Congestion Control Approaches in Wireless Environment

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Abstract – **Modern communication networks using both wired and wireless communications including the Internet, are being designed for fast transmission of large amounts of data, for which congestion control is very important. Wireless networks are characterized by mobility, random changes in connectivity, fluctuations in channel and interference due to neighboring nodes. etc. TCP cannot provide efficient congestion control for wireless networks due to noncongestion losses. To alleviate the performance degradation of conventional TCP in wireless networks, many schemes have been proposed so far. This paper gives out a survey of proposed congestion control mechanisms in wireless environment and points the pros and cons of the wireless congestion control mechanisms, and evaluates their characteristics.**

Keywords – **Congestion Control, TCP, Wireless Networks**

I. INTRODUCTION

Communication networks are developing at an outstanding speed, with the evidence of mobile and wireless access networks. For accessing plentiful resources in the Internet through wireless mobile hosts, diverse wireless network standards and technologies have been developed and progressed significantly. The most successful examples include IEEE 802.11, Wi-Max for wireless networks and 3G-LTE/HSPA for cellular communications. Packet switching technologies have merged the traditional voice networks and data networks together into a converged integrated network.

All IP-based applications are the primary motivations to make these networks successful. Most IP-based networks rely on the Transmission Control Protocol (TCP) in the hosts to detect congestion in the network and reduce the transmission rates accordingly. In TCP/IP transmissions, the TCP congestion control operates well in the wired network, but it is difficult to determine an accurate congestion window in a heterogeneous wireless network that consists of the wired Internet and various types of wireless networks. The primary reason is that TCP connections are impacted by not only networks congestion but also wireless link errors. TCP/IP needs to depart from its original wired network oriented design and evolve to meet the challenges introduced by the wireless portion of the network.

Clearly, going forward, our network will become more heterogeneous in which protocols that react to different congestion signals interact.

About congestion algorithms existing literature generally assumes that all sources are homogeneous in that, even though they may control their rates using different algorithms, they all adopt to the same type of congestion signals. But when sources with heterogeneous protocols that react to different congestion signals share the same network as in proposed next generation networks (4G and beyond), the current congestion control framework is no longer applicable.

II. CHALLENGES IN WIRELESS CONGESTION CONTROL

One of the more challenging environments for the Internet Protocol, and TCP in particular, is that of mobile wireless.

Compared with wired networks, one-hop wireless networks have some inherent adverse characteristics that will significantly deteriorate TCP performance if no action is taken. In essence, these characteristics include bursty channels errors, mobility and communication asymmetry.

III. TCP MODIFICATIONS FOR WIRELESS CONGESTION CONTROL

Among the various solutions proposed to improve TCP performance, there are four major categories: split-connection solutions, proxy-based solutions, link-layer solutions, and end-to-end solutions. The split-connection solutions attempt to improve TCP performance by splitting a TCP connection into two at the base station so that the TCP connection between the base station and the mobile host can be specially tuned for the wireless links. Realizing the base station is a critical point, approaches based on proxy put an implicit or explicit intelligent agent at the base station, detecting packet losses over wireless links and taking corresponding actions (such as duplicate ACK suppression and/or local retransmission) to ensure the TCP sender responds correctly. For the third category, a reliable link layer is built by adopting some link error recovery mechanisms, seeking to hide link errors from the TCP sender. Unlike the previous three classes, the end-to-end approaches enhance TCP by using SACK to quickly recover from multiple packet losses or by predicting incoming handoffs to avoid unnecessary congestion control invocation.

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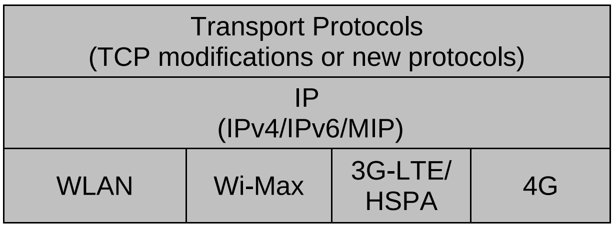

Fig. 1. Future Wireless Internet Protocol Stack

Indirect-TCP (I-TCP) [13] splits the connection on the wireless edge to protect TCP session from wireless media inconsistencies and losses. This results in two different flow and congestion controls working in wired and wireless sections separately and may result in serious inequalities on the two sides. In such attempt, I-TCP eventually violates end-to-end semantics of TCP as well. The M-TCP [14] is similar to I-TCP and splits the connection at super host. It differs only in a way, that super host does not generate acknowledgment (*Ack)* of last received segment until it receives the *Ack* from mobile node. In this way it too breaks end-to-end semantics of the TCP and disparities of two sides flow and congestion control mechanism still exist. Another problem that may arise is the source can take inaccurate decision about receipt of all data on the basis of last byte acknowledgement. If the acknowledgment of last byte is not received, the sender resends the all data which mobile node already received.

The TCP Westwood (TCP-W) and TCP Westwood + (TCP-W+) are true extension of TCP Reno (Reno). TCP-W uses the bandwidth estimation as a parameter to control the congestion window and slow-start (SS) threshold (*ssthresh*). The protocol separates the congestion control from the error control. This mechanism helps it to improve performance over lossy wireless links. Despite, some advantages, TCP-W is unable to present its preeminence over Reno when higher packet losses occur or the blackout time is longer. TCP-Peach (TCP-P) was developed for the satellite network to overcome long propagation delays and elevated link error rate. It uses two new algorithms; namely *sudden start* and *rapid recovery* to overcome the limitations of TCP in satellite network. It also uses dummy packet to estimate the available network resources. The successful delivery of the dummy segments indicates better resource availability and transmission rate can amplify. The TCP-Peach+ (TCP-P+) further improve the network utilization by sending Nil packet instead of dummy packet. It also replaces sudden start and rapid recovery algorithms by jump start and quick start. Jump start is extension of sudden start and it replaces dummy segment with Nil segment. TCP-P+ presents improved performance as compare to TCP-P.

TCPVeno (Veno) [20] introduces sender side solution, by combining the feature of the Reno and TCP Vegas (Vegas). The Reno and Vegas use reactive and proactive congestion control strategies respectively. Veno integrates the congestion detection mechanism of Vegas with Reno to distinguish between the congestive and non-congestive loss. Veno efficiently deals with single packet loss but it suffers form performance degradation when multiple packet losses occur in the network. The reason behind this degradation is the continuous reduction of window size on successive loss. Another sender side solution named; TCP-Jersey (Jersey) is proposed to improve the TCP performance in heterogonous wireless networks [21]. Jersey adopts the similar idea of TCP-W to estimate the bandwidth at sender side by monitoring arrival rate of *Ack*. Jersey uses the *Available Bandwidth Estimator (ABE*) at sender side to estimate the bandwidth and re-computes the *cwnd* on every *rtt*. It uses *ECN* for identifying congestion in the network. For further tuning of congestion control, Jersey also uses two parameters, namely; *intervals of jitter (IJ)* and *jitter ratio (JR)* to determine the ratio of congestion on the network. Freeze TCP (F-TCP) [27] proposed a recipient side solution which improves the performance of the transport protocol TCP in networks where handoffs and disconnections are more common and significant. If MN detects the low quality signal it sends *zero-window-probes (zwp)* with *Ack* to the sender. On the receipt of *zwp* sender freezes the timers and waits for positive *zwp*.

In [25], an inter-layer collaboration protocol for TCP (ILC-TCP*)* presented by introducing a sender side solution for mobile and wireless network. ILC-TCP introduces a new layer parallel to the network protocol stack named as *State Manger (SM)*. The SM communicates with core layers and notifies the status to network. It can handle the temporary disconnection. The ILC TCP is similar to the Freeze TCP except that it is sender side solution while Freeze TCP is a receiver side solution. So both protocol shares the same merits and demerits.

TCP Delayed Congestion Response (TCP-DCR) also improves congestion handling mechanism for wireless networks. It identifies the congestion by sensing retransmission timeout or receipt of DUPACKs. It also suggests modification in calculation of retransmission timer. On the receipt of duplicate acknowledgement, it introduces the bounded delay period τ and sets it equal to one *rtt*. This helps the sender to recover the link-layer loses otherwise the retransmission algorithm is activated.

Adaptive Delayed Acknowledgement (TCP-ADA) [7] is also a sender side solution for mobile ad-hoc networks. It uses Delayed Acknowledgement (DelAck) to block acknowledgement for a specific time period.

Chandran et al., proposed a router assisted solution named as; TCP-Feedback (TCP-F*)* [10][9] for Ad hoc wireless networks. TCP-F detects route failures in case an intermediate node move or fails the next node detects route fail. When route failures detected the next node transmits *route failure notification (RFN)* packet to destination. On the receipt of *RFN* packet each node invalidates the previous route and stops incoming packets. If the alternate path does not exist each node relays the *RFN* packet to source node.

David X. Wei et al., [16] presents a TCP congestion control variant for high speed and high latencies suffering networks. It highlights the four difficulties which TCP faces in high speed networks. It devised a mathematical and analytical model of FAST-TCP. The results show that FAST-TCP shows some improvements over other TCP variants with respect to the throughput and fairness.

TABLE I

SUMMARY OF TECHNIQUES FOR CONGESTION CONTROL IN WIRELESS ENVIRONMENT

Schemes	TCP semantics	Support for mobility	Modification requirement	Targeted application
I-TCP [13]	Split	High	Base station	Cellular
M-TCP [14]	Split	High	Router and end stations	Cellular
SNOOP [15]	End-to-end		Base station	
TCP-Peach [16]	End-to-end	High	Router and end stations	Satellite
ATCP [17]	End-to-end	High	TCP stack	Ad hoc
TCP-ADA [7]			Sender side	Ad hoc
Freeze-TCP [18]	End-to-end	High	Base station	Cellular
TCP-New Reno	End-to-end	Low	Sender side	Heterogeneous
TCP-SACK	End-to-end	Low	Sender side	Heterogeneous
TCP-Vegas [6]	End-to-end	Low	Sender side	Heterogeneous
TCP-Veno [20]	End-to-end	Low	Sender side	Heterogeneous
TCP-Westwood [19]	End-to-end	High	Sender side	Heterogeneous
TCP-Jersey [21]	End-to-end	High	Router and sender side	Heterogeneous
TCP-New Jersey [12]	End-to-end	High	Router and sender side	Heterogeneous
MA-TCP [24]		High		Heterogeneous
ECN			Sender, receiver	
ELN			Sender, receiver	
JTCP [22]	End-to-end		Sender, receiver	Heterogeneous
ILC-TCP [25]	End-to-end	High	Sender side	Heterogeneous

J. Liu et al. Presents ATCP [14] for mobile ad hoc networks. ATCP uses the ECN and ICMP to put the sender in one of four states such as normal congested, loss, and disconnected. Beside some improvement over ad hoc networks it unable to prove strength in situation where blackout and disconnection are frequent.

In [9], challenges in heterogeneous network environment are addressed, and the TCP schemes for different wireless applications (i.e. cellular, ad-hoc and satellite networks) and type of implementation (i.e. split mode or end-to-end approach) are classified. In [10], the performance characteristics of four representative TCP schemes are studied, namely TCP New Reno, SACK, Veno, and Westwood, under the network conditions of asymmetric end-to-end link capacities, correlated wireless errors, and link congestion in both forward and reverse directions. Then a new TCP scheme, called TCP New Jersey is proposed, which is capable of distinguishing wireless packet losses from congestion packet losses, and reacting accordingly, as an improvement of TCP Jersey.

[12]The performance of TCP degrades over wireless links due to high rate of data losses, which are falsely perceived as network congestion state. TCP performance metrics also diminish due to low data rate, since large delays may occur in last link i.e. wireless link. Similarly in heterogeneous wireless network, packet loss may also occur due to mobility-events that can cause burst-losses, service-disconnection. This motivates to reevaluate TCP control operations and embed some mobility related services to optimize its performance for new generation of wireless networks.

In [11] a new wireless congestion control protocol (WCCP) is proposed, based on the channel busyness ratio. In this protocol, each forwarding node determines the inter-node and intra-node fair channel resource allocation and allocates the resource to the passing flows by monitoring and possibly overwriting the feedback field of the data packets according to its measured channel busyness ratio. The feedback is then carried back to the source by the destination, which copies it from the data packet to its corresponding acknowledgment. Finally, the source adjusts the sending rate accordingly. Clearly, the sending rate of each flow is determined by the channel utilization status at the bottleneck node. There are two components in WCCP. One is at the transport layer. It replaces the window adjusting algorithm of TCP with a rate control algorithm to regulate the sending rate. The other is between the networking layer and the MAC layer. It monitors and possibly modifies the feedback field in TCP data packets when it passes the outgoing packets from the networking layer to the MAC layer and the incoming packets in the reverse direction.

Mobility Aware Transmission Control Protocol (MA-TCP) [24]. The MA-TCP consist off the handoff state identification and adaptation mechanism (HIAM) which is responsible for the receipt of the triggers from media independent handoff (MIHF) and generate appropriate message.

In [29] it is foreseen that next generation mobile terminals would be suitable to have transport layer that is possible to be downloaded and installed (Open Transport Protocol - OTP). Such mobiles shall have the possibility to download TCP version which is targeted to a specific wireless technology installed at the base stations. Such transport layer will be open to different implementations of the transport protocols, which may differ from today's main transport protocols.

Another idea about application of congestion control methods is to integrate different schemes into operating system (i.e. Linux) [30].

IV. Conclusion

In this paper, we provide a survey of existing congestion control mechanisms for wireless networks.

It is clear that each of the proposed solutions has characteristics which best suit a given environment. Next generation wireless networks, which will support the ABC (Always Best Connected) concept, will integrate heterogeneous wireless communication environments with different characteristics. TCP algorithms do not hold any more for the emerging wireless networks. As it is given in this paper there are many different TCP modifications for congestion control as well as new proposed transport protocols. Since the wireless resources are very scarce the accommodation of transport protocols is necessary with aim to provide higher utilization of radio interface as well as lower latency. Hence, our future work is targeted to development of open transport protocol layer in wireless terminals.

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