



**Faculty of Computer Science and Information Technology**

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

**Aref Hassan Kurd Ali**

**Doctor of Philosophy  
2022**

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

Aref Hassan Kurd Ali

A thesis submitted

In fulfillment of the requirements for the degree of Doctor of Philosophy

(Computer Science)

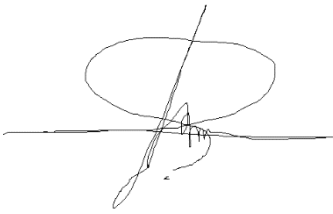
Faculty of Computer Science and Information Technology

UNIVERSITI MALAYSIA SARAWAK

2022

## 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.



.....

Signature

Name: Aref Hassan Kurd Ali

Matrix No.: 15010214

Faculty of Computer Science and Information Technology

Universiti Malaysia Sarawak

Date: 24 August 2022

## **ACKNOWLEDGEMENT**

Above all, I thank Allah Almighty for his countless blessings. I thank him for helping me complete this research, and I ask him to accept it sincerely for him and to make this research at the service of humanity.

My sincere gratitude to my supervisor Assoc Prof Dr Halikul bin Lenando for the advice and support he gave to me during my period of study at Universiti Malaysia Sarawak. I have learned a lot from his profound knowledge, insight, and wisdom.

I want to thank my lovely parents; my father Hassan Aref ; and my mother Aminah Ayoubi. In addition, I want to thank my brother Bader and all my sisters: Hawra, Zenab, and Nour, for their prayers and encouragement.

I want to thank my lovely wife; Dania Al-Otri, and all my lovely kids; Sara, Hassan, Osama, Rukkay, for their patience and for supporting me spiritually to complete this work.

I would like to thank all my friends who support me a lot during my PhD journey; many thanks to Mohamad Alrfaay, Slim Chaoui, Abdallah Garib, and all who have contributed directly or indirectly to this research.

## 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 Bepeluang Tanpa Infrastuktur Bukan Sosial***

### **ABSTRAK**

*Rangkaian bepeluang (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 penguguran mesej terhadap prestasi penyebaran data. Ini akan memastikan bahawa mesej tidak digugurkan selagi masih ada kemungkinan bahawa mesej itu akan sampai ke destinasiya. Untuk mencapai tujuan ini, keputusan penguguran 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 destinasiya 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 PProPHET 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.*



## TABLE OF CONTENTS

	<b>Page</b>
<b>DECLARATION</b>	i
<b>ACKNOWLEDGEMENT</b>	ii
<b>ABSTRACT</b>	iii
<b><i>ABSTRAK</i></b>	v
<b>TABLE OF CONTENTS</b>	vii
<b>LIST OF TABLES</b>	xii
<b>LIST OF FIGURES</b>	xiv
<b>LIST OF ABBREVIATIONS</b>	xvii
<b>CHAPTER 1 INTRODUCTION</b>	1
1.1 Study Background	1
1.2 Problem Statement	5
1.3 Objectives	7
1.4 Research Scope	7
1.5 Research Contribution	8
1.6 Research Methodology Framework	9
1.7 Thesis Structure	11
<b>CHAPTER 2 LITERATURE REVIEW</b>	13
2.1 Introduction	13

2.2	Background	13
2.2.1	Probability-based Routing Protocols	16
2.2.2	Contact History-based Routing Protocols	18
2.2.3	Contact Rate-based Routing Protocols	29
2.3	Performance Analyses of OppNets	31
2.4	Node's Attributes-based Routing Protocols	33
2.5	Message Dropping Schemes in OppNets	35
2.6	Workload's Fairness Researches in OppNets	43
2.7	Summary	50
<b>CHAPTER 3 PERFORMANCE ANALYSIS OF ROUTING PROTOCOLS</b>		<b>51</b>
3.1	Introduction	51
3.2	Opportunistic Routing Protocols	52
3.2.1	Epidemic Routing Protocol	53
3.2.2	PRoPHET Routing Protocol	54
3.2.3	MaxProp Routing Protocol	56
3.2.4	Spray and Wait Routing Protocol	59
3.2.5	EBR Routing Protocol	60
3.3	Performance Evaluation	63
3.3.1	System Model	63
3.3.2	Experiments Procedures	65

3.3.3	Simulation Setup	66
3.3.4	Performance Evaluation Metrics	67
3.4	Numerical Results of Experiments	68
3.5	Results and Discussions	69
3.5.1	Impact of Different Buffer Sizes on Time	69
3.5.2	Impact of Varying the Traffic Load	73
3.5.3	Impact of Varying the Number of Nodes	78
3.5.4	Impact of Varying the Message's Lifetime	82
3.5.5	Design Guidelines of Routing Protocols in the Limited-resources OppNets	82
3.5.6	Recommendations	83
3.6	Conclusion	84
<b>CHAPTER 4 MUTUAL INFORMATION-BASED WEIGHTING SCHEME</b>		<b>86</b>
4.1	Introduction	86
4.2	Entropy Concept	87
4.3	Mutual Information-based Weighting Scheme	88
4.3.1	Case Study	93
4.4	Performance Evaluation and Simulation Settings	97
4.5	Results and Discussion	99
4.5.1	Weights Estimation of Scenario 1	99
4.5.2	Impact of Optimal Attribute on Network Performance	101

4.5.3	Weights Estimation of Scenario 2	109
4.6	Conclusion	112
<b>CHAPTER 5 AN ACUMEN MESSAGE DROP SCHEME (AMD)</b>		113
5.1	Introduction	113
5.2	The Acumen Message Scheme	115
5.2.1	Demonstration of Theorem 5.1	121
5.3	Performance Evaluation and Simulation Settings	122
5.4	Results and Discussion	123
5.5	Conclusion	138
<b>CHAPTER 6 A DYNAMIC RESOURCE-AWARE ROUTING PROTOCOL</b>		139
6.1	Introduction	139
6.2	Design Details of the Resource-Aware Routing protocol (ReAR)	141
6.2.1	Buffer Management	142
6.2.2	Message Forwarding Strategy	142
6.2.3	ReAR Protocol Algorithm	147
6.3	Performance Evaluation and Simulation Settings	151
6.3.1	System Model	151
6.3.2	Simulation setup	152
6.3.3	Performance Evaluation Metrics	153
6.4	Experiments and Results	153

6.4.1	Performance Metrics Against Simulation Time	154
6.4.2	Performance Metrics Against Traffic Load	165
6.4.3	Performance Metrics Against Number of Nodes	169
6.4.4	Performance Metrics Against Message's Lifetime	173
6.5	Conclusion	178
<b>CHAPTER 7 CONCLUSION</b>		179
7.1	Thesis Contributions	179
7.2	Recommendations	181
7.3	Future Work	182
<b>REFERENCES</b>		184
<b>APPENDIX</b>		203

## LIST OF TABLES

	<b>Page</b>
Table 1.1 Ad hoc Networks comparison	3
Table 2.1 Message Dropping Schemes	40
Table 2.2 Workload's fairness schemes	47
Table 3.1 Simulation settings	66
Table 3.2 Summary of results	68
Table 4.1 Data obtained by node $n$ from its neighbors	94
Table 4.2 Joint and conditioned probabilities	95
Table 4.3 Simulation settings of Scenario 1	98
Table 4.4 Simulation settings of Scenario 2	98
Table 4.5 The number of the relayed messages of Scenario 1	101
Table 4.6 Message Types Statistics	104
Table 4.7 Comparison of percentage improvement of different routing protocols when using the optimal value of attributes	109
Table 4.8 The number of the relayed messages of Scenario 2	110
Table 5.1 The used symbols of the proposed scheme	115
Table 5.2 Simulation settings	123
Table 6.1 Simulation settings	152
Table 6.2 Delivery ratio vs Simulation time	155
Table 6.3 Delivery ratio variance according to simulation time	155
Table 6.4 Overhead ratio vs Simulation time	157
Table 6.5 Efficiency vs Simulation time	159
Table 6.6 Latency vs Simulation time	160
Table 6.7 Latency variance according to simulation time	160
Table 6.8 Average buffer occupancy vs Simulation time	162

Table 6.9	Average buffer occupancy variance	162
Table 6.10	Number of dead nodes vs Simulation time	164
Table 6.11	Delivery ratio vs Traffic load	166
Table 6.12	Delivery ratio variance according to traffic load	166
Table 6.13	Overhead ratio vs Traffic load	168
Table 6.14	Delivery ratio vs Number of nodes	170
Table 6.15	Delivery ratio variance according to number of nodes	170
Table 6.16	Overhead ratio vs number of nodes	172
Table 6.17	Delivery ratio vs Message's lifetime	174
Table 6.18	Delivery ratio variance according to message's lifetime	174
Table 6.19	Overhead ratio vs message's lifetime	176

## LIST OF FIGURES

	<b>Page</b>
Figure 1.1 Ad hoc Network subtypes	2
Figure 1.2 Research methodology framework	10
Figure 2.1 Categorization of Routing Protocols in OppNets	16
Figure 3.1 System Model	64
Figure 3.2 ONE Simulator Graphical User Interface	64
Figure 3.3 ONE Simulator Environment	65
Figure 3.4 Delivery ratio against time and buffer size	70
Figure 3.5 Average buffer occupancy comparison	72
Figure 3.6 Delivery ratio comparison for different traffic loads	75
Figure 3.7 Overhead ratio comparison for different traffic loads	76
Figure 3.8 Delivery ratio comparison for different number of nodes	79
Figure 3.9 Average latency comparison for different number of nodes	80
Figure 3.10 Overhead ratio comparison for different number of nodes	81
Figure 4.1 Case study scenario	94
Figure 4.2 Weights of node's attributes at $W = 100$	100
Figure 4.3 Weights of node's attributes at $W = 200$	100
Figure 4.4 Delivery ratio comparison	102
Figure 4.5 Comparison of performance metrics	103
Figure 4.6 Weights estimation of mobility speed and buffer for different routing protocols for Scenario 1	108
Figure 4.7 Weights estimation of mobility speed and buffer for different routing protocols for Scenario 2	111
Figure 4.8 Average buffer occupancy comparison between Scenario 1 and Senario 2	112



Figure 5.1	The AMD scheme flowchart	120
Figure 5.2	Theorem 5.1 Demonstration	121
Figure 5.3	Theorem 5.1 numerical example	121
Figure 5.4	Delivery ratio comparison between PRoPHET and PRoPHET+AMD	124
Figure 5.5	Overhead ratio comparison between PRoPHET and PRoPHET+AMD	125
Figure 5.6	Efficiency comparison between PRoPHET and PRoPHET+AMD	125
Figure 5.7	Average hop count comparison between PRoPHET and PRoPHET+AMD	126
Figure 5.8	Delivery ratio comparison between Epidemic and Epidemic+AMD	127
Figure 5.9	Overhead ratio comparison between Epidemic and Epidemic+AMD	128
Figure 5.10	Efficiency comparison between Epidemic and Epidemic+AMD	128
Figure 5.11	Average hop count comparison between Epidemic and Epidemic+AMD	129
Figure 5.12	Average latency comparison for PRoPHET	130
Figure 5.13	Average latency comparison for Epidemic	130
Figure 5.14	Delivery ratio of PRoPHET and PRoPHET+AMD against buffer size	132
Figure 5.15	Overhead ratio of PRoPHET and PRoPHET+AMD against buffer size	133
Figure 5.16	Efficiency of PRoPHET and PRoPHET+AMD against buffer size	133
Figure 5.17	Average hop count of PRoPHET and PRoPHET+AMD against buffer size	134
Figure 5.18	Delivery ratio of Epidemic and Epidemic+AMD against buffer size	136
Figure 5.19	Overhead ratio of Epidemic and Epidemic+AMD against buffer size	136
Figure 5.20	Efficiency of Epidemic and Epidemic+AMD against buffer size	137
Figure 5.21	Average hop count of Epidemic and Epidemic+AMD against buffer size	137
Figure 6.1	The ReAR Forwarding decision Flow Chart	150

Figure 6.2	Comparison of routing protocols in terms of delivery ratio versus simulating time	156
Figure 6.3	Comparison of routing protocols in terms of overhead ratio versus simulating time.	158
Figure 6.4	Comparison of routing protocols in terms of efficiency versus simulating time.	159
Figure 6.5	Comparison of routing protocols in terms of average latency versus simulating time.	161
Figure 6.6	Comparison of routing protocols in terms of average buffer occupancy versus simulating time.	163
Figure 6.7	Comparison of routing protocols in terms of number of the dead nodes versus simulating time.	164
Figure 6.8	Comparison of routing protocols in terms of delivery ratio versus traffic load.	167
Figure 6.9	Comparison of routing protocols in terms of overhead ratio versus traffic load.	169
Figure 6.10	Comparison of routing protocols in terms of delivery ratio versus number of nodes.	171
Figure 6.11	Comparison of routing protocols in terms of overhead ratio versus number of nodes.	172
Figure 6.12	Comparison of routing protocols in terms of delivery ratio versus message's lifetime.	175
Figure 6.13	Comparison of routing protocols in terms of overhead ratio versus message's lifetime.	177

## 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

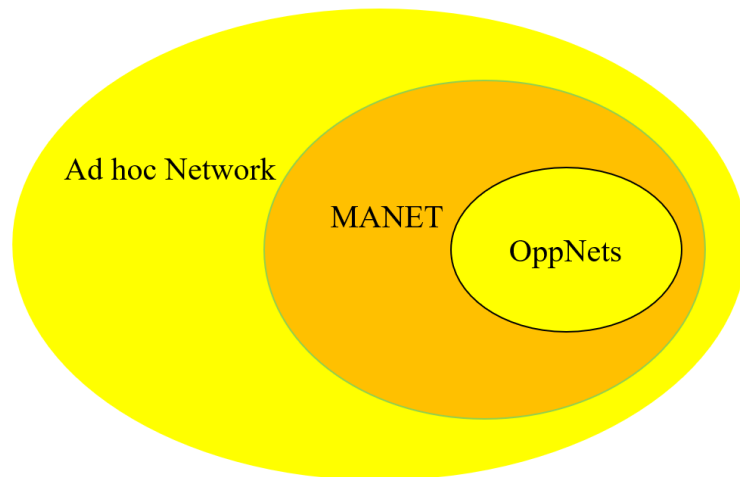
## INTRODUCTION

### 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 Networks comparison

<b>Topic</b>	<b>Ad hoc Network</b>	<b>MANET</b>	<b>OppNet</b>
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