CHAPTER SIX

CONCLUSION AND FUTURE WORK

This thesis has presented an enhanced congestion control mechanism for TCP NewReno based on the TCP Westwood bandwidth estimation method. The new modified mechanism named PETRA. The PETRA congestion control modification is proposed to enhance TCP performance over wireless networks, especially LTE networks. In this chapter, we will give a research summary in section 6.1. In section 6.2, we list the study's contributions and finally in section 6.3 we end the thesis with possible future work.

6.1 Study summary

This thesis was organized into six chapters. The first chapter provided a detailed introduction about this study. This chapter presented the research problem, followed by the objectives. Then, the research scope and limitations were presented. Furthermore, chapter one reviewed the significance and the research framework.

Chapter two presented a background study on the common transport protocols in communication systems. The literature review started by presenting a brief introduction on layering concepts. Then, TCP fundamentals were elaborated in details. Also, chapter two presented a detailed study on the congestion control mechanisms of the common TCP variants. Moreover, this chapter presented the literature on TCP congestion control mechanisms over wireless networks. The main solutions were discussed, including: Split-connection, End-to-End solutions, and Link-Layer solutions. Chapter two also discussed the SCTP protocol.

The research methodology was discussed in chapter three. Firstly, it introduced the performance evaluation techniques in computer networks. Then, details of the selected network simulator were presented. Moreover, chapter three discussed the simulation experiments design, experiments hardware and software, validation and verification, and the network performance evaluation metrics.

Chapter four introduced a new End-to-End congestion control mechanism based on TCP NewReno. The new modifications are based on the TCP Westwood bandwidth estimation technique. Three new modifications were presented in this chapter. Firstly, we proposed new slow start modifications. Two modifications were presented: a new method was proposed to calculate the initial slow start threshold (*ssthresh*) value, and a faster start phase to accelerate the congestion window growth. Secondly, we introduced two new modifications to the Fast Retransmission and Fast Recovery algorithm: faster retransmission and congestion check methods. Finally, we introduced a new modification to the timeout procedure to prevent TCP from resting its congestion window size every timeout event unless real congestion is shaped. For each modification, we compared the results of the proposed enhancements with TCPW and TCP NewReno. For the comparison, we used Network Simulator-3 (ns-3) to obtain the results of two network performance metrics: the average throughput and the congestion window size. We used GNUPLOT version 4.2 to plot graphs to make the comparison more obvious.

Chapter five discussed implementing and evaluating the proposed modifications in chapter four over the LTE networks. Moreover, this chapter introduced the LTE technology, implementing LTE in ns-3, and TCP performance over LTE. Moreover, chapter five discussed the implementation of TCP PETRA in ns-

3. The evaluation process included more network performance metrics: throughput, congestion window size, average delay, and jitters. Also, chapter five extended the evaluation process to test the fairness of the proposed implementation.

As a result, the new modifications showed better performance compared to the TCP NewReno and TCP Westwood variants.

6.2 Study contributions

The poor performance of TCP congestion control mechanisms over wireless networks is a very active study area. Many improvements have been proposed to enhance TCP performance over wireless links in the past few years. Nevertheless, there is no optimal solution, as every solution uses different criteria to recognize congestion losses from other types of packet losses. This was the motivation behind the research.

The main aim of this study was to propose a new enhancement to the TCP congestion control mechanisms over wireless links. This objective was carried out by a series of connected contributions, including:

- A new method to properly set the initial Slow Start threshold value based on the current bandwidth capacity. Toward this end, we probe the link's bandwidth by counting the bytes acknowledged between two sequences *ACKs* at the sender side.
- A new method to accelerate the Slow Start exponential increment based on the estimated bandwidth. We proposed using a state called the "Faster Start" in which we can increase the *cwnd* according to bandwidth utilization.
- A new method to enhance the Fast Retransmission mechanism. The TCP sender waits until receiving three duplicate *ACKs* in order to trigger a Fast

Retransmission procedure. However, if the last round trip time is too long, then the sender will keep waiting for an unachievable condition. Thus, the retransmission timer will expire before the fast retransmission is triggered. For this reason, we proposed checking if the sender can receive the three duplicate *ACKs* based on the last *RTT* value. If this condition is not achievable, then the sender should retransmit the unacknowledged packet immediately.

- A new method to enhance the Fast Recovery mechanism. This modification was presented to achieve better recovery for the *cwnd* size in the fast recovery phase based on the last *RTT* and the bandwidth estimation.
- A new method to enhance TCP Retransmission Timeout procedure. The proposed method prevents TCP from resetting its *cwnd* size every timeout event, unless real congestion is shaped.

6.3 Future work

This research opens up further avenues for investigation. In this section, we present some of the future work recommendations. Hopefully, this research will be further extended and improved. The following summarizes some of these recommendations:

6.3.1 Extended the simulations topologies and scenarios

In this research, we used two simulation topologies: a simple wired-wireless source/sink topology, and a LENA model to represent the LTE network environment. In the second topology, we have used different scenarios, including a fixed single UE, multiple fixed UE connected to different eNBs, and mobile UE movies with constant velocity.

For future recommendations, other topologies and scenarios could be used to test the proposed mechanisms, for example Satellite, ad-hoc, and WiMAX networks, among others.

6.3.2 Performance metrics

In this research, we evaluated the proposed modifications based on certain performance metrics, including *cwnd* size, throughput, packet loss ratio, average delay, jitter, and fairness. For future recommendations, more performance metrics could be tested to validate the new modifications, such as Packet Delivery Ratio, friendliness, and average End-to-End delay, among others.

6.3.3 More TCP implementations

As mentioned in this thesis in the first chapter, one of the research limitations was the network simulator limitations. ns-3 supports certain TCP implementations, including TCP Tahoe, Reno, NewReno, and TCP Westwood. For future work, other simulators could be used to compare the new modification with other TPC implementations, such as Vegas, FAST, and Veno, among others.

6.3.4 Using Testbed or real measurements

One recommended future work is to use a testbed or real measurements to test the proposed modifications. Real measurements and the testbed will obtain more reliable results; however, these are expensive.