, the GEO satellite has been replaced with a HAP, while the data flow maintains the same characteristics. The proximity of the HAP to the earth greatly decreases link latency and facilitates the connectivity of mobile users. In more detail, in the GEO satellite scenario, a mobile terminal should be equipped with high power transmission amplifier as well as sizeable antennas, so as to compensate the high free-space attenuation imposed by the long propagation path. These features lead to bulky and power consuming (limited autonomy) terminals, completely inappropriate for mobile use. On the contrary, providing access via a HAP located at an altitude of 20 km allows the use of small, cost-efficient, and user-friendly devices. Consequently, the stand-alone HAPS scenario considers mobile users, which are further divided into three categories based on their mobility characteristics: highway-users, suburban-users, urban-users. In particular, highway-users move in open areas with maximum LoS probability, while, as the city centre (suburban and urban users) is approached, the higher building in combination with the narrow streets hinder the LOS path and the received signal is the result of successive reflections (multipath). Moreover, according to the channel model, even in the case of a highway user, the average PER is much higher than in case of a fixed user that is served by a GEO system.

*Integrated GEO satellite—HAP*

The rationale behind the integration of the two systems is that one satellite can provide connectivity to multiple HAPs both among each other and toward the core network, without the deployment of extra infrastructures. In this case, as described in Section 3.4, the PER of the end-to-end link is determined by the PER of the user-HAP segment (equal to the of stand-alone HAP system), while the long RTT is imposed by the GEO-satellite segment (equal to the case of stand-alone GEO system).

As it becomes evident, the scenario involving a stand-alone GEO system with fixed users presents the highest RTT and the lowest PER, while the scenario involving a stand-alone HAP system presents the highest PER and the lowest RTT. Finally, the integrated GEO-HAP scenario combines the characteristics of both of them, that is maximum RTT and maximum PER. Moreover, beyond the fact that these network scenarios present a wide range of RTT and PER values, they are also the most significant in terms of services and applications. Therefore, the analysis of these case studies can provide solid conclusions regarding the ability of the proposed TCP-CAC interaction to improve the network performance, in terms of both blocking probability and average throughput, in a great variety of channel conditions.

### 4.2. Simulation scenario and parameters

All the users are classified into three QoS classes according to the nominal rate of their connections: 128, 256, and 512 kbps. The implementation of a weighted priority CAC scheme, as the one proposed in [15], guarantees the provision of equitable service of multiple parallel flows with different bandwidth requirements. According to this admission control algorithm, the aggregate capacity of the system is divided into a number of segments equal to the number of QoS classes. The width of each segment (i.e., the capacity percentage assigned to each QoS class) is determined by manipulating the desired blocking probability ratio between the QoS classes. Thus, a new flow belonging to the $QoS_i$ class is admitted to the network on the basis of the bandwidth committed to the particular $QoS_i$ class. Instead, in the case of a CAC scheme without any prioritization based on QoS class, the users of the higher QoS classes would be practically excluded from the network, as it would be difficult to satisfy their excessive bandwidth needs and they would be usually blocked in favor of users with lower data rate requirements. Therefore, a weighted priority CAC scheme as defined in [15] has been taken as reference in our analysis presented hereafter. Furthermore, the TCP driven CAC scheme has been derived from exactly the same notion, with the only difference that, as it has been described in Section 2, the TCP-CAC algorithm takes into account the TCP feedback of the flows instead of their nominal data rate in the process of computing the utilization of the channel and the availability of resources.

Both the TCP driven and the reference CAC scheme, have been simulated through an offline combination of two simulation tools that run sequentially. In particular, the network simulator ns-2 [16] is used to configure the communication scenario (nodes, link parameters, and communication protocols) and to obtain TCP statistics. Additionally, a C++

simulation tool gets as input the TCP statistics and provides the following functionalities:

(i) it runs alternatively either the reference or the TCP driven CAC scheme;
(ii) it calculates the instantaneous and the average throughput of the network;
(iii) it computes the connection blocking probability for each QoS class as well as the connection blocking probability of the network.

To reproduce a trustworthy network traffic, we have considered packet error distribution (derived at TCP level) compliant to the HAP communication characteristics [13, 17], while satellite-HAP or satellite-user terminal link have been considered as almost error free. The latter assumption is rather realistic since satellite gateway EIRP can be set in order to counterbalance the atmosphere attenuation. Then, depending on the terminal mobility, the following PER distributions have been considered.

(i) Fixed and portable terminals have been assumed always in line-of-sight (LoS) with the HAP/satellite. Thus, uniform packet loss distributions (TCP level) are considered with relatively low mean values ($10^{-4}$ for fixed terminals and $10^{-3}$ for portable terminals).
(ii) In case of mobile terminals, a two-state channel model [13] is considered to feature the alternating LoS and shadowing conditions. Durations of "bad" and "good" states depend on the motion environment according to the values reported in [17].

Furthermore, both arrival and termination of TCP connections are managed by the C++ event driven simulator as Poisson processes [15]. Thus, the time between two successive arrivals of users ($\tau$) and the duration of each admitted connection ($d$) follow exponential distribution with mean value $1/\lambda$ and $1/\mu$, respectively:

$$\begin{aligned} \text{pdf}(\tau) &= \lambda \cdot e^{-\lambda \cdot \tau}, \qquad E[\tau] = \frac{1}{\lambda}, \\ \text{pdf}(d) &= \mu \cdot e^{-\mu \cdot d}, \qquad E[d] = \frac{1}{\mu}. \end{aligned} \tag{2}$$

The parameters $E[d]$ and $E[\tau]$ along with the aggregate number of users in the network ($S$) determine the traffic load of the network ($L$).

### *4.3. Results*

The impact of the TCP-CAC interaction on all the three selected network configurations (GEO, HAPS, and GEO-HAPS) has been evaluated in terms of blocking probability and average throughput. Moreover, the blocking probability and the average throughput are calculated for both the basic and the TCP-based call admission control scheme.

Figure 6 presents the system blocking probability for different traffic loads. Regardless the network architecture, the basic-CAC algorithm leads in every case to the same blocking probability for the whole variety of traffic loads, which is expected, since only the nominal data rate of both the candidate and the already admitted users is taken into account during the acceptance/rejection procedure. The fluctuations in the TCP rate caused by the latency and the errors imposed by the different channels do not affect the admission procedure and therefore the curves regarding the basic-CAC algorithm for all the three scenarios completely coincide with each other. On the contrary, TCP-CAC algorithms present much lower blocking probability. Due to the TCP feedback, the system is able to calculate the actual occupancy of the available channels which is much lower than the one declared by the users initially during their admittance. Therefore, the unused bandwidth is reassigned to new users that would otherwise be blocked.

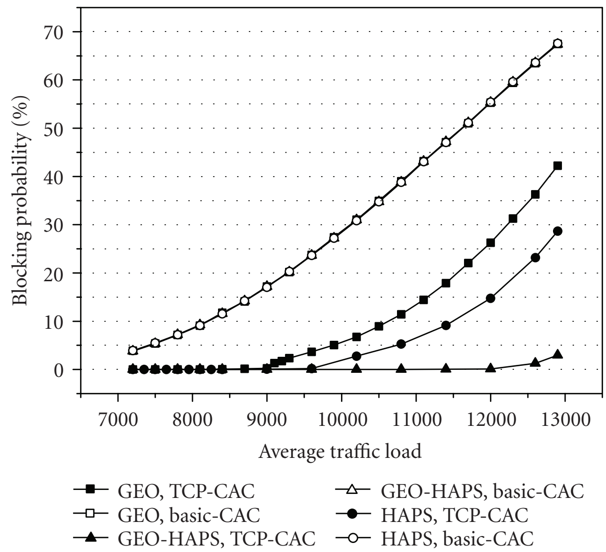


FIGURE 6: Blocking probability versus average traffic load.

Figure 7 presents the improvement (decrease) introduced to the system blocking probability by the TCP driven CAC scheme in comparison to the basic-CAC scheme. It allows the reader to compare the impact of the proposed scheme on architectures with different propagation characteristics. As it becomes apparent,

$$BP\_\text{decrease}_{\text{GEO}} < BP\_\text{decrease}_{\text{HAP}} < BP\_\text{decrease}_{\text{GEO-HAPS}}. \tag{3}$$

This can be easily explained by the fact that in the case of the integrated GEO-HAPS system, the harsh reception environment (long latency and high reception error probability) leads to a severe degradation of the TCP performance and thus to an intense decrease in the actual data rate of the TCP connections. In fact, letting $x$ be the aggregate amount of nominal traffic load applying for network resources and $y$ the amount of traffic actually forwarded through the network channels, simulations have demonstrated that

$$\begin{aligned} x &> y_{\text{GEO}} > y_{\text{GEO-HAPS}}, \\ x &> y_{\text{HAP}} > y_{\text{GEO-HAP}}. \end{aligned} \tag{4}$$

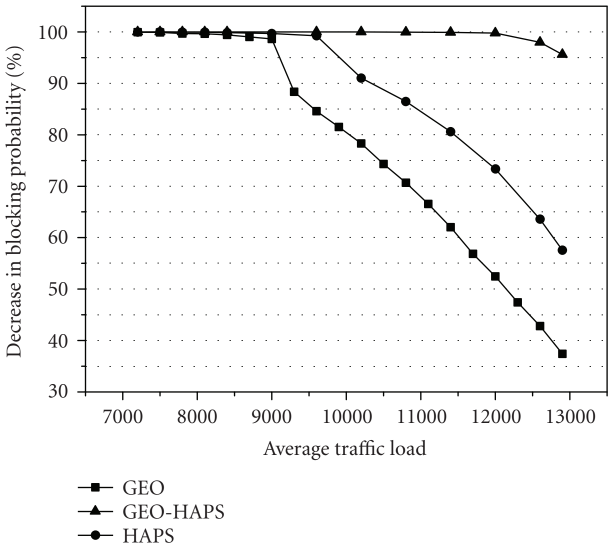


Figure 7: Blocking probability decrease versus average traffic load.

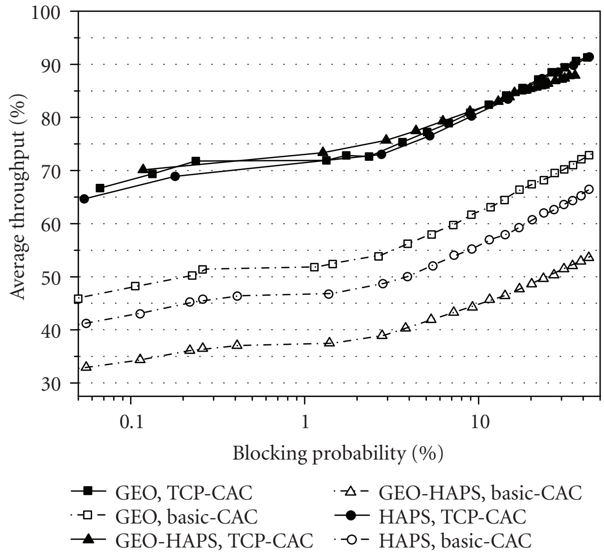


Figure 8: Average throughput versus blocking probability.

This means that users of the GEO-HAPS network leave a great percentage of the system resources unutilized and thus, in comparison with other architectures, the number of users that can be simultaneously served by a channel of given capacity is much higher (lower blocking probability).

Moreover, results shown in Figure 7 lead us to the conclusion that the exploitation of TCP-feedback is much more crucial in a stand-alone HAP system (high PER, low RTT) than in a stand-alone GEO (high RTT, low PER) configuration. Then, an error prone communication path, even with low RTT, can cause abrupt decrease in the connection transmission rate.

Blocking probability and average throughput are the two main metrics of the network performance, each dealing with the issue of the system efficiency from a different perspective. Blocking probability must be minimized to maximize the QoS (minimum delay) guaranteed to the users, while average throughput must be maximized to maximize revenues for the network administrator. Figure 8 shows that there is always a tradeoff between these two factors: increased average throughput leads to increased blocking probability, while limitation of the blocking probability results in a low bandwidth utilization. In addition, from Figure 8 it is evident that, regardless of the network scenario, the implementation of the integrated TCP-CAC scheme results in the same average throughput for any given value of blocking probability. This is due to the fact that the admission control algorithm bases the acceptance/rejection decision upon the knowledge of the real traffic load forwarded at that given time through the network.

Therefore, a new connection is blocked only if there is no further available bandwidth. Thus, since the availability of resources occurs on the basis of the new connection nominal rate, for a given throughput, the blocking probability is the same for all the possible scenarios (GEO, GEO-HAPS, HAPS). On the contrary, the basic-CAC algorithm assumes that the occupancy of the network capacity is equal to the aggregate of the nominal rates of all the active users. Consequently, the requests for new connections are rejected while there is still spare bandwidth. The average throughput for a given blocking probability relies now upon the amount of TCP data rate degradation. Therefore, the stand-alone GEO case presents the higher average throughput and the integrated GEO-HAPS architecture the minimum one, as they present, respectively, the minimum and the maximum decrease in the TCP data rate.

Finally, according to Figure 9 the lower the network blocking probability is, the higher the gain from the utilization of the TCP feedback is. Moreover, the gain for the scenarios with the worst reception conditions is higher, since the basic-CAC algorithm severely limits the system throughput.

## 5. CONCLUSIONS AND FUTURE PERSPECTIVES

New and innovative wireless telecommunication architectures (including HAPs and satellite segments) are identified to provide broadband services in a cost-efficient and ubiquitous manner, ensuring seamless interoperation with the existing infrastructure. To ensure network efficiency for such architectures it is worth optimizing the performance of protocols originally designed for terrestrial networks and for classical architectures. Cross-layer techniques are becoming fundamental to cope with the dynamic variations characterizing wireless environments. The present paper focuses on optimal utilization of the precious wireless resources when flows running TCP share the channel. Referring to 5 different architectures based on HAP/satellite links, we have analyzed the potential drawbacks leading to suboptimal end-to-end performance. A TCP driven CAC scheme has been proposed in order to guarantee QoS for multimedia services with different bandwidth requirements, guarantee an

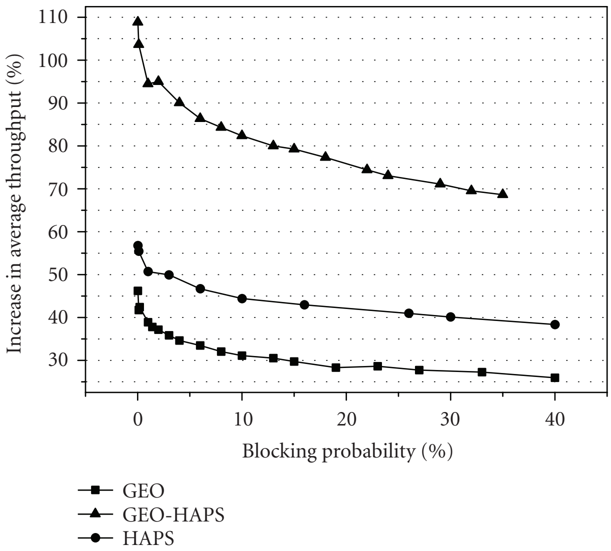


Figure 9: Average throughput increase versus blocking probability.

optimal resource utilization, and reduce the system blocking probability, without altering the TCP standard mechanisms.

Through simulation, we demonstrated a considerable improvement on the performance with respect to a reference CAC algorithm that takes into account only QoS requirements and physical parameters.

## ACKNOWLEDGMENT

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