LOAD DISTRIBUTION MESH ROUTING FOR WIRELESS MESH NETWORK

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Specially dedicated to my beloved father and mother
Ibrahim bin Husin and Sapinah binti Yusof
Also my beloved wife
Anith Adibah binti Hasseim
My daughter Nur Auni Imtithal binti Ismadi
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ABSTRACT

Wireless Mesh Network (WMN) has been strongly investigated by many researchers because of its potential to extend network connectivity to various network scenarios such as in internet broadband access and Wireless Local Area Network (WLAN). WMN comprises of multiple wireless routers that relay packets in a multihop fashion such as in ad hoc network. These mesh routers are connected to mesh clients, which can be any other type of ad hoc networks and they can also communicate with the Internet through one or more gateways. Routing protocol is very important in WMN because it is responsible to forward packet from the source to the destination. The primary objective of this research is to develop a routing protocol namely Load Distributed Mesh Routing (LDMR) protocol that is specifically designed for WMN with IEEE 802.11 standard. The proposed LDMR protocol is developed according to the design concept of Real Time Load Distribution (RTLD) routing protocol that is designed for Wireless Sensor Network (WSN).The LDMR protocol determines potential next hop node based on quadrant and distance information. Then, the Next Hop Forwarding (NHF) decision is used to select the best next hop nodes based on Packet Success Rate (PSR) and maximum velocity of a packet.In addition, a new module of the proposed LDMR protocol is developed in Network Simulator 3 (ns3). The proposed LDMR protocol has been successfully studied and verified through simulation. The WMN's performance is measured in terms of throughput and average end-to-end delay for both randomly distributed and grid network topologies. The network performance of LDMR is compared with the existing routing protocol, which are Ad Hoc on Demand Distance Vector (AODV) and Hybrid Wireless Mesh Protocol (HWMP). Simulation results show that LDMR protocol outperforms other protocols in most of the simulated scenarios where the highest improvement of throughput is 67.39% than HWMP and 60.15% than AODV in the scenario where the connections from multiple sources are routed to a single destination. The LDMR protocol also maintains a low average end-to-end delay which is lower than 0.01s in almost all cases when compared with AODV and HWMP protocols. The proposed LDMR routing protocol in this research has significantly enhanced the network performance in WMN.

ABSTRAK

Rangkaian jejaring tanpa wayar (WMN) telah dikaji oleh ramai penyelidik kerana potensinya untuk melanjutkan sambungan rangkaian untuk pelbagai scenario rangkaian seperti akses jalur lebar internet dan rangkaian kawasan setempat tanpa wayar (WLAN). WMN terdiri daripada pelbagai penghala tanpa wayar yang menyampaikan paket-paket dalam fesyen multihop seperti dalam rangkaian ad hoc. Penghala jejaring ini dihubungkan dengan jaringan pelanggan, yang boleh terdiri daripada apa-apa jenis rangkaian ad hoc dan rangkaian ini juga boleh berkomunikasi dengan Internet melalui satu atau lebih get laluan. Protokol penghalaan adalah sangat penting dalam WMN kerana ia bertanggungjawab untuk menghantar paket dari sumber ke destinasi. Objektif utama kajian ini adalah untuk membangunkan protocol penghalaan iaitu protocol penghala jejaring agihan beban (LDMR) yang direka khusus untuk WMN dengan standard IEEE 802.11. Protokol LDMR yang dicadangkan dibangunkan mengikut konsep reka bentuk protocol penghalaan agihan beban masa nyata (RTLD) yang direka untuk rangkaian peranti pengesan tanpa wayar (WSN). Protokol LDMR menentukan nod lompatan seterusnya yang berpotensi berdasarkan maklumat sukuan dan jarak. Kemudian, keputusan hop penghantaran seterusnya (NHF) diguna untuk memilih nod lompatan seterusnya yang terbaik berdasarkan kadar kejayaan paket (PSR) dan halaju maksimal paket. Di samping itu, satu modul baru protokol LDMR yang dicadangkan dibangunkan dalam Network Simulator 3 (ns3). Protokol LDMR yang dicadangkan itu telah Berjaya dikaji dan disahkan melalui simulasi. Prestasi rangkaian diukur dari segi pemprosesan dan purata selang masa hujung-ke-hujung untuk kedua-dua topologi rangkaian secara rawak dan grid. Prestasi rangkaian LDMR dibandingkan dengan protocol penghala yang sedia ada, iaitu ad hoc atas permintaan jarak vektor (AODV) dan protocol hybrid rangkaian jejaring tanpa wayar (HWMP). Keputusan simulasi menunjukkan bahawa prestasi protokol LDMR melebihi prestasi protokol lain di sebahagian besar scenario simulasi di mana peningkatan tertinggi pemprosesan adalah 67.39% daripada HWMP dan 60.15% daripada AODV dalam scenario sambungan daripada sumber pelbagai ke destinasi tunggal. Protokol LDMR juga mengekalkan selang masa hujung-ke-hujung yang rendah iaitu di bawah 0.01 saat dalam hampir semua kes berbanding protokol AODV dan HWMP. Protokol penghalaan LDMR yang dicadangkan dalam kajian ini telah mempertingkatkan prestasi rangkaian dengan ketara di dalam WMN.

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LIST OF ABBREVIATIONS

ALM	-	Airtime Link Metric
AODV	-	Ad Hoc On Demand Distance Vector
AODV-MQ	-	Multipath Qos Routing
AP	-	Access Point
BSSs	-	Basic Service Sets
CBR	-	Constant Bit Rate
CGSR	-	Cluster Head Gateway Switch Routing
DS	-	Distributed System
DSDV	-	Destination Sequenced Distance Vector
DSDV	-	Destination-Sequenced Distance-Vector Routing
DSR	-	Dynamic Source Routing
EOA	-	Expected One-Transmission Advance
ESS	-	Extended Service Set
GHWMP	-	Geographical Hybrid Wireless Mesh Protocol
GNU GPL	-	Gnu General Public License
HWMP	-	Hybrid Wireless Mesh Protocol
IBSS	-	Independent Basic Service Set
IEEE	-	Institute Of Electrical And Electronics Engineers
IP	-	Internet Protocol
LDMR	-	Load Distribution Mesh Protocol
LQSR	-	Link Quality Source Routing Algorithm
LSGR	-	Link State Aware Geographic Routing Protocol
MAC	-	Media Access Control
MAP	-	Mesh Access Points
MP	-	Mesh Points/Mesh Station

MPP	-	Mesh Portal Point
NHF	-	Next Hop Forwarding
ns2	-	Network Simulator 2
ns3	-	Network Simulator 3
OF	-	Optimal Forwarding
OLSR	-	Optimized Link State Routing Protocol
oTcl	-	Oriented Tool Command Language
PER	-	Packet Error Rate
PERR	-	Path Error
PMP-AODV	-	Priority Setting, Multi-Point Relay And Path Stability Routing Protocol Based On AODV
PREP	-	Path Reply
PRR	-	Packet Reception Rate
QoS	-	Quality Of Service
RM-AODV	-	Radio Metric Aodv
RREP	-	Route Reply
RREQ	-	Route Request
RTLD	-	Real Time Load Distribution
$RTLD_U$	-	Unicast Real Time Load Distribution
RTR	-	Route To Request
SRTLD	-	Secure Real Time Load Distribution
SSID	-	Service Set Identifier
STAs	-	Stations
TCP	-	Transmission Control Protocol
TORA	-	Temporally Ordered Routing Algorithm
UDP	-	User Datagram Protocol
VANETs	-	Vehicular Ad Hoc Network
WDS	-	Wireless Distribution System
WLAN	-	Wireless Local Area Network
WMN	-	Wireless Mesh Network
WSN	-	Wireless Sensor Network
ZRP	-	Zone Based Routing Protocol

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CHAPTER 1

INTRODUCTION

1.1 Background of the Research

Internet broadband access delivery, wireless local area network coverage and network connectivity for stationary or mobile host at low cost can be implementwith Wireless Mesh Network since it has the potential to support all that services. A wireless mesh network (WMN) is a communication network comprises of several nodes that are organized in a mesh topology. Mesh topology is a type of networking where each node must serve as a router for other nodes, apart from disseminating its own data. In other words, in this type of network, all nodes must collaborate in order to relay each other's packet in a multihop fashion [1]. Wireless mesh networks can easily be constructed even at a location with no network infrastructure such as a wireless local area network (WLAN) access point. The advantages of wireless mesh networks that are self-configuration, self-healing, robustness and low expenses make it to be strongly investigated by many researchers.

In 802.11standard, multiple basic service sets (BSSs) that are connected through a distributed system (DS) and integrated with wired LANs are known as extended service set (ESS). Such fixed network architecture limits the flexibility of network deployment and increases cost. Thus, the mobility of BSS and multihop networking are needed. Ad hoc networking has been specified in the independent basic service set (IBSS) mode starting from the first IEEE 802.11 standard [2].

In IBSS, stations (STAs) can connect to each other without any central coordinator like access point (AP). However, there is no access or connection to the distributed system (DS) and STAs are totally self-contained as an ad hoc network. It has been realized that the IBSS mode is not enough for many interesting application scenarios where ad hoc networking is needed but Internet access and support of client nodes are also necessary. Thus, it is a good strategy for both infrastructure mode and IBSS mode shall be integrated in a new type of multihop networks known as WMN.For years, many companies have developed their proprietary solutions to build 802.11 based WMN. However, the proprietary solutions are usually not inter-operable. In order to resolve such an issue and meet the ever-increasing demands of 802.11 mesh networks, IEEE 802.11s is formed to develop a standard for 802.11 mesh networks.

In general, mesh networks are composed of two types of nodes which are mesh routers and mesh clients. As the name implies, mesh routers functioned as relays to support mesh networking and form backbone to mesh clients. Mesh routers can also connect the network to other types of network such as Internet. On the other hand, mesh clients do not have the capability to connect to the Internet directly. However, mesh clients can also functioned as routers to support routing within mesh clients. Wireless mesh network brings many advantages such as self-organized and allows establishing typical ad-hoc network automatically by client nodes [3]. Mesh network also automatically maintains connectivity and supports dynamic reconfiguration.

1.2 Problem Statement

With wireless mesh network (WMN), a high-speed wireless network can be easily established although there is lack of networking infrastructure available. However, the entire performance of a WMN is affected by its routing protocol. Finding optimum route with minimal delay, avoiding congested routes, and taking into account interference patterns existent in a WMN are just some of the factors that directly affect the performance of WMN.

Supporting communication among mesh routers and mesh clients demanded the use of routing protocol that must be integrated with certain routing metrics. This is done to determine the route that must be taken by data packets among all possible routes between a pair of node. Different routing protocols apply different routing metrics which depend on the specific characteristic of the targeted network. In addition, different target network requires particular network performances to be achieved and hence, routing protocols are developed with various aims according to these requirements. For example, the Wireless Sensor Network (WSN) demands the design of energy efficient routing because of limited energy supply in WSN nodes. Meanwhile, the mobility of nodes in ad hoc networks requires the design of routing protocols that can preserve network connectivity effectively.

Over the years, a lot of routing protocols have been developed for ad hoc networks that take into account issues such as mobility, scalability, energy consumption and connectivity. However, for wireless mesh networks, the design of a routing protocol must consider issues such as fixed applications, throughput enhancement and efficient routing within fixed infrastructure [3, 4].Several routing protocols have been reviewed in [5] to be used in WMN and in most of the routing protocols, throughput decreases when the load in the network is increased. A routing protocol that can minimize the congestion in the network and increase the throughput needs to be considered to operate with WMN.

Based on finding in [6], a routing protocol named Real Time Load Distribution (RTLD) that is developed specifically for WSN experiences a high

packet delivery ratio compared to other baseline routing protocols. This routing protocol is designed based on IEEE 802.15.4 WSN architecture and has proved to improve the network lifetime and produces high data delivery at the destination. With regard to this finding, this research proposes a routing protocol for WMN that is based on the design concept of RTLD. Due to the fact that WMN architecture is based on 802.11 with higher power consumption than 802.15.4, this RTLD protocol must be heavily adapted in order to implement it in WMN. In addition, mesh routers that form WMN are static with minimum mobility and has no problem with the power constraint. Other factor that needs to be considered is, RTLD is designed to route the packet from source nodes to a base station and basically the location of the base station is known by all the sensor nodes. On the other hand in WMN, the destination nodes are always changing since all mesh nodes can communicate with each other. To cope with this situation, comparison of distance and quadrant between destination nodes and source nodes need to be done when a node is required to send data. The modifications of the RTLD's algorithms are expected to give good performance in terms of throughput and end to end delay when it is applied in WMN.

1.3 Objectives of the Research

i. To design a routing protocol for wireless mesh network that is based on the characteristics of Real-Time Load Distribution (RTLD) routing protocolwhich isexpected to perform better in term of throughput and end to end delay.

ii. To develop an algorithm to determine distance and quadrant in location management module so that the routing protocol can operate in WMN where the destination node can be more than one.

iii. To implement the proposed routing protocol forwireless mesh networks topology in various network scenarios using Network Simulator 3 (ns3) and compare it with other routing protocol such as Ad Hoc On demand Distance Vector (AODV) [7] and Hybrid Wireless Mesh Protocol (HWMP) [8].

1.4 Scope of the Research

The development of a routing protocol for wireless mesh networks includes three different phases which are the design of routing protocol, simulation of routing protocol using simulator and performance comparison of the proposed protocol with other routing protocols. In order to achieve the objectives, the scope of the study has been confined as follows:

i. Some characteristic of RTLD needs to be changed to make it suitable and works efficiently with the WMN environment. RTLD is used in WSN with limited node's energy supply whereas mesh routers in WMN do not have problem with the power constraint. Hence the energy factor is not one of the major issues to consider when designing the routing protocol for WMN.

ii. Research is conducted in terms of simulation works using Network Simulator 3 (ns3). The protocol is developed from scratch using programming language C++ in ns3 since RTLD was developed in different network simulator with different programming language, which is network simulator 2 (ns2). The network topology created is based on 802.11s that consists of mesh routers and mesh access point (gateway). Mesh routers are modeled as static, where there is no mobility involved. Mesh clients are assumed to be connected to mesh routers and mesh routers function is to forward the data packet from mesh clients to the destination.

iii. The end-to-end performance such as throughput and end to end delay will be evaluated to determine the performance of the proposed protocol in WMN.

1.5 Significance of the Research

The output of this research is an improved routing protocol for wireless mesh networks that is able to achieve high throughput and low end to end delay compared to existing routing protocols that are suitable for this network. The proposed routing protocol can work efficiently in a mesh network with 25 to 36 numbers of nodes where the performance of this protocol is optimum when the density of the network is average.

1.6 Thesis Contributions

The following describes the contributions achieved in this research:

1. A routing protocol named Load Distribution Mesh Protocol (LDMR) has been designed specifically for wireless mesh network that is based on RTLD routing. Since RTLD is developed for wireless sensor networks (IEEE802.15.4) that is more suitable for low power and low data rate sensor nodes, several modifications have been made to this protocol to make it work efficiently in wireless mesh environment. The modification made are:
    a. Simplification of functional modules in the routing protocol where LDMR does not consider node's power management since mesh routers in WMN does not have limited energy constraint.
    b. In LDMR, three important functional modules were created in ns3 namely location management, neighbour management and routing management. These modules cooperate with each other to make forwarding decisions for data packet.
    c. The forwarding decision in LDMR takes into account the quadrant of the node, link quality to the destination that impacted the network throughput, as well as packet velocity that is related to time delay.
    d. In addition, LDMR uses distance and quadrant to determine the potential next hop node when a node wants to sent a packet. Every

node can communicate with each other and not only to one destination.

2. The proposed LDMR is developed from scratch in network simulator 3 (ns3) for wireless mesh networks environment. Network parameters for IEEE802.11s are considered when performing simulation for this protocol. To investigate the proposed routing protocol performance in WMN, the simulation is done in various networks scenarios which are:

    a. Nodes located randomly in a specific area. In this scenario, the effect of number of nodes and size of area on the routing performance is studied.

    b. Nodes located in a grid position. A gateway is set at the center of the network grid in this scenario. The data connections are between the gateway to multiple destination nodes and also from multiple source nodes to the gateway.

    Besides, performance comparisons are made with well-known routing protocol which isAd Hoc on Demand Distance Vector (AODV) routing protocol and default routing in IEEE 802.11s which is Hybrid Wireless Mesh Protocol (HWMP). It is found based on the simulation results that LDMR can improve the throughput and average end to end delay when compared to AODV and HWMP in most of the simulated cases. The improvement is more significant when LDMR is used in the network with multiple sources to a single destination.

1.7 Thesis Organization

This thesis consists of five chapters. The introduction part describes in the Chapter 1 emphasizes on the problem statement, objectives, scope of the research, and significance of the research and thesis contributions.

Chapter 2 presents the related background of wireless mesh networks which includes the architecture of 802.11s in wireless mesh networks. In addition, well known routing protocols developed for ad hoc networks and wireless mesh networks are described in this chapter.

Chapter 3 describes the details on the methodology for this research. Specifically, this chapter introduces the design concept of the proposed routing protocol and the functional modules utilized in this protocol. The simulator used in this research is explained in this chapter, in addition to metrics that are used for performance evaluation of all protocols.

Chapter 4 elaborates the simulation results for LDMR and two comparative protocols, AODV and HWMP. The analyses for different network scenarios are presented in this chapter. The results obtained in terms of throughput and average end to end delay are also justified in this chapter.

Finally the conclusion of the thesis is expressed in Chapter 5 and the contributions achieved are highlighted. Additionally, suggestions for future work are provided in this chapter.

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