International Journal of Information, Control and Computer Sciences
ISSN: 2517-9942
Vol:8, No:5, 2014

Augmentation Opportunity of Transmission Control Protocol Performance in Wireless Networks and Cellular Systems

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Abstract**—**The advancement in wireless technology with the wide use of mobile devices have drawn the attention of the research and technological communities towards wireless environments, such as Wireless Local Area Networks (WLANs), Wireless Wide Area Networks (WWANs), and mobile systems and ad-hoc networks. Unfortunately, wired and wireless networks are expressively different in terms of link reliability, bandwidth, and time of propagation delay and by adapting new solutions for these enhanced telecommunications, superior quality, efficiency, and opportunities will be provided where wireless communications were otherwise unfeasible. Some researchers define 4G as a significant improvement of 3G, where current cellular network's issues will be solved and data transfer will play a more significant role. For others, 4G unifies cellular and wireless local area networks, and introduces new routing techniques, efficient solutions for sharing dedicated frequency bands, and an increased mobility and bandwidth capacity. This paper discusses the possible solutions and enhancements probabilities that proposed to improve the performance of Transmission Control Protocol (TCP) over different wireless networks and also the paper investigated each approach in term of advantages and disadvantages.

Keywords**—**TCP, Wireless Networks, Cellular Systems, WLAN.

I. INTRODUCTION

SEVERAL challenges are faced when mobile or wireless networks are associated with wired networks in transport layer side. This is because the wireless networks have various essential features, which will considerably weaken the performance of the protocol that was originally designed for wired networks, if it is not modified to coop with new situation. Most data applications are built on top of a TCP, since TCP provides end-to-end reliability via retransmissions when IP packets are missing. As TCP was originally designed for wired networks, where packet loss was due to network congestion, and consequently, the TCP window size was adjusted upon detection of the loss. However, packet loss within wireless networks is mostly due to bad radio conditions, and not network congestion. Errors in the air-link are often caused by several factors e.g., interference from other sources, fading due to mobility, or scattering due to a large number of reflecting surfaces [1]. The performance metric of TCP in a cellular environment is the average throughput, which is the same in the wired networks.

The average throughput in the cellular case does not only depend on network congestion, but may also be attributed to other factors, such as the bit error rate of the wireless medium, the cell handoff time, and the cell resident time [2]. TCP is typically used in wired communication systems with very small error probabilities. However, the error characteristics of wireless channels differ significantly from that of wired channels. Therefore, TCP gives very poor performance if it is directly applied to a wireless communication system. Wired channels are characterized by miniscule packet-loss probabilities and randomly spaced errors. In contrast, wireless channels are characterized by time varying packet loss probabilities that are generally much larger than that for wired channels. In addition, errors are typically burst in wireless channels [3]. Meanwhile, 4G wireless users should not see any difference between a wired and a wireless network, and will have multiple connectivity options. For these reasons, we should seek to provide a new TCP, which can meet these requirements. An instant way of improving TCP performance would be to modify the TCP itself, since that the inherent assumptions of TCP that are the cause of its poor performance within a wireless environment [4].

The differences between wired and wireless networks imply that packet losses are no longer mainly due to network congestion, as they may well be due to other wireless specific reasons. Actually, in wireless LANs or cellular networks, most packet losses are due to high bit error rates in wireless channels, and handoffs between two cells. Meanwhile, in mobile networks, most packet losses are due to medium contention and route breakages, as well as radio channel errors [5]. Therefore, even though TCP performs well in wired networks, it suffers from serious performance degradation in wireless networks, especially when networks have a high rate of data transferring reach over a bandwidth of one Gbps (Giga Bit per Second). TCP flow control was originally governed, simply by a maximum allowed window size, advertised by the receiver, and a policy that allowed the sender to send new packets only after receiving an acknowledgment for the previous packet [6]. It is also true that protocols, such as TCP, perform very badly over wireless links – lost or delayed packets can signal to the TCP that congestion is taking place and cause flows to slowdown.

Wireless links – with their unpredictable losses and packet delays - can cause the TCP to assume network congestion is taking place, even when the wireless link is well below its full capacity [7]. Numerous studies have found that TCP supports only wireless internet access very inefficiently [8]. The key

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problem is that wireless channel errors lead to frequent expirations of the TCP's retransmission timer, which is then interpreted as congestion by the TCP [9]. In addition, most data applications are built on top of TCP, since TCP provides end-to-end reliability via the retransmissions of missing IP packets [1]. Furthermore, TCP was originally designed for wired networks where packet loss was due to network congestion, and hence, the TCP window size was adjusted upon detection of the loss. However, packet loss in wireless networks is mostly due to bad radio conditions and not network congestion [10].

II. TCP CONFIGURATION

In mobile and wireless networks, there are several challenges that are associated with wired networks, because wireless networks have several essential adverse features that will considerably weaken TCP performance, if no actions are taken. These features involve mobility, link asymmetry, and channel errors.

A. Connection Asymmetry

As all mobiles have limited power, restricted processing capability and limited buffer space, the mobile terminal and the base station are interfaced with wireless asymmetric link.

B. Channel Errors

Generally, high error rate is expected in wireless channel due to the fading of multipath; the shadowing may drop packets in data transfer process, which leads towards the wide loss in segments or acknowledgments.

C. Mobility and Handover

The cellular systems are characterized with handovers due to the user's mobility. Usually, the handovers cause short-term interruptions in connections, which in turn causes packet loss and add extra delay over networks connections.

Theoretically, the TCP is independent of the underlying layers, and if these layers reduce the reliability, then the TCP will be exposed to several shortcomings. On the other hand, wireless network is characterized with high probability of random errors and irregular connectivity of links. Commonly, when the IP packet is sent on wireless links, the IP layer observes the availability of one or more capacity, delay characteristics and loss amount, which differ with time. While the link layer employs, the accessible layer control techniques, such as retransmission scheduling, power controlling, and adapts flow rate, in order to balance the loss, latency and capacity. However, it is not easy to keep constant and suitable level of low latency, low losses, and high capacity, as these represent the individual characteristics of wired links.

Therefore, any protocol that uses congestion control will suffer from packet losses and need to rebuild the congestion window frequently. As the result of packets dropping, some of the TCP versions decrease the cwnd and the flow rate, to maintain connection throughput [11]. The mechanism of congestion control for most TCP variants adapts the style and the requirements of wired networks. In wired network, the accessible bandwidth changes according to the cross traffic and the irregular routing of the network. In addition, the changing in capacity and delaying in wired links, initiate the constant values [12].

If TCP is used over cellular infrastructure, the performance frequently reduced in both, the end-to-end and radio links employment. Researchers are focused with TCP over wireless channels in order to achieve good or at least acceptable level of end-to-end throughput. The individualities of the actual nature and the requirements of the wireless networks are taken into account the strategies to employ TCP over wireless. For example, satellite networks involve large propagation delay, while the ad-hoc network lacks infrastructure. Moreover, the development of TCP for wireless networks need to obviously distinguish the reason behind packet loss. Researches are carried out to identify explicit techniques to notify the TCP senders, the reasons of dropping of packet, congestion, or random errors occurrences [13].

III. TCP ENHANCEMENT POSSIBILITIES

Efficient protocols are needed to overcome the problems and the challenges of wireless networks, especially in the 4G systems as they expect high data rate. Various methodologies have been suggested to optimize the performance of TCP over 4G networks. These methodologies are classified either as TCP improvement approaches or as layer limitations. The TCP improvement depends on end-to-end TCP variations, link level solution, or by split TCP connections with the help of intelligent agents. The following sections elucidate the possible solutions to develop TCP performance over 4G wireless networks.

A. Split TCP Connection Solution

The wired section of any wired-wireless network is more reliable than the wireless part in terms of connection bandwidth capacity and bit error rates. TCP performance can be improved by separating the connection in base station as shown in Fig. 1. The idea of splitting TCP connection is to break an end-to-end TCP connection into two or three segments. Each segment is itself a complete TCP connection. Data streams are forwarded from one segment to another (buffering if necessary). For example, if the first and the last TCP segments span a low latency network, the TCP slow-start can speed up more quickly and the congestion window size will work fine. While in the middle segment, should implement special features and use large windows to cope with extended latency.

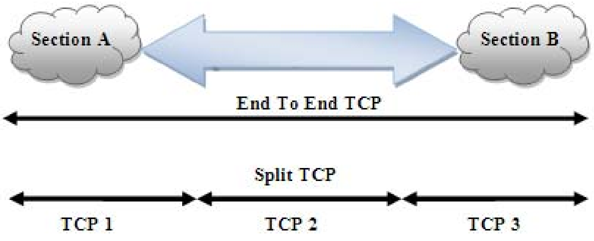

Fig. 1 Splitting TCP connection

Therefore, the performance of TCP can be improved only by implementing minor changes to application software. Furthermore, the splitting approach protects the wireless part from the wired part in network, by isolating the flow control in intermediate base stations from cellular networks (or routers). Hence, the wireless activities have the minimal effect and role is compared with the wired section in the network. The intermediate base stations act as terminals in wireless and fixed parts, and all end hosts are connected with this intermediate station and there is no need to acknowledge the other end [14].

I-TCP (Indirect-TCP) [15] is a protocol proposed on the concept that the TCP connection, between any machine on a fixed network, and the mobile host, must be split into two separated connections. The first is between the base station and the mobile host within the wireless portion, and the second is between the fixed host and the base station within the fixed network as shown in Fig. 2.

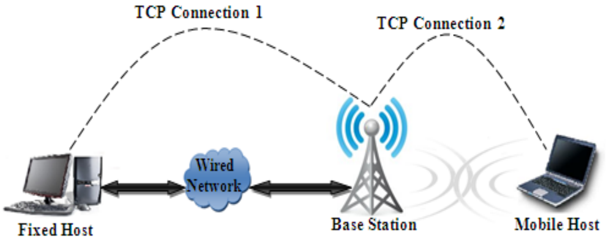

Fig. 2 TCP splitting connection in I-TCP

When a segment is transmitted to a mobile host; first, it is received by the base station and 'ACK' is sent to the fixed host. Then, the segment is forwarded to the mobile host. When the mobile host travels to another cell within the connection, it establishes with the fixed host, and then, full information of connection (kept at the most recent base station) will be transferred to the next base station.

The fixed host is not actually informed of this process, and is not affected whilst this switching occurs. Furthermore, when the end-to-end connections are split, the TCP connection for the wireless portion is able to use some variation of the wireless link aware TCP, where it is tailor-made to handle wireless link errors and possible handover disruptions [15]. M-TCP is another split connection approach. It is based on dividing the TCP connection between the mobile host and the fixed host into two parts.

The first is between the base station and the fixed host, whilst the second is between the mobile host and the base station [16]. M-TCP differs from I-TCP because it manages to preserve the end-to-end semantics of the TCP. In addition, M-TCP is proposed to operate on the architecture of the underlying three levels, which are shown in Fig. 3.

Fig. 3 Underlying architecture of M-TCP

The mobile host connects via a cell with the base station. There are many base stations under the control of the supervisor host, which serves as a gateway to communicate with the wired medium. The developer of this approach had two specific aims. The first was that base station functionality could be transferred to the supervisor host, thus reducing network costs, as one supervisor host would be in control of the many base stations. The second was the possibility of significantly reduced handovers occurrences, as the mobile host roaming between cells would not need to execute handovers when the two cells are controlled by one supervisor host.

B. Link Level Solution

The link layer solution provides more reliable link level, by making network transport layer shielded from wireless connection. The most popular models used in the link level are Forward Error Correction (FEC), Automatic Repeat Request (ARQ), and Hybrid ARQ (HARQ). The FEC technique can increase the probability of the packet delivery by accumulating various redundancies to the transmitted packet. While by natively retransmitting the lost packets, the ARQ technique can offer more reliability to the link layer. Therefore, reliability level at link layer will depends on the persistency of ARQ and redundancy of FEC [10]. Snoop protocol is one of the earlier link layer solutions, which introduces an extra snoop agent at the base station of the wireless medium [17].

The protocol is named as Snoop as it adds snooping elements to the network layer, to observe each packet that passes through the base station in any route [18]. The Snoop protocol provides a reliable solution by maintaining the end-to-end semantics of TCP, while locally recovering the wireless errors. The Snoop uses link level buffers at the base station for the following purposes:

1) To cache the packets that pass across the wireless link.

2) To retransmit the unacknowledged packets.
3) To avoid unnecessary timeouts.

In addition, the Snoop filters duplicate the acknowledgements to avoid duplicated packets. These functions are performed by two main routines such as, snoop-data and snoop-ACK [11]. Fig. 4 illustrates the basic idea of Snoop protocol for transmitting data to the mobile host.

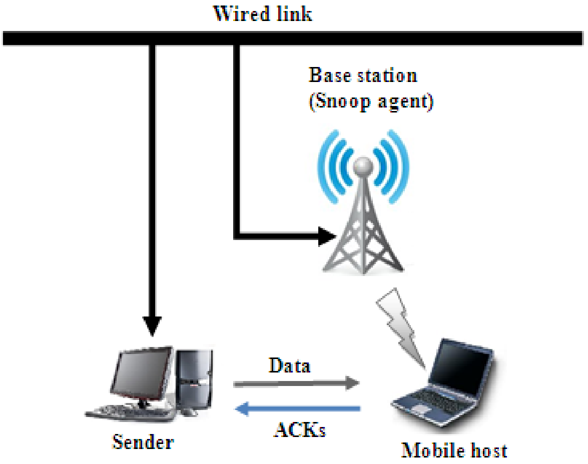

Fig. 4 TCP Snoop protocol model

Snoop agent can allocate timer to the sent packets, thus the lost packet may be noticed by the subsequent duplicated ACK number and by timer expiration. The main benefit of using link level protocol is to achieve packet loss recovery. The link level protocol is capable of recovering packet loss, because this approach logically fits with the layering organization of network and it works independently with higher layers [10].

On the other hand, even if the performance of TCP during handovers may be enhanced, it may still suffer with multicast base station group and with transmission from base station to another.

C. End-To-End Solution

End-to-end approaches can also be employed to improve TCP performance, to make the end hosts contribute in flow control. The modeling of this solution is shown in Fig. 5.

The sender is responsible for adjusting the congestion within the network, whilst the receiver provides feedback, which reflects the condition of the network. This procedure is shown in Fig. 3. In the end-to-end approach, the ability to correctly analysis the accessible bandwidth represents the larger challenge of discovering the best performance.

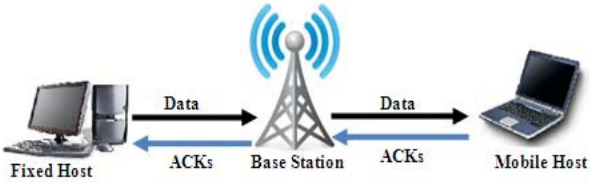

Fig. 5 End-to-end connection of a wireless TCP

The end-to-end approach has a congestion control mechanism that is realized by two methods, namely proactive and reactive. In the proactive mode, the congestion control mechanism obtains feedback from the network-guide to the sender, thus reallocating resources of the network to avoid congestion. Meanwhile, in reactive mode, the congestion control mechanism relies on the sender to rectify the congestion window if the network’s situation is peripheral or has a cross over threshold [13]. Several augmentations are suggested for the congestion control of a standard TCP. Several of these schemes seek to expand the TCP performance of unreliable networks, including wireless.

Explicit Congestion Notification (ECN) is a perfect example of this end-to-end approach, in which routers report congestion to the TCP sender using an IP header. ECN supposes that dynamic queuing management is arranged at the central group of routers, allowing the discovery of congestion, before loss occurs and before the queue overflows [19]. Another end-to-end approach method, which is similar to the ECN technique, is utilizing an influenced queuing management pattern to be recognized at the routers to separate random loss from congestion losses [20]. The main concept of this protocol, called TCP-Casablanca, is to de-randomize the losses of congestion, so that the spread of congestion losses changes from that of random losses resulting from the wireless network [21].

IV. CONCLUSION

This paper demonstrated the ability to improve standard TCP variants to operate over wireless networks and the next generation of cellular systems. Most protocols, such as TCP, perform very badly over wireless links and cause lost or delayed packets. Wireless links, with unpredictable packet losses and delays, can cause the TCP to assume that network congestion is taking place, even when the wireless link is well below its full capacity. There are many solutions to improve TCP over cellular communication systems during the handover period or through increasing the TCP window size. However, the drawback is that it requires modification of existing TCP protocols. TCP actually provides a very good service and its reliability is paramount. However, it is not generally suitable when delays are critical or when networks have low latency, such as a 4G system, where it supports many applications (such as voice and video transfer), where the occasional loss of data is much less important than its timely delivery performance. Mobile high speed links is an area of on-going research that needs to be addressed, taking into consideration the particular transmission characteristics presented by the network.

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