PROBABILISTIC NETWORK CODING TECHNIQUES FOR VEHICULAR AD-HOC NETWORKS

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I dedicate this work to

My parents,

My little family,

My beautiful sister,

and

My brothers

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Therefore remember Me. I will remember you, and be grateful to Me and never be ungrateful to Me” (Holly Quran). First, all praises and thanks be to Allah, without His blessing, guidance, mercy, and subtleness, this work would never see the light. I would like to express my sincere gratitude to Dr. Sharifah Hafizah Ariffin for being my supervisor, for her patience, enthusiasm, kindness, for her efforts in editing and revising my writing, and for her endless support and guidance throughout my PhD journey. I would also like to thank Prof Norshiela Fisal for her time, encouragement, insightful comments, and hard questions that helped to shape my thesis. I thank my parents, my mother Safia and my father Ali for believing in me, for their love, prayers, and encouragement. I thank my little family, my husband Ala for his endless support and help, and my kids Yazan and Yousif for being my inspiration and motivation, and for living the whole experience with me, I couldn’t have done it without you.

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ABSTRACT

Vehicular ad hoc network (VANET) is an emerging technology that enables moving vehicles on the road to connect and communicate as network devices. VANETs enhance roads safety measures and improve traffic efficiency. However, due to the lack of centralization and the large number of highly mobile nodes, VANETs are considered as highly congested networks with significant packet collisions and retransmissions. On the other hand, network coding is an emerging technique known to effectively utilize network resources by significantly reducing the number of transmissions. In network coding, intermediate nodes minimize the number of transmission by combining different packets before transmitting. However, a fundamental problem for network coding relay when it receives a packet is whether to wait for a coding opportunity to reduce network congestion; or to send the packet immediately without coding to reduce packet delay. This thesis proposes network coding techniques to reduce the number of transmissions and the bandwidth consumption in VANET multi-hop scenario. It also presents an analytical study on the trade-off between the average packet delay and the network throughput in network coding. It proposes a probabilistic approach for the intermediate nodes and therefore develops an analytical framework to present the effect of using such technique on the network performance. The system stability conditions have also been investigated. Moreover, flows with different and same priorities are considered and different mechanisms that consider the nature of the different applications are proposed. For fair delay, this thesis provides the optimum transmission probability which achieves the minimum fair delay and results in an optimum throughput. While for different priority flows, a queue state based probabilistic scheduling schemes are proposed to avoid unbounded packet delays. To highlight the result, for symmetric rate flows, fairness scheme shows that the optimum fair delay can be achieved with probability of transmission of 0.5. It also shows that despite the flow data rate, using this probability will result in 33% improvement in the bandwidth consumption, and in an equal hop delay for both flows that is $0.5/\lambda$, where λ is the average flow data rate. Moreover, for asymmetric rate flows the work provides the optimum transmission probability and its corresponding fair delay and throughput improvement. Simulation is carried out to verify the analytical results where it is closely matched the theoretical results.

ABSTRAK

Rangkaian ad hoc kenderaan (VANET) merupakan teknologi terbaharu yang membolehkan kenderaan yang bergerak di jalan raya bersambung dan berkomunikasi sebagai peranti rangkaian. VANET meningkatkan langkah-langkah keselamatan jalan raya dan memperbaiki tahap kecekapan lalu lintas. Walau bagaimanapun, disebabkan kurangnya pemusatan dan bilangan nod yang dengan mobiliti yang tinggi, VANET dianggap sebagai rangkaian yang sangat sesak dengan perlanggaran dan penghantaran semula paket yang ketara. Sebaliknya, pengekodan rangkaian adalah satu teknik baharu yang menggunakan sumber rangkaian secara berkesan dengan mengurangkan bilangan penghantaran. Dalam pengekodan rangkaian, nod perantaraan mengurangkan bilangan penghantaran dengan menggabungkan paket yang berbeza sebelum menghantarnya semula. Walau bagaimanapun, masalah asas dalam geganti pengekodan rangkaian apabila ia menerima paket, adalah sama ada perlu untuk menunggu peluang pengekodan supaya dapat mengurangkan kesesakan rangkaian; atau menghantar paket dengan segera tanpa pengekodan bagi mengurangkan kelewatan paket. Tesis ini mencadangkan teknik pengekodan rangkaian bagi mengurangkan bilangan penghantaran dan penggunaan jalur lebar dalam senario berbilang hop VANET. Tesis ini juga membentangkan satu kajian analisis untuk pengimbangan antara purata kelengahan paket dan daya pemprosesan rangkaian dalam pengekodan rangkaian. Seterusnya mencadangkan satu pendekatan berkebarangkalian untuk nod perantaraan dan dengan itu membangunkan satu rangka kerja analisis untuk membentangkan kesan penggunaan teknik tersebut ke atas prestasi rangkaian. Syarat-syarat kestabilan sistem juga telah dikaji. Selain itu, aliran keutamaan yang berbeza dan sama dipertimbangkan, supaya mekanisme yang berbeza yang mengambil kira sifat aplikasi yang berbeza dicadangkan. Bagi kelengahan yang adil, tesis ini menyediakan kebarangkalian penghantaran optimum yang mencapai kelengahan adil yang minimum dan memberikan hasil daya pemprosesan yang optimum. Manakala bagi aliran keutamaan berbeza, skim penjadualan berkebarangkalian berdasarkan keadaan giliran dicadangkan untuk mengelakkan kelengahan paket yang tidak terhad. Hasilnya, dalam skim kesaksamaan dalam kadar aliran simetri ini menunjukkan bahawa kelengahan saksama yang optimum boleh dicapai dengan kebarangkalian penghantaran 0.5. Ia juga menunjukkan walaupun kadar aliran data, menggunakan kebarangkalian ini dalam aliran simetri, akan memberikan hampir 33% peningkatan penggunaan jalur lebar, dan kelengahan hop yang sama untuk kedua-dua aliran iaitu $0.5/\lambda$, dengan λ adalah kadar aliran data purata. Selain itu, bagi kadar aliran asimetrik, kajian ini menyediakan kebarangkalian penghantaran yang optimum dan kelengahan saksama yang sepadan dan peningkatan daya pemprosesan. Simulasi telah dijalankan untuk mengesahkan keputusan analisis yang didapati amat sepadan dengan keputusan teori.

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LIST OF ABBREVIATIONS

3GPP	-	3rd Generation Partnership Project
ACK	-	Acknowledgement
AU	-	Application Unit
BSCS	-	Buffer Size Control Scheme
CAM	-	Cooperative Awareness Message
CCH	-	Control Channel
CSMA	-	Carrier Sense Multiple Access
CSMA/CA	-	Carrier Sense Multiple Access With Collision Avoidance
CTB	-	Clear To Broadcast
DABS	-	Density Aware Broadcasting Scheme
DONC	-	Delay-Based Opportunistic Network Coding
DSRC	-	Dedicated Short-Range Communications
EBT	-	Equal Buffered Traffic
EDB	-	Efficient Directional Broadcast Protocols
EDCA	-	Enhanced Distributed Channel Access
EED	-	Equal Experienced Delay
FCC	-	Federal Communications Commission
FEC	-	Forward Error Correction
FRPS	-	Fast Rate Priority Scheme
NS3	-	Network Simulator 3
IEEE	-	Institute Of Electrical And Electronics Engineers
IP	-	Internet Protocol
IPv6	-	Internet Protocol Version 6
ITS	-	Intelligent Transportation System
LANs	-	Local Area Networks
LLC	-	Logical Link Control

LWRBMD	-	Light-Weight Reliable Broadcast Message Delivery
MAC	-	Medium Access Control
MANET	-	Mobile Ad-Hoc Networks
MIB	-	Management Information Base
MLME	-	Mac Sub Layer Management Entity
NCCARQ	-	Network Coding-Based Cooperative ARQ Scheme
NIBS	-	Neighbor Information-Based Broadcast Scheme
NP-hard	-	Non Deterministic Polynomial Time Hard
OBU	-	On Board Unit
OFDM	-	Orthogonal Frequency Division Multiplexing
ONC	-	Opportunistic Network Coding
PLME	-	Physical Layer Management Entity
RBLSM	-	Reliable Broadcasting Of Life Safety Messages
RF	-	Radio Frequency
RMSM	-	Relay Of Multi-Hop Safety Message
RSU	-	Roadside Unit
RTB	-	Request To Broadcast
SB	-	Smart Broadcasting
SCH	-	Service Channel
SF	-	Segment Forwarder
SRPS	-	Slow Rate Priority Scheme
TA	-	Time Advertisement Frames
TCP/IP	-	Transmission Control Protocol/Internet Protocol
TDMA	-	Time Division Multiple Access
ThMS	-	Throughput Maximization Scheme
UDP	-	User Datagram Protocol
UMB	-	Urban Multi-Hop Broadcasting
V2I	-	Vehicle To Infrastructure
V2V	-	Vehicle To Vehicle
VANET	-	Vehicular Ad-Hoc Network
VSA	-	Vendor Specific Action
WAVE	-	Wireless Access For Vehicular Environments
WiMAX	-	Worldwide Interoperability For Microwave Access

WSM	-	Wave Service Messages
WSMP	-	Wave Short Message Protocols
XOR	-	Exclusive OR

LIST OF SYMBOLS

p	-	Probability of Transmitting a native (un-encoded) packet
p^c	-	Probability of queuing a packet
p_1^i	-	Probability of sending a native (un-encoded) packet from RSU1 at$relay_i$
p_2^i	-	Probability of sending a native (un-encoded) packet from RSU2 at $relay_i$
P_{Dir1}	-	Probability of the packet to be from RSU1
P_{Dir2}	-	Probability of the packet to be from RSU2
P_{s1}	-	Probability to queue a packet from RSU1
P_{s2}	-	Probability to queue a packet from RSU2
$p_{optsymm}$	-	Optimum probability of Transmitting an un-encoded packet for symmetric flows
λ_1	-	Average packets generation rate of RSU1
λ_2	-	Average packets generation rate of RSU2
λ_1^i	-	Packet arrival rate toward $realy_i$ from RSU1
λ_2^i	-	Packet arrival rate toward $realy_i$ from RSU2
λ_{qi}	-	Packet arrival rate of queue i
λ_{q1}^i	-	Packet arrival rate of queue 1 at $relay_i$
λ_{q2}^i	-	Packet arrival rate of queue 2 at $relay_i$
μ_{qi}	-	Packet departure rate at queue i
μ_{q1}^i	-	Packet departure rate of queue 1 at $relay_i$
μ_{q2}^i	-	Packet departure rate of queue 2 at $relay_i$
$P(0)_i$	-	Probability of queue i to be empty
$P(0)_{q1}^i$	-	Probability of queue 1 at $relay_i$ to be empty
$P(0)_{q2}^i$	-	Probability of queue 2 at $relay_i$ to be empty
$Delay_{qi}$	-	Average queuing delay at queue i

$Delay_{q1}^{i}$	-	Average queuing delay of queue 1 at $relay_i$
$Delay_{q2}^{i}$	-	Average queuing delay of queue 2 at $relay_i$
$Delay_{Dir1}^{i}$	-	Average delay experienced by packets from RSU1 at $relay_i$
$Delay_{Dir2}^{i}$	-	Average delay experienced by packets from RSU2 at$relay_i$
$Delay_{system}^{i}$	-	Average delay experienced by packets from RSU1 or RSU2 at $relay_i$
$Delay_{Dir1}^{end-to-end}$	-	Average End-to-end N hops delay for packets of RSU1
$Delay_{Dir2}^{end-to-end}$	-	Average End-to-end N hops delay for packets of RSU2
$Delay_{system}^{end-to-end}$	-	Average End-to-end N hops delay for packets of RSU1 and RSU2
$Delay_{Dir1symm}^{i}$	-	Average delay experienced by packets from RSU1 at $relay_i$ for symmetric flows
$Delay_{Dir2symm}^{i}$	-	Average delay experienced by packets from RSU2 at $relay_i$ for symmetric flows
$Delay_{Dir1asymm}^{i}$	-	Average delay experienced by packets from RSU1 at $relay_i$ for asymmetric flows
$Delay_{Dir2asymm}^{i}$	-	Average delay experienced by packets from RSU2 at $relay_i$ for asymmetric flows
$Throughput_{non-NC}$	-	Average network throughput without network coding
$Throughput_{NC}$	-	Average network throughput with network coding

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CHAPTER 1

INTRODUCTION

1.1 Background

Network coding is emerging technique used to improve the network performance in many aspects. With network coding, intermediate nodes are no longer solely packet forwarders, instead they are allowed to manipulate and modify the actual payload of the received packets. On the other hand, vehicular Ad-hoc Network (VANET) is mobile ad hoc technology turns the vehicles on the roads into network devices. Using such technology, the vehicles on the road will be able to form a distributed network, thus communicate and exchange messages.

Unlike the internet where data are typically unicasted, VANET applications such as safety applications and traffic information have a broadcasting nature, since these applications are generally destined for general interest and not for individuals. VANET applications are assumed to enhance the road safety measures and enrich the user experience. For example, applications such as pre-crash warning and break down warning use communication between the vehicles to exchange the warning signals more reliably than in the conventional vehicle warning system (e.g. Tail lamp system), which will help in reducing the human reaction time and leading to less road traffic risks. To implement such system, dissemination of small payload warning messages between vehicles can be realized using the broadcasting technique. However, using multimedia data is often useful. For instance, in some situations, visual information such as images and even short video clips for a dangerous situation on the road ahead will provide the drivers with more precise information than the plain text, which may allow them to make more informed decisions based on their priorities and their vehicle capabilities. Furthermore, comfort applications such as Point of Interest Notification, which informs about the presences of locally based services or/and point of interests, use multimedia data dissemination in most of their implementations [1].

The main challenge with multimedia data dissemination is that the size of the data is relatively large. Moreover, in VANET scenarios, there might be more than one data dissemination session on the same road at the same time. For example, in safety applications, it is common in a bad weather situation (e.g. heavy rains) that both directions of the road are affected and the drivers in both directions need to be updated about the instant situation on the road ahead. In this case, vehicles in each road direction need to cooperate in order to disseminate such data among themselves. Similar scenario can be repeated for comfort applications where it is possible for more than one service provider to co-exist at the same area. However, if available, stationary nodes such as roadside units (RSUs) could also be used to further rebroadcast the data. In cases where there is more than one source willing to broadcast their multimedia data into the same area of interest, conventional VANET broadcasting protocols that are usually used to disseminate the short alert messages will lead to severe network congestion and poor bandwidth utilization.

Network coding is a good candidate to address the aforementioned problem. Network coding is a powerful technique known to efficiently improve the performance of the network by significantly minimizes the number of transmissions. Network coding exploits the broadcasting nature of the wireless medium and mixes various traffic flows via algebraic operations in order to improve the network throughput and/or reduce the power consumption. In network coding the decoding process is carried out using packets that are owned or overheard by the destination node [2-5].

However, common issues when using the network coding in wireless networks are the randomness and the asymmetric nature of the traffic, which reduces the coding opportunities and introduces additional delays. Due to the random nature of the arrival packets, packets from different sources will not be available at the same time for the relay to encode them. Thus, upon a new packet arrival, the relay can either hold the packet waiting for the arrival of the right packet to encode, or sends the packet directly as a native (not encoded) packet. Holding the packet to obtain a coding opportunity will reduce the number of transmissions, but it will impose additional delay which might not be acceptable by some applications, on the other hand, in distributed networks such as VANET, it is desirable to reduce the number of the transmissions in order to reduce the bandwidth consumption. So, when the relay receives a packet, the main question will be whether to rebroadcast the packet directly and decreases the latency or to wait until receives a packet from the other source and combine them together to reduce the bandwidth consumption.

Designing a transmission policy, that compromises between the packet delay and the bandwidth consumption known as Opportunistic Network Coding (ONC) [6]. In ONC, a scheme that combines between the traditional routing and the network coding is usually used to address the trade-off between the delay and the bandwidth consumption. A number of researchers have proposed different ONC schemes to trade-off the delay and the number of transmissions in wireless networks [7-9]. However, in most of their work the fairness between the flows is not considered, and thus in their models the throughput and/or the power consumption is improved by adding more delay to some flows over the others, which is unfairly biased for equal priority flows.

This work proposes the usage network coding for VANET data dissemination to enhance the throughput of the network. Analytical study of the opportunistic network coding in VANET multi-hop wireless network is presented to address the delay throughput trade-off, and to show how the throughput and the imposed delay are affected by the probability of transmission. Both priority and fairness scenarios are considered, and the optimum probability of transmission for the relay to achieve the minimum fair delay between the two flows is provided.

1.2 Problem Statement

Conventional VANET broadcasting protocols that are usually used to disseminate the short alert messages will lead to severe network congestion and poor bandwidth utilization if used in VANET scenarios where multi-sources multimedia data broadcasting is considered. Thus those methods are not suitable for multimedia multisource data dissemination. So, there is a need to develop a better technique that will effectively utilize the bandwidth and eliminates the network congestion. Although, network coding sounds promising since it has proven to improve the network throughput, yet, the network coding methods that are available in the literature lack the consideration of the nature of the flows [7-9] where some of these flows are of equal priorities and others are not.

In lights of the above, the problem statement of this work is as follow:

1. The communication channel in VANET is likely to be overloaded. That may refer to many factors, for example, in addition to the broadcasting nature of its applications, the dynamic and the open nature of VANET makes it possible for the network to grow into a highly dense network. Moreover, the nature of the wireless medium and the packet losses due to the collisions and the channel fading lead to a high number of retransmissions and thus a waste of the network resources. All these factors lead the bandwidth to become a limited resource in VANETs. Considering multisource multimedia data dissemination, the current short alert messages broadcasting protocols will only lead to further inefficient bandwidth utilization. So, implementing a technique to minimize the number of transmissions and improve the throughput of the network is a crucial issue in VANET.

2. Network coding technique is considered promising to improve the network throughput. However, pure network coding where the relay obtains all the coding opportunities by holding all the packets in order to wait to be sent as encoded packets, leads to unbounded packet delays. So developing a network coding scheme that combines between the traditional routing and the network coding is critical to improve the network throughput while maintain the reasonable packet delay. Many of the work in the literature studies the network coding in time division multiple access (TDMA) medium access control (MAC) scenario [6-7, 10-11], however, wireless access for vehicular environments (WAVE), which is the protocol suit that is proposed for VANETs, is employing carrier sense multiple access with collision avoidance (CSMA/CA) as a random access protocols for the MAC layer. Thus the performance of network coding on wireless multi-hop networks employing random access protocols should be analyzed so as to address the trade-off between the achievable throughput and the packet delay in such network.

3. Applications in VANET can be real time or non-real time applications which make them of either equal or different priorities. Most of the work in the literature that considers network coding for equal priority flows, does not treat the flows equally, for example in [7-9] they set the probability of sending a packet without decoding to depend on the queues state. In fact, this implicitly gives the priority to the slow rate traffics, since it is more likely for the fast rate traffic queue to be utilized and builds up. However, for equal priority flows, a network coding scheme that maximizes the throughput by mostly buffering packets from one flow over the other could be unfairly biased, as the most of the average calculated system delay would be a contribution from one flow. Thus when the network coding is deployed to improve the throughput, it needs to consider the priorities of the applications in a way that the privilege to be given to the high priority application if the flows are of different priories or, the two flows to be treated fairly if they are of the same priority.

1.3 Objective of the Thesis

The main objective of this thesis is to develop an opportunistic network coding scheme that enhances the bandwidth utilization in VANET while consider the fairness and/or the priorities between the flows. This thesis also aims to study the effect the network coding on the imposed packet delay in such network. The specific objectives of this thesis are as follows:

1. Develop a mechanism that minimizes the number of transmissions in VANET in order to improve the bandwidth utilization in case of multisource multimedia data dissemination. Network coding technique is used to develop this mechanism.

2. Study the trade-off between the bandwidth consumption and the packet delay in the mechanism that is developed above in 1 considering (CSMA/CA) as a random access protocols for the MAC layer, and to study the effect of the probability of transmission on the imposed delay and the bandwidth consumption.

3. Propose mechanisms that consider the nature of the different applications. For instant, for different priorities flows the privilege is to be given to the high priority applications without starving the low priority application, while for the equal priorities applications the respective scheme should be optimum that it provides the minimum fair delay and the optimum throughput that can be achieved.

1.4 The Scope of the Work

This work proposes the usage of the network coding technique by exploiting the broadcast nature of the VANET wireless medium in order to reduce the number of transmissions. A situation where there are multimedia data broadcasting sessions at both ends of the same road at the same time is considered. Such network can be considered as a multi-hop random access network with two sources and N relays between them. Each source wants to disseminate its packets into the whole area between the two sources. In other words, packets from both sources share the same path but traverse the network in opposite directions.

All the nodes have one transceiver with an omnidirectional antenna. Therefore, a node can be either transmitting or receiving, but not both simultaneously. One fundamental requirement is that all the nodes should store the overheard packets, those stored packets will be used later for decoding purposes, and thus the buffer size to store packets is assumed to be sufficiently large for all nodes. In fact the buffer capacity is assumed to be infinite for all nodes in the system in order to analyze the throughput and packet delay. However, the storage is not a real problem in VANET, since the space in the vehicle is assumed to be large enough.

The applications addressed in this work are non-real time applications, for non-real time applications the delay constrains are relatively relaxed than in real time applications (e.g. Video conference), however, drivers may need to take an action depending on what they have seen on the screen, therefore, delays in the order of several seconds might not be tolerated.

This work develops a protocol that uses the interflow network coding method and implemented it in VANET scenario. The protocol aims to minimize the number of transmissions so as to increase the throughput of the network and well utilized the bandwidth.

The relay in this work is assumed to be able not only to forward the packets, but it could actually perform a bitwise Exclusive OR (XOR) operation on the received packets before broadcasting them. The main reason to adopt the XOR coding scheme is the simplicity of coding and decoding operations of XOR codes which facilitates implementation issues. This property motivates us to use this sub-optimal code in inter-session network coding[12].

1.5 Research Contribution

This work presents an analytical study of the average delay and network throughput for packet dissemination using network coding in multi-hop wireless VANET scenario, where the generation of the packets is a stochastic process. The main challenge for the relay when receives a packet is whether to wait for a coding opportunity and therefore reduce the network congestion or to send the packet directly without coding and reduce the packet delay. The contribution in this thesis is as follows

1. A network coding based probabilistic approach for the intermediate node when receiving a packet is provided, and then an analytical framework to address the trade-off between the throughput and the delay is developed. Here, the optimum transmission probability which achieves the minimum fair delay between the two sources and results in an optimum throughput is provided. Following, the condition to maintain the stability of the system is investigated. Burke's Theorem is used to find the approximate end-to-end delay in N hops scenario, and, the trade-off between the throughput and the delay is highlighted by showing how the throughput and the imposed delay change as the probability of transmission changes.

2. Different network schemes that support different flows scenarios are provided, for example the priority based schemes where the priority could be given to either the fast or the slow traffic flow are studied, on the other hand, different fairness based schemes are provided where packets from both flows are treated equally. As a result, in the symmetric case (e.g. two flows with the same rate) for fairness based scheme, the optimum fair delay could be achieved with probability of transmission 0.5. And despite of the flow data rate, using this probability in symmetric flows, will result in 33% improvement in the bandwidth consumption, and in an equal hop delay for both flows that is $0.5/\lambda$, where λ is the average flow data rate. Moreover, for asymmetric rate flows, the optimum transmission probability and its corresponding fair delay and throughput improvement are provided. Simulation is carried out to verify out the analytical model. Finally, a relay selection mechanism that helps to implement the network coding in a mobile relay VANET scenario is proposed.

1.6 Thesis Outline

This thesis consists of six chapters, organized as follows:

Chapter 2 shed the light on VANET as an emerging technology, it discusses on the architecture of VANET networks taking into the account the standards and protocols that are developed to aid such technology. The specifications of IEEE standards for VANET are explained such as the data rate, the radio range, and the channel access modes of the radio device. Detail description of different layers of Wireless Access for Vehicular Environments (WAVE) standard has been carried out. Chapter 2 also discusses on the applications of VANET explaining the different requirements of each type of application. In this chapter, the data dissemination in VANET is particularly considered, and the different protocols that are currently used for such purpose are highlighted. Network coding is reviewed in the chapter; a brief background on network coding and its different approaches is provided. Then detail discussion on network coding in VANET is carried out, explaining different cases where the technique has been used in VANET. Finally, related works are provided, including the work in the literature that tackles similar problems as of this work.

In Chapter 3 the details of the methodologies that have been used are described. First, the detail of the network scenario is showed, providing a working example that presents how the network coding is useful for VANET network. A step by step description is also provided in order to show the coding and decoding process in the network. Then, the probabilistic network coding approach is presented. The two network coding policies have been proposed in the chapter. Priority based network coding schemes, where flows of different priorities are considered, and fairness based network schemes, where flows of equal priorities are proposed. Finally, a mobile relay selection mechanism is proposed to aid the implementation of the network coding in a fully mobile VANET environment.

In Chapter 4 provides the development of our network coding technique that are proposed in Chapter 3.The chapter presents an analytical study of the average delay and network throughput for packet dissemination using network coding in multi-hop wireless network scenario. An analytical model is provided to analyze the behavior of the relay in the opportunistic network coding scenario, and to show the stability condition of this network, Chapter 4 also shows how Burke's Theorem is used to find the approximate end-to-end delay in N hops scenario. Finally, the trade-off between the throughput and the delay is explained by showing how the throughput and the imposed delay change as the probability of transmission changes.

Chapter 5 provides the development of the proposed network coding policies. Analytical results as well as simulation have been provided for both priority based network coding and fairness based network coding policies.

This thesis is concluded in Chapter 6, where overall discussion on the performance of the network under different schemes has been conducted. Development and future work are also discussed in Chapter 6.

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