EFFICIENT HYBRID FLOODING SCHEME FOR *AD HOC* ON-DEMAND DISTANCE VECTOR ROUTING PROTOCOL IN MANET

By

BASSAM M.S. WAHEED

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirement for the Degree of Doctor of Philosophy

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DEDICATION

To my dearest family and friends,
...for their unconditional and everlasting love and support

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Doctor of Philosophy

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A mobile ad-hoc network (MANET) consists of multiple wireless mobile nodes that can freely and dynamically organize themselves into arbitrary and temporary network topologies, enabling users and devices to seamlessly internetwork in areas without aid of any established infrastructure or centralized administration. Efficacious routing among set of mobile nodes is one of the most important activities in MANETs. Existing on-demand routing protocols perform route discovery process by flooding the network with a query message (RREQs) requesting a route to the destination. As flooding involves querying all reachable network nodes, frequent flooding can rapidly deplete the energy reserved at each node, in addition to consuming significant portion of the available network bandwidth. Further, as the number of communicating nodes increases, more congestion and collisions can be expected leading to what is known a broadcast storm problem.

Many approaches have been developed to resolve the broadcast storm problem; some of them were based on developing a virtual backbone that takes the responsibility of forwarding control packets with the wireless ad-hoc network, where only nodes that recognize themselves as gateways will forward the RREQ packets. An example of such approach is the Connected Dominating Set (CDS). The dominating-set-based routing is a promising approach, where the searching space for a route is reduced to nodes in the set. Another prominent approach is the Dominant Pruning (DP) which is a distributed dominating set algorithm developed to alleviate the impact of flooding in mobile ad-hoc networks. Both dominant pruning and connected dominating set require 2-hop neighbor information. This information can be collected with the aid of neighbor protocol.

In this thesis an enhanced neighbor protocol (ENP) has been developed to collect and maintain 2-hop neighbor information at each node. Neighbor information is essential for guiding the hosts in determining their status if they are gateway hosts or not. The protocol is a distance-based one, which depends on the change in the nodes geographic location to make them exchange their neighbor information. Thresholds selection is based on three performance metrics namely: maintenance overhead, number of times the links break and data delivery ratio. These metrics often conflict against each other in trying to achieve the most optimum threshold distance. Therefore, a trade-off is needed to obtain fair threshold values between them.

The other optimization in this thesis is the handling of unidirectional links between nodes in MANET. In this context, the algorithm responsible for determining whether or not the a node is gateway is adapted to check for such links, this is done by looking for mutual existence of nodes in the neighbor tables of their respective neighbors. Finally, focus is given to the routing cost reduction through the incorporation of Dominant Pruning (DP) as assisting factor that works together with the constructed Connected Dominating Set (CDS). Thus, a hybrid flooding scheme is obtained which combines sender and -receiver-based schemes. The benefit is to reduce the length of paths between the source and destination nodes by providing more options for the flooded packets while they travel in the network.

To show the benefit of the ENP protocol, it has been utilized as the neighbor protocol with the CDS and both are integrated into AODV routing protocol. ENP performance is compared against the original neighbor protocol of the CDS, DP and the periodic approach followed by the AODV. To evaluate CDS performance for unidirectional links, both original and enhanced marking process, are incorporated separately into AODV. Simulation results show that CDS generated by the enhanced marking process exhibits better data delivery rate and lower link broke count than CDS generated by the original marking process. Finally, in terms of routing cost reduction, the hybrid flooding scheme is incorporated into AODV to evaluate its benefits. The scheme showed better data delivery and lower average-end-to-end delay with good flooding efficiency. All the simulations mentioned above have been carried out with QualNet version 5.02 from Scalable Networks Technologies.

Abstrak tesis yang dikemukakan kepadaSenat Universiti Putra Malaysia
Sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

SKIM BANJIRAN HYBRID CEKAP UNTUK *AD HOC* ATAS PERMINTAAN JARAK VECTOR LALUAN PROTOCOL DALAM MANET

Oleh

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Walaupun rangkaian berasaskan infrastruktur menyediakan cara yang baik untuk peranti mudah alih untuk mendapatkan perkhidmatan rangkaian tetapi ia mengambil masa untuk memasang komponen rangkaian, dan kos yang berkaitan boleh agak tinggi, dan dalam beberapa keadaan infrastruktur tidak ada atau tidak boleh dipasang kerana masalah geografi atau ekonomi. Sebagai alternatif, mudah alih rangkaian ad-hoc (MANETs) boleh digunakan untuk menyediakan sambungan yang diperlukan dan perkhidmatan rangkaian.

MANET A terdiri daripada pelbagai nod tanpa wayar mudah alih yang bebas dan dinamik boleh mengatur diri mereka ke dalam rangkaian sewenang-wenangnya dan sementara topologi, membolehkan pengguna dan peranti untuk lancar internetwork di kawasan tanpa bantuan mana-mana infrastruktur yang ditubuhkan atau pentadbiran berpusat. Routing berkesan di kalangan set nod mudah alih adalah salah satu aktiviti yang paling penting dalam telefon bimbit rangkaian ad-hoc. Atas permintaan protokol routing yang sedia ada melaksanakan proses penemuan laluan oleh banjir rangkaian dengan mesej query (RREQs) meminta laluan ke destinasi. Ini RREQs yang dibiakkan menggunakan sama ada siaran terhad iaitu banjir buta atau carian cincin berkembang. Sebagai banjir melibatkan menyoal semua nod rangkaian dicapai, banjir yang kerap dengan cepat boleh mengurangkan tenaga yang dikhaskan di setiap nod, di samping memakan sebahagian besar jalur lebar rangkaian yang sedia ada. Di samping itu, kerana bilangan berkomunikasi nod meningkat, kesesakan lebih, perdebatan, dan perlanggaran yang boleh dijangkakan, dan ini membawa kepada apa yang dikenali masalah ribut siaran terutama dalam rangkaian tanpa wayar menggunakan perdebatan berasaskan akses saluran. Itulah sebabnya protokol itu mungkin tidak sesuai untuk menangani secara besar-besaran alih rangkaian ad-hoc. Banyak pendekatan telah dibangunkan untuk menyelesaikan masalah siaran ribut; sebahagian daripada mereka adalah berdasarkan kepada pembangunan tulang belakang maya yang mengambil tanggungjawab penghantaran paket kawalan dengan rangkaian ad-hoc wayarles, hanya nod yang mengenali diri mereka sebagai pintu masuk akan mengemukakan paket RREQ. Satu contoh bagi pendekatan itu Set Bersambung mendominasi (CDS). Penghalaan-set berasaskan mendominasi adalah satu pendekatan yang cerah, di mana

ruang yang mencari jalan yang dikurangkan kepada nod dalam set. Walau bagaimanapun kecekapan terutamanya bergantung kepada overhed dalam membina dan mengekalkan set mendominasi dan saiz juga. Satu lagi pendekatan penting adalah pemangkasan yang dominan (DP) yang merupakan satu set diedarkan mendominasi algoritma maju untuk mengurangkan kesan banjir di rangkaian ad-hoc bimbit. Kedua-dua mencantas dominan dan yang berkaitan set mendominasi memerlukan maklumat jiran 2-hop. Maklumat ini boleh dikumpulkan dengan bantuan protokol jiran.

Dalam tesis ini protokol jiran dipertingkatkan (ENP) telah dibangunkan untuk mengumpul dan menyimpan up-to-tarikh maklumat jiran 2-hop pada setiap nod. Maklumat ini adalah penting untuk prestasi dipercayai dalam kebanyakan skim banjir, yang bergantung kepada maklumat topologi terhad dikumpul oleh setiap nod dalam menentukan negara jiran mesti mengemukakan paket kawalan diterima. Maklumat jiran adalah penting dalam membimbing tuan rumah dalam menentukan status mereka jika mereka adalah tuan rumah pintu masuk atau tidak. Protokol adalah satu jarak berasaskan, yang bergantung kepada perubahan dalam lokasi nod geografi untuk membuat mereka bertukar-tukar maklumat sesama mereka.

Pengoptimuman lain dalam karya ini adalah pengendalian link satu arah antara nod di Manet. Dalam konteks ini, algoritma yang bertanggungjawab untuk menentukan sama ada atau tidak nod adalah gerbang disesuaikan untuk memeriksa pautan itu, ini dilakukan dengan melihat kewujudan bersama nod dalam jadual jiran jiran masing-masing. Akhirnya, tumpuan diberikan kepada pengurangan kos laluan melalui penubuhan Pemangkasan Dominan (DP) sebagai faktor yang bekerja bersama-sama dengan dibina Bersambung Set mendominasi (CDS) membantu. Oleh itu, skim banjir hibrid diperolehi yang menggabungkan penghantar skim dan penerima berasaskan. Manfaat ini adalah untuk mengurangkan panjang laluan antara sumber dan nod destinasi dengan menyediakan lebih banyak pilihan untuk paket dibanjiri manakala mereka perjalanan dalam rangkaian.

Untuk menunjukkan manfaat protokol ENP itu, ia telah digunakan sebagai protokol jiran dengan CDS dan kedua-duanya bersepadu ke AODV laluan protokol. Prestasi ENP dibandingkan dengan protokol asal jiran CDS, DP dan pendekatan berkala diikuti oleh AODV. Untuk menilai prestasi CDS untuk link satu arah, kedua-dua asal dan proses menandakan dipertingkatkan, dimasukkan berasingan ke AODV. Keputusan simulasi menunjukkan bahawa CDS dihasilkan oleh proses yang dipertingkatkan menandakan mempamerkan data yang lebih baik kadar penghantaran dan link patah yang lebih rendah daripada kiraan CDS dihasilkan oleh proses asal menandakan. Akhir sekali, dari segi laluan pengurangan kos, skim banjir hibrid dimasukkan ke AODV untuk menilai faedahnya. Skim ini menunjukkan lebih baik penghantaran data dan kelewatan purata akhir-ke-akhir yang lebih rendah dengan kecekapan banjir yang baik. Semua simulasi yang disebutkan di atas telah dijalankan dengan QualNet versi 5.02 dari Networks berskala Technologies.

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ABPL	Average Backbone Path Length
AHBP	Ad hoc Broadcast Protocol
ARPL	Average Routing Path Length
AODV	Ad hoc On-demand Distance Vector
AOMDV	Ad hoc On-demand Multipath Distance Vector
BN	Backbone Node
BSC	Base-Station Controller
CAMRP	Caching And Multipath Routing Protocol
CDMA	Code Division Multiple Access
CDS	Connected Dominating Set
CDSMIS	CDS with Maximal Independent Set
CH	Clusterhead
CHS	Clusterhead Stability
DDR	Dynamic Distributed Routing
DG	Disk Graph
DP	Dominant Pruning
DRM	Dynamic Route Maintenance
DSDV	Destination-Sequenced Distance Vector
DSR	Dynamic Source Routing
EDP	Enhanced Dominant Pruning
ENP	Enhanced Neighbor Protocol
FN	Forwarding Node
GPS	Global Positioning System
GPSR	Greedy perimeter stateless routing
GSC	Greedy Set Cover
HDSR	Hierarchical Dynamic Source Routing

IARP	Intrazone Routing Protocol
IERP	Interzone Routing Protocol
LAR	Location-aided routing
LANMAR	Landmark Routing Protocol
LDR	Labeled Distance Routing
LSR	Labeled Successor Routing
MANET	Mobile Ad-hoc Network
MCDM	Multi Criteria Decision Making
MCFT	Minimal Cost Flooding Tree
MDS	Minimal Dominating Set
MEDSR	Minimum Energy Dynamic Source Routing
MSC	Mobile Switching Center
MPR	Multipoint Relay
MN	Mobile Node
NES	Neighbor Elimination Scheme
NPDU	Network Protocol Data Unit
NXP	Neighbor Exchange Protocol
OLSR	Optimized Link State Routing
PDP	Partial Dominant Pruning
PSO	Particle Swarm Optimization
RREQ	Route Request
RREP	Route Reply
SAW	Simple Additive Weighting
SoC	System on Chip
SCDAS	Strongly Connected Dominating and Absorbent Set
SCDS	Strongly Connected Dominating Set
SP	Self Pruning
TDP	Total Dominant Pruning

TC	Topology Control
TCDS	Two-hop Connected Dominating Set
THEP	Three-hop Horizon Enhanced Pruning
THP	Three-Hop horizon Pruning
TOPSIS	Technique for Ordered Preference by Similarity to Ideal Solution
TMPO	Temporarily Management and Priority Ordering
TTL	Time-to-Live
UADND	Unaided Directional Neighbor Discovery
UDG	Unit Disk Graph
VBB	Virtual Backbone
VRR	virtual radio range
WLAN	Wireless Local Area Network
WCDS	Weakly Connected Dominating Set
ZBMRP	Zone-Based Multicast Routing Protocol
ZRP	Zone Routing Protocol

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N	One-hop neighbor set	12
N_2	Two-hop away neighbors	12
T	Random back-off waiting time	21
R	Random uniform variable	21
K	contention window parameter of the MAC control protocol	21
P_{rec}	Received power	23
P_T	Transmission power	23
P_{TH}	Threshold power for successful reception	23
G	Graph representing ad-hoc network	26
V	Vertices set	26
E	Edges set	26
D	Directed graph	28
A	Set of directed edges	28
O	Algorithm complexity with big-O notation	29
n	Maximum network size in number of nodes	29
Δ	Node degree “number of neighbors”	29
α	Path length factor	30
S_w	Weakly induced subgraph	31
δ_u	Node degree	32
$d(s)$	Node coverage disk	32
P_t	Sending probability	60
P_r	Receiving probability	60
X_co	Node x coordinate	53
Y_co	Node y coordinate	53
dx	Change in node x coordinate between two readings	54
dy	Change in node y coordinate between two readings	54
Th_{max}	Maximum threshold distance	54
Th_{min}	Minimum threshold distance	54
N	Overhead in terms of broadcast hello packets	62
N_o	Proportionality constant	62

x	The selected TH_{min}	62
α	Attenuation factor	62
D	Decision matrix	71
w_j	Attribute weight	72
A^*	Ideal solution	74
A^-	Negative ideal solution	74
r_{ij}	Normalized value for an attribute	74
S_i^*	Separation from ideal solution	75
S^-_i	Separation from negative ideal solution	75
C_i^*	Relative closeness to ideal solution	75

CHAPTER 1

INTRODUCTION

1.1 Background

The abundance of mobile computing devices (smart phones, tablets, laptops, etc) ever since the past decade has transformed the computing world, and made a transform from personal computer age to the ubiquitous computing age. Over the same period several wireless technologies have emerged to meet the connectivity needs of these devices, and among these technologies the wireless local area network (WLAN) is arguably the most pervasive of them all. WLAN offers an easy and affordable solution to connect computing devices to the internet and among other local devices. The most likely scenario for the next generation networks will be a mix of network solutions consisting of a high-speed wired backbone and WLANs for local network access. However, WLAN is still considered an infrastructure based network where a central Access Point (AP) serves as the hub and a router will connect it to the internet, and in certain situations, infrastructure-based networks are not suitable because of the dynamic of situations as in search and rescue operations and military. In such situations network nodes themselves can act as AP and routers, which forwards packets hop-by-hop to the destinations whether they be another network node, or an internet gateway. This is called mobile ad hoc network or MANET (Hu and Kumar, 2006; Wu et al., 2005).

Because of its potential usefulness as part of future internet of things (IoT), this subject has been a subject of much research over the past decade or so. One of the main objectives of the research is to come out with a network that similar to that offered in cellular networks and even in conventional wired networks (Kayastha et al., 2011; Kiess and Mauve, 2007; Conti and Ricerche, 2003).

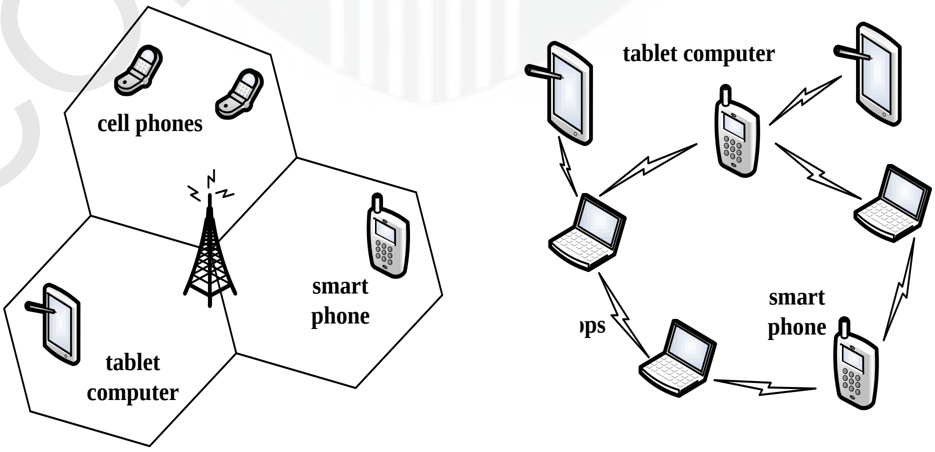


Figure 1.1: Cellular network versus ad-hoc network
(Wu et al., 2005)

1.2 Problem Statement

Route discovery phase within on-demand routing protocols is based on the broadcast of route request packets (RREQ), each node that receives the RREQ packet for the first time will re-broadcast it, this process continues until the RREQ packet reaches a node with valid route to the destination or the destination itself. This procedure is known as “blind flooding” and in many cases it can cause transmission of the same packet to many nodes or the entire network (Alotaibi and Mukherjee, 2012; Boukerche et al., 2011).

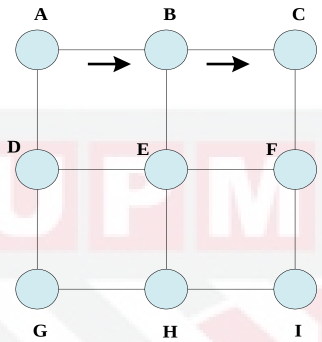
However, ad-hoc networks are characterized with scarce resources in terms of wireless bandwidth, battery power and processing capabilities and blind flooding can become very inefficient because of redundant forwarding. The superfluous flooding increases link overhead and lead to wireless medium congestion that in turn leads to considerable packets collisions in a network that uses contention-based channel access protocol. The resulting redundancy, contention and collisions can lead to what is called the “Broadcast Storm Problem” (Wisitpongphan et al., 2007).

To alleviate the blind flooding impact, several approaches have been developed to restrict the number of flooded control packets. Connected-Dominating-Set (CDS) is a prominent approach aimed at building a Virtual Backbone (VBB) inside the mobile ad-hoc network in order to organize broadcasting and routing activities (Wu and Li, 2001). However, the CDS still has some problems which are highlighted in the following points:

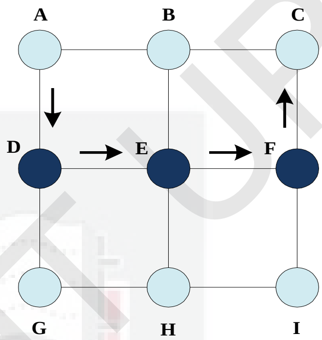
- Maintenance overhead: in CDS construction, each node decides whether to belong to the set or not based on its topological information “neighborhood information”. Since nodes in MANET are in continuous mobility, then the corresponding topological information will change frequently, therefore there is a crucial need to keep this information up-to-date with a minimum maintenance overhead.

- In many literature, CDS construction was made under assumption of homogeneous nodes (Liu et al., 2007; Wu et al., 2001; Wu and Li, 2001). It is assumed that all nodes have the same transmission range. In other words if there is a link between two nodes ‘x’ and ‘y’ it indicates both of them are located within each other’s transmission range. However, after a while some nodes may exhaust their batteries faster than others especially if they have been assigned a gateway role that require many broadcast actions. Also the presence of different types of obstacles like foliage or buildings can block the transmission between nodes. Such conditions need to be considered in virtual backbone design by taking into account the existence of unidirectional links between nodes.

- Sometimes the generated CDS becomes rather small and this is attributed to the algorithm followed for CDS calculation and the reduction rules that were used after a CDS generation to reduce its size. However, smaller CDS size results in less effort paid for maintenance but when the CDS becomes small, then routing options and the broadcasting activity will be exclusive to few nodes inside CDS and this can lead to elongated routing paths compared to what is available in the traditional on-demand routing protocols like AODV and DSR. These protocols follow the shortest route concept beside the freshness of sequence number in case of AODV in making routing decision. It is obvious that longer routing paths incur lower packet delivery ratio and longer delay as well. Therefore it is necessary to keep a trade-off between the size of CDS and routing cost. In Fig 1.2 part-a the shortest route between nodes A and C in AODV is {A, B, C} which includes just two hops, while through the regular CDS in part-b the routing path will become {A, D, E, F, C} with four hops which is twofold the original route.



(a) regular routing path in AODV



(b) routing path in CDS

Figure 1.2: Difference in routing path length between CDS and traditional AODV (Ding et al. 2011)

1.3 Aims and Objectives

The main objectives in this thesis are as follows:

1. To design a reliable and responsive neighbor protocol that consistently collects and maintains 2-hop neighbor information at each node, where this neighbor information is essential requirement for constructing any type of dominating sets. The proposed protocol has to keep neighbor tables up-to-date with lowest maintenance cost.

2. To adjust the CDS construction algorithm to consider the unidirectional links between nodes. This is done by looking for the mutual existence on nodes in the neighbor tables of their neighbors.

3. To investigate the functionality of the multipoint relay scheme which is recognized as a sender-based flooding approach and append it as an assistant flooding scheme beside the already constructed CDS. The approach used in this concern is the Dominant Pruning (DP) which creates a dynamic dominating set at each flooding step. This set is a subset from the neighbor set for the node in concern must cover by its broadcasts all the neighboring nodes that are located 2-hops away from that node. In this way the resultant flooding scheme, will be a hybrid which is a sender-receiver-based scheme.

4. To incorporate the enhanced neighbor protocol (ENP), the adjusted CDS and the hybrid flooding scheme with AODV to examine and compare their performance against another approaches in terms of the metrics stated in Fig. 1.3.

1.4 Overall Methodology and Research Scope

In this thesis we focus on the design of an efficient neighbor protocol that will be responsible for gathering the topological information for each node. However, development of such protocol is not trivial due to the frequent movement of nodes that can render the already collected information to be stale after a short while. Two-hop neighborhood information is the minimum requirement for CDS construction. The neighborhood information is arranged in two tables, the first table is elementary one which includes only the 1-hop neighbor set for a node, whereas the second one includes the whole 2-hop neighborhood information "neighbors of neighbors" beside other details about the gateway status of neighbors and link conditions. An event-driven approach is adopted to update neighbor tables' information rather than periodic broadcasts to save unnecessary broadcasts which can exhaust nodes' energy and occupy the wireless channel.

The CDS is adapted to take into consideration the existence of unidirectional links "directed edges" between neighboring nodes. Since nodes can have disparate battery charges due to differences in their roles and activities, they will have different transmission ranges. Therefore the mutual existence of nodes at neighbor tables' of their neighbors is ensured to verify the connectivity of the resulting dominating set.

Finally, as a flooding scheme, CDS and DP are combined to obtain a hybrid sender-receiver based scheme that enjoys the advantages of both schemes. But the main motivation behind this integration is to overcome the shortcoming of elongated paths in CDS. DP which is a Multipoint Relay technique (MPR) (Wu et al., 2006) can compensate the absence of CDS forwarders at many places by giving a boost to the flooding activity at each hop that packet traverses. Fig. 1.3 shows the conducted research scope and the last section from the figure indicates the traced performance metrics in this work, namely:

- Data delivery ratio: it is the ratio of the number of correctly received packets by their intended destinations to the whole number of transmitted packets.

- Average end-to-end delay: is the time average for a packet to be transmitted across the network from the originator to the destination, which encompasses the transmission, propagation and processing delays. This metric and the first one are considered as quality of service (QoS) parameters. QoS is planned to provide qualitative and quantitative definition for the network expected performance in terms of several characteristics and it must afford a guarantee for these characteristics to some extent.

- Maintenance overhead: is the total number of hello packets broadcast during the simulation time in order to keep up-to-date 2-hop neighbor information at each node.

- Link breakage: the total number of link failures through the active paths between the sources and destination nodes.

- Energy Consumption: the amount of consumed energy by the total nodes in the network during the simulation time. This metric is divided into two parts: the energy consumed in transmitting mode and the energy consumed in receiving mode.
- Broadcast Redundancy: determination of the developed flooding scheme efficiency. The efficiency is traced through the investigation of certain metrics provided by the considered simulator.

1.5 Contributions

Thesis contributions can be summarized as follows:

- An enhanced distance-based neighbor protocol (ENP) has been developed to collect and maintain 2-hop neighbor information at each node and two MCDM algorithms are employed to find the optimum solution among 56 pairs of thresholds that have been examined with the created networks scenarios, such that the optimum solution has been found for each scenario in a way that compromises between the examined conflicting metrics (maintenance overhead, data delivered packets and links breakages).

- Marking process for CDS construction has been adjusted to consider "unidirectional links", furthermore, the "computational complexity" has been determined for both original and modified marking process.

- A multipoint relay approach called "dominant pruning" has been implemented to work in conjunction with the constructed CDS to solve the elongated paths problem.

All the above mentioned approaches were integrated with AODV protocol to build a virtual backbone in an ad-hoc network to optimize several different parameters as stated in Fig. 1.3.

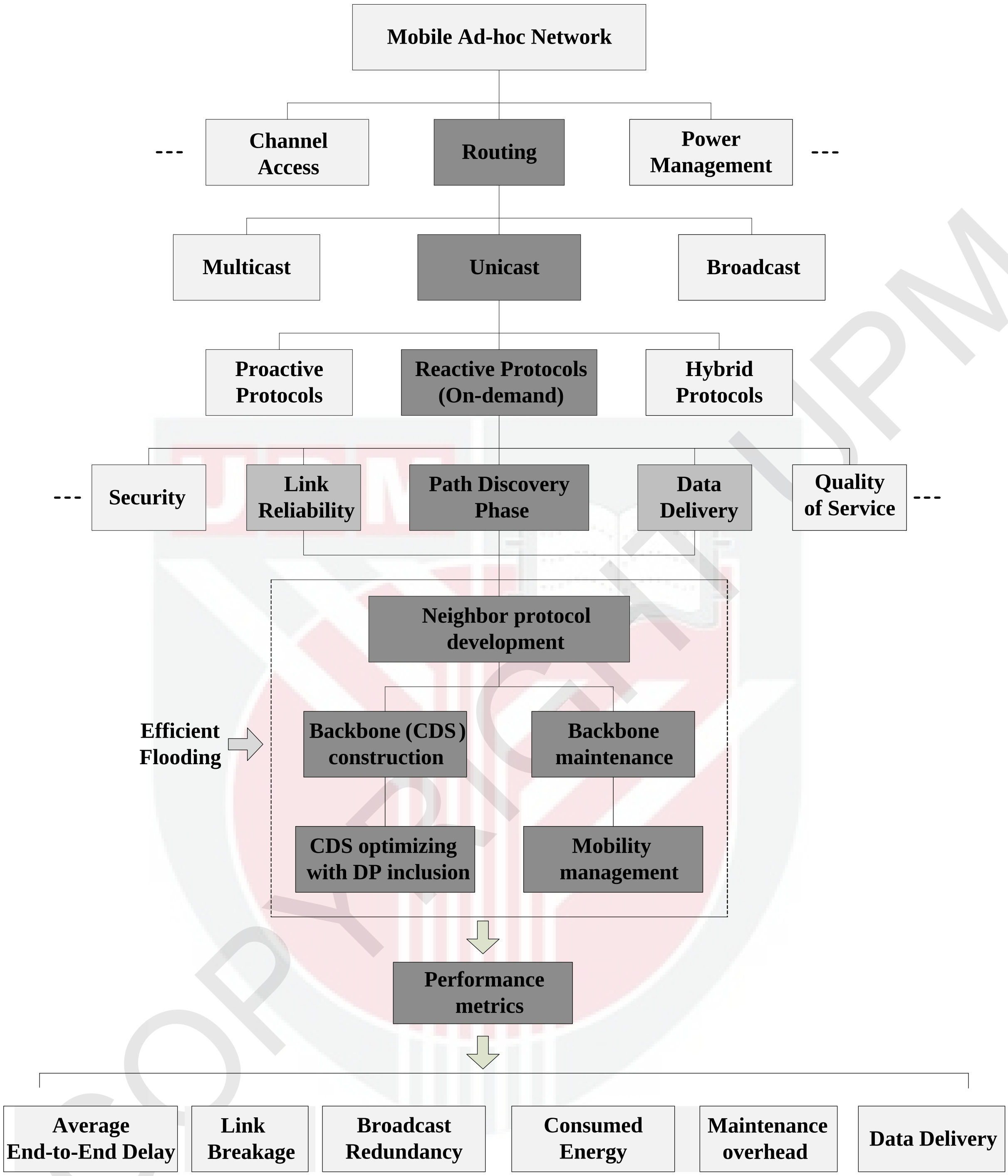


Figure 1.3: Conducted research scope

1.6 Thesis Outline

The rest of this thesis is arranged as follows:

Chapter 2 gives a review for the efficient flooding approaches that have been developed over the recent years and categorize them according to their methodology for virtual backbone construction. They are compared in respect to their neighbor information requirement and time complexity. Chapter 3 provides a detailed description for the neighbor protocol design and highlights the optimization made for CDS in terms of delay reduction through DP inclusion; it also shows the consideration of unidirectional links existence. Chapter 4 presents the simulation results of the enhanced neighbor protocol. It's also show the benefits of the CDS generated with considering unidirectional links over that obtained in unit disk graph. In its last section, the simulation results of the developed hybrid scheme are presented and compared against CDS, DP and AODV. Chapter 5 gives conclusions and the suggestions for future research.

1.7 Summary

In this chapter, a brief introduction is given about MANET in the background section that highlighted its properties and a comparison is made between MANET and cellular networks in terms of their architecture. Problem statement in section 1.2 specifies the disadvantages related to blind flooding and shortcomings in the formerly proposed solutions represented by CDS. The solutions for the indicated problems are given by the determined objectives in section 1.3 while the scope and the measured metrics are outlined in section 1.4. Thesis Contributions are declared in section 1.5 while the thesis outline is made in section 1.6.

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