BATTERY AWARE HYBRID FORWARDING SCHEME FOR 6LOWPAN

By
FARHAD MESRINEJAD

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirement for the Degree of Doctor of Philosophy

June 2012
DEDICATION

Dedicated to

My family members particularly to my understanding and patient wife, Elaheh, our precious children Houra and Amir Mohammad and my ever-encouraging parents for their love.
Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

BATTERY AWARE HYBRID FORWARDING SCHEME FOR 6LOWPAN

By

FARHAD MESRINEJAD

June 2012

Chairman: Prof. Nor Kamariah Noordin, PhD

Faculty: Engineering

This thesis mainly focuses on fragments forwarding of 6LoWPAN through adaptation layer since the fragmentation and header compression, the main responsibilities of the adaptation layer, are necessary to fit the IPv6 packets with the sensor nodes. Proposed energy model considers the data payload size and the header size of different layers to evaluate the energy consumption and lifetime of network before and after fragmentation and header compression. Likewise, an analysis of simulation based scenario is carried out to investigate the effect of fragmentation on energy consumption. In order to improve the functionalities of adaptation layer, battery level of each node located at the first level of sensor network -the nodes that can directly communicate with the gateway- is used as a primary parameter to manage data forwarding between 6LoWPAN gateway and the sensors at the first level.

Furthermore, two existing forwarding schemes namely route-over and mesh-under are evaluated. Based on evaluation in this thesis, route-over and mesh-under suffers
from high end-to-end delay and energy consumption respectively. Therefore, 6LoWPAN requires a more efficient forwarding scheme in terms of energy consumption and delay. In this research, Hybrid Forwarding Scheme (HFS) is proposed which exploits the features of route-over and mesh-under. In HFS, all fragments of each packet are sent to the same destination. Intermediate nodes, in addition to forward the fragments to the next hop, check the lost fragments and request from the previous hop. Reassembling process will be done at the final destination. The proposed method reduces the delay, decreases energy consumption especially when there is retransmission, and increases the lifetime of network.

The research data in this thesis is drawn from two main sources: mathematical model and QualNet simulator. Based on the obtained results, the fragmentation increases the energy consumption from 57.8 to 69.8 percent. Higher energy consumption reduces the lifetime of the networks; accordingly the lifetime is reduced from 7.7% to 38.5%. Thus, the number of alive nodes especially at the first level is decreased during the simulation time. By using the battery level as a decision parameter to deliver fragments to the next hop, the lifetime is increased from 6.9 to 20.9 percent. Furthermore, the number of alive nodes is also a parameter which is improved during the simulation time. HFS reduces delay about four times compared to the route-over and from 20.3 to 29.8 percent compared to the mesh-under scheme. Hybrid forwarding scheme also decreases energy consumption from 18.1 to 35.1 percent compared to the route-over scheme and 50.68 to 58.43 percent compared to the mesh-under. Finally, by combining two methods (using battery level and HFS), the improvements are of lifetime from 17 to 19.22 percent, energy consumption from 25.57 to 26.3, and delay from 1 to 6.44 percent.
Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

BATERI SEDAR PENGHANTARAN SKIM BERGABUNG UNTUK 6LOWPAN

Oleh

FARHAD MESRINEJAD

Jun 2012

Pengerusi:     Prof. Nor Kamariah Noordin, PhD
Fakulti:          Kejuruteraan

Thesis ini difokuskan kepada pembawaan kehadapan fragment-fragment 6LoWPAN melalui adaptasi lapisan dari fragmentasi dan kompresi pengepala, tanggungjawab utama adaptasi lapisan yang penting untuk memutakan paket-paket IPv6 degan nod sensor. Model tenaga yang telah dicadangkan mengambil kira akan saiz muatan data dan saiz pengepala bagi lapisan-lapisan yang berbeza bagi menilai penggunaan tenaga dan jangka hayat jaringan sebelum dan selepas pemecahan serta mampatan pengepala. Sebagaimana juga sebuah analisis kepada simulasi berdasarkan senario telah dijalankan bagi menyiasat kesan bagi pemecahan kepada penggunaan tenaga. Bagi memperbaiki kegunaan lapisan yang diadaptasi, tahap bateri bagi setiap nod yang ditempatkan di aras pertama bagi jaringan pengesan – nod-nod yang mana boleh berhubung secara lansung dengan pintu masuk – adalah digunakan sebagai parameter utama bagi menyusun penghantaran data di antara pintu masuk 6LoWPAN dan pengesan-pengesan pada tahap satu.

Data kajian dalam tesis ini adalah diperoleh dari dua sumber utama: model matematik dan ‘QualNet’ simulator. Berdasarkan kepada hasil yang diperolehi, pemecahan telah meningkatkan penggunaan tenaga dari 57.8 kepada 69.8%. Penggunaan tenaga yang lebih tinggi mengurangkan jangka hayat bagi jaringan-jaringan tersebut secara tersusun mengikut jangka hayat yang dikurangkan dari 7.7% kepada 38.5%. Maka, bilangan bagi nod yang hidup terutamanya pada tahap pertama berkurang semasa waktu simulasi. Dengan menggunakan tahap bateri sebagai parameter penentu bagi menghantarkan pecahan-pecahan ke hop yang seterusnya, jangka hayat adalah ditingkatkan dari 6.9 kepada 20.9%. Tambahan pula, bilangan nod-nod yang hidup juga adalah satu parameter yang mana telah ditingkatkan semasa
waktu simulasi. HFS mengurangkan penangguhan sekitar empat kali berbanding dengan route-over dan dari 20.3 kepada 29.8% berbanding dengan skim mesh-under. Skim lanjutan hibrid juga mengurangkan penggunaan tenaga dari 18.1 kepada 35.1% berbanding dengan skim ‘route-over’ dan 50.68 kepada 58.43% berbanding dengan mesh-under. Akhirnya, dengan menggabungkan dua teknik, (menggunakan aras bateri dan HFS), peningkatan bagi jangka hayat, penggunaan tenaga, dan pengangguhan adalah dari 17 kepada 19.22%, dari 25.57 kepada 26.3%, dan dari 1 kepada 6.44% secara tepatnya.
ACKNOWLEDGEMENT

Thanks God, the merciful and the compassionate, for providing me the opportunity to step into the excellent world of science. To be able to step strong and smooth in this route, I have also been supported and supervised by many people to whom I would like to express my deepest gratitude.

Foremost, I would like to express my sincere gratitude to my supervisor Professor Dr. Nor Kamariah Noordin for the continuous support of my Ph.D study and research, for her patience, motivation, enthusiasm, and immense knowledge. Her guidance helped me in all the time of research and writing of this thesis.

Besides my supervisor, I would also like to thank the rest of my supervisory committee: Assoc. Prof. Dr. Mohd Fadlee A. Rasid and Assoc. Prof. Dr. Raja Symsul Azmir Raja Abdullah for their encouragement, insightful comments, and hard questions. Many thanks go particularly to Dr. Fazirulhisyam Hashim. I am much indebted to Dr. Fazirul for his valuable advice in discussion, supervision and furthermore, using his precious times to read this thesis and gave his critical comments about it. I am very grateful to all staffs in the Department of Communication and Computer Engineering of Universiti Putra Malaysia (UPM) for helping me during my PhD.

Where would I be without my family? I would thank my understanding and patient wife who has put up with these many years of research, and to our precious children who are the joy of our lives. My parents deserve special mention for their inseparable
support and prayers. I would like to thank my parents. There is no doubt in my mind that without their continued support and counsel I could not have completed this process.

I thank my fellow labmates in network and wireless lab: Ayyoub Akbari, Abbas Mehdizadeh, Mojtaba Mohammadpour, Mohammad Mehdi Gilanian Sadeghi, Hadi Sargolzaei and Seyed Masoud Seyed Shohadaie for the discussions, for the days and nights we were working together, and for all the fun we have had in the last four years. Also I thank my friends Mohesn Sarraf and Amir Hossein Zaeri for the relieve they gave me during the life in Malaysia.

My special gratitude is for Islamic Azad University for supporting me during my PhD. My special appreciations are extended to Mr Mohammad Hasan Gheisraian vice chancellor of Islamic Azad University Majlesi Branch.

Finally, I would like to thank everybody who was important to the successful realization of thesis, as well as expressing my apology that I could not mention personally one by one.
APPROVAL

I certify that a Thesis Examination Committee has met on 25 June 2012 to conduct the final examination of Farhad Mesrinejad on his thesis entitled “Battery Aware Hybrid Forwarding Scheme for 6LoWPAN” in accordance with the Universities and University colleges act 1971 and Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the candidate be awarded the Doctor of Philosophy.

Members of the Thesis Examination Committee were as follows:

Ahmad Fauzi Abas, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Borhanuddin b. Mohd. Ali, PhD
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Khairulmizam b. Samsudin, PhD
Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Nirwan Ansari, PhD
Professor
Faculty of Engineering
New Jersey Institute of Technology
(External Examiner)

SEOW HENG FONG, PhD
Professor and Deputy Dean
School Of Graduate Studies
Universiti Putra Malaysia

Date:
This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

**Nor Kamariah Bt Nordin, PhD**  
Professor  
Faculty of Engineering  
Universiti Putra Malaysia  
(Chairman)

**Mohd Fadlee bin A. Rasid, PhD**  
Associate Professor  
Faculty of Engineering  
Universiti Putra Malaysia  
(Member)

**Raja Syamsul Azmir Bin Raja Abdullah, PhD**  
Associate Professor  
Faculty of Engineering  
Universiti Putra Malaysia  
(Member)

**Fazirulhisyam Bin Hashim, PhD**  
Lecturer  
Faculty of Engineering  
Universiti Putra Malaysia  
(Member)

---

**BUJANG BINJ KIM HUAT, PhD**  
Professor and Dean  
School Of Graduate Studies  
University Putra Malaysia

Date:
DECLARATION

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

FARHAD MESRINEJAD

Date: 25 June 2012
TABLE OF CONTENTS

DEDICATION ii
ABSTRACT iii
ABSTRAK v
ACKNOWLEDGEMENT viii
APPROVAL x
DECLARATION xii
LIST OF TABLES xv
LIST OF FIGURES xvi
LIST OF ABBREVIATIONS xix

CHAPTER

1 INTRODUCTION 1
1.1 Background 1
1.2 Problem Statement and Motivation 3
1.3 Research Aim and Objectives 5
1.4 Thesis Scope 6
1.5 Brief Methodology 7
1.6 Study Module 8
1.7 Thesis Organization 9

2 LITERATURE REVIEW 10
2.1 Introduction 10
2.2 Overview of Wireless Personal Area Networks 12
  2.2.1 Standards IEEE 802.15 Family 13
  2.2.2 IEEE 802.15.4 Standard 15
2.3 An Overview of IP-Based Wireless Sensor Networks 19
2.4 Required Internet Protocols Based on 6LoWPAN Scalability 25
  2.4.1 IPv6 Over Low Power Personal Area Networks 31
    2.5.1 6LoWPAN Protocol Stack 32
    2.5.2 Adaptation Layer 33
    2.5.3 Mesh Under and Route Over 39
    2.5.4 Battery Level Power Aware Forwarding 47
    2.5.5 Highlighted Challenges on 6LoWPAN 51
2.5 Energy Consumption in Wireless Sensor Networks 54
2.6 Sensor Networks Lifetime 59
2.7 Summary 64

3 METHODOLOGY 66
3.1 Background 66
3.2 Overview of Proposed Method 67
3.3 Effect of Fragmentation and Header Compression 69
  3.3.1 6LoWPAN Lifetime 72
  3.3.2 6LoWPAN Energy Consumption Payload Base 78
3.3.3 6LoWPAN Time Based Energy Consumption 80
3.3.4 Key Role of the First Level FFD Scenarios in Proposed Method 85
3.4 A Prioritized Battery Aware Adaptation Layer for 6LoWPAN 87
3.5 Hybrid Forwarding Scheme 94
3.6 Simulation Design and Implementation 99
3.6.1 6LoWPAN System Definition and Assumptions 100
3.7 Summary 105

4 RESULTS AND DISCUSSIONS 106
4.1 Introduction 106
4.2 Performance Evaluation of 6LoWPAN 108
4.3 Energy Behavior of Different Level 119
4.4 Battery Aware Method Evaluation 122
4.5 Performance Evaluation of HFS 131
4.6 Combination of the Proposed Methods 139
4.7 Summary 142

5 SUMMARY, GENERAL CONCLUSIONS AND FUTURE WORKS 144
5.1 Summary and Conclusion 144
5.2 Contributions 146
5.3 Future Works 148

REFERENCES 151
BIODATA OF STUDENT 161
LIST OF PUBLICATIONS 162