HIGH PERFORMANCE OPPORTUNISTIC ROUTING ALGORITHMS FOR POWER CONSTRAINED NODES WITH MESSAGE DELIVERY DEADLINE IN SPARSE NETWORK ENVIRONMENT

BY

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**A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF
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A Thesis Presented

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Abstract

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Opportunistic Network (OppNet) is a challenge network exploiting contact opportunities and node mobility to route the messages even a complete path from source to destination never exists. The example applications for such extreme networks are in the environments of battlefield network, wildlife monitoring or disaster response where movements are random with highly intermittent connections. This opportunistic routing relies on store-carry-forward paradigm which a data holing node such as source or neighbor node can carry the data and finds an opportunity to forward data by discovering its nearest neighbor node and uses it to forward messages toward the destination node. However, the performance of opportunistic routing algorithm largely depends on several factors such as limited knowledge of contact behavior or the density of mobile nodes. The problems arise in sparse network environment with limited delivery deadline results in low delivery ratio. Several researches attempted to address the sparseness problem by a special node such as data mules or message ferries. Nevertheless, proposed solutions impractical under some application environments especially with limited power constraints.

In order to improve the delivery ratio in such sparse network while maintaining the energy consumption, we proposed a novel Dynamic Rendezvous based Routing Algorithm on Sparse Opportunistic Network Environment where the rendezvous concept is implemented to address the problem of routing in sparse environment. In addition, we proposed DORSI: Data-wise Opportunistic Routing with Spatial Information where the significant of data content is accounted for the forwarding algorithm of the nodes. This DORSI can improve the delivery ratio for the important messages thus increase the delivery ratio if the weight of each class is accounted. In those algorithms, our common objective is to increase the network performance such as delivery ratio or composite matrices under given circumstances. We also present intensive simulation results regarding the performance comparison of the proposed algorithms with the tradition OppNet routing algorithms.

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List of Acronyms

DTNs	Delay/Disruptive Tolerant Networks
ICNs	Intermittently Connected Networks
IETF	Internet Engineering Task Force
MANET	Mobile Ad-Hoc Network
OppNets	Opportunistic Networks
OR	Opportunistic Routing

Chapter 1

Introduction

Opportunistic networks are one of the most interesting evolutions of multi-hop wireless network especially in Mobile Ad-hoc Networks (MANETs). In this network scheme, mobile nodes are enabled to communicate with each other even without connected route and prior network topology knowledge [15]. Several concepts behind opportunistic network come from the studies on DTN that led to the specification of its architecture. Source and destination nodes might never be fully connected at the same time in opportunistic network, so the forwarding algorithms in such networks follow a store-carry-forward paradigm. Typical algorithms differ based on their decisions as how to forwards the data, at what time the data is forwarded and to whom the data is sent [9]. However, the decision algorithms of what the data to sent has never fully implemented. Messages are en route between the sender and the destination on the routes that dynamically built, and any possible node can opportunistically be used as next hop, provided it is likely to bring the message closer to the final destination.

1.1 Problem Statement

In this store-carry-forward paradigm, the network suffers the decreasing of performance in the insufficient collaborating nodes environment [2, 22] Since the node holding the data requires next-hop neighbor nodes to forward the data to, the sparse network environment is normally unable to satisfy opportunistic routing. As a result, there is a need for an innovative protocol design to address this deficiency of OppNets.

In addition, none of the traditional routings in OppNets concern about the data content of the messages. If the significance of data is considered as the performance matrix, the network effectiveness of OppNets also drops in sparse network. In several environments, it is essential that the important messages from source to the destination nodes should be specially treated in order to guarantee deliverable. Therefore, it is crucial to implement a new protocol to increase the delivery ratio of important data for critical data network such as military tactical network or disaster relief network.

In this thesis, we study the algorithms to address the perform deficiency in sparse opportunistic network environment. In each approach, we use different routing techniques and work on different OppNets scenarios, however our common aim is to increase the performance in sparse network.

1.2 Objective and Scope

Objective of this research is to increase the network performance in OppNets especially the delivery ratio and other key composite matrices performance index in different schemes.

The scope of this research is based on the assumption of mobile nodes and environment in different network schemes that elaborate in each proposed approaches.

1.3 Proposed Approaches

From aforementioned problem statements, this thesis proposed the following approaches:

- We proposed a protocol to classify the messages based on the information sensitivity concept along with nodes prioritization technique corresponding to the their delivery probability computed by spatial data. This protocol classifies the messages according to their significant level, security level and deadline relative to the sensitivity level of data. In addition we adapts the geographical routing technique to select the best candidate node to forward the messages to the destination. Simulation experiments clearly illustrate that two key performance indexes: (1) effective delivery ratio and (2) effective replication ratio remarkably improve over the traditional Epidemic routing.

- In order to address the problem in sparse network, we proposed the use of Rendezvous based concept in order to maintain the messages in one place as long as the messages are delivered. By injected a special node N_{rv} into the network, the gap between time and space domain of mobile nodes are bridge. Messages can be transferred from source node to destination node even if they are not in the same location at the same time with the help of rendezvous node. The results clearly show that the delivery ratio of Rendezvous based protocol significant improve over Epidemic protocol especially in the sparse environment.

1.4 Our Contributions

This thesis contains five chapters. Chapter 1 gives an introduction of the research. In addition, the problem statement, objective and scope, and proposed approaches are included in this chapter. In Chapter 2 the background and related works on opportunistic networks are provided. Chapter 3 describes our message prioritization technique to differentiate the routing based on the significant level of messages. The details of proposed method, simulation model, and performance evaluation are included in this chapter. Chapter 4 presents our approach of using the rendezvous place concept to overcome the limitation of insufficient collaborating nodes in sparse network environment. The details of proposed method, simulation model, and performance evaluation are included in this chapter. Chapter 5 includes the discussion, the conclusion and the recommendations for future studies.

Chapter 2

Background and Related Work

Recently, wireless networking are witnessing several deployments in various extreme environments where they usually suffer from different levels of link disruptions depending on the severity of the operations. Commonly, these networks are known as Intermittently Connected Networks (ICNs). An ICNs, also known as a Challenged Network, is an infrastructure-less wireless network that supports the proper functionality of the wireless applications operating in stressful environments, where excessive delays and no existence of end-to-end path(s) between any arbitrary source-destination pair, result from highly repetitive link disruptions [10]. In order to handle ICNs, the Internet Engineering Task Force (IETF) [3] proposed an architecture called Delay-/Disruption-Tolerant Networks (DTNs). DTNs can basically be categorized into 3 types: scheduled networks, predictable networks and opportunistic networks. In this thesis, we focus on the research on the most extreme case of DTNs which is the opportunistic networks.

This chapter gives the background knowledge of this thesis. The background of Delay Tolerant Networks is presented in Section 2.1. Additionally, an explanation of Opportunistic Networks is presented in Section 2.2.

2.1 Delay Tolerant Networks

DTNs is an overlay architecture with an aim to operate over the protocol stacks of the ICNs and enable gateway functionality between them through the use of storage capacity, a variety of protocol techniques, replication and parallel forwarding, forward error correction and many other techniques for overcoming the impairments of communication [10]. DTNs enable the transferring of data in extremely challenging environments where networks are assumed to experience frequent, long-duration partitioning and may have no end-to-end connectivity between source and destination [14]. Therefore, the timer and acknowledgement mechanisms of the traditional TCP/IP protocol definitely fail in such circumstances [4]. In addition, the routing algorithms designed for Mobile Ad hoc NETworks (MANETs) can not perform effectively under aforementioned constraints as well, since the availability of contemporaneous end-to-end connectivity is essential for conventional routing algorithms [2].

Basically the types of DTNs can be classified in 3 categories: scheduled networks, predictable networks and opportunistic networks as seen in Figure 2.1. In DTNs, predictable and scheduled networks are the common aim in designing the routing protocols in the highly disruptive environments such as Interplanetary Internet (IPN) [1] where the contact time is not completely random but in periodic interval. In the thesis, we study in the most extreme case of DTNs which is the opportunistic networks where the contact time is undetermined along with stochastic movements.

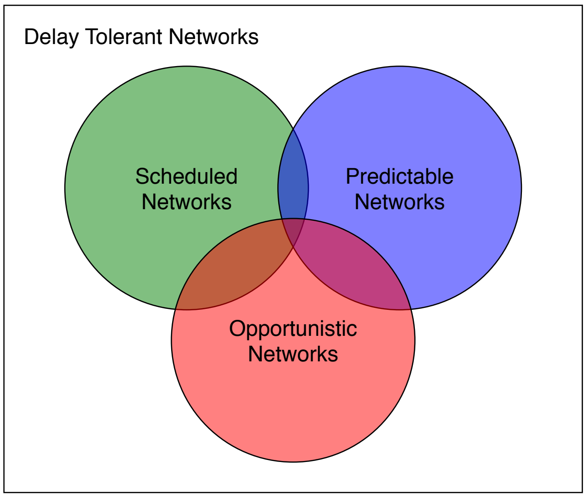

Figure 2.1: Types of DTN

2.2 Opportunistic Networks

In fact, Opportunistic networks focus on mobile ad-hoc DTNs, where tolerant delayed routes between the source and destination are built dynamically. However, OppNets is different from MANETs that it does not assume the existing end-to-end connectivity. Therefore, instead of depending on end-to-end MANETs routing protocols, the messages are delivered through one hop data transmission among opportunistic node encounters with intermediate node storage and mobility, called *Store-Carry-Forward paradigm* [7].

2.2.1 Opportunistic Routing

In this opportunistic routing, the nodes can exchange data in a spontaneous manner whenever they come in close. If there is no direct connection from source to destination, data holding nodes will discover their nearest neighbor nodes to forward messages toward the destination node. Thus, this opportunistic route is determined at each hop when messages traverse through different hops. In this routing scheme, mobile nodes are normally equipped with local knowledge of the best nodes around them to determine the best path to transmit the messages with this knowledge. In the case of such nodes absence, the node currently holding the message simply stores the messages and wait for an opportunity to forward the packets. This infrastructure-less wireless network environment requires common 2 factors to facilitate the opportunistic routing [16] :

- Destination path finding: Intermediate nodes are used to form paths dynamically since there is no fixed path from source to destination nodes.
- Next hop forwarder selection: Data holding nodes need to find a helper node that can forward the messages to the destination as soon as possible.

2.2.2 Classification of Opportunistic Routing

Several researches proposed opportunistic routing algorithms based on store-carry-forward mechanism. The existing common OR algorithms can be classified based on their data forwarding behavior as shown in Figure 2.2

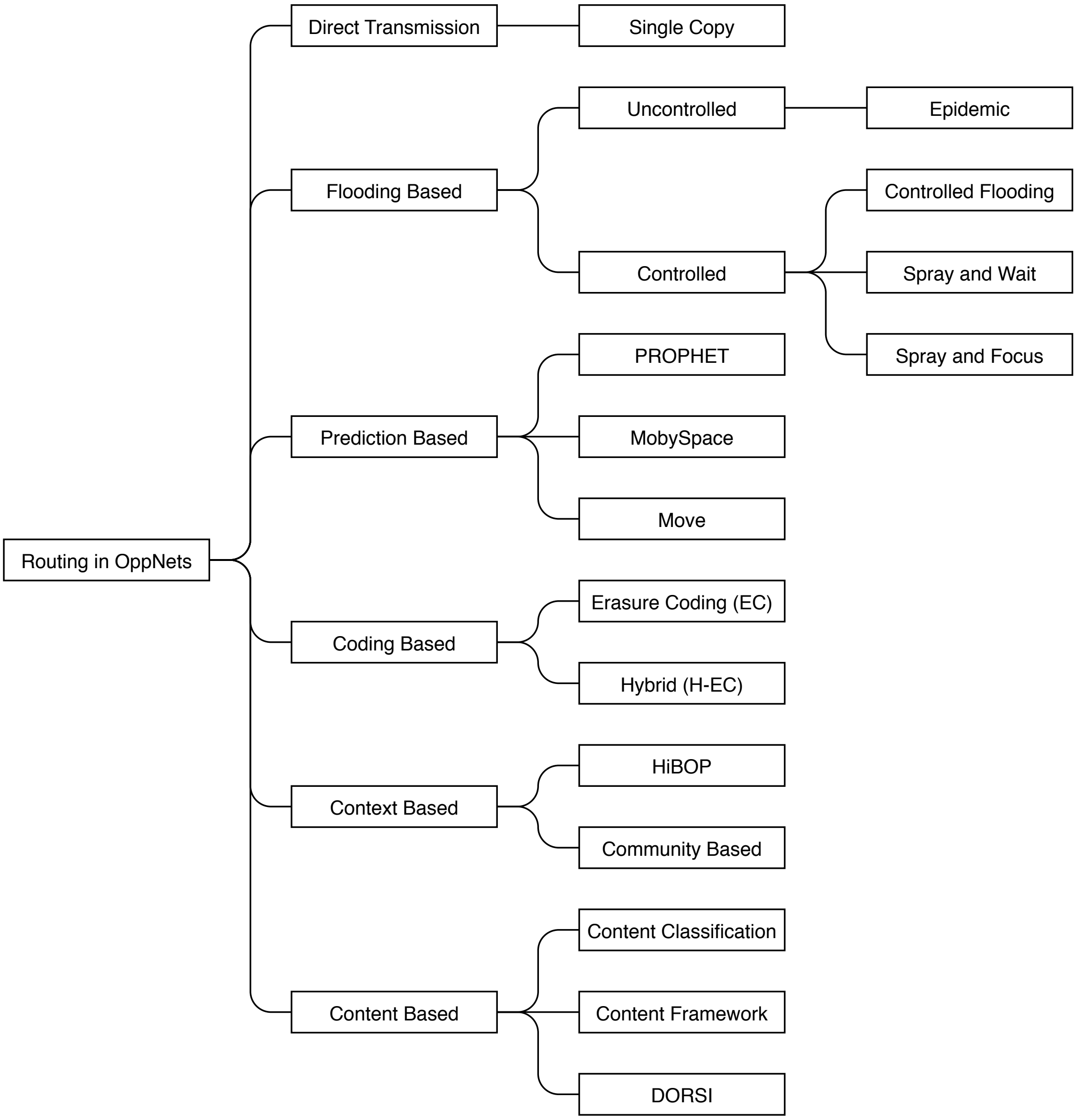

Figure 2.2: Classification of Opportunistic Routing

Direct Transmission

The source node in direct transmission routing generates the messages and stores it until it directly meet the destination node. Spyropoulos et al [17] proposed a single-copy routing in intermittently connected mobile networks using hop-by-hop routing model. In this single-copy routing, only one copy per message can be transmitted from source node to destination node. This routing algorithm significantly reduces the resource requirements of flooding-based algorithms [19]. However, this scheme produces significantly long delays since the delivery delay is unbounded for this direct transmission routing [5].

Flooding Based

The flooding based routing (multiple copies) approach may generate several copies of the same message to be routed independently to increase the efficiency and robustness [8]. This flooding based routing can be divided into 2 types:

- Uncontrolled: In this approach, each node broadcasts the received packet to all of the neighbors without restricted to any limited. Epidemic routing [24] is proposed utilizing epidemic algorithm to send each message to all nodes in the network. Even tough the Epidemic routing can guarantees all nodes will eventually receive all messages, it incurs significant demand on both bandwidth and buffer.

- Controlled: Undoubtedly, uncontrolled flooding consume network resources which can seriously degrade the performance if the resources are scarce [23]. Therefore, there is a need to control the flooding by limit the number of packets to be replicated to reduce the network contention. Several researches proposed the algorithms to control the flooding such as controlled flooding, spray and wait and spray and focus.

  - Controlled Flooding: Khaled et al [6] proposed a set of Controlled Flooding schemes to address the excessive network resources from flooding. Four schemes have been examined in this study: Basic probabilistic (BP), Time-to-live (TTL), Kill time and Passive one. The extensive experiments show that proposed schemes can save substantial network resources while incurring a negligible increase in the message delivery delay. As a result, the ability to provide reliable data delivery while resolving excess traffic overhead, controlled flooding protocol can greatly reduce the network overhead.
  - Spray and Wait: Spyropoulos et al [21] introduced a Spray and Wait routing scheme consisting of two phases: first, *sprays* a number of copies into the network, and then *waits* till one of these nodes meets the destination to bound the overhead of delivering message. In the *spray* phase, a number of L messages are created in which L indicates the maximum allowable copies of the messages in the network to L distinct relays. In the *wait* phase, when the destination nodes are not encountered by a node with a copy of the message in the spraying phase, each node with a copy of message will perform the direct transmission.
  - Spray and Focus: Another controlled flooding approach by Spyropoulos et al [18] was designed to eliminate some deficiencies of Spray and Wait routing algorithm in some network schemes. Similar to Spray and Wait protocol, this algorithm consists of two phases: Spray phase and Focus phase. The *spray* phase is operated the same way as in Spray and Wait which L message copies are spread

to all L different nodes for every message creating at source node. The different from the *wait* phase is that in the *focus* phase, each copy in a single node is attempted to be routed to a closed node using a single-copy utility based scheme [20].

Prediction Based

The prediction based routing algorithms are proposed to overcome the overhead carried by flooding based routing schemes. In Prediction based routing, nodes estimate the probability of forwarding messages to the destination based on the history of observations instead of blindly forward the messages to all/some neighbors. With the information, nodes can decide whether they should store or wait for the better chance to forward the messages as well as deciding which nodes to forward the messages to.

- PROPHET: Lindgren et al [13] proposed PROPHET (Probabilistic Routing Protocol using History of Encounters and Transitivity) as a probabilistic routing protocol. This protocol estimates a probabilistic metric called delivery predictability to indicate the probability of successful delivery of a message from local node to the destination. Two nodes can exchange both a summary vector containing delivery probability vector when they meet. The delivery probability metric is derived from previous encounters and subject to an aging factor, meaning if two nodes are often encountered, they have high delivery predictability to each other. On the other hand, if a pair of nodes rarely encounter, they are intuitively not a good candidate to forward messages to each other. The results from the simulations show that PROPHET is able to deliver more messages than Epidemic Routing with a lower communication overhead.

- MobySpace: Leguay et al [11, 12] proposed a MobySpace: Mobility Pattern Space Routing for DTNs which using a high-dimensional Euclidean space constructed upon nodes' mobility patterns. In this MobySpace protocol, the routing decisions are taken using nodes mobility patterns (a virtual Euclidean space) with the notion that a node is a good candidate for taking custody of a bundle if it has a mobility pattern similar to that of the bundles destination.

  These decisions rely on the notion that a node is a good candidate for taking custody of a bundle if it has a mobility pattern similar to that of the bundles destination. Routing is done by forwarding bundles toward nodes that have mobility pat- terns that are more and more similar to the mobility pattern of the destination. Since in the MobySpace, the mobility pattern of a node provides its coordinates, its MobyPoint, routing is done by forwarding bundles toward nodes that have their MobyPoint closer and closer to the MobyPoint of the MobySpace outperforms the other single copy schemes we evaluated in delivery ratio while keeping a low number of transmissions

- Move:

Coding Based

- Erasure Coding (EC):

- Hybrid (H-EC):

Context Based

- HiBOP:
- Community Based:

Content Based

- Content Classification:
- Content Framework:
- DORSI:

Chapter 3

Data-wise Opportunistic Routing with Spatial Information

3.1 Data-wise Routing

3.2 Simulation Model and Results

3.3 Summary of Contributions

Chapter 4

Dynamic Rendezvous based Routing Algorithm on Sparse Opportunistic Network Environment

4.1 Rendezvous Place

4.2 Simulation Model and Results

4.3 Summary of Contributions

Chapter 5

Conclusion and Future Work

5.1 Discussion

5.2 Conclusion

5.3 Future Work

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Appendix A

List of Publications

International Journals

- Jiradett Kerdsri, Komwut Wipusitwarkun, ”Dynamic Rendezvous based Routing Algorithm on Sparse Opportunistic Network Environment”, *International Journal of Distributed Sensor Networks*, Vol. x, No. xx, pp. xx-xx, 2014 (in ISI, impact factor=0.727) (To appear)
- Jiradett Kerdsri, Komwut Wipusitwarkun, ”DORSI: Data-wise Opportunistic Routing with Spatial Information”, *JCIT: Journal of Convergence Information Technology*, Vol. 8, No. 13, pp. 91-103, 2013 (in SCOPUS, impact factor=??)

International Conferences

- Jiradett Kerdsri, Komwut Wipusitwarkun, ”Rendezvous Based Routing in Opportunistic Networks” *2014 International Telecommunications Symposium*, pp.xx-xx, 17-20 Aug. 2014 (To appear)
- Jiradett Kerdsri, Komwut Wipusitwarkun, ”Data-wise Routing in Virtualization Environment (DRIVE) with multiple level of security for tactical network” *2012 IEEE/SICE International Symposium on System Integration (SII)*, pp.933-938, 16-18 Dec. 2012
- Jiradett Kerdsri, Komwut Wipusitwarkun, ”Network virtualization for military application: Review and initial development of conceptual design”, *14th International Conference on Advanced Communication Technology (ICACT)*, pp.61-66, 19-22 Feb. 2012