UNIVERSITI PUTRA MALAYSIA

TCP PERFORMANCE OPTIMIZATION IN INTERACTION WITH MAC LAYER OVER MULTI-HOP AD-HOC NETWORKS

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By

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Thesis Submitted to the School of Graduate Studies, University Putra Malaysia, in Fulfillment of the Requirement for the Degree of Master of Science

September, 2008

DEDICATION

This thesis is dedicated to

ALL I LOVE

Specially

MY BELOVED PARENTS

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Master of Science

TCP PERFORMANCE OPTIMIZATION IN INTERACTION WITH MAC LAYER OVER MULTI-HOP AD-HOC NETWORKS

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September 2008

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Transport Control Protocol (TCP) has been designed to provide reliable data delivery between end hosts in traditional wired networks and is the most widely used reliable transport protocol over the internet. TCP keeps looking at the traffic inside the network by employing the congestion control mechanisms. The basic assumption underlying TCP congestion control is that packet losses are an indication of congestion in the wired network. The effect of such an assumption on TCP's performance in wireless environments has been a long-standing research study. The reason is specific wireless properties such as high medium access contention; route breakage and high bit error rate in radio channels pose different challenges in TCP performance when it runs over wireless networks. In this thesis, the focus is given on the interaction between TCP and Medium Access Control (MAC) layer in multi-hop ad-hoc networks to deal with the effect of high medium access contention on TCP throughput.

The main problem of TCP over IEEE 802.11 MAC protocol is the extensive number of medium access carried out by TCP. In fact, TCP sender will be informed of successful transmissions by receiving the acknowledgment (ACK) from the other end host to achieve the reliability. In this way, the MAC overhead may be caused by generating redundant ACK packets that compete in the same route with data packets for the media. As the load increases, the well-known hidden terminal effects caused by interference between ACK and data packets can degrade TCP performance dramatically if TCP acknowledges every incoming data packets.

To address above problem, in this thesis a dynamic TCP-MAC interaction strategy is proposed which tries to reduce the number of induced ACKs by monitoring the channel condition. To this end, the total collision probability collected along the path from sender to receiver in MAC layer is used to properly set the number of the delayed ACKs (DA) in TCP. Based on the measured collision probability, TCP sender dynamically adjusts itself to the channel condition by delaying less ACKs in high traffics and more in low traffic conditions. Upon this strategy, an enhanced TCP throughput has been achieved in trade-off between moderate and high traffics. Finally, the relationship between the TCP throughput and optimized number of delayed ACKs has been investigated in different hop counts scenarios which employ a dynamic traffic. The findings show that for a given hop count, there exists an optimized delay window size which maximizes the TCP throughput. Overall, the achieved throughput increments are up to about 30% over the regular TCP with DA extension and *cwnd* limit and about 10% over the existing method called Dynamic Adaptive Acknowledgment (TCP-DAA and TCP-DAAp).

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Master of Sains

KEBERKESAN PRESTASI TCP DIDALAM PENGARUHNYA TERHADAP LAPISAN MAC KE ATAS RANGKAIAN MULTI-HOP AD-HOC

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TCP di rekabentuk bagi menyediakan kebolehpercayaan penghantaran data antara hos di dalam rangkaian berwayar dan ia adalah antara protocol yang digunakan dalam penggunaan internet. TCP memantau trafik di rangkaian dengan menggunakan mekanisma kawalan kesesakan. Secara asasnya kesesakan pada rangkaian akan terjadi apabila adanya kehilangan paked di dalam rangkaian berwayar. Di dalam rangkaian tanpa wayar, penyelidikan berdasarkan andaian tersebut juga telah dilakukan. Antara penyelidikan yang di jalankan ialah terhadap capaian medium (medium access); rangkaian yang putus-putus(route breakage) dan kadar “Bit Error Rate” (BER) yang tinggi. Ia menjadi salah satu cabaran di dalam keberkesanan TCP terhadap rangkaian tanpa wayar. Thesis ini memfokuskan kepada interaksi antara TCP dan lapisan MAC (Medium Access Control) pada rangkaian “multi-hop ad-hoc” dan kesannya kepada daya pemprosesan TCP.

Masalah utama yang dihadapi oleh TCP di dalam IEEE 802.11 ini ialah bilangan data yang besar yang di bawa oleh medium oleh TCP. Berdasarkan teori, ACK yang akan dihantar oleh penerima kepada penghantar sebagai bukti penerimaan. Kesan teori ini,

MAC overhead akan terhasil akibat penghasilan berulang-ulang paket-paket ACK yang berada didalam jaringan yang sama.Kesan pengkalan tersorok atau ”well known terminal effects” akibat daripada gangguan antara ACK dan packet data juga akan menurunkan prestasi TCP pada masa yang sama.

Bagi mengesan punca masalah di atas, strategi interaksi secara dinamik TCP-MAC telah di buat dengan mengurangkan bilangan ACK dengan berdasarkan keadaan channel tersebut. Hasilnya, kebarangkalian perlanggaran (collision probability) yang terhasil pada laluan penghantar dan penerima akan digunakan sebagai “delayed ACKs (DA)” kepada TCP. Cara ini akan mengurangkan proses penghantaran ACK pada keadaan traffic yang tinggi dan proses sebaliknya apabila keadaan trafik yang rendah. Akhirnya, hubungan antara perolehan TCP dan “delayed ACK” yang paling berkesan telah diselidik melalui bilangan perantara(hop) yang berbeza bagi menghasilkan trafik yang dinamik. Berdasarkan penyelidikan tersebut, didapati setiap bilangan hop itu mempunyai “delay window size” yang paling berkesan dan memaksimakan daya pemprosesan TCP.

Kesimpulannya, melalui alternatif ini, daya pemprosesan akan meningkat sebanyak 30% daripada daya pemprosesan TCP yang mempunyain DA Extension and *cwnd* limit. Ia juga meningkat 10% berbanding cara yang ada dikenali sebagai (TCP-DAA) dan (TCP DAAp).

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APPROVAL

I certify that an Examination Committee has met on …………….. to conduct the final examination of Farzaneh R. Armaghani on her Master of Science thesis "TCP Performance Optimization in Interaction with MAC Layer over Multi-hop Ad-hoc Networks" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

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DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

FARZANEH R. ARMAGHANI

Date:

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LIST OF ABBREVIATIONS/ SYMBOLS

TCP	Transport Control Protocol
MAC	Medium Access Control
ACK	Acknowledgment
DA	Delayed ACK
WLAN	Wireless Local Area Networks
WWAN	Wireless Wide Area Networks
AP	Access Point
Wi-Fi	Wireless Fidelity
IP	Internet Protocol
FTP	File Transfer Protocol
SMTP	Simple Mail Transport Protocol
HTTP	Hyper Text Transfer Protocol
OSI	Open System Interconnection
ISN	Initial Sequence Number
RTO	Retransmission Time Out
RTT	Round Trip Time
AIMD	Additive Increase-Multiplicative Decrease
SACK	Selective Acknowledgment
SWS	Silly Window Syndrome
CSMA/CA	Carrier Sensing Multiple Access with Collision Avoidance
DCF	Distributed Coordination Function
PCF	Point Coordination Function

NAV	Network Allocation Vector
IFS	Inter-Frame Space
SIFS	Short IFS
DIFS	DCF IFS
EIFS	Extended IFS
CTS	Clear to Send
RTS	Request to Send
LRL	Long Retry Limit
SRL	Short Retry Limit
CWL	Congestion Window Limit
BDP	Bandwidth Delay Product
RTHC	Round-Trip Hop-Count
TCP-LDA	Large Delayed Acknowledgment
TCP-ADA	Adaptive Delayed Acknowledgment
TCP-DCA	Delayed Cumulative Acknowledgment
TCP-DAA	Dynamic Adaptive Acknowledgment
TCP-DAAp	TCP-DAA plus
TCP-MDA	Monitoring Delayed Acknowledgment
AODV	Ad-hoc On-Demand Distance Vector Routing
WL	Window Limit

List of Symbols

cwnd	congestion window
rwin	advertised window
ssthresh	slow start threshold
win	transmission window
dwin	delay window
$non\_collision\_prob_i^{tot}$	non collision probability
$collision\_prob_i$	local collision probability
transmitted_pkts	total transmitted packets
retransmitted_pkts	total retransmitted packets
total_collision_prob	total collision probability
collision_ thresh	collision threshold
ack_count	ACK counter
maxdwin	maximum delayed window
μ	speeding factor
μ'	enlargement factor
δ_i	inter-arrival time
$\overline{\delta}_i$	smoothed average inter-arrival time
α	inter-arrival smoothing factor
k	tolerance factor
h	number of hops

CHAPTER 1

INTRODUCTION

1.1 Background

Recent demands on affordable, portable wireless communication and computation devices have resulted in the exponential growth of wireless networks ranging from Wireless Local Area Networks (WLAN) and Wireless Wide Area Networks (WWAN) to Ad-Hoc and Sensor networks. The major goal of wireless communication is to allow users to communicate together and have access to global network anytime anywhere. This has led to wide acceptance of infrastructure based cellular networks (WWANs) where mobile stations communicate with a centralized controller, often referred as Access Point (AP) that is connected to the wired networks. On the other hand, WLANs have appeared as dominant popular technologies in many venues including a local area such as an academic campus or an airport terminal. These wireless networks mostly rely on IEEE 802.11 Wi-Fi (Wireless Fidelity) technology and its various derived versions (i.e. 802.11a,b,g).

IEEE 802.11 standard supports two operational modes: The infrastructure-based Wireless Local Area Networks (WLANs) and an infrastructure-less Ad-Hoc Networks. A WLAN [1] typically imposes the existence of an AP and normally is connected to the wired networks to provide internet access for mobile devices. Obviously, only one hop link is needed to communicate between mobile devices and AP. In contrast, there is no AP or infrastructure in ad-hoc networks. Any two stations can communicate directly when they are in the range of reception of each other. To this end, the stations may use multi-hop routing to deliver their packets to destinations.

The ad-hoc protocols [1, 2] are self-configured of address and routing in the face of mobility and the network topology may change in each configuration. The multi-hop wireless ad-hoc networks, simply called as multi-hop wireless networks enable wireless networking in the environments where the wired or cellular connections are impossible, inadequate, or cost effective (e.g. battle field, disaster recovery, etc.).

The popularity of internet over the last decades has resulted in rapid advancement of demanding applications. The Transmission Control Protocol/Internet Protocol (TCP/IP) [3] protocol is a well-known de facto protocol in developing today's internet. Basically, TCP provides a connection-oriented and reliable end-to-end data delivery between two hosts in traditional wired networks. Since TCP is well tuned and due to its wide acceptance in internet, it is desirable to extend and adopt its functionality to wireless networks. On the other hand, unique characteristics and usage of multi-hop wireless networks require robust, reliable and adaptive designs. This may be achieved by considering the interaction of different layers to meet the increasing demands of these networks. As a conclusion, how TCP behaves over multi-hop ad-hoc networks and how the interaction of TCP and different layers affects the network performance has been a challenging issue in developing the usage of TCP for multi-hop ad-hoc networks.

1.2 Problem Statement and Motivation

The TCP/IP suite has become the industry-standard of interconnecting hosts, networks, and the internet. As such, it is seen as the engine behind the internet and networks worldwide [4]. Besides, many applications such as File Transfer Protocol (FTP), Simple Mail Transport Protocol (SMTP), Hyper Text Transfer Protocol

(HTTP) and Telnet have been developed to this protocol. So, it is desirable to extend the usage of TCP/IP in the wireless and ad-hoc environments.

On the other hand, TCP has been designed to provide reliable data delivery between end hosts in traditional wired networks. The reliability in TCP is achieved by retransmitting lost packets and acknowledgment (ACK) confirmation. If the sender does not receive any acknowledgment within a timeout interval or receives duplicate ACKs in the case of out-of-order packets, the packet will be retransmitted. Any packet loss is assumed as congestion in wired networks. When a packet loss is detected, TCP invokes its congestion control mechanism to slow down the sending rate to reduce the congestion. However, packet losses are not mainly due to congestion in wireless networks. It might be due to some wireless specific properties such as high medium access contention, route breakage and high bit error rate in radio channels [5, 6].

The key challenge of TCP protocol is its poor bandwidth utilization and performance when it runs over 802.11 multi-hop wireless networks. The reason can be explained due to the extensive number of medium access carried out by TCP. Basically, TCP sender will be informed of successful transmission by receiving the acknowledgment from the other end host. The MAC overhead can be caused by generating redundant ACK packets that compete in the same route with data packets for the media. Although the TCP-ACK packets are small, they may cause the same overhead as data packets in MAC layer resulting in wastage of wireless resources [7, 8]. In fact, as it is discussed in [9], the short RTS/CTS control frames to provide the data delivery implemented by 802.11 MAC protocol, cannot eliminate the interference in large topologies. As the load increases, the well-known hidden terminal effects caused by interference between ACK and data packets can impact TCP performance dramatically in long paths if TCP acknowledges every incoming data packets as described later in chapter 2.

One way to improve the TCP performance over 802.11 in multi-hop ad-hoc networks is to alleviate the medium access contention by reducing the number of generated ACKs, simply called as *delayed ACKs*. This can be done by merging several ACKs in one ACK which is possible due to cumulative ACK scheme used in TCP. Referring to the already proposed approaches to reduce the number of the induced ACKs, the TCP performance is still affected by a limitation of a method which dynamically selects the number of delayed ACKs based on the channel condition [7, 8]. This motivates us to study the performance of TCP-ACKs in interaction with 802.11 over the multi-hop ad-hoc networks and develop a dynamic delayed ACK strategy to adjust TCP to these kinds of networks.

1.3 Aim and Objectives

TCP performance in interaction with 802.11 MAC protocol in ad-hoc networks has been investigated in this research. The main aim of this research is to increase the TCP throughput by decreasing the flow of TCP-ACKs and minimizing the spatial contention between ACK and data packets in MAC layer, so as to give more bandwidth to TCP data packets.

To meet this aim, the main objectives of this study are following:

- To identify the TCP-MAC interaction in multi-hop ad-hoc networks.

- To develop a dynamic TCP-MAC interaction strategy that controls the numbers of delayed ACKs by monitoring the channel collision probability.
    - To employ a model to measure the channel collision probability in 802.11 MAC protocol.
    - To develop a dynamic delayed ACK approach based on the measured collision probability.
- To investigate the optimized number of delayed ACKs in different hop counts scenarios when the *cwnd* is not limited.
- To analyze and compare the performance of the proposed approach with the existing related research works.

1.4 Scope of Research

In standard TCP, sender will be informed of successful transmission by receiving the acknowledgment from the other end host. To this end, there will be one ACK for every data packet received. The concept of Delayed Acknowledgments (DA) strategy was first defined in RFC 1122 [10] and then refined in RFC 2581 [11].With standard delayed ACK option, TCP receiver generates one ACK on receiving two in-order data packets from the sender.

Delaying more than two ACKs has been proposed in recent literature to adopt TCP ability in wireless environments. However, this field needs more investigation due to unique features of wireless multi-hop networks.

On the other hand, it is motivated by the fact that providing lower layer information to upper layer may help the upper layer to perform better [6]. This is called as cross-layering design which relies on interaction between two layers of Open System Interconnection (OSI) architecture. The importance of the designs based on the interaction between different layers has been also discussed in [5]. Since the purpose of ACK thinning in ad-hoc networks is to alleviate the MAC contention, it is desirable to approach a TCP-MAC interaction strategy to set the number of the ACKs based on the channel feedback.

In this thesis a dynamic TCP-MAC interaction strategy is proposed which tries to reduce the number of induced ACKs by monitoring the channel condition. The TCP and 802.11 protocols are the reality respectively in today's internet and wireless environments. Thus, the proposed solutions in this thesis focus on better interaction between TCP and 802.11 to effectively enhance the end-to-end TCP throughput over multi-hop ad-hoc network in different traffics. Developing a new reliable transmission or MAC protocol that is specially tailored to cope with the characteristics of multi-hop ad-hoc networks is not in the scope of this research. Moreover, the proposed strategy is tailored to monitor the channel collision probability when losses are caused by reasons other than congestion to properly set the number of the delayed ACKs. Investigating the error detection methods to identify the type of a packet loss and to determine the internal network state is not considered.

1.5 Study Module

Figure 1.1 illustrates the summary of the direction in this research where the bold lines represent the direction followed in this thesis to achieve our objectives and the dotted lines represent the other directions that are already considered in previous researches in the area of ad-hoc networks. The category is driven based on the concepts in [2, 6].

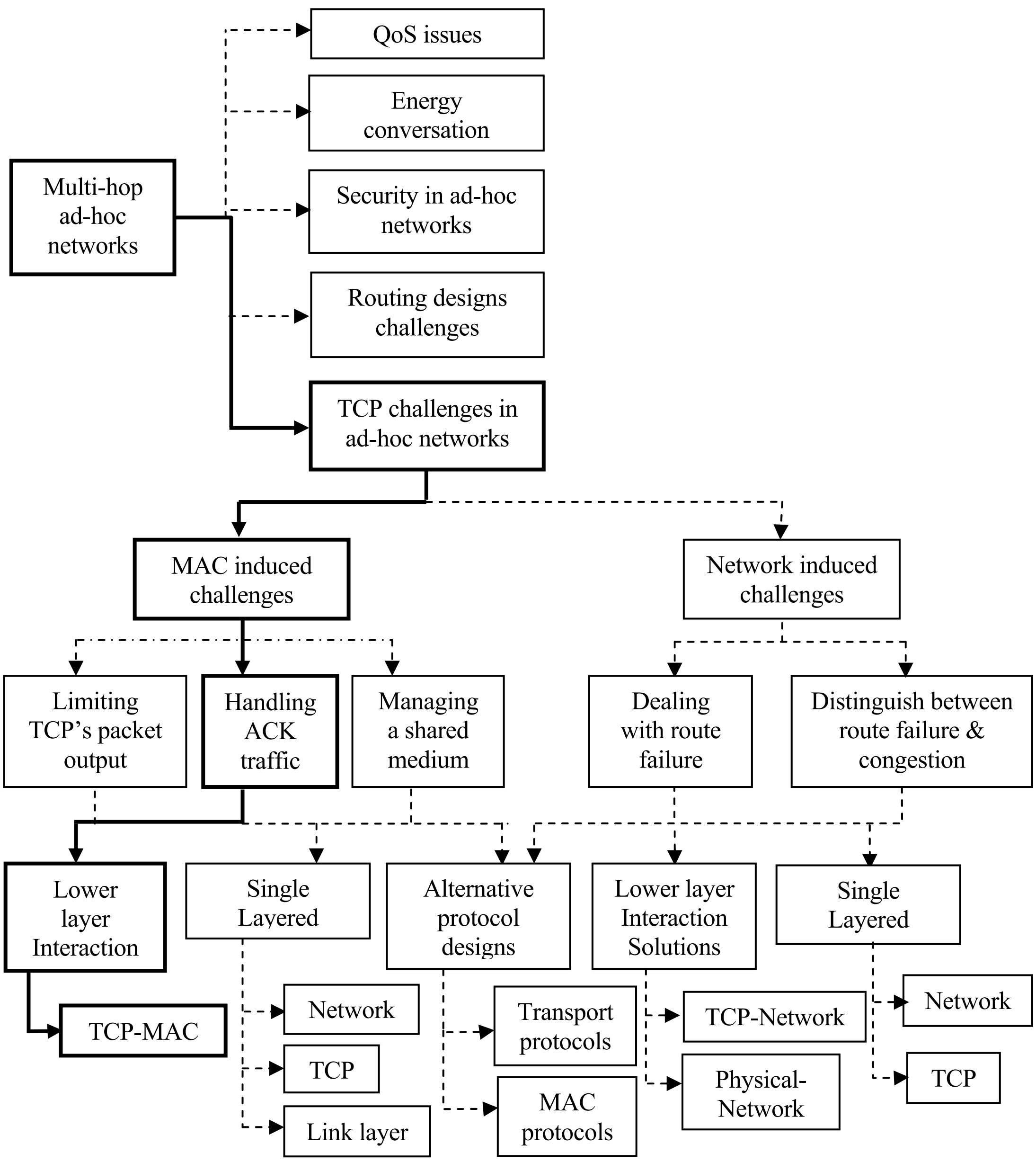

Figure 1-1: Study module

1.6 Thesis Organization

This Thesis has five chapters: