CHAPTER 7

CONCLUSIONS AND FUTURE WORK

7.1 CONCLUSIONS

The dissertation contributes to improve the performance of TCP in infrastructure-based wireless networks using cross-layer approach. Various layers are collectively exploited to make TCP competent in wireless networks. The throughput of TCP is improved by addressing channel errors, mobility and SRTO. TCP fairness is enhanced as the issue of asymmetry in wireless link is handled. Vital contributions of the research along with some of the investigations are discussed below:

Chapter 3 presents a link-layer-based scheme, LLCLAMP-TCP to improve TCP performance by suppressing the transmission of TCP ACK packet over the wireless channel. As the link-layer ACK is received, the AP or BS generates the ACK and the actual TCP ACK generated by the receiver is discarded by the LLCLAMP client. The congestion measure is also computed at the AP or BS and is sent to the sender along with the ACK; the sender then calculates the AWND value. The wireless link resources such as bandwidth and the transmission delay associated with the transmission of ACK packet over the wireless channel is released, thereby improving the performance of TCP.

LLCLAMP-TCP is compared with NewReno and CLAMP using simulation. The throughput of the three protocols is analyzed for various
packet sizes and queue delay. LLCLAMP improves the throughput by 113% compared to NewReno and 41% compared to CLAMP for various packet sizes. For various queue delays, the percentage improvement is 70% compared to NewReno and 22% compared to CLAMP. The performance is also analyzed in an error-prone environment and the improvement in percentage with respect to NewReno is 36% and CLAMP is 24%.

The statistical analysis using Hypothesis testing is performed to verify if there is a statistical difference in throughput of the three models. The analysis concludes that LLCLAMP has a statistical Median difference compared to other models, considering 95% Confidence Interval. There is a relevant improvement in TCP throughput as there is a reduction in medium busy time and passive reduction in channel error rate due to the absence of TCP ACK packets on the wireless channel. The RTT is reduced as the time required for TCP ACK transmission over the wireless link is minimized.

Chapter 4 presents TCP-DDA scheme to detect and avoid SRTO along with loss differentiation and to detect and differentiate the loss in the retransmission. The SRTO is detected on removing the ambiguity in the ACK by splitting the retransmitted packet into two before retransmission and SRTO is avoided by modifying the RTO recovery phase of TCP. The losses in the original transmission and retransmission are differentiated using cross-layer based LDA. MAC layer LDA is used to differentiate the wireless losses and cross-layer LDA is used to differentiate the congestion losses. The loss in the retransmitted packet is detected by calculating the LDP after retransmitting the lost packet by fast retransmission.

TCP-DDA is compared with NewReno and the throughput of two schemes is analyzed for various signal loss duration and delay. TCP-DDA improves the throughput over NewReno by 22% for various signal loss duration and by 15% for various delays. The performance is also analyzed in
an error-prone environment and the percentage improvement observed is 19%.

Statistical analysis is performed to verify if there is a statistical difference in throughput of the two models, TCP-DDA and NewReno. The analysis concludes that TCP-DDA has a statistical Median difference compared to NewReno, considering 95% Confidence Interval. There is a relevant improvement in TCP throughput as the losses in the original transmission and retransmission are detected and differentiated, the SRTO is detected and avoided; the CWND in TCP-DDA is less fluctuating compared to NewReno and the congestion control is less frequently invoked.

Chapter 5 presents two schemes to augment the performance of TCP during handoff. The EPRN scheme executes immediate recovery of lost packets during hard handoff and maintains the throughput by keeping the ssthresh and CWND unaltered. The receiver informs the TCP sender about the packet losses that occur due to hard handoff through a special ACK. The sender then differentiates between loss due to congestion and loss due to wireless link errors. Loss differentiation is carried out by measuring the E2ED encountered by the packet during transmission from the source to destination and then comparing it with the DT. If the loss is distinguished as wireless link loss, PRN is invoked to retransmit the lost packets; slowstart of TCP is initiated if the loss is identified as congestion loss.
modified to estimate the RTT and CWND of the new link which is used to resolve premature timeouts. ETCP-VHO adapts to the new path efficiently, enhancing its performance over the wireless end.

EPRN is compared with TCP SACK and PRN to analyze the throughput in two different scenarios: with wireless loss and with both wireless and congestion loss. The credibility of the protocols is judged by varying the disconnection periods and packet loss fractions. In scenario with only wireless loss, EPRN improves the throughput by 13% on comparing with TCP SACK and 5% comparing with PRN for various disconnection periods; for various packet loss fractions, it is improved by 27% compared to TCP SACK and 14% compared to PRN. In scenario with wireless and congestion loss, the percentage improvement for various disconnection periods is 20% with respect to TCP SACK and 9% with respect to PRN; the improvement in throughput of EPRN on introduction of packet loss fraction is 27% compared to TCP SACK and 13% compared to PRN. The total number of packets delivered by EPRN increases in both scenarios i.e., by about 20% than TCP SACK and about 11% than PRN.

Hypothesis testing performed to verify the statistical difference in throughput of the three models, EPRN, PRN and TCP SACK corroborates that EPRN has a statistical Median difference compared to other models, considering 95% Confidence Interval. There is a notable improvement in terms of TCP throughput of EPRN as the packets lost during handoff are recovered and the CWND and ssthresh are kept unaltered. The normalized throughput attained by EPRN, PRN and TCP SACK shows that EPRN is TCP friendly.

ETCP-VHO is compared with TCP SACK and NewReno and the performance is analyzed in two different scenarios: when the MN moves from Wi-Fi to WiMAX and from WiMAX to Wi-Fi. ETCP-VHO outperforms TCP
SACK and NewReno in terms of reduced $CWND$ fluctuations and increased throughput in both the scenarios. As the issues of packet reordering and premature timeouts are resolved, the $CWND$ does not drop down to zero and move to slowstart during handoff. Hence it has reduced $CWND$ fluctuations, which increases the throughput. The scheme is also observed to perform well in error-prone environment.

The statistical analysis verifies that ETCP-VHO has a statistical Median difference compared to NewReno and TCP SACK, considering 95% Confidence Interval. There is a considerable improvement in terms of total number of packets delivered after handoff as the packets are not reordered, and the premature timeouts are prevented by ETCP-VHO.

Chapter 6 presents a pragmatic approach, TCP-OQS to mitigate the unfairness issue in asymmetric wireless networks. A dual queue approach at the AP, one for the data packet and other for the ACK packet is presented. A packet classifier categorizes the TCP packets and stores them in the respective queues. The queue size modifier adjusts the size of the ACK queue based on the number of packets stored in the TCP data queue. The priority scheduling and probability scheduling are the two approaches used to select the queue to be served. If priority scheduling is used, the ACK queue is given higher priority and data queue the lower priority. If probability scheduling is used, the queues are served with different probabilities; the data queue is selected with probability ‘$p$’ and ACK queue with probability ‘$1-p$’. The optimal value of ‘$p$’ is chosen based on the number of uplink and downlink flows to achieve fairness among the flows. Using the optimal probability, a simple mathematical expression for the optimal queue size and the queuing delay of ACK queue is derived.

The performance of TCP-OQS is analyzed by comparing with NewReno (single queue). The dual queue approaches significantly improve
TCP fairness over a number of network configurations with different asymmetry ratios, varying number of uplink and downlink flows and delay. The dual queue approach with probability scheduling achieves better fairness compared to dual queue approach with priority scheduling. Appropriate improvement in fairness is observed by the dual queue approach with probability scheduling as the size of the ACK queue is dynamically adjusted based on the number of data packets queued. The queuing delay of the ACK queue is adjusted dynamically depending on the number of uplink and downlink flows. Fairness is assured by TCP-OQS without affecting total throughput.

7.2 SCOPE FOR FUTURE RESEARCH

This section suggests few promising future research directions and possible enhancement to the current research work on improving TCP performance in infrastructure-based wireless networks. The performance of LDA used in TCP-DDA can be further optimized using a dynamic value of Retry Limit instead of a default value of six at each Retry Limit increase stage. The break-before-make handoff results in packet losses and unused connection time. The RTO timer expires many times during the disconnection period, each time doubling the RTO value, depending on the value of the timer and the duration of disconnection. When the connectivity is resumed, the TCP sender waits until the retransmission timer expires again before attempting another retransmission. This unused connection time increases the recovery time of the lost packets. The issue of packet losses during disconnection is alone addressed in the dissertation; the unused connection time is yet to be handled.

The thesis focuses on improving the performance of TCP in infrastructure-based wireless networks. However, there are many shortfalls in infrastructureless wireless networks that challenge TCP performance. Hence
it is necessary that schemes are designed for infrastructureless networks. All the results presented are based on simulation rather than direct experiments i.e., the results depend significantly on the wireless propagation and other models implemented in simulation. This problem highlights the need for developing testbed environments that support complex and realistic analysis.