Faculty of Computer Science and Information Technology

Resource Aware Routing Protocol for Infrastructure-less Non-social Opportunistic Networks

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Resource Aware Routing Protocol for Infrastructure-less Non-social OppNets

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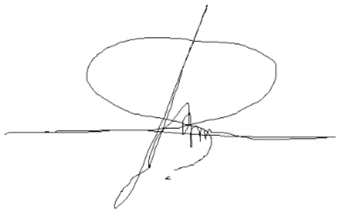
DECLARATION

I declare that the work in this thesis was carried out in accordance with the regulations of Universiti Malaysia Sarawak. Except where due acknowledgements have been made, the work is that of the author alone. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.



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ABSTRACT

The Opportunistic Networks (OppNets) have emerged as a new communication paradigm of Delay Tolerant Networks (DTNs). It becomes dominant due to the emergence of smart devices equipped with wireless facilities. Nodes in OppNets are in constant and unpredictable mobility and connections are interrupted continuously. In these networks, routing relies on seizing the opportunity of nodes' encounters to disseminate messages in the network. In resource-constrained stateless non-social OppNets, new challenges arise such as information scarcity, low energy, and low memory capacity. In these networks, routers should have enough acumen to deal with message routing duty. Consequently, in such harsh environments, routing becomes more challenging. To cope with these challenges, this thesis presents a novel resource-aware routing (ReAR) protocol that includes two schemes; the Mutual Information-based Weighting Scheme (MIWS) and the Acumen Message Drop (AMD) scheme. MIWS estimates the impact (weight) of the nodes' attributes on data forwarding performance. The high weight of certain attributes implies a correspondingly high impact in achieving efficient data forwarding. The weights are estimated in real-time in stateless non-social OppNets. MIWS is used to estimate buffer weight. The main objective of buffer weight estimation is to control buffer consumption in the network. The AMD scheme is a buffer management scheme. AMD takes into consideration the impact of the message drop decision on the data dissemination performance. This will assure that the message is not dropped as long as there is still a possibility that it will reach its destination. To achieve this goal, the message's drop decisions are made based on the considerations that play a vital role in determining the feasibility of message retention. AMD proposes to drop the message based on the estimated time of message's arrival to its destination and the message lifetime. AMD works as a plug-in in any routing protocol. Simulation results show that combining the AMD scheme with the Probabilistic Routing Protocol using History of Encounters and Transitivity (PRoPHET) increases efficiency by up to 60%, while if combined with Epidemic routing protocol, efficiency increases by up to 31%. Both, MIWS and AMD, depend only on the contact history information which is the only information available in the stateless non-social OppNets. Further, this thesis provides a comprehensive analytical study of the performance of the most distinguished routing protocols in OppNets. Based on the results of this study in addition to the two aforementioned schemes (MIWS and AMD), the ReAR protocol was developed to raise performance. ReAR achieves the following objectives: Imposes an upper bound on message's copies in the network, achieves an equitable distribution of traffic loads among nodes based on resource consideration, avoids congestion proactively, and regulates buffer consumption in the network. ReAR raises the delivery ratio, on average, by 45%, 72%, 200%, 849%, 1008% compared with EBR, ES&W, PRoPHET, MaxProp and Epidemic routing protocols respectively.

Keywords: OppNets, delay tolerant networks, routing protocols, buffer management, resource-constrained networks.

Protokol Penghalaan Sedar Sumber untuk Rangkaian Berpeluang Tanpa Infrastuktur Bukan Sosial

ABSTRAK

Rangkaian berpeluang (OppNets) telah muncul sebagai paradigma komunikasi baru Rangkaian Toleran Kelewatan (DTN). Ia menjadi dominan kerana munculnya peranti pintar yang dilengkapi dengan kemudahan tanpa wayar. Nod di dalam OppNets berada dalam pergerakan tetap dan tidak dapat diramalkan serta sambungannya terganggu secara berterusan. Dalam rangkaian ini, penghalaan bergantung kepada sejauh mana peluang pertemuan direbut oleh nod untuk menyebarkan maklumat dalam rangkaian. Dalam OppNets yang bukan sosial tanpa status yang terhad sumbernya, cabaran baru muncul seperti kekurangan maklumat, tenaga dan kapasiti memori yang rendah. Dalam rangkaian ini, penghala harus cukup cekap untuk menangani tugas penghalaan mesej. Nahtijahnya, dalam persekitaran yang sukar dijangkakan, penghalaan menjadi lebih mencabar. Untuk mengatasi cabaran ini, tesis ini mempersembahkan protokol sumber-sedar penghala (ReAR) yang novel yang terdiri daripada dua skema; Skema berasaskan maklumat berpemberat bersama (MIWS) dan skema kebijaksanaan penguguran mesej (AMD). MIWS menganggarkan kesan (pemberat) ciri-ciri nod kepada prestasi penghantaran data. Pemberat yang mempunyai ciri-ciri nilai yang tinggi menunjukkan impak yang besar dalam mencapai penghantaran data yang cekap. Pemberat adalah dianggarkan secara langsung di dalam OppNets bukan sosial tanpa status. MIWS digunakan untuk mengira pemberat penyangga. Tujuan utama menganggarkan pemberat penyangga adalah untuk mengawal penggunaan penyangga dalam rangkaian. Skim AMD adalah skema pengurusan penyangga. AMD mempertimbangkan kesan keputusan pengguguran mesej terhadap prestasi penyebaran data. Ini akan memastikan bahawa mesej tidak digugurkan selagi masih ada kemungkinan bahawa mesej itu akan sampai ke destinasinya. Untuk mencapai tujuan ini, keputusan pengguguran mesej dibuat berdasarkan *pertimbangan yang mana ini memainkan peranan penting dalam menentukan kebolehsimpanan sesebuah mesej tersebut. AMD mencadangkan untuk menggugurkan mesej berdasarkan anggaran masa ketibaan mesej di destinasinya dan jangka hayat mesej tersebut. AMD berfungsi sebagai alat yang boleh digunakan oleh mana-mana protokol penghalaan. Hasil simulasi menunjukkan bahawa menggabungkan skema AMD dengan protokol penghala PRoPHET meningkatkan kecekapan sehingga 60%, sementara jika digabungkan dengan protokol penghala Epidemik, kecekapan meningkat sehingga 31%. Kedua-duanya, MIWS dan AMD, hanya bergantung kepada maklumat nod interaksi yang lalu yang mana ini adalah merupakan satu-satunya maklumat yang terdapat di rangkaian oportunistik bukan sosial tanpa status. Selanjutnya, tesis ini memberikan kajian analitik yang komprehensif mengenai prestasi protokol penghalaan yang paling terkemuka dalam rangkaian oportunistik. Berdasarkan hasil kajian ini selain dua skema yang telah disebutkan sebelum ini, protokol ReAR dibina untuk meningkatkan prestasi. ReAR mencapai objektif berikut: Mengenakan had maksimum pada salinan mesej dalam rangkaian, mencapai pengagihan beban trafik yang saksama di antara nod berdasarkan pertimbangan keadaan sumber, mengelakkan kesesakan secara proaktif dan mengawal penggunaan penimbal di dalam rangkaian. ReAR meningkatkan nisbah penghantaran, secara purata masing-masing sebanyak 45%, 72%, 200%, 849%, 1008% berbanding dengan protokol routing EBR, ES&W, EPRoPHET, MaxProp dan Epidemic.*

Kata kunci: *Rangkaian berpeluang, rangkaian toleransi kelewatan, protokol penghalaan, pengurusan penyangga, rangkaian sumber terhad sumber.*

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LIST OF ABBREVIATIONS

AMD	Acumen Message Drop
CAR	Community Aware Routing
CF	Consumption Factor
CFS	Controlled Forwarding Strategy
CRPO	Cognitive Routing Protocol for Opportunistic networks
DD	Direct Delivery
DEEP	Distance and Encounter based Energy-efficient Protocol
DF	Delegation Forwarding
DTN	Delay-tolerant networking
EBR	Encounter-Based Routing
ES&W	Energy Spray and Wait
FARS	Fairness-Aware Routing Strategy
FC	First Contact
FIFO	First In First Out
FOG	Fairness-based Opportunistic Network
FPOR	Fixed Point Opportunistic Routing
IPRA	Improved Probabilistic Routing Algorithm
kROp	k-Means clustering based routing protocol
MADM	Multiple Attribute Decision Making
MANET	Mobile Ad-hoc Networks
MAODV	Multicast Ad hoc On-Demand Distance Vector
MIWS	Mutual Information-based Weighting Scheme
MRPTPAE	Multicast Routing Protocol using Transfer aim-listed Probability

	And Energy
NBC	Naive Bayesian Classifier
ONE	Opportunistic Network Environment
OOF	Optimal Opportunistic Forwarding
OPF	Optimal Probabilistic Forwarding
OppNets	Opportunistic Networks
PQB-R	Priority Queue Based Reactive
ReAR	Resource-Aware Routing
SaW	Spray and Wait
SCF	Store-Carry-Forward
SCGR	Social Contact Graph-based Routing
TTL	Time-To-Live
VDTN	Vehicular Delay Tolerant Networks

CHAPTER 1

INTRODUCTION

1.1 Study Background

The emergence of intelligent devices equipped with wireless communication facilities led to a broad range of mobile applications. In 2020, the global data traffic of these devices amounted to 50 Exabyte per month, and it is estimated to grow by a factor of 4.5 to reach 226 Exabyte per month in 2026 (*Ericsson*, 2022). Their popularity has increased due to the variety of its types; Smartphones, laptops, tablets, iPads, and etcetera. This rapid development inspired new areas of knowledge and shed light on different ways of deploying these devices. Opportunistic Networks (OppNets) are one of the communication networks that anticipating the mobility issue in facilitating communication in unstable networks.

Figure 1.1 shows that OppNet is a subtype of Mobile Ad hoc Network (MANET), which in turn is a subtype of Ad hoc Network. Ad hoc Network is a network created between two or more wireless PCs together, without the use of a wireless router or an access point. The computers communicate directly with each other. Ad hoc Networks can be very helpful during meetings or in any location where a network doesn’t exist and where people need to share files. Whereas, MANET is a type of Ad hoc Network in which nodes (users) can mobile and change their locations. Unlike MANET, nodes in OppNets characterized by a higher mobility speed in which nodes appear in and disappear from the network dynamically. Hence, senders and receivers in OppNets might be completely unaware of each other, and may never be connected to each other at the same time and the same place. Therefore, routing protocols in OppNets heavily rely on human mobility and contact opportunity. Table 1.1 summarizes the key differences among the aforementioned types of networks. It is noteworthy that all the aforementioned types of networks (Ad hoc Networks, MANET, and OppNet) belong to the Delay-Tolerant Networking (DTN) approach which is a computer network architecture that seeks to address the technical issues in heterogeneous networks that may lack continuous network connectivity. Examples of DTN networks are those operating in mobile or extreme terrestrial environments, or planned networks in space.

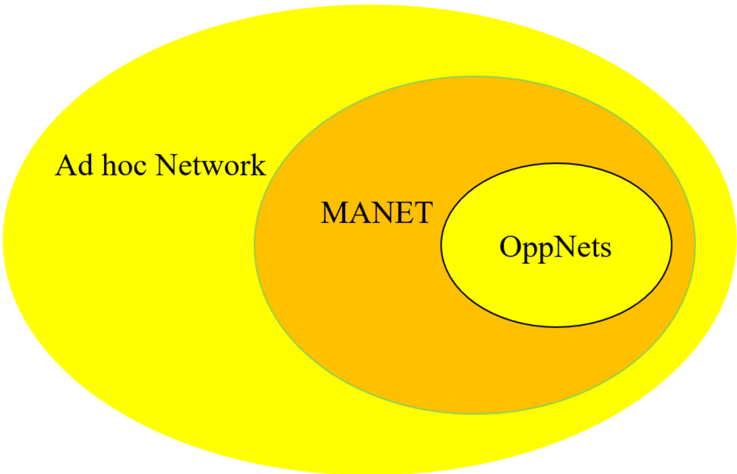

Figure 1.1: Ad hoc Network subtypes

Table 1.1: Ad hoc Netwoks comparison

Topic	**Ad hoc Network**	**MANET**	**OppNet**
Connectivity between source and destination	each node participates in routing by forwarding data for other nodes, so the determination of which nodes forward data is made dynamically on the basis of network connectivity	Due to nodes mobility, there is a path only for a while between source and destination	Due to high mobility of nodes, there is no path between source and destination. Intermediate nodes are used to form paths dynamically
Connection establishment	Nodes directly communicate with each other without a router	Sender sends message after path establishment	Store-Carry-Forward paradigm is adopted
Delay	Low	Medium	High

Based on the information availability, OppNets can be classified into two main categories; stateless and stateful OppNets. In stateless OppNets, nodes have not any global information about the network topology. Therefore, routing depends mainly on the contact history information collected during nodes roaming in the network (Chau & Basu, 2011). On the contrary, in stateful OppNets, nodes perform routing based on global topology information which they attain from an available central entity (Zeng et al., 2011). Another classification of OppNets is social and non-social OppNets. In non-social OppNets, there is no knowledge about the communities that the nodes (users) belong to. On the contrary, nodes in social OppNets hold useful information about their affiliation, i.e., about the communities they belong to. This social information is valuable for routing processes (Wu et al., 2017). For instance, when a node knows the affiliations of other nodes, it forwards messages only to nodes that belong to the same community of the destination nodes. This will certainly reduce the redundancy of messages in the network and speed up the arrival of messages to their destinations. Consequently, this will save network resources and increase delivery ratios.

Due to the lack of network topology information in OppNets, routing is more difficult than traditional networks which use fixed and dedicated hardware devices such as routers and switches to control network traffic. Moreover, unlike MANET networks, the intermittent connectivity which caused by the high mobility of the nodes in OppNets leads into instability of the paths between sources and destinations. Therefore, OppNets rely on the Store-Carry-Forward (SCF) transport paradigm where all relay nodes have to carry the message and forward it until it is delivered to the final destination. Many routing protocols for OppNets have been developed to improve the SCF implementation. Simple opportunistic routing protocols, which are called flooding-based protocols, rely on flooding the network with messages by duplicate them and disseminate their copies across the network in hopes of reaching their destination. As an attempt to save network resources, smarter protocols, which are called guided-based protocols, deliver the message only to the most suitable nodes that are most likely to meet the message destination. Epidemic routing protocol (Vahdat & Becker, 2000) is an example of flooding-based routing protocol which perform better when the resources (i.e., buffers, energy, bandwidth, etc.) are unlimited. However, both flooding-based and guided-based routing protocols did not give a satisfactory cost solution. Therefore, a lot of protocols have been proposed to balance the delivery ratio and the cost (Abdelkader et al., 2016; Bhattacharjee et al., 2016; Huang et al., 2010; Lindgren et al., 2004; Xue et al., 2009).

Examples of OppNets application are: disaster environments (Hazra et al., 2019), under water communications (Rajpoot & Kushwah, 2016), rural remote patient monitoring