Evaluation of TCP Variants and Bandwidth on Demand over Next Generation Satellite Network

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Abstract—the Internet has become an important part of day to day activities. There is hardly a day without using Internet, such as reading Emails and articles as well as enjoying music and video. Thus, it is very important for the Internet to be provided to anyone anywhere. Terrestrial network has been the underlying infrastructure for the Internet. However, terrestrial network by itself cannot always satisfy all of the growing demands for the Internet, particularly in the remote areas. Thus, the deployment of the Next Generation Satellite Network (NGSN) is needed to fill in the gap and break the digital divide. This paper evaluates how the performances of TCP over NGSN with dynamic bandwidth allocation mechanism. The TCP used in this work is a real-world TCP based on both Linux and Window Vista implementations which have been integrated into a network simulator, INET. The study reveals that the TCP performances in terms of utilization and robustness, friendliness and fairness, and user's perceived Quality of Service are clearly affected by the dynamic bandwidth allocation mechanism.

Keywords—Linux, TCP, Next Generation Satellite Network, Bandwidth on Demand

I. INTRODUCTION

Over the Internet, transmission Control Protocol or TCP [1] is the most dominant protocol since it is the protocol on which ‘legacy’ Internet applications are based. Although NewReno, the latest IETF standard TCP [2], performs exceptionally well over the traditional network, its performances are quite limited in the next generation network having large Bandwidth Delay Product (BDP). Thus, various developments have been carried out to improve TCP performances. Linux TCP is a part of the Linux TCP/IP network stack which provides ten other TCP variants, i.e. bic, cubic, highspeed, hamilton, hybla, scalable, vegas, veno and westwood, in addition to the standard TCP, reno. Details of these variants can be found in literatures. In addition, the Window Vista based TCP, known as compound, is integrated into Linux kernel by [3]. Thus, to obtain realistic TCP dynamic, TCP functionalities of Linux TCP/IP network stack (ver. 2.6.21.3) are integrated into a network simulator, INET [4, 5]. As a consequence, more accurate TCP dynamic can be observed in simulated network environments of INET.

The advance in satellite technologies, i.e. powerful coding, highspeed link, multiple spotbeam and on-board processor, presents NGSN. Moreover, the adoption of the latest standards in Digital Video Broadcasting (DVB), i.e. DVB-S/S2 [6, 7] and DVB-RCS [8] enables fully interactive Internet services over NGSN at a relatively low cost. With dynamic bandwidth allocation, i.e. Bandwidth on Demand (BoD), NGSN is able to utilize bandwidth efficiently. Nonetheless, BoD when coupled with network characteristics, such as large BDP and high data loss rate, can considerably affect TCP performances and thus Internet services over NGSN.

This work is to evaluate the performances of non standard TCP, based on Linux and Windows Vista implementations, against reno in terms of utilization and robustness, friendliness and fairness, and user’s perceived Quality of Service over the NGSN with BoD. Simulation setup is outlined in Section II whereas simulation results and discussions are given in section III. Finally, section IV presents conclusions and future works.

II. SIMULATION SETUP

The setup is based on NGSN. The satellite itself is the next generation geostationary satellite having multiple spotbeams, highspeed links and on-board processor. The downlink/uplink is based on TDM/TDMA and both have the same bandwidth. The uplink bandwidth is segmented into frames. Each frame contains 48 time slots; one of which is a preamble slot and the rest are data slots. A data slot is equivalent to eight MPEG-II (188-bytes) frames or 1504 bytes; thus supporting Ethernet frames or 1500 bytes. In general, given bit rate ($R$) and slot length ($SL$), slot duration ($SD$) can be calculated as follow.

$$SD = \frac{SL}{R}$$  (1)
The total frame duration is 48-SD. The bandwidth is allocated dynamically according to a request/ allocation scheme of BoD [9]. The request is based on Volume Based Dynamic Capacity (VDBC) and the allocation is based on proportional allocator. Bandwidth is requested and allocated in numbers of slots and is performed once every superframe, i.e. multiple frames. The allocator is located on board the satellite where all the requests are collected and data slots are computed and then allocated in a round robin manner. Let \( R_i \) and \( A_i \) be slot request and slot allocation whereas \( Q(\Delta t) \) and \( D(\Delta t) \) be queue occupancy and slot deficit since the last request for terminal \( i \),

\[
R_i = \left\lceil \frac{Q(\Delta t)}{L} \right\rceil + D_i(\Delta t)
\]

(2)

and

\[
A_i = \begin{cases} 
R_i & \text{if } \sum R_i \leq DS \\
\left\lceil \frac{R_i}{\sum R_i} \right\rceil & \text{if otherwise and s.t. } \sum A_i \leq DS
\end{cases}
\]

(3)

where \( \lceil x \rceil \) is the smallest integer greater than \( x \), \( DS \) is the data slots per frame and ‘s.t.’ is the abbreviation for ‘subject to’.

The slot allocation, i.e. Terminal Burst Time Plan (TBTP), is broadcasted at the beginning of the next superframe. Once receiving the TBTP, satellite terminals can begin transmitting data but only in the designated data slots of the corresponding superframe. The allocation time \( T \), i.e. time needed for a slot request to become effective, follows this expression,

\[
T = n \cdot (F \cdot DS \cdot SL) \quad \text{s.t. } T \geq P
\]

(4)

where \( n \) is the smallest integer that satisfies the condition, \( F \) is frames per superframe and \( P \) is the propagation delay, roughly 500 ms for geostationary satellite. If the request is not entirely satisfied, slot deficit is added to the next request. In this study, the request/ allocation is performed every three frames and the network is setup as displayed in Fig. 1.

Client network consists of standard and enhanced peers and connects to a satellite gateway. Two corresponding servers are on the other side of the network and connect to two gateways. A TCP application (200 MB file download) is requested by peers at a random time which is exponentially distributed and one second on average. The uplinks are setup for three cases (a) 2-Mbps with 100-packet, (b) 4-Mbps with 200-packet and (c) 8-Mbps link with 400-packet buffer. The choices of buffer sizes are simply to accommodate the BDP of the satellite link. The network simulator used is the modified INET [5].

III. RESULTS AND DISCUSSIONS

A. Utilization and Robustness

In general, utilization and robustness indicate the efficiency of TCP when utilizing a bottleneck link and when dealing with packet losses. In this study, the satellite links are assumed to be lossy with bit error rate (BER) ranging from \( 10^{-10} \) to \( 10^{-7} \). Utilizations and robustness of TCP over the satellite link with BoD for the three link setups are displayed in Fig. 2.

Fig. 2 (a) illustrates that with 2-Mbps link and 100-packet buffer, all variants achieve utilization at 40 percents or lower. For low BER, i.e. \( 10^{-10} \) to \( 10^{-9} \), reno, bic, cubic, highspeed and scalable achieve utilization at roughly 30-40 percents whereas compound, hamilton, hybla, veno and westwood are at 20-30 percents. For high BER, i.e. \( 10^{-8} \) to \( 10^{-7} \), cubic, hamilton and hybla are the only variants that do not suffer significant drop in utilization. However, vegas displays the lowest utilization at 10 percents or less regardless of BER. Fig. 2 (b) illustrates that with 4-Mbps link and 200-packet buffer, all variants display improvement in utilization but still limited to 60 percents. It is clear that variants having the highest and the lowest utilization are veno and vegas respectively. For low BER, bic and cubic achieve utilization at 50 percents whereas the rest are around 40-50 percents. For high BER, cubic, hamilton and hybla are the only variants having utilization maintained at 20 percents or more. Fig. 2 (c) illustrates that with 8-Mbps link and 400-packet buffer, all variants appear to display utilization similar...
to the results previously found in Fig. 2 (b). But, compound and highspeed are the only variants able to achieve utilization at 80 and 70 percents respectively whereas vegas still displays the lowest utilization.

These low utilizations are rather uncommon when a large file download is considered but it is all due to the interaction between TCP and BoD. Prior to data transmission, bandwidth has to be first allocated. According to (2) and (4), the numbers of data slots that can be requested given the buffer size of 100, 200 and 400 are 102, 141 and 141 slots per superframe and the allocation time given the links of 2, 4 and 8 Mbps are 0.866, 200 and 400 are 102, 141 and 141 slots per superframe and the allocation time given the links of 2, 4 and 8 Mbps are 0.866, 0.866 and 0.649 s; therefore, increasing the overall latency and resulting in 1, 2 and 3 idle superframes prior to transmission.

Thus, to have all 141 data slots allocated per superframe, the minimum buffer size of 141 is needed. Likewise, to request all data slots in the subsequent superframe, a buffer size of 282 or more is required in order to avoid any packet drops if another 141 packets arrive before any of the previous 141 packets can be transmitted. Evidently, when BoD is used, queued packets do not necessarily imply full utilization and larger buffers are essential to maintain full utilization.

According to the results, TCP using an increase in delay as a sign for network congestion, like vegas, is likely to display significantly degraded performances due to large variations in delay caused by BoD mechanism. In addition, the buffer size of 100 or 200 packets are insufficient to request all 141 data slots in the subsequent superframe, a buffer size of 282 or more is required in order to avoid any packet drops if another 141 packets arrive before any of the previous 141 packets can be transmitted. Evidently, when BoD is used, queued packets do not necessarily imply full utilization and larger buffers are essential to maintain full utilization.
slots for two consecutive superframes, therefore resulting in poor utilizations. Although two consecutive superframes can be requested by the 400-packet buffer, three superframes are idle and cannot be utilized before TBTP arrives. Given that TCP requires feedbacks, i.e. acknowledgement, to increase its transmission rate, having more idle superframes can lead to even lower utilization. Clearly, BoD adversely affects the performances of TCP by increasing both round trip time and delay variation as well as leaving a number of superframes unutilized. In addition to BoD, lower BER is also necessary to obtain higher utilization particularly for larger bandwidth.

According to the results, compound, highspeed and veno achieve higher utilization for very low BER whereas cubic, hamilton, hybla and scalable appear to be more robust when compared to reno.

B. Friendliness and Fairness

In general, TCP is said to be friendly if its throughput is no higher than that of reno under the same conditions and to be fair if its throughput is relatively the same as that of reno when competing on the same bottleneck link. In this study, four concurrent file downloads are used; two of which are reno while the other two are other competing variants. The satellite links are assumed to be error free and the smoothed aggregate throughputs of reno flows and competing variants for the three link setups are displayed in Fig. 3.

Fig. 3 (a) illustrates that with 2-Mbps link and 100-packet buffer, all variants are friendly and fair except for vegas that is friendly but unfair. In addition, even with four concurrent flows, i.e. two reno and two competing flows, 100-percent utilization is yet to be achieved. This is due to the effects of BoD on TCP mentioned earlier. As a result, the aggregate throughputs in any cases are unable to achieve the fair share of bandwidth at 1 Mbps, i.e. half of the available bandwidth. Fig. 3 (b) illustrates that with 4-Mbps link and 200-packet buffer, all variants are friendly and fair except for vegas that is friendly but unfair. In addition, in the cases of reno, bic, compound, cubic, highspeed, scalable, veno and westwood being competing flows, the aggregate throughputs are able to achieve the fair share of 2-Mbps bandwidth but not in the cases of hamilton and hybla. Fig. 3 (c) illustrates that with 8-Mbps link and 400-packet buffer, all variants still remain friendly and fair except for vegas that remains friendly but unfair. In addition, the aggregate throughputs in all cases are able to achieve the fair share of 4-Mbps bandwidth. A closer investigation reveals that the throughput displays trajectory with three distinct characteristics when converging to the fair share. The first one is the sudden convergence, forming a triangle-like shape, i.e. reno, compound, highspeed and westwood. The second one is the slow convergence, forming a triangle-like shape, i.e. bic, cubic and scalable. The third one is similar to the second one except with higher variation during convergence, i.e. hamilton and hybla.

Despite the fact that some variants, such as bic, cubic, hamilton, hybla and scalable, are known to be unfriendly and unfair to reno in the terrestrial network, the study reveals that BoD mechanism is able to entirely change their characteristics when competing with reno such that they become friendly and fair. According to the results, all TCP variants, except vegas, are found to be both friendly and fair whereas vegas is found to be friendly but fails to be fair.

C. User’s Perceived Quality of Service

User’s perceived QoS (UQoS) is used to indicate on how well the given services perform from the user point of view. In general, higher throughput often implies better UQoS, particularly for downloading services. Based on the results of Fig. 3, average throughput of individual competing flows is displayed in Fig. 4. In each group, the first two bars are the average throughput of reno whereas the other two bars are that of other competing variants. The “tcp?” indicates the competing variant that is labeled on the x-axis. In this study, the average throughput is loosely used as UQoS.

Fig. 4 (a) illustrates that with 2-Mbps link and 100-packet
TABLE I. TCP PERFORMANCES

<table>
<thead>
<tr>
<th>Buffer Size</th>
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<tbody>
<tr>
<td>1 flow</td>
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<td>++</td>
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<tr>
<td>Robustness</td>
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<tr>
<td>Fairness</td>
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<td>UQoS</td>
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<td>++</td>
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<tr>
<td>4 Concurrent</td>
<td>++</td>
<td>++</td>
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</tbody>
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When compared to reno
+ means better  o means comparable  - means lower
buffer, bic, compound, highspeed, hamilton, hybla and veno, when competing against reno, achieve relatively the same throughput as reno does whereas cubic and scalable achieve slightly higher throughput than reno. However, vegas and westwood display lowest and slightly lower throughput respectively. Fig. 4 (b) illustrates that with 4-Mbps link and 200-packet buffer, bic, compound, highspeed, hamilton, hybla and veno achieve throughput similar to reno whereas cubic and scalable still achieve slightly higher throughput than reno. But, vegas and westwood display throughput that is lower than reno. Fig. 4 (c) illustrates that with 8-Mbps link and 400-packet buffer, besides vegas and westwood, all variants achieve throughput comparable to reno. Still, vegas and westwood displays lower throughput.

According to the results, UQoS based on bic, compound, highspeed, hamilton, hybla and veno are at the same level as reno whereas UQoS based on cubic and scalable is slightly better. However, UQoS provided by westwood is marginally lower and UQoS provided by vegas is the lowest.

IV. CONCLUSIONS AND FUTURE WORKS

This paper evaluates the performances of real-world TCP based on Linux and Microsoft Vista implementations over a satellite link of NGSN with BoD. The metrics of interest are utilization and robustness, friendliness and fairness, and UQoS. The findings based on the study are summarized in TABLE I. The Novelties of this work are first the use of the existing protocol implementation in simulated environment in which more realistic protocol behaviors can be produced and captured, and second the discovery that real-world TCP may not perform optimally over a typical NGSN particularly with BoD. Evidently, the performances of TCP can easily be degraded by a simple BoD mechanism.

The result suggests that given the satellite environments, compound and highspeed are best at utilization while cubic, hamilton and hybla are best at robustness. Additionally, all variants, other than vegas, are both friendly and fair when competing against reno. Lastly, cubic and scalable delivers slightly better UQoS when sharing the same link with reno. Although not having the best utilization, cubic and scalable appear to be the best TCP from the user’s point of views.

With BoD, the presence of queue occupancy no longer implies full utilization and additional slot waiting time has to be added to the overall round trip time. Therefore, larger buffer size is required not only to accommodate larger BDP but also to allow a number of superframes to be requested. It is clear that BoD causes several superframes to be idle and unutilized in which it contributes to even lower utilization. Thus, to optimize TCP performances over NGSN with BoD, buffer size, bandwidth and frame structure have to carefully be fine tuned, since they are related to one another. The final aim is to optimize the slot waiting time and the number of unutilized superframes caused by BoD. In addition to BoD, Adaptive Coding and Modulation (ACM), a mechanism that adapts transmission rate to best suit wireless environment, also affect TCP performances by causing the total available bandwidth to vary. Moreover, if interworking between the next generation terrestrial network and NGSN is important, IP QoS architecture, such as Differentiated Service, has to be considered in order to provide end-to-end QoS across the integrated next generation network.

The future works include further study on the impacts of BoD, i.e. different buffer sizes, different request/allocation setups and different BoD schemes, on TCP performances. Next, the impact of ACM and later the combined effects of both BoD and ACM on TCP performances will be studied. Finally, the performances of TCP over the integrated next generation satellite-terrestrial network, utilizing BoD, ACM and IP QoS, will be investigated.

ACKNOWLEDGMENT

Songrith Kittiperachol thanks the Royal Thai Navy and EPSRC for financial support.

REFERENCES