TCP Performance in Hybrid Satellite - WiFi Networks for High-Speed Trains

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Abstract. Satellite communications have a significant potentiality in the railway scenario, but suffer from strong variations in the received signal power and need suitable solutions to deal with long channel disruptions due to tunnels. The approach envisaged in this paper is based on the adoption of a hybrid network (satellite and terrestrial WiFi coverage) and a *Vertical Handover* (VHO) scheme to switch seamlessly from one segment to another whenever link quality degrades and a new segment is available. Details are provided for the adoption of MIH and MIPv6 in such a context, referring to the BSM standard. Transport layer performance is evaluated considering different TCP versions (e.g., NewReno, BIC, and CUBIC) as well as possible cross-layer approaches to improve the performance in the presence of VHOs. Design criteria are provided taking into account train speed and overlap area size. Finally, interesting TCP performance results are achieved by updating the ssthresh value and limiting the cwnd value after VHOs by means of cross-layer approaches. This work has been carried out within the framework of the ESA SatNEx III project.

Keywords: Satellite Networks, WiFi, Inter-segment (Vertical) Handover, MIH, MIPv6, TCP.

1 Introduction

Railway passengers are expecting reliable broadband communication services available on board and the demand for such services is increasing. In the railway scenario, satellite communications suffer from strong variations in the received signal power due to shadowing and multipath fading. Shadowing due to obstacles (tunnels, buildings, bridges, trees, etc.) causes link unavailability for short or long time intervals. Short-term events (on the order of tens to hundreds of ms) are due to power line structures, trees, buildings, and small obstacles, in general. While, long disruptions (on the order of seconds) can be caused by relatively-long tunnels [1].

The interest of this paper is on the transport layer performance in the presence of channel disruptions due to tunnels. Several approaches are possible, as follows [1]:

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– *Disruption-Tolerant Networking* (DTN)
– *Performance Enhancing Proxy* (PEP)
– Satellite signal relays (gap fillers)
– Hybrid networking with the use of a local wireless coverage.

This paper focuses on the hybrid scenario (satellite and terrestrial WiFi systems) and considers a *Vertical Handover* (VHO) scheme to switch from one segment to another, and different transport-layer schemes, including cross-layer approaches. The study made here based on a hybrid network and a local wireless coverage could also be applied to other environments, such as dense urban areas and railway stations.

We consider a scenario where a Ku-band GEO bent-pipe satellite is used for communication services to the train during the trip. As soon as the train approaches a tunnel, a VHO is performed to switch seamlessly the link to a local WiFi coverage [2]. Within the tunnel, more WiFi *Access Points* (APs) are needed to provide a seamless coverage, thus implying horizontal handover procedures that are considered not to be problematic since they do not entail a *Delay-Bandwidth Product* (DBP) change.

Traditionally, the decision about transferring a connection from one link to another is made by comparing the link quality on the basis of *Received Signal Strength* (RSS), power degradation estimation, and *Bit Error Rate* (BER). Moreover, positioning information could be used in the train scenario to decide about VHO due to the predictability of tunnels positions [3].

2 Survey of TCP Problems Due to VHOs in the Railway Scenario

Several problems affect TCP performance during a VHO procedure [4]; in particular, the sudden DBP variation and a significant change in the *Round-Trip Time* (RTT). Another aspect is that during a VHO there could be a time interval during which the train exchanges data over both satellite and WiFi paths (e.g., ACK and TCP packets propagate quickly via WiFi so that they could anticipate those sent via the satellite link: out-of-sequence problems) according to a ‘soft’ VHO scheme.

Parameters that are crucial for the TCP performance during a VHO are: the duration of the handover phase (including layer 2 and layer 3 signaling), the overlap area between the satellite coverage and the WiFi one (allowing the execution of the VHO in advance with respect to the physical link disconnection), the average train speed, the buffer sizes (sender, satellite network gateway, and WiFi AP).

We examine below the detailed effects on TCP behavior due to the two possible VHO cases for our scenario [4],[5]: from satellite to WiFi and from WiFi to satellite. We refer here to ‘soft’ VHO procedures. Moreover, we consider that a mobile collective terminal on the train is the receiver of TCP downstream flows.

2.1 VHO from Satellite to WiFi Network

In this case (train entering the tunnel), we could expect that DBP and RTT have significant reduction in moving towards the WiFi network. The problems that TCP could encounter during this handover process are:

- TCP packets are anticipated (received out of order) due to the fact that when TCP packets are still propagating to the satellite, new TCP packets can be quickly received via WiFi. Then, TCP packets need to be reordered at the receiver before being delivered to upper layers (this might cause a receiver window partly closing).
  - DUPACKs are generated due to the arrival of TCP packets out of order. This may cause useless retransmissions and halving the *congestion window* (cwnd).
- ACK packets are anticipated as soon as the new WiFi path is activated (many ACKs could be anticipated if the handover is performed when the cwnd value is high). In this case, large bursts of data could be injected in the WiFi AP buffer to be sent to the mobile collective terminal on the train, thus entailing the risk of packet losses due to buffer overflow.

2.2 VHO from WiFi to Satellite Network

In this case (train leaving the tunnel), DBP of WiFi is much smaller than that of the satellite network (during the WiFi segment cwnd is temporarily reduced). The problems that TCP encounters during this handover process are as follows:

- Too short RTO at the beginning of the connection via satellite with the risk of timeout expiration and cwnd reset (multiple RTO expirations could lead ssthresh to 1, thus slowing the cwnd increase, restarting from the congestion avoidance phase for TCP NewReno).
- Slow cwnd increase at the beginning of the connection via satellite (if the process starts when TCP is in the congestion avoidance phase) with consequent slow traffic injection increase in the satellite segment.

3 Scenario Description and Handover Procedure

We consider the reference network architecture shown in Figure 1, where a collective terminal on a train receives a downstream Internet traffic via a GEO bent-pipe satellite. When the train approaches a tunnel a new WiFi connection is used by means of a VHO. This can be realized under the assumption that the train collective terminal supports multiple air interfaces (i.e., satellite and IEEE 802.11 interfaces) and that WiFi APs are located in the tunnel. Terrestrial wired links bit-rates have been set to 500 Mbit/s to neglect their impact on congestion events and to emphasize the bottleneck nature of wireless links.

The mobility and related handover events need to be managed at both layer 2 (selection of a new link) and layer 3 (new IP address for the mobile node and

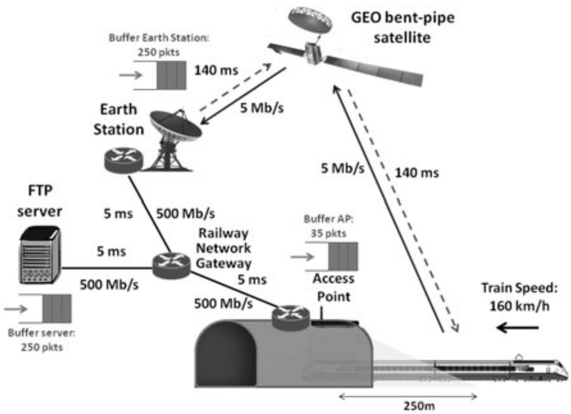

Fig. 1. Reference system architecture

new path for the IP traffic). To support the *Layer 2* (L2) handover procedures we consider that MIH (*Media Independent Handover*, IEEE 802.21 standard) is adopted at layer 2+, referring to the *Broadband Satellite Multimedia* (BSM) standard scenario [6]. With MIH a mobile node discovers a new access link, registers itself to the new network, disconnects from the old network (when some handover criterion is meet), and communicates with the corresponding host via the new access link. As for the IP layer, we adopt MIPv6 that entails an efficient management of IP traffic and a low *Layer 3* (L3) handover latency.

VHO requires some preparatory L2 and L3 signaling exchange to detect the new link and to define automatically the new IP address, *Care of Address* (CoA), by means of *Router Advertisement* (RA) and *Router Solicitation* (RS) messages. Then, as soon as the handover is decided a *Binding Update* L3 message is sent via the new link to the corresponding node (i.e., the sender) to notify about the new IP address of the mobile node. In this work, we consider that the packets are transmitted on the new interface soon after the Binding Update message is sent, without waiting for the Binding Update ACK ('soft' handover). This permits to reduce the VHO latency. The VHO procedure is mobile-initiated.

Let us denote by t_{HO} the total handover latency, that is the time interval from the new link detection instant to the instant when the binding ACK message is received at the mobile node or to the instant when the last TCP packet is received through the 'old' air interface. During t_{HO} there are L2 and L3 signaling messages as well as data packets going through both air interfaces. Note that ACK packets are sent on the new link soon after the Binding Update message is transmitted by the collective terminal. The following Figure 2 describes the (simplified) signaling implemented to support satellite-to-WiFi VHO with MIH; in this case, the most critical issue is the arrival of out-of-sequence ACKs and packets. In particular, Figure 2 describes the case with the maximum t_{HO} value (handover executed -with Binding Update message sent- after the complete reception of a window of data at the satellite).

In order to characterize the overlap coverage area between satellite and WiFi, we write the following constraint:

$$\max\{t_{HO}\} = 2RTD_{WiFi(AP)} + T_{HO\_decision} + \frac{RTD_{e2e\_sat}}{2} + \frac{RTD_{e2e\_WiFi}}{2}$$

$$< \frac{\text{overlap distance (sat} - \text{WiFi)}}{\text{train speed}}$$

$$\Rightarrow \quad \text{overlap distance (sat} - \text{WiFi)} >$$

$$\left(2RTD_{WiFi(AP)} + T_{HO\_decision} + \frac{RTD_{e2e\_sat}}{2} + \frac{RTD_{e2e\_WiFi}}{2}\right) \times \text{train speed} \tag{1}$$

where $RTD_{WiFi(AP)}$ (on the order of μs) denotes the round-trip propagation delay from the collective terminal to the WiFi AP, $T_{HO\_decision}$ is the VHO decision time (determined as outlined below), $RTD_{e2e\_sat} = 580$ ms represents the end-to-end round-trip propagation delay via satellite, and $RTD_{e2e\_WiFi} = 20$ ms denotes the end-to-end round-trip propagation delay via the WiFi AP.

In our study, referring to the VHO scenario in Figure 2, we reasonably assume that the WiFi AP coverage is able to reach a distance $d_{max} = 250$ m at the entrance (and at the end) of the tunnel. Moreover, the $T_{HO\_decision}$ time can be determined by considering a suitable propagation model and a threshold criterion on the WiFi *Signal-to-Noise-Ratio* (SNR) variation[1]. In particular, we consider the two-ray ground propagation model (path loss exponent is 4) and we adopt the handover decision criterion and related handover distance d_{th} that corresponds to a WiFi SNR increase of 3 dB (threshold) with respect to the SNR at d_{max} (WiFi border of coverage). We obtain the following formula:

$$10\ \log_{10}\left(\frac{d_{\max}}{d_{th}}\right)^4 = 3\text{ dB} \tag{2}$$

Hence, $d_{max} - d_{th} = 40$ m. Moreover, for a train speed of 160 km/h, we have:

$$T_{HO\_decision} = \frac{d_{\max} - d_{th}}{\text{train speed}} = 0.9\text{ s} \tag{3}$$

On the basis of the above values, condition (1) is fulfilled.

Finally, Figure 3 describes the signaling and the maximum t_{HO} time for the WiFi-to-satellite VHO. In this case, the maximum t_{HO} value is complementary to that in (1) with $T_{HO\_decision}$ time depending on the satellite propagation model. The main criticality for TCP during the VHO process is that RTO could expire for those packets that have been sent via WiFi and for which ACKs are sent via satellite.

[1] A further element characterizing $T_{HO\_decision}$ is related to the visibility of the satellite in the proximity of the tunnel that depends on the satellite elevation angle, the latitude and the position of the tunnel (and related mountain) with respect to the GEO satellite. The analysis of these aspects is left to a future study.

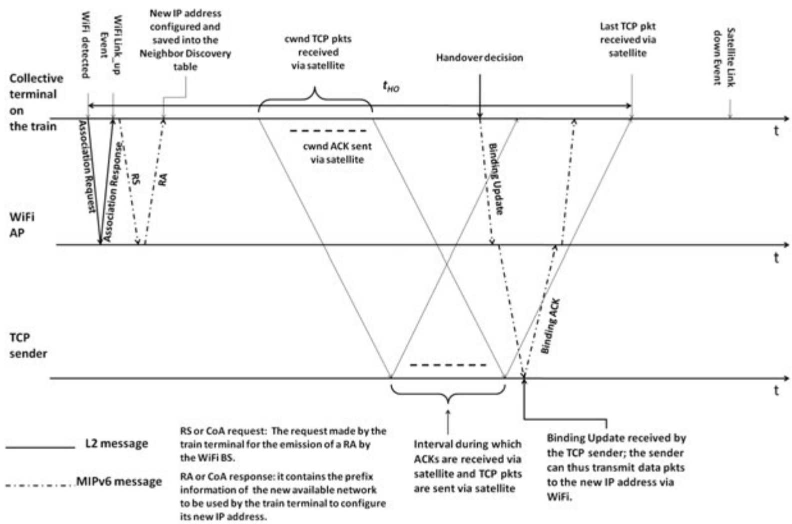

Fig. 2. Satellite-to-WiFi VHO: scenario for maximum t_{HO}

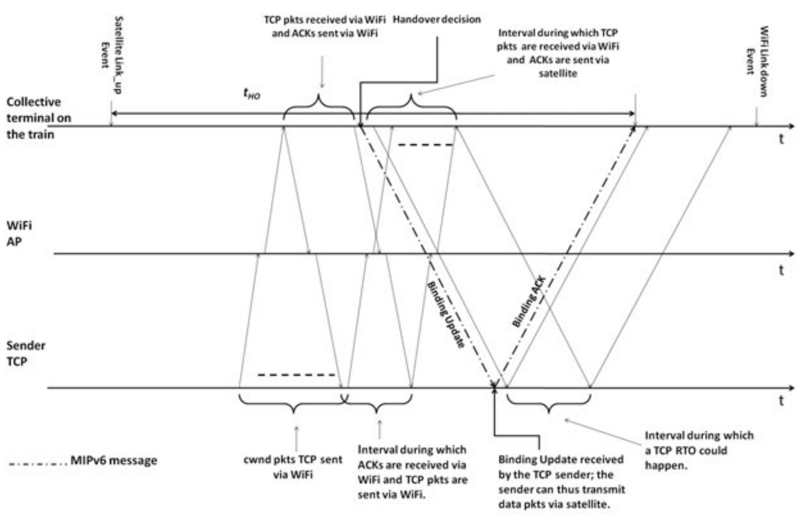

Fig. 3. WiFi-to-satellite VHO: scenario for maximum t_{HO}

4 Techniques for TCP Performance Improvement in VHO

Table 1 provides details on different techniques available in the literature to improve TCP performance in the presence of VHOs from satellite to WiFi networks and viceversa. In particular, we consider both TCP versions that have been proposed for high-speed terrestrial networks and cross-layer schemes that involve L2 and L3. In this paper, we compare two alternative composite methods to support VHOs in the railway tunnel scenario; in both cases we exploit cross-layer signaling that could be supported by the SI-SAP interface of the BSM standard.

- *VHO method #1* – Reordering approach for the satellite-to-WiFi VHO case (see Table 1) and RTT estimation (the timestamp of the Binding Update message is used to update RTO) for the WiFi-to-satellite case;
- *VHO method #2* – Limitation of cwnd on the basis of the WiFi AP buffer size (MAC buffer size limitation technique in Table 1) for the satellite-to-WiFi VHO and ssthresh update for the WiFi-to-satellite VHO by restoring ssthresh to the value assumed before the previous satellite-to-WiFi VHO (this solution is an original proposal that comes from the Hoe approach [12] and requires a cross-layer signaling: the Binding Update message received at the sender triggers the restoring of the ssthresh value).

Moreover, we will investigate TCP-friendliness problems and RTT-fairness[2] issues [14] that arise from concurrent flows experiencing different RTT values (i.e., WiFi and satellite).

5 Results

We have built an ns-2 simulator [15] for the scenario depicted in Figure 1, considering trains that encounter tunnels along their trip with active (persistent) FTP flows. Parameter values are according to Table 2. We have selected the buffer size on the basis of the DBP value (to fill the pipe). The tunnel length is 5.3 km that corresponds to a tunnel duration of about 120 s (we consider here a sufficiently-long tunnel that would create a link disruption in the absence of a local WiFi coverage) for an average train speed of 160 km/h.

We have compared in Figure 4 the behaviors of NewReno, Vegas (as used by SCPS-TP), Westwood+, *Binary Increase Congestion control* (BIC) [7], and

[2] For a TCP variant with an average TCP throughput that depends on c/p^d, where c and d are protocol-related constants and p is the packet loss rate, RTT-unfairness [13] is roughly proportional to $(RTT_2/RTT_1)^{d/(1-d)}$. As d increases, the RTT unfairness increases. For BIC $d = 0.5$ as with NewReno, but c of BIC is much bigger. Note that the occurrence of a tunnel could be macroscopically similar to a packet loss event for cwnd. Hence, the above considerations may also give some insights for our VHO cases.

Table 1. Survey of techniques suitable for TCP performance improvement in VHO

Method	Modifications	Description	Signaling	Satellite-to-WiFi VHO impact	WiFi-to-satellite VHO impact
BIC-TCP [7]	Sender side TCP modification (new congestion control protocol suitable for high-speed networks)	A new cwnd increase function is used with linear, logarithmic, and exponential increase phases. More details are provided in Section 5.	Standard TCP level signaling	No impact	This VHO is managed better since a sudden cwnd increase is supported, thus achieving a better utilization of resources in the new (satellite) network.
CUBIC-TCP [8]	Sender side TCP modification (new congestion control protocol suitable for high-speed networks)	This is similar to BIC, but a cubic cwnd increase law is adopted. More details are provided in Section 5.	Standard TCP level signaling	No impact	This VHO is managed better since a sudden cwnd increase is supported, thus achieving a better utilization of resources in the new (satellite) network.
Reordering approach [9]	Sender and receiver sides TCP modification	This modification allows managing the arrival of out-of-sequence packets due to the VHO from a high RTT network (satellite) to a low RTT one (WiFi). Instead of DUPACKS, ACKs are sent during the interval for which out-of-sequence packets are received (i.e., "HO_mode" time interval), as detailed below. Receiver side "HO_mode": a new header field is used in the ACK to describe the number N of outstanding packets still in the old network. When N reaches 0 the "HO_mode" is over. Sender side "HO_mode": a congestion avoidance phase is performed during the time interval that the receiver needs to acknowledge all the out-of-sequence packets. When an ACK with $N = 0$ is received, TCP returns to its standard behavior.	Cross-layer signaling L3 and L4: when the Binding Update (L3) message is sent, the receiver notifies its TCP layer about the "HO_mode"; moreover, when the sender receives the Binding Update message, it notifies its TCP layer about the "HO_mode".	DUPAKS are not sent so that there is no need to retransmit the delayed packets sent via the old (satellite) network before the VHO decision.	No impact
Adaptive retransmission timer [9]	Sender side TCP modification	When the Binding Update message is received for a VHO procedure, the sender updates the RTO value for the new network on the basis of the *timestamp information* that is included in the Binding Update message (the difference between the Binding Update message arrival instant and the timestamp information is used to update RTO).	Cross-layer signaling L2 and L3	No impact	It is possible to avoid an RTO expiration since RTO is soon updated in the new network. In the standard TCP, the sender updates the RTO value as soon as the ACK is received of the first TCP segment sent via satellite.

Table 1. (*continued*)

Method	**Modifications**	**Description**	**Signaling**	**Satellite-to-WiFi VHO impact**	**WiFi-to-satellite VHO impact**
MAC buffer size notification [10]	Sender side TCP modification	The MAC buffer size of the new wireless network reached by VHO (the downlink of the new wireless segment is considered as the downstream bottleneck link) is communicated via the Association Response message by means of a new header field. Then, this information is sent back to the sender by means of the Binding Update message. The MAC buffer size is used to determine an upper bound to the cwnd value at VHO time in the new network.	Cross-layer signaling L2, L3, and L4 by means of the Binding Update message including MAC buffer size information	This method can adapt (reduce) cwnd to the WiFi network, thus avoiding the risk of buffer overflow.	No impact
Forward-RTO (F-RTO) [11]	Sender side TCP modification	F-RTO is executed only after an RTO expiration: the packet generating the timeout is retransmitted, ssthresh is halved, and cwnd is kept unchanged. Then, if the sender receives the ACK of a new packet, two new TCP packets are transmitted and cwnd = ssthresh; otherwise, if a DUPACK is received, the standard RTO protocol is executed (i.e., cwnd = 1 and a slow start phase is performed).	Standard TCP level signaling	No impact	F-RTO can avoid spurious RTO expirations caused by the VHO from a low RTT network to a high RTT network.
Hoe algorithm [12]	Sender side TCP modification	With this algorithm the initial ssthresh is set as half of the DBP estimated on the basis of RTT and the interarrival time between two consecutive ACKs. This algorithm could be modified and performed at VHO time to estimate the characteristics of the new visited network. However, DBP estimation in a new network (visited by VHO) entails a delay due to the arrival of the two first ACKs received via the new network.	Standard TCP level signaling	This algorithm could be used to lower ssthresh in the new visited network (WiFi), thus reducing the risk of buffer overflow and packet losses in the new network.	This algorithm could be used to increase ssthresh in the new visited network (satellite), thus permitting a faster utilization of the satellite bandwidth.

Table 2. Simulation parameters and settings

IEEE 802.11b settings	
Frequency	2.4 GHz
Nominal bandwidth	11 Mbit/s
Transmit Power	15 dBm
Received power threshold (for 250 m radius of coverage)	−74 dBm
System parameters	
TCP packet size (downstream)	1500 bytes
DBP of the satellite link	233 pkts
DBP of the wireless terrestrial link	9 pkts
Sender buffer size = satellite buffer size	250 pkts
WiFi buffer size	35 pkts
Satellite information bit-rate	5 Mbit/s

CUBIC [8] in the presence of VHOs between satellite and WiFi (single flow case). BIC and CUBIC have been proposed for terrestrial high-speed networks with high latency and allow a fast increase of the cwnd value. BIC combines linear, concave, and convex cwnd growth portions based on S_{min} (controlling the TCP-friendliness) and S_{max} (controlling the RTT-fairness), such as: additive increase (linear cwnd increase of S_{max} on RTT basis), binary search (logarithmic cwnd increase: $S_{max}/2$, $S_{max}/4$, ...), max probing (exponential cwnd increase: $2S_{min}$, $4S_{min}$, ...), and again additive increase (linear cwnd increase of S_{max}). All these phases are involved in a WiFi-to-satellite VHO to identify the new maximum cwnd of the satellite network that is much bigger than the WiFi one. In the additive increase phase there is a fast cwnd increase of S_{max} ($\gg 1$) on an RTT basis. This is much faster than the cwnd increase of 1 on an RTT basis for TCP NewReno in the congestion avoidance phase. It is convenient to have $S_{max}/S_{min} = 2^n$ with $n \geq 4$ for a fast cwnd increase. A high S_{max} value allows improving scalability and a low S_{min} improves TCP-friendliness. However, a too high S_{max} could entail a too [7] burst TCP traffic injection with consequent losses (congestion situation). Therefore, we have used [7]: Smin = 0.25 and Smax = 64. With CUBIC, the different phases of cwnd increase are substituted by a cubic law: cwnd $= c\,(t-K)^3 + W_{max}$, where t is the elapsed time from the last window reduction, c (= 0.4) is a scaling constant, W_{max} is the maximum cwnd value before the last reduction (e.g., maximum value in the WiFi segment at the WiFi-to-satellite VHO), β (= 0.8) is the cwnd reduction factor after a packet loss, and $K = \sqrt[3]{W_{\max}\beta/C}$; S_{max} (= 160 packets) now represents the maximum cwnd increment on RTT basis. BIC and CUBIC are implemented as default in several linux versions.

Referring to Figure 4, we can note that both BIC and CUBIC allow the highest cwnd (goodput) values in all conditions and a very fast cwnd increase at the WiFi-to-satellite VHO[3]. Moreover, all TCP versions reduce the cwnd value when a VHO is performed from satellite to WiFi (this change does not necessarily imply a bit-rate reduction because the WiFi link has a much lower RTT than the satellite one). We can see that there is a risk of RTO expiration at the WiFi-to-satellite VHO, as it occurs with Westwood+, thus entailing a cwnd reset to 1 and a slow cwnd increase in the satellite segment (congestion avoidance phase) due to a low value of ssthresh (Westwood+ uses the minimum RTT to estimate ssthresh and, thus, this RTT value is constrained by the WiFi segment in our case).

Figure 5 compares the TCP versions cwnd behaviors (single flow) in a case with random *Packet Error Rate* (PER) of 10^{-3} in the satellite segment. We can note that Westwood+ has a good performance before the second (WiFi-to-satellite) VHO, while its performance is reduced soon after due to a low ssthresh value. Moreover, CUBIC seems to maintain a sufficiently good performance before and after the tunnel.

[3] With BIC, the cwnd increase time at the WiFi-to-satellite VHO is about equal to $2\log_2(S_{\max}/S_{\min}) + 2DBP/S_{\max}$ in RTT unit of time. For NewReno, the same time would be about equal to $2DBP$.

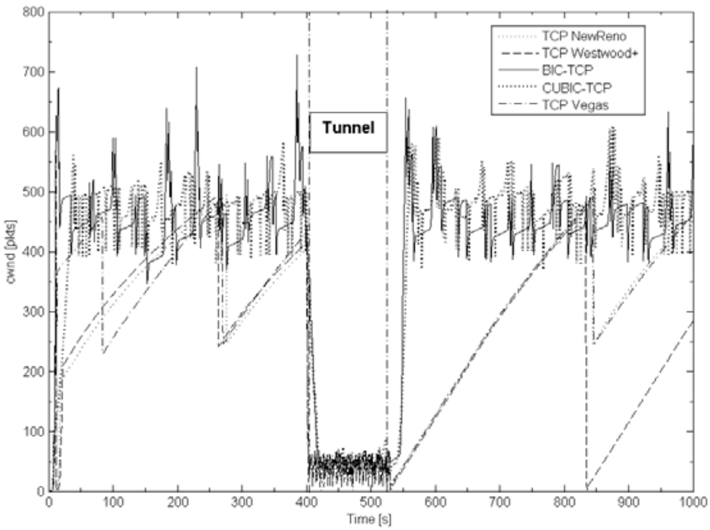

Fig. 4. Comparison of cwnd behaviors with different TCP versions in the presence of satellite-to-WiFi VHO (405 s) and WiFi-to-satellite VHO (525 s); no random errors

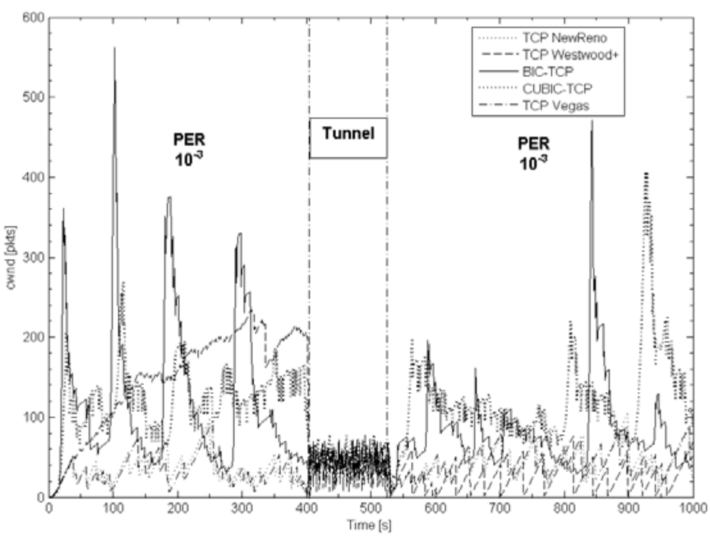

Fig. 5. Comparison of cwnd behaviors with different TCP versions in the presence of satellite-to-WiFi VHO (405 s) and WiFi-to-satellite VHO (525 s) VHO; PER = 10^{-3}

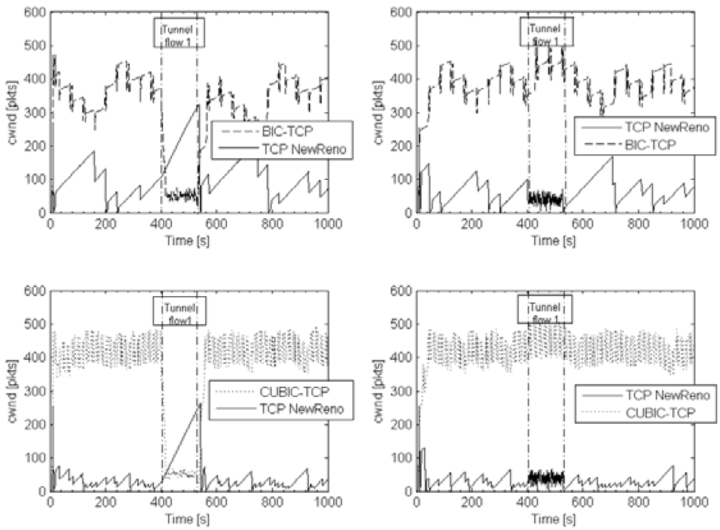

Fig. 6. Cwnd behaviors for two concurrent flows on two trains using different TCP versions (only flow #1 encounters a tunnel); no packet losses are considered

Figure 6 analyzes TCP-friendliness issues in the presence of two concurrent flows using different TCP variants and from two trains[4], so that only flow #1 encounters a tunnel in the time interval under investigation. From these results it is evident that BIC is more friendly than CUBIC with respect to NewReno; this is consistent with the study made in [14] in a scenario with high RTT.

In Figure 7, TCP performance is investigated with VHO methods #1 and #2; we refer here to TCP NewReno as this is the basic scheme (since the buffer size is equal to DBP, the cwnd behavior in the congestion avoidance phase is not linear but curved). We can note that VHO method #2 permits to achieve a faster cwnd increase after the WiFi-to-satellite VHO. Moreover, methods #1 and #2 avoid the occurrence of RTO after the satellite-to-WiFi VHO due to the arrival of packets and ACKs out of sequence (such improvement cannot be appreciated with the cwnd scale in the graph); however, method #1 is unable to avoid an RTO expiration at the the WiFi-to-satellite VHO because the Binding Update message allows measuring the RTT on the basis of the return path, without accounting for the forward path congestion.

Figure 8 shows the instantaneous goodput averaged over 10 repeated runs with different starting phases for two flows on distinct trains. This study permits to appreciate better the performance of method #1 and method #2 with respect to classical NewReno. Note that during the WiFi segment the total goodput is much higher than in the case of the satellite segment, because we have two

[4] In the presence of multiple TCP flows (e.g., browsing sessions) for the same train, they experience synchronized losses since they share the use of buffers along the same path.

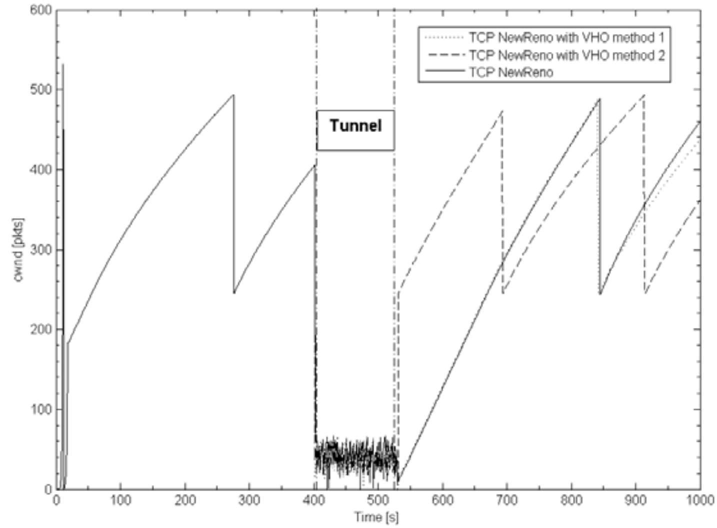

Fig. 7. Comparison of VHO techniques with TCP NewReno and single flow

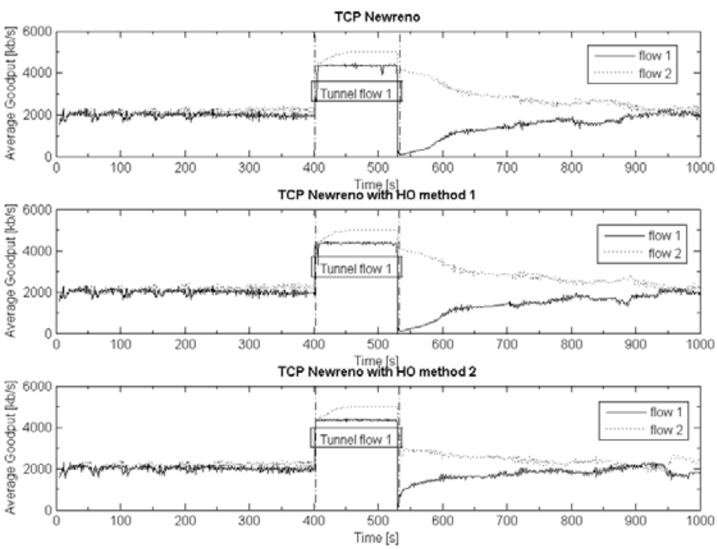

Fig. 8. Mean goodput for two TCP flows (only flow 1 encounters a tunnel)

flows exploiting separate bottleneck links (i.e., WiFi and satellite). These results confirm that method #2 permits to achieve a much better performance at the WiFi-to-satellite VHO.

Finally, Figure 9 compares the two envisaged VHO methods (applied to TCP NewReno), considering two concurrent flows on two trains. Only flow #1

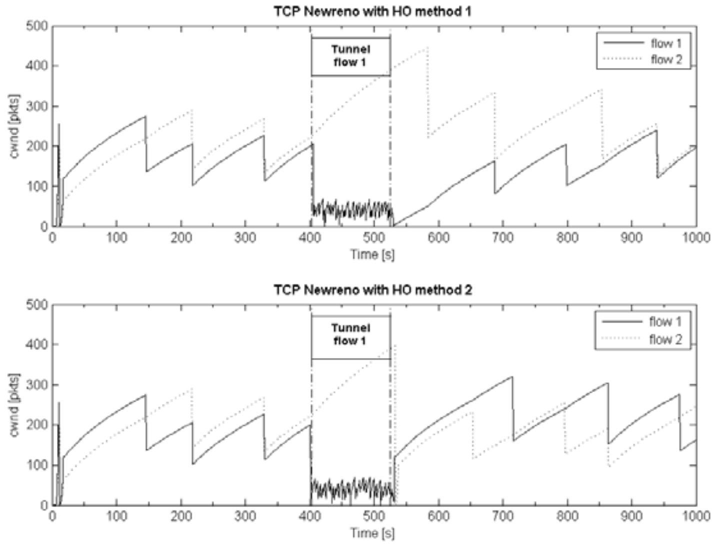

Fig. 9. Cwnd behavior of the two proposed handover methods used with TCP NewReno (only flow #1 encounters a tunnel); no packet errors are considered

encounters a tunnel during the simulation time. We can note that method #2 permits to achieve a better RTT-fairness and TCP-friendliness at the WiFi-to-satellite VHO.

6 Conclusions

This paper has dealt with transport layer performance in the presence of channel disruptions due to tunnels in a GEO satellite railway scenario. The approach considered here is based on a hybrid network with WiFi coverage in the tunnels. Suitable VHO procedures have been described on the basis of MIH and MIPv6 applied to the BSM standard scenario. Moreover, different enhanced TCP versions have been envisaged to increase the speed of traffic injection in the VHO from WiFi to satellite. TCP-friendliness and RTT-fairness issues have been discussed due to the occurrence of VHOs and the presence of flows on distinct trains. Finally, two cross-layer schemes have been investigated (method #2 contains a proposal made in this study) to improve the TCP goodput at the satellite-to-WiFi VHO and at the WiFi-to-satellite VHO. Future work is needed to investigate further TCP-friendliness and RTT-fairness issues considering also other TCP versions (e.g., Scalable TCP), to study the impact of different WiFi AP buffer sizes, and to propose other cross-layer options to improve TCP performance during VHOs. This work has been carried out within the framework of the SatNEx III Network of Experts supported by ESA (ESA Contract RFQ/3-12859/09/NL/CLP).

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