AN ENHANCED MULTICAST-BASED OPTIMIZED LINK STATE ROUTING FOR WIRELESS COMMUNITY NETWORK

BY

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A thesis submitted in fulfilment of the requirement for the degree of Doctor of Philosophy (Computer Science)

Kulliyyah of Information and Communication Technology
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MARCH 2023

ABSTRACT

Wireless community networks (WCNs) are a solution for people who are living in some areas facing difficulties for accessing the Internet because no Internet service providers (ISPs) are providing them with the service due to the long distance, the high cost of infrastructure, and the less number of people in these areas. The current routing protocols for WCNs have two performance issues. The first issue is routing stability. Because of the heterogeneous characteristics of links, link quality should be considered as one of the main metrics used to control the routing of packets. However, current routing techniques depend on the shortest path as the main metric to control the routing of packets which results in non-stable routes. Non-stable routes affect communication speed which is a main requirement for large scale of real time applications. The second issue is routing scalability. The scalability is more challenging in the presence of both large number of nodes and mobility. As current routing protocols are inefficient when faced with the dynamic changes and poor links that occur in real-life and self-managed deployments. This results in too much overhead during communications due to flooding as most of the current routing protocols uses unicast traffic. In this research, the ad hoc routing protocol, optimized link state routing (OLSR) is selected and enhanced so that it can meet the standards of efficiency in terms of stability and scalability. OLSR is enhanced through three phases. The first phase is the multicasting expansion where Multicast traffic is expanded to the OLSR routing protocol in WCNs in order to decrease the overhead caused by flooding as OLSR uses unicast traffic. The second phase is the multipoint relay (MPR) selection based on analytical hierarchical process (AHP). Multiple criteria are taken into account simultaneously in the Multi-Criteria Decision Making (MCDM) method to create a flexible decision making process. Multiple metrics can be weighted according to MCDM: AHP. Each node establishes an MPR set based on a single cost determined with the given metrics. The third phase is a composite metric for optimal route selection. The composite metric is proposed using multiple parameters in order to ensure good knowledge of the status of links that can guarantee picking the most stable links in the network. The aim of the new proposed metric is to make finding the best routes extremely easier with the dynamic topology of WCNs. In addition, it aims to avoid the use of hop count metric which is used in the OLSR protocol and is not suitable to the dynamic link characteristics of WCNs. The new proposed routing protocol is developed using C++ programming language under the NS-2 simulator. The performance of the proposed routing protocol is measured using four performance metrics: average end-to-end delay, network control overhead (NCO), packet delivery ratio (PDR), and energy consumption in terms of network density and traffic load with varying mobility speeds. The proposed routing protocol outperforms the OLSR protocol in terms of average end-to-end delay, NCO, and PDR by 5%, 11%, and 12% respectively. While, the energy consumption for the proposed routing protocol is approximately similar to the standard OLSR protocol.

خلاصة البحث

تعد شبكات المجتمع اللاسلكية (WCNs) حلاً للأشخاص الذين يعيشون في بعض المناطق التي تواجه صعوبات في الوصول إلى الإنترنت نظرًا لعدم توفر مزودي خدمة الإنترنت (ISP) لهم بالخدمة بسبب المسافة الطويلة والتكلفة العالية للبنية التحتية وقلة عدد الأشخاص في هذه المناطق. بروتوكولات التوجيه الحالية لشبكات WCN لها مشكلتان في الأداء. المشكلة الأولى هي توجيه الاستقرار. بسبب الخصائص غير المتجانسة للروابط، يجب اعتبار جودة الارتباط كأحد المقاييس الرئيسية المستخدمة للتحكم في توجيه الحزم. ومع ذلك، تعتمد تقنيات التوجيه الحالية على أقصر مسار باعتباره المقياس الرئيسي للتحكم في توجيه الحزم مما يؤدي إلى مسارات غير مستقرة. تؤثر المسارات غير المستقرة على سرعة الاتصال التي تعد مطلبًا رئيسيًا لنطاق واسع من التطبيقات في الوقت الفعلي. المسألة الثانية هي توجيه التوسع. تعد قابلية التوسع أكثر صعوبة في وجود عدد كبير من العقد والتنقل. نظرًا لأن بروتوكولات التوجيه الحالية غير فعالة عند مواجهة التغييرات الديناميكية والروابط الضعيفة التي تحدث في عمليات النشر الواقعية والمدارة ذاتيًا. ينتج عن هذا الكثير من الحمل الزائد أثناء الاتصالات بسبب الفيضانات لأن معظم بروتوكولات التوجيه الحالية تستخدم حركة مرور أحادية الإرسال. في هذا البحث، تم تحديد بروتوكول التوجيه المخصص وتوجيه حالة الارتباط المحسن (OLSR) وتحسينه بحيث يمكنه تلبية معايير الكفاءة من حيث الاستقرار وقابلية التوسع. يتم تحسين OLSRمن خلال ثلاث مراحل. المرحلة الأولى هي توسيع الإرسال المتعدد حيث يتم توسيع حركة الإرسال المتعدد إلى بروتوكول توجيه OLSR في شبكات WCN من أجل تقليل الحمل الناتج عن الفيضانات حيث يستخدم OLSR حركة مرور أحادية الإرسال. المرحلة الثانية هي اختيار الترحيل متعدد النقاط (MPR) بناءً على عملية هرمية تحليلية (AHP). يتم أخذ معايير متعددة في الاعتبار في وقت واحد في طريقة اتخاذ القرار متعدد المعايير (MCDM) لإنشاء عملية صنع قرار مرنة. يمكن ترجيح المقاييس المتعددة وفقًا لـ MCDM: AHP. تنشئ كل عقدة مجموعة MPR بناءً على تكلفة واحدة محددة باستخدام المقاييس المحددة. المرحلة الثالثة هي مقياس مركب لاختيار المسار الأمثل. يُقترح القياس المركب باستخدام معلمات متعددة لضمان معرفة جيدة بحالة الروابط التي يمكن أن تضمن اختيار الروابط الأكثر استقرارًا في الشبكة. الهدف من المقياس الجديد المقترح هو جعل العثور على أفضل المسارات أسهل للغاية باستخدام الهيكل الديناميكي لشبكات WCN. بالإضافة إلى ذلك، تهدف إلى تجنب استخدام مقياس عدد القفزات المستخدم في بروتوكول OLSR وغير مناسب لخصائص الارتباط الديناميكي لشبكات WCN. تم تطوير بروتوكول التوجيه الجديد المقترح باستخدام لغة برمجة C ++ ضمن محاكي NS-2. يتم قياس أداء بروتوكول التوجيه المقترح باستخدام أربعة مقاييس للأداء: متوسط التأخير من طرف إلى طرف، والتحكم في الشبكة (NCO)، ونسبة تسليم الحزمة (PDR)، واستهلاك الطاقة من حيث كثافة الشبكة وحمل المرور مع التنقل المتنوع سرعات. يتفوق بروتوكول التوجيه المقترح على بروتوكول OLSR من حيث متوسط التأخير من طرف إلى طرف و NCO و PDR بنسبة 5٪ و 11٪ و 12٪ على التوالي. بينما، فإن استهلاك الطاقة لبروتوكول التوجيه المقترح مشابه تقريبًا لبروتوكول OLSR القياسي.

APPROVAL PAGE

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DECLARATION

I hereby declare that this thesis is the result of my own investigations, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

Safaa Saad-Eldeen Ahmed Mohammed Matter

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It is my utmost pleasure to dedicate this thesis to my beloved parents.

ACKNOWLEDGEMENTS

First of all, many thanks and praise to Allah s.w.t for giving me the strength, patience, courage, and determination in completing this work.

I would like to express my sincere gratitude to my supervisor Prof. Dr. Aisha Hassan Abdalla Hashim for her valuable guidance, enthusiastic encourage and support in every stage of my research. I am also grateful to my co-supervisor, Prof. Dr. Imad Fakhry Al Shaikhli, whose support and cooperation contributed to the outcome of this work. Special thanks also to Dr. Andi Fitriah Binti Abdul Kadir for her support and help. This thesis represents a great deal of time and effort not only on my part, but also on the part of my supervisors.

I would also like to take this opportunity to thank my viva examiners, for their very helpful comments, suggestions, and constructive criticisms, in addition for letting my defense be an enjoyable moment.

My gratitude extends to the Kulliyyah of Information and Communication Technology (KICT), International Islamic University Malaysia (IIUM), for giving me the opportunity to carry out my doctoral research and undertake my studies to the fullest. In addition, my personal thanks go to all lecturers and staff members at the Kulliyyah as well as the university for all their considerate guidance and whose wisdom have shaped my way of looking at things one way or another, because they have the ability for creativity, dedication, and hard work.

Words cannot express the gratitude I have for my parents for the way they raised me, without them I simply would not be where I am now.

Likewise, I am greatly indebted to my beloved husband, Dr. Mahmoud Khattab for his continuous support and words of encouragement throughout the journey of this PhD study. This thesis would not have been completed without his help and support.

Special thanks to my lovely children Mostafa and Seela for their unwavering support and patience throughout this journey.

Once again, we glorify Allah for His endless mercy on us one of which is enabling us to successfully round off the efforts of writing this thesis. Alhamdulillah.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AHP	Analytical Hierarchical Process
AODV	Ad Hoc On-demand Distance Vector
AoI	Age of Information
AOLSR	Airborne Optimized Link State Routing
Aps	Access Points
AWMN	Athens Wireless Metropolitan Network
B4RN	Broadband for the Rural North
BGP	Border Gateway Protocol
BMX6	BatMan-eXperimental version 6
BW-OLSR	BandWidth Optimized Link State Routing
CBR	Constant Bit Rate
Cc	Closeness centrality
CPU	Central Processing Unit
DAT	Directional AirTime
DIY	Do-It-Yourself
DSP	Dynamic Shortest Path
D-WCETT	Dynamic- Weighted Cumulative Expected Transmission Time
EFW	Expected ForWarding counter
ELARM	Energy-Load Aware Routing Metric
EM-OLSR	Energy and Mobility Optimized Link State Routing
ETX	Expected Transmission Count
FFDN	Federation French Data Network
FIFO	First In First Out
FON	Fiber Optic Network
GB	GigaByte
GHz	GigaHertz

HWMP	Hybrid Wireless Mesh routing Protocol
IANA	Internet Assigned Numbers Authority
IFQ	InterFace Queue
IHU	I Heard You
IP	Internet Protocol
IPv6	Internet Protocol version 6
ISPs	Internet Service Providers
JEFW	Joint Expected Forwarding Counter
LCR	Link Change Rate
L-OLSR	Localization technology Optimized Link State Routing
MAC	Media Access Control
MACT	Multicast ACTivation
MANETs	Mobile Ad hoc NETworks
MB	MegaByte
MBA-OLSR	Multipath Battery Aware Optimized Link State Routing
MCDM	Multi-Criteria Decision Making
MD	Minimum Delay
MEFW	Minimum Expected Forwarding Counter
MID	Multiple Interface Declaration
ML	Minimum Loss
MOLSR	Modified Optimized Link State Routing
MP-OLSR	MultiPath Optimized Link State Routing
MPR	MultiPoint Relay
NCO	Network Control Overhead
NGO	NonGovernmental Organization
NHDP	NeighborHood Discovery Protocol
NPC	Node Performing the Computation
NS-2	Network Simulator V2.35
NS-3	Network Simulator Version 3

NWNP	Nepal Wireless Networking Project
OGM	OriGinator Messages
OLSR	Optimized Link State Routing
OPNET	OPtimized Network Engineering Tools
PDR	Packet Delivery Ratio
PPO	Packet Priority-Oriented
PP-QoS	PPO-Quality of Service
QoS	Quality of Service
RFC	Request For Comment
RP	RePort
RREP	Route REPly
RREQ	Route REQuest
RSSI	Receive Signal Strength Indicator
Rxcost	Link Cost
SDN	Software Defined Networking
TakNet	Tanzania Knowledge Network
TB	Terabyte
TC	Topology Control
TCP/IP	Transmission Control Protocol/Internet Protocol
TLVs	Type Length Values
TTL	Time To Live
UDP	User Datagram Protocol
VoIP	Voice over Internet Protocol
WCETT	Weighted Cumulative Expected Transmission Time
WCNs	Wireless Community Networks
WiFi	Wireless Fidelity
WMN	Wireless Mesh Network
W-OLSR	Weighted Optimized Link State Routing

CHAPTER ONE

INTRODUCTION

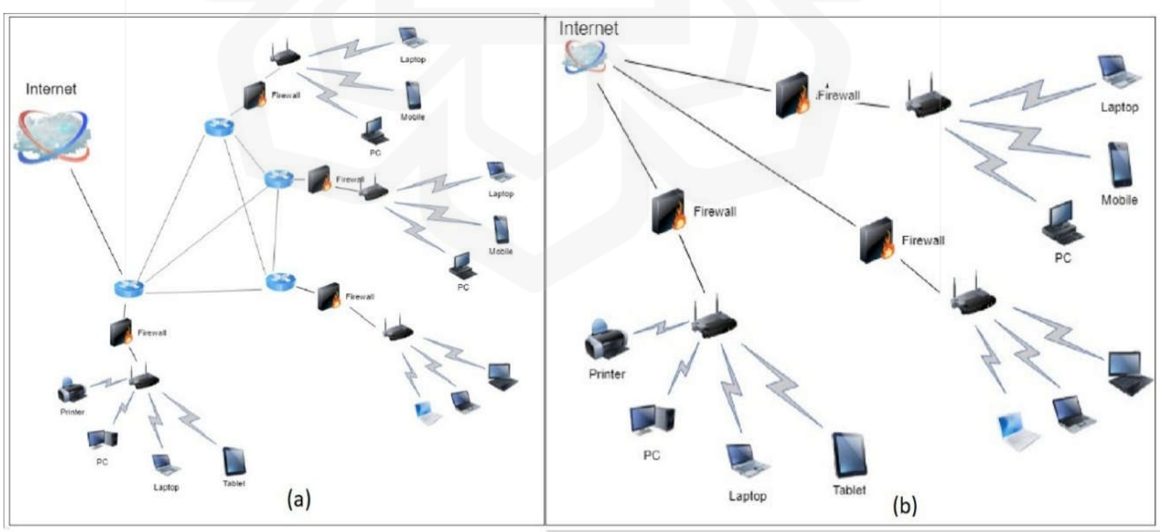
1.1 RESEARCH BACKGROUND

Wireless Community Networks (WCNs) are considered as another form for ownership of Internet Protocol (IP) networks, where community members manage and own every piece of equipment in a decentralized way, and routing for traffic is done in a cooperative manner. These networks are determined to beat on the gap between Internet access and the weak coverage of Internet Service Providers (ISPs) in rural areas. WCNs have been widely spreading in many countries as time went on; access to the Internet becomes more necessary for individual and collective participation in society (Neumann et al., 2015).

From technical perspective, WCNs are considered large-scale networks as it consists of numerous nodes, links, content, and services. In addition, they are distributed and decentralized systems. There is a mix of wired and wireless connectivity, diverse routing mechanisms, and a wide range of applications and services in these decentralized networks. As a consequence of this, they have a very active and diversified nature. These networks are governed by an open peering agreement that removes any obstacles for joining the network (Picopeer.net, 2018). The network's governance, ownership, and knowledge are all open. Therefore, the decentralization, self-management, and self-ownership are characteristics of WCNs. Furthermore, WCNs are considered as self-growing networks especially in links, capacity, and services provided (Om, 2021). Due to the Do-It-Yourself (DIY) approach in WCNs, there is a need for a robust routing protocol to deal with topology changes and frequent breakdowns (Braem et al., 2015). Furthermore, the internal structure of WCNs obligates the routing to be highly scalable and distributed. Moreover, the routing must allow for continuous connections and reconfiguration for new, broken or congested links by using self-adaptive algorithms.

1.1.1 Classification of WCNs Design Schemes

There are two approaches to constructing a WCN. The first approach is called Wireless mesh-based WCN which is based on cautiously constructing a multi-hop network with nodes in specific locations and directional antennas in order to design high-quality radio links. This type of network structure results in fine connectivity and high throughput. However, it requires well-coordinated groups with technical expertise. This scheme is used often in WCNs that have arisen from private initiatives. Figure 1.1 (a) shows nodes with multi-interface that build a wireless mesh, where some other nodes work as gateways to the public Internet. These gateways can be reached through the wireless backbone (Navarro et al., 2016). The second approach is Hotspot-based WCNs. Figure 1.1 (b) shows that clients directly connect to individuals operating "hot-spot" Access Points (APs). This type of network structure doesn't provide high coverage such as multi-hop networks. However, no much coordination to deploy and operate is required. This network scheme is usually intended for roaming users who use wireless hotspots to connect to the Internet. This structure is often used by Municipality-initiated WCNs (Navarro et al., 2016).



(a) A wireless mesh architecture (b) hotspot-based architecture

Figure 1.1 WCN design approaches (Navarro et al., 2016)

1.1.2 Architecture and Technologies

1. **Node Types**: There are two kinds of nodes that form the WCN (Navarro et al., 2016). First, the backbone nodes are those who construct the backhaul of the network. They run routing software and often have more than two network interfaces. They function as APs. Moreover, they operate omnidirectional antennas. Second, the client nodes which is the "leaves" of the network. These client nodes can be connected to those APs and to benefit from the network's services.
2. **Links**: The network backbone is relying on directional point-to-point links. Links for long distances that assisted by directional antennas are being set up by using IEEE802.11, while it is designed for local communication as a broadcast protocol. Initially, IEEE802.11b is the decided protocol for the backbone; however, it is replaced with IEEE802.11a in order to minimize interference and contention from APs and clients. APs still use IEEE802.11b.
3. **Services and applications**: WCNs can provide many services in addition to the Internet access. The most common services are community-wide Voice over Internet protocol (VoIP) and file sharing.

1.1.3 Representative WCN Examples

In recent years, WCNs have sparked a great deal of excitement due to the promise that they hold of providing low-cost and participatory connectivity solutions for citizens. Such solutions can be especially helpful in developing nations or in secluded areas that have been neglected by public institutions or private network providers. Concurrently, there has been a rise in both the use of wireless devices as well as interest in them as a result of the development of low-cost laptops and mobile devices that come pre-equipped with wireless fidelity (WiFi) access. As a logical progression, a multitude of non-profit projects have emerged in recent years to construct WCNs in order to provide internet access (Neumann, 2017). These WCNs are intended to serve as an alternative to traditional internet service providers (ISPs).

- Freifunk in Germany (freifunk).
- Athens wireless metropolitan network (AWMN) in Greece (AWMN).
- FunkFeuer in Austria (Funkfeuer).
- Guifi.net in Spain (guifi.net).
- Ninux org in Italy (Ninux).
- Nepal wireless networking project (NWNP) in Nepal (NWNP).
- Broadband for the rural north (B4RN) in England (B4RN).
- Federation French data network (FFDN) in France (FFDN).

1.1.4 Routing Protocols

Since routing decides the route that each packet has to follow to reach its destination, it is a crucial function in WCNs. It is insistent that a routing protocol for a community network must be capable of adapting to network changes continuously (Neumann, 2017). Where, any WCN organically grows, with several hops and community members are doing the network administration in a decentralized manner.

As mentioned earlier, the fact that WCNs are made up of a number of layer 2 devices means that they form a network of nodes. The connectivity between the various nodes is not guaranteed and the stability of links may change over time. Therefore, some WCNs use mesh routing protocols for Mobile Ad hoc NETworks (MANETs), while others use the traditional routing protocols. In certain networks, numerous routing protocols are used at the same time. It is possible, for example, that they employ a mesh network within each island and use traditional routing protocols to link them altogether.

1.2 PROBLEM STATEMENT

Since routing decides the route that each packet has to follow to reach its destination, it is a crucial function in WCNs. It is insistent that a routing protocol for a community network must be capable of adapting to network changes continuously (Neumann, 2017). Where, any WCN organically grows, with several hops and community members are doing the network administration in a decentralized manner. Routing in WCNs have investigated to propose a more stable and scalable routing technique.

Links of WCNs always have heterogeneous characteristics. Therefore, link quality is one of the main factors that affect routing stability. Current routing protocols such as optimized link state routing (OLSR) depend on the shortest path as the main metric to control the routing of packets (Barz et al., 2015). Shortest paths are not always the optimal paths as it can suffer from high packet loss and instability (Abdel-Nasser, Mahmoud, Omer, Lehtonen, & Puig, 2020). Therefore, beside the shortest path metric, routing techniques should also consider the quality of the paths (links) during the communication lifetime (Saldana et al., 2016).

In addition, the scalability is more challenging in the presence of both large number of nodes and mobility. As current routing protocols are inefficient when faced with the dynamic changes and poor links that occur in real-life and self-managed deployments. This results in too much overhead during communications due to flooding as most of the current routing protocols uses unicast traffic.

Many researches and extensions for OLSR routing protocol have been proposed to solve the problems of stability and scalability. However, to my knowledge, none of the current researches presents a complete, integrated, and coherent prototype to solve all the problems of WCNs. According to all previously mentioned reasons, an enhanced routing protocol is proposed to achieve optimal routing performance. This protocol is designed to consider the heterogeneous characteristics of WCNs to produce more efficient routing technique in terms of stability and scalability.

1.3 RESEARCH QUESTIONS

This section describes the research questions to be answered in this research work. The research questions are as follows:

1. What are the main factors which affect the performance of common routing protocols in WCNs?
2. How to enhance the current routing protocols in terms of stability and scalability?
3. How to evaluate the performance of the enhanced routing protocol?

1.4 RESEARCH OBJECTIVES

The main aim of this research work is to propose an enhanced routing protocol for WCNs that considers the heterogeneous characteristics of WCNs in order to produce more stable and scalable networks. Therefore, to achieve this aim, the following objectives are set

1. To investigate the various routing protocols that used for WCNs to identify the main factors that affect the performance of these protocols.
2. To design an enhanced routing protocol for WCNs in terms of stability and scalability.
3. To implement and test the proposed routing protocol using NS-2 simulator.
4. To evaluate and analyze the proposed routing protocol with the OLSR routing protocol.

1.5 RESEARCH SIGNIFICANCE

The Internet has made the world a little community in recent years, linking millions of people, organizations, and equipment for different purposes. Sometimes WCNs become a popular solution for people who can’t access the Internet services directly from ISPs (M