UNIVERSITI PUTRA MALAYSIA

EFFICIENT NODE COOPERATION STIMULATION MECHANISM IN WIRELESS MULTIHOP NETWORKS

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FSKTM 2018 13

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By

NORMALIA BINTI SAMIAN

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

December 2017

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DEDICATIONS

I dedicate this thesis to my beloved ***children*** *with the hope that all of you will hold stronger endurance and perseverance in order to accomplish greater success than what your mother has achieved…*

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Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirements for the degree of Doctor of Philosophy

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By

NORMALIA BINTI SAMIAN

December 2017

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In an autonomous environment of wireless multihop networks, like wireless ad hoc and sensor networks, nodes need to cooperate with one another to relay information effectively across the network. However, due to limited resources especially energy, nodes may be compelled to adopt selfish behaviour by not participating in forwarding packets for other nodes. Most, if not all, existing works on cooperation stimulation approaches assumed that this behaviour can be detected but do not explicitly describe how selfishness is actually quantified which leads to inaccurate behaviour judgment. This scenario may be worsened by false accusation issues induced by group of colluding nodes which might cheat in evaluating node behaviour during global/second-hand observation process, for their own communication gains in the network. In addition, cooperation of nodes is hampered by the lack of efficient scheme that is able to stimulate node cooperation effectively to achieve optimum communication rate in the network.

This thesis proposes a mechanism named Compare and Measure Selfishness Detection (CMSD) to evaluate node behaviour more accurately and promptly by adopting quantification elements such as correlation co-efficient tool that are able to classify node into several selfishness/cooperativeness and fairness types. Based on simulation results, CMSD mechanism is able to provide more accurate and prompt behaviour information and increase network performance in term of low false positive and high packet delivery ratio.

Moving further, this study proposes a mechanism that can avoid false recommendation and illegitimate node collusion during global observation. The mechanism is called Trust Features-based Evidence (TFE) which is developed based on significant and unique trust features to ensure that the reported information is of actual behaviour of an observed

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node. Assisted by an efficient cross-checking algorithm on several cheating and colluding cases, TFE mechanism is able to reduce the number of cheating nodes over time and the rate of illegitimate collusion as proven in the simulation results.

Ultimately, a hybrid cooperation stimulation scheme named Recharge-As-Reward (RAR) and Credit-As-Reward (CAR) which functions as an explicit reward (i.e. in the form of token/flag) for cooperative nodes has been proposed in this study. Combining good features in reputation-based and credit-based mechanisms, this hybrid scheme is able to reduce the message/communication overheads suffered by many of existing hybrid schemes by reducing the reliance on a central agent. Performance evaluations demonstrate that the proposed mechanisms are able to reduce the number of dropped packets, increase nodes' forwarding ratio and reduce message and communication overhead.

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Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

MEKANISMA RANGSANGAN KERJASAMA NOD YANG EFEKTIF DALAM RANGKAIAN TANPA WAYAR BERBILANG HOP

Oleh

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Dalam persekitaran rangkaian multihop tanpa wayar berautonomi seperti rangkaian ad hoc tanpa wayar dan rangkaian sensor, nod perlu bekerjasama antara satu sama lain untuk menghantar data secara berkesan ke seluruh rangkaian. Walau bagaimanapun, disebabkan sumber yang terhad terutamanya tenaga, nod bermungkinan untuk mementingkan diri sendiri dengan tidak membantu menghantar paket untuk nod lain. Kebanyakan, jika tidak semua, mekanisma cadangan sedia ada mengandaikan bahawa bahawa sikap mementingkan diri dapat dikesan, tetapi tidak menjelaskan dengan nyata bagaimana sikap tersebut diukur secara kuantitatif yang mengakibatkan penilaian menjadi tidak tepat. Senario ini boleh diburukkan lagi oleh isu tuduhan palsu oleh nod-nod yang bersubahat yang mungkin menipu dalam menilai tingkah laku nod yang dinilai semasa proses pemerhatian global/tidak langsung demi kemaslahatan komunikasi mereka sendiri di dalam rangkaian. Di samping itu, kerjasama daripada nod terjejas akibat kekurangan skim yang efektif untuk merangsang kerjasama nod dengan berkesan untuk mencapai kadar optimum komunikasi di dalam rangkaian.

Tesis ini mencadangkan satu mekanisma yang dipanggil Banding dan Ukur Pengesanan Mementingkan Diri (CMSD) untuk menilai tingkah laku nod dengan lebih tepat dan segera menggunakan elemen kuantifikasi seperti kaedah korelasi koefisian yang dapat mengklasifikasikan nod kepada beberapa kategori sikap mementingkan diri/kerjasama dan keadilan. Berdasarkan keputusan simulasi, mekanisma CMSD dapat memberikan maklumat tentang sikap nod dengan lebih tepat dan cepat, serta meningkatkan prestasi rangkaian dari segi kadar rendah positif palsu dan kadar penghantaran paket yang tinggi.

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Seterusnya, tesis ini mencadangkan satu mekanisma yang boleh mengelakkan rekomendasi palsu dan persubahatan nod yang tidak sah semasa pemerhatian global. Mekanisma ini dikenali sebagai Bukti Berasaskan Ciri-ciri Percaya (TFE) yang dibangunkan berdasarkan ciri-ciri percaya yang signifikan dan unik bagi memastikan bahawa maklumat yang dilaporkan adalah kelakuan sebenar nod yang diperhatikan. Dibantu oleh algoritma silang-semak yang efisien terhadap beberapa kes penipuan dan persubahatan, mekanisma TFE dapat mengurangkan jumlah penipuan nod dan kadar persubahatan yang tidak sah seperti terbukti dalam keputusan simulasi.

Kemuncaknya, sebuah skim rangsangan kerjasama hibrid bernama Mengecas Sebagai Ganjaran (RAR) dan Kredit Sebagai Ganjaran (CAR) yang berfungsi sebagai ganjaran nyata (dalam bentuk token/bendera) untuk nod yang bekerjasama telah dicadangkan dalam kajian ini. Menggabungkan ciri-ciri yang baik dalam mekanisma berasaskan reputasi dan berasaskan kredit, skim hibrid ini bertujuan untuk mengurangkan overhed mesej dan komunikasi yang dialami oleh kebanyakan skim hibrid sedia ada dengan mengurangkan pergantungan terhadap ejen sentral. Penilaian prestasi menunjukkan bahawa mekanisma yang dicadangkan dapat mengurangkan jumlah paket tercicir, meningkatkan kadar penghantaran nod dan mengurangkan overhed mesej dan komunikasi.

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ACKNOWLEDGEMENTS

Alhamdulillah… Praise be to Allah S.W.T for giving me the guidance and strength to complete my Ph.D thesis throughout the roller-coaster journey.

First of all, I would like to express my appreciation to my UPM supervisors, Assoc. Prof. Dr. Zuriati Ahmad Zukarnain, Dr. Azizol Abdullah and Assoc. Prof. Dr. Zurina Mohd Hanapi for their precious support and encouragement throughout the course of this research study till I found light at the end of the tunnel. Against all odds, to my external supervisor from VUW, Prof. Dr. Winston K. G. Seah, I thank you more than words can say for your endless commitment that inspires me to become a better researcher. I look forward to working with you in future and having much more interesting challenges ahead.

I am in debt with my wonderful parents; Samian Sawiyo and Masnah Jamin, and my siblings; Hariz, Haizad and Atiqah, who have always been supporting and sacrificing for me in all possible angles. Wonderful thanks to my family in-law in Sabah who have been so supportive and understanding despite of the long distance we are apart. Not to forget to all my close friends who have always been the best listeners and support me in struggling with my battle. Thank you dear friends, you know who you are.

A special appreciation goes to my husband, Muhammad Daniel Hafiz Abdullah who has been going through many hurdles and challenges together with me in this journey to complete our PhD studies. Finally, both of us have reached the finishing line (I made it first though ¯_(ツ)_/¯).

Ultimately, my appreciation goes to my lovely and cheeky children, Nur Qystina and Adam Uqayl. Both of you are the main reasons why your parents are still standing strong.

~ NS ~

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LIST OF ABBREVIATIONS

ACK	Acknowledgment
AODV	Ad hoc On-Demand Distance Vector
CA	Central Agent
CAR	Credit-As-Reward
CC	Cooperative Communication
CCS	Credit Clearance Service
CMSD	Compare and Measure Selfishness Detection
CPS	Credit Payment Scheme
CRP	Cooperative Routing Protocol
DP	Dynamic Programming
DSR	Dynamic Source Routing
FSC	Feasible Solution Construction
FSM	Finite State Machine
HS	Hybrid Scheme
ID	Identity
IETF	Internet Engineering Task Force
IoT	Internet of Things
LRI	Local Routing Instance
MAC	Medium Access Control
MANET	Mobile Ad hoc Network
NE	Nash Equilibrium
ORA	Optimal Relay Assignment
OSI	Open Systems Interconnection
PDR	Packet Delivery Ratio
PPM	Packet Purse Model
PTM	Packet Trade Model
RAR	Recharge-As-Reward
RREP	Route Reply
RREQ	Route Request
RRER	Route Error

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RS	Reputation Scheme
SC	Settlement Centre
SSA	Single Set of Action
SDN	Software Defined Networking
TFE	Trust Features-based Evidence
TFT	Tit-for-Tat
TTP	Trusted Third Party
VANET	Vehicular Ad hoc Network
VoIP	Voice over IP
WBTFT	Worst Behavior Tit-for-Tat
WMN	Wireless Mesh Network
WSN	Wireless Sensor Network

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Wireless multihop networks consist of autonomous nodes that perform network tasks in a self-organizing manner. The networks which fall under infrastructure-less category includes several class of networks such as wireless sensor network (WSN) (Yick *et al.*, 2008) , mobile ad hoc network (MANET) (Macker & Corson, 1998), wireless mesh network (WMN) (Akyildiz & Wang, 2005), and vehicular ad hoc network (Sharef *et al.*, 2014) (VANET). As they are infrastructure-less, there is no central controller or wired backbone to handle the communication process. Therefore, the nodes in these networks have to act as routers and hosts simultaneously and utilize hop-by-hop packet transmission. Consequently, with these processes occurring in the network, high frequency of communication among peer nodes is expected. Examples of applications utilizing wireless multihop networks for data transmission exist in military battlefield, catastrophe recovery, event monitoring sites, vehicular ad hoc technology system, health monitoring services and many other civilian applications.

As applications based on wireless multihop networks have evolved rapidly, much attention has been given to address issues that may affect the performance of such networks. These include issues related to resource constraint, security, cooperation and connectivity where the main concern is to ensure that data can be efficiently transmitted across the networks to reach intended recipient. In the case where packets that need to be transmitted are between nodes within direct wireless transmission range, a successful rate of data transmission is assured if connectivity is good. However, when the source and destination nodes are beyond direct wireless transmission range of each other, the source node has to rely on relay nodes or intermediaries to help forward the packets towards intended destination node.

When dealing with relay nodes in wireless multihop networks, the issue of uncooperative forwarding behaviour will most likely occur because each node has different motivations and intentions. The intentions are very subjective and may result in good, selfish or malicious behaviours. Ideally, if each node shows a good behaviour by cooperatively relaying packets from other nodes, an optimum network performance can be achieved. However, such assumption is not valid in the real environment of wireless multihop networks where nodes are autonomous and most importantly, have resource constraints. With these characteristics, nodes are compelled to preserve their own energy to sustain in the network, which is why cooperative relaying is difficult to achieve.

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This behaviour is known as selfishness and can exist in any node, affecting topology design and network operations like routing and packet forwarding. The level of selfishness can be very abstract, making it difficult to measure and quantify because unlike a node with malicious intent, selfishness may be shown intermittently depending on the network scenarios that it needs to handle. For example, if a node is handling heavy forwarding loads due to its location being the closest to a particular hectic destination, it may decide to favour certain requesting nodes or drop any incoming packets that arrive after certain forwarding periods to avoid excessive energy depletion. From the energy conservation principle, such behaviour is reasonable for a node's own benefits but if it is done excessively and unfairly, the final effect towards the network may be the same as those by malicious nodes.

In contrast to malicious nodes which intentionally plan to disrupt network services through harmful attacks, selfish nodes do not mean to harm the network. However, the effect of selfishness may eventually cause network disruption if all nodes decide to be self-centered by not forwarding packets for other nodes. Although selfishness can be classified as a type of malicious behaviour, it may not be effectively overcome with security approaches. Generally, security approaches are often implemented using cryptographic-based mechanism in order to thwart bad nodes from the network such as in (Zhong & Wu, 2010). Although this kind of security mechanism may work well in reducing selfishness, it has high computational overheads and is not a suitable countermeasure for selfish nodes, which are not as malign as malicious nodes. Hence, cooperation mechanisms have been introduced to solve the problem of selfishness by detecting nodes that show uncooperative behaviour and provide a means to discourage selfishness (i.e. stimulate cooperativeness) using either incentive-based or punishment-based mechanisms. Hence, the main goal of this research is to investigate and identify voids and gaps in existing cooperation approaches for wireless multihop networks and proposes new mechanisms/schemes to solve the identified issues/problems pertaining to node selfishness.

1.2 Background and Motivation

Node selfishness issue has become one of major focus research problems in wireless multihop networks which have been widely addressed with the proposal of cooperation stimulation mechanisms/schemes in many relevant existing works. Nonetheless, there are several challenges in developing an efficient cooperation stimulation mechanism/scheme. This can be viewed from general structure and components of cooperation stimulation schemes that are still requiring efficiency enhancement. In general, cooperation stimulation scheme consists of five major components as has been summarized in Figure 1.1. Detailed explanation about this structure is discussed in Chapter 2 (cf. Section 2.5).

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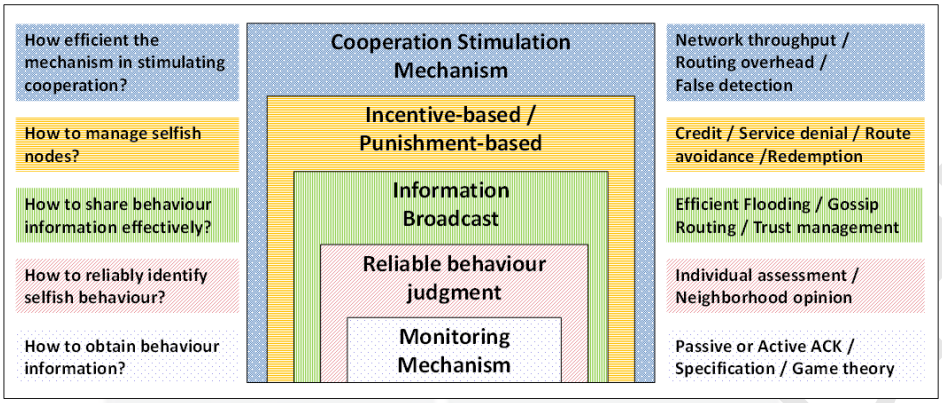

Figure 1.1 : Structure and Components of Cooperation Stimulation Mechanism

Starting from the most basic element which is on the detection and evaluation of node behaviour, choosing the suitable (if not optimal) monitoring mechanism for accurate behaviour detection can be investigated and improved in several different angles. This element itself has already opened up tremendous amount of research study especially on determining accurate node behaviour using several monitoring tools in order to detect selfish node correctly prior to enforcing subsequent actions. Several monitoring mechanisms that are based on four major techniques as shown in Figure 2.2 (cf. Section 2.3) have been proposed. Nonetheless, the proposed approaches impose some similar weaknesses such as inaccuracy of behaviour information, delay in collecting sufficient information, and false judgment which open up rooms for improvement.

The study can be further expanded throughout upper layers' components of cooperation stimulation mechanisms' structure specifically on the utilization of the node behaviour information obtained towards achieving the final effect i.e. optimal node cooperation. However, having multiple layers also means that there are multiple issues may arouse. These have been discussed in many existing works such as and among other popular issues which remain open research problems to be addressed are on node collusion in falsely praise/accuse other nodes, flooding overhead during information sharing with neighbourhood nodes, inefficient punishment mechanisms, high communication and storage overhead for assessing node behaviour.

The aforementioned issues have become major motivations to be investigated and addressed in this research whereby details of literature survey related to this research field are discussed in Chapter 2.

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1.3 Problem Statement

In cooperation stimulation mechanism research, the key challenge in designing an efficient scheme is the ability to answer as to whether or not the proposed scheme is able to stimulate node cooperation effectively by reducing (if not fully thwarting) selfish behaviour and thus, improve network performance. By means of effective scheme, this does not come without imposing trade-offs in implementing the scheme such as high communication and message overheads, undetected selfish nodes, and inaccurate node behaviour judgment, etc. In this thesis, based on rigorous study on the cooperation mechanism elements in Figure 1.1, three major problems in cooperation stimulation mechanisms been identified as follows:

1. Inaccurate measurement of behaviour information based on local observation

Detecting node behaviour accurately during local observation is crucial as having wrong evaluation on a particular node behaviour will most likely impose negative consequences towards the observed node itself and the network performance as a whole. Hence, it is very important for any observer node to perform an accurate first-hand/local observation process prior to sharing the information so that false judgment can be reduced (if not totally avoided). However, there is a lack of accurate and prompt measurement on node behaviour during local observation in existing works whereby selfishness is assumed detected, but did not explicitly describe how selfishness is actually measured. Hence, there is a need to provide a quantification method that is able to measure a node's behaviour more accurately in a quicker manner.

2. Node collusion in falsely accusing/praising node during global observation

The behaviour information obtained from first-hand/local observation may be shared with other nodes upon requested. The process of getting other nodes' opinions about a particular node's behaviour is known as a second-hand/global observation, which forms a global report to rate the reputation level of a particular node via voting system that is formed by group of nodes in proximity. This is where information might be tampered with false accusation by a group of colluding nodes which might simply lie to manipulate the network for their own benefits. In many existing works such issue is handled by relying on a central agent to aggregate behaviour information from as many other nodes as possible. Although this approach helps in reducing false accusation, but, the communication overhead is high and still susceptible to large number of colluding lying nodes. Having said that, such schemes are actually lacking of efficient distributive methods to assure that the information shared is genuine before being counted as a vote. Thus, the authenticity of the nodes and their corresponding shared information need to be validated by an efficient mechanism to ensure that the shared information is hard to be falsified.

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3. Inefficient scheme to stimulate node cooperation in wireless multihop networks

A cooperation stimulation scheme can be generally classified as reputation-based, credit-based or hybrid-based (combination of reputation and credit) scheme. As depicted in Table 2.3 (cf. Section 2.5.4), each type of scheme possesses pros and cons criteria that need to be carefully considered during the design process. For reputation scheme, the voting system component motivates node to be persistent in cooperative mode as its behaviour is continuously being assessed by neighbouring nodes. Nonetheless, it comes with several drawbacks such as susceptibility to large numbers of cheaters that leads to false accusation, the possible need of long behavioural assessment to ensure up-to-date information and high communication overhead. Credit-based scheme was introduced to overcome the overhead imposed by reputation scheme during behaviour observation and assessment which could take long time. By having virtual credit as remuneration for being cooperative and loss of credit as an implicit punishment for being selfish, the highly resources consumption to perform behaviour observation and evaluation can be avoided. However, issues like undetected selfish node, communication bottleneck when dealing with central agent and unfairness of credit distribution do occur in credit-based scheme and remain open research problems to be addressed. As a result, hybrid of reputation-based and credit-based schemes has been introduced whereby the good aspects of both schemes are combined into creating a more efficient scheme. But, it also comes with dis-advantageous especially on the tendency to have very high communication and processing overhead due to the hybrid features, which have become the focus issues to be addressed in this thesis.

Overall, the research presented in this thesis will help answer the following main research questions:

1. How to quantify a node's effort in forwarding packet for other nodes in order to accurately determine its level of cooperativeness or selfishness?
2. How to assure the authenticity of node behaviour information that is shared across the network such that cheating actions can be reduced?
3. How to develop an efficient scheme that is able to stimulate node cooperation effectively so that optimum communication rate in wireless multihop network can be achieved at reasonable communication/message overheads?

1.4 Research Objectives

The main goal of this research is to develop an efficient scheme that is able to stimulate cooperation among nodes in wireless multihop networks so that optimal communication rate can be achieved. Efficiency-wise, the proposed scheme should be able to identify node behaviour more accurately and promptly, broadcast the behaviour information genuinely at a reduced cheating rate to avoid false judgment, punish selfish node more efficiently such that eventually every node realizes that being cooperative is the best way to sustain in the network and ultimately, successfully stimulate node cooperation to

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improve network performance. In order to achieve the main goal, the following objectives have been identified:

1) To devise a mechanism that is able to quantify and classify node behaviour accurately and promptly during first-hand/local observation process using suitable measurement method and statistical tool to increase packet delivery ratio and thus, improving network performance.
2) To design a mechanism that can avoid node collusion during second-hand/global observation using relevant trust features such that the authenticity of the broadcast behaviour information can be assured and cheating rate can be reduced to decrease and increase packet forwarding ratio of selfish nodes and cooperative nodes respectively.
3) To develop an effective hybrid cooperation stimulation scheme combining good features in reputation-based and credit-based mechanisms by proposing an alternative explicit reward other than just rewarding using reputation level for the earlier and reducing node reliance on central agent to manage credit transactions for the latter, to reduce message/communication overhead and increase forwarding ratio of nodes.

1.5 Research Scopes

The scopes of this research are as follows:

1. The network considered is ad hoc networks in which nodes require multi-hop transmissions to send and forward packets for each other.
2. This research focused on network layer whereby selfish behaviour of a node in forwarding packets for other nodes has been investigated.
3. Only nodes with selfish behaviour are considered in this research, whereas, nodes with malicious intent aiming to purposely attack the network are out of the scope.
4. All proposed schemes in this research are built onto the Ad hoc On-Demand Distance Vector (AODV) routing protocol. AODV is an on-demand (reactive) routing protocol which finds a route only when needed and requires a node to only have information of its neighbours. The ability of our schemes to work with such limited network information make them more scalable, and can be extended to other routing protocols such as Dynamic Source Routing (DSR) that provide more information, albeit, incurring overheads. On other node, a reactive protocol has been chosen over proactive routing protocol such as Optimized Link State Routing (OLSR) and Destination Sequence Distance Vector (DSDV) due to the unnecessary of constant propagation of routing information in the network which can lead to high routing traffic overheads.

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1.6 Research Contributions

The main contributions of this thesis are as follows:

1. **Accurate and prompt measurement of node forwarding behaviour**

   Current approaches on evaluating node behaviour based on local observation rely mainly on single set of action (SSA) approach. SSA is a condition of when a node observes another node's forwarding effort towards its own requests while at the same time disregarding that node's effort towards other nodes' requests. This scenario leads to inaccurate judgment and would require conducting another round of observations or acquiring global observation reports from other nodes to verify the behaviour information, which inducing delay. The research in this thesis addresses the issues with the proposal of a quantification mechanism that is based on correlation coefficient that could measure levels of forwarding effort (cooperativeness or selfishness) and fairness imposed by a relay node based on their speed of packet forwarding for more than one node at the same time. The proposed quantification method which is named Compare and Measure Selfishness Detection (CMSD) is aiming to provide (1) a metrics to quantify selfishness based on nodes' effort to forward data packets for corresponding requesting nodes; (2) application of the (selfishness) metrics to evaluate a node's fairness in forwarding packets for different requestors; and (3) a more accurate and prompt classification of different types of selfish/cooperative behaviour. Based on simulation results, the implementation of CMSD mechanism has able to provide more accurate and prompt behaviour information and increase the network performance in term of low false positive and high packet delivery ratio.

2. **A filtering mechanism to reduce false recommendation and avoid node collusion**

   In evaluating a node's cooperativeness/selfishness behaviour, global reports from other nodes in MANET may be required to strengthen the judgment made using local observation. However, it cannot be assumed that a node is always honest in sharing the behaviour information. A group of nodes might collude to falsely accuse/praise a particular node to gain communication benefits at the cost of other nodes' resources. This paper proposes a filtering mechanism named Trust Features-based Evidence (TFE) by formulating evidence that is based on trust features to reduce the number of liar nodes and thus, ensuring the authenticity of the shared information. Assisted by an efficient punishment element, TFE mechanism is able to reduce the number of cheating nodes over time and the rate of illegitimate collusion, by having detected cheaters aware that the only way to survive in the network is by presenting genuine information.

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3. A new type of reward mechanism for reputation scheme

In reputation scheme, assigning good reputation level alone does not provide strong motivation either for node to remain cooperative or to stimulate selfish node to become cooperative. Thus, in this research, an explicit reward other than just providing reputation level incentive for nodes has been proposed to strengthen motivation for nodes to cooperate. The proposed reward is known as Recharge-As-Reward (RAR) and works by giving a cooperative node a recharge session which is represented in the form of token/flag every time a node has reached a particular forwarding threshold value. This would allow cooperative nodes to recuperate without being labelled as selfish, thus avoiding unnecessary punishment. Significant achievement of proposing this type of instant reward mechanism is that nodes can maintain longer operational lifetime in the network without having to wait for too long for their rewards to be verified and approved, which may degrade motivation to cooperate.

4. A hybrid cooperation scheme with less message/communication overheads

Hybrid of reputation-based and credit-based schemes has been proposed to improve the efficiency in mitigating selfishness by adopting the pros sides of both schemes. However, implementing hybrid scheme is commonly at the cost of high communication/message overhead mainly due to (1) wide-broadcast of packets to collect and evaluate reputation level of a node, and (2) high traffic due to node-to-node and node-to-central agent (CA) communications. This thesis addresses the overhead issues in hybrid scheme with the proposal of a Credit-As-Reward (CAR) mechanism that is combined with RAR mechanism to create the hybrid feature. From the credit-based element, significant difference in our proposed scheme compared to other existing hybrid schemes is that nodes are stimulated to being less reliant to the CA although its usage to process credit transaction is retained, which also signifies that credit provision is not a mandatory reward for cooperative nodes. This is done with the help of RAR mechanism whereby if the amount of RAR flags collected is enough to sustain nodes lifetime in the network, credit transaction is not necessary be done. This is also apply for the case of when credit processing fails to complete due to factors like observer node is reluctant to submit report on other nodes' forwarding information to the CA, which has mostly been neglected in existing schemes. The idea is that, nodes need not rely on credit reward only as RAR works as an alternative to reduce reliance on CA, thus reducing communication/message overheads. Through a comparison with another hybrid scheme, it has been shown that the proposed hybrid scheme in this research is able to detect selfish nodes and reward cooperative nodes more efficiently while reducing reliance on a central agent to reduce message/communication overhead.

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1.7 Structure of Thesis

The outcome of this research is documented and organized into a thesis of seven chapters as follows:

Chapter 1 overviews the main motivation in conducting research in cooperation stimulation for wireless multihop networks and generally guides readers on what to anticipate from this thesis. This is done by discussing the research problems identified through rigorous literature survey which derives the objectives to address the issues within specified scopes of research. Summary of all proposed contributions is also discussed at the end of this chapter.

Chapter 2 discusses the literature survey that has been done for this research by reviewing existing related works on selfishness mitigation cum cooperativeness stimulation in wireless multihop networks. Based on the rigorous survey which includes performing comparative analysis, issues and problems related to cooperation in wireless multihop network are highlighted and potential gaps that need to be fulfilled are identified.

Chapter 3 describes the research methodology applied for this research which is illustrated in a general framework. The methodology framework explains the overall steps that involved in this research based on several phases which were carried out consecutively but may be repeated when necessary. There are three main phases which have involved in this research; namely analysis, theoretical design and validation. Discussions on the simulation tool used and the routing protocol chosen as platform to simulate all proposed contributions are also done in this chapter.

Chapter 4 introduces a new mechanism to quantify a node's forwarding effort during local observation named Compare and Measure Selfishness Detection (CMSD) scheme. The discussion covers the steps that have involved in the quantification method's design and its applications to classify a node's behaviour based on its forwarding effort. This chapter also discusses the efficiency of CMSD to work under several network scenarios and its strength in improving network performance.

Chapter 5 presents a filtering mechanism to prevent illegitimate node collusion and cheating behaviour during global/indirect observation whereby information about particular node behaviour is shared across the network upon requested by certain nodes. The proposed mechanism named Trust Features-based Evidence (TFE) is developed based on significant and unique trust features which are effective to thwart cheating behaviour of nodes to ensure that the reported information is of actual behaviour of an observed node.

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Chapter 6 presents the final contribution for this thesis which is the development of a hybrid cooperation scheme which consists of a combination of reputation-based and credit-based schemes. The explanation is mainly divided into two parts whereby the first part focuses on proposed enhancement for reputation scheme using RAR scheme, and the second part discusses on CAR scheme which is an enhancement of credit-based scheme.

Chapter 7 concludes this thesis by highlighting all contributions and discussing some potential future works.

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