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JITTER MANAGEMENT IN MULTIPATH ROUTING
FOR MOBILE AD HOC NETWORK

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โครงข่ายเคลื่อนที่แบบแอดฮอกเป็นโครงข่ายที่ไม่มีโครงสร้างล่วงหน้าและสามารถทำงานได้โดยไม่จำเป็นต้องมีสถานีฐาน ดังนั้นโนดแต่ละโนดในโครงข่ายต้องสามารถเป็นได้ทั้งตัวรับส่งข้อมูลและตัวหาเส้นทาง ปัญหาที่สำคัญอันหนึ่งในโครงข่ายแอดฮอกนี้จึงเป็นปัญหาเรื่องของการหาเส้นทาง ซึ่งโครงข่ายจำเป็นต้องสามารถหาเส้นทางที่เหมาะสมต่าง ๆ จากต้นทางถึงปลายทางที่อาจจะยังไม่ทราบล่วงหน้าได้ นอกจากนี้เพื่อให้สอดคล้องกับความต้องการในปัจจุบันโครงข่ายแอดฮอกควรจะสามารถส่งผ่านข้อมูลแบบสื่อผสมได้อีกด้วยซึ่งเป็นเหตุผลเพิ่มเติมว่าทำไมกลไกการหาเส้นทางนั้นควรต้องนำความต้องการพื้นฐานของข้อมูลสื่อผสมมาพิจารณาประกอบ จิตเตอร์จัดว่าเป็นตัววัดที่สำคัญอันหนึ่งในการส่งข้อมูลสื่อผสมแบบเวลาจริงโดยจิตเตอร์ควรจะมีค่าต่ำที่สุดเท่าที่จะเป็นไปได้เพื่อให้การส่งข้อมูลสื่อผสมดังกล่าวมีคุณภาพสูง การควบคุมจิตเตอร์ให้ลดลงนั้นสามารถทำได้ด้วยเทคนิคง่าย ๆ โดยการใช้บัฟเฟอร์เพื่อจัดเรียงแพ็กเก็ต ในสถานการณ์ที่มีการส่งต่อหลายทอดจิตเตอร์รวมต้องนับจากต้นทางจนถึงปลายทางสุดท้ายของการส่งข้อมูลซึ่งสามารถหาได้จากการรวมค่าจิตเตอร์ของการส่งแต่ละทอด ด้วยเหตุผลดังกล่าววิทยานิพนธ์ฉบับนี้จึงประยุกต์การควบคุมจิตเตอร์ในโนดระหว่างทางทุกโนดแทนที่จะให้เพียงโนดปลายทางโนดเดียวทำหน้าที่จัดการจิตเตอร์ นอกจากนี้วิทยานิพนธ์ยังได้เสนอให้ใช้เทคนิกการจัดหาเส้นทางแบบพหุวิถีเพื่อปรับปรุงจิตเตอร์ ทั้งนี้กระบวนการหาเส้นทางจะหาเส้นทางที่เป็นไปได้มากกว่าหนึ่งเส้นทางโดย ณ ขณะเวลาหนึ่ง ๆ จะมีเพียงเส้นทางหลักเส้นทางเดียวที่ถูกใช้งาน และเส้นทางอื่น ๆ ถูกเก็บเป็นเส้นทางสำรอง เส้นทางต่าง ๆ นี้จะถูกตรวจสอบค่าจิตเตอร์อยู่ตลอดเวลาอย่างสม่ำเสมอเพื่อให้มั่นใจได้ว่าเมื่อมีเส้นทางสำรองใดที่ให้ค่าจิตเตอร์ที่ดีกว่าเส้นทางหลักที่กำลังใช้อยู่ เส้นทางสำรองนั้นจะถูกเปลี่ยนมาเป็นเป็นเส้นทางหลักสำหรับใช้ส่งข้อมูลแทน ด้วยการดำเนินการเช่นนี้เราสามารถหาเส้นทางสื่อสารข้อมูลสื่อผสมที่มีค่าจิตเตอร์ที่ต่ำเพียงพอได้

ภาควิชา	วิศวกรรมไฟฟ้า	ลายมือชื่อนิสิต	
สาขาวิชา	วิศวกรรมไฟฟ้า	ลายมือชื่ออาจารย์ที่ปรึกษา	
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##4670623121: MAJOR ELECTRICAL ENGINEERING

KEY WORD: MOBILE AD HOC NETWORK (MANET) / DELAY / JITTER / MULTIPATH ROUTING

SIGIT BASUKI WIBOWO: JITTER MANAGEMENT IN MULTIPATH ROUTING FOR MOBILE AD HOC NETWORK, THESIS ADVISOR: CHAODIT ASWAKUL, Ph.D., THESIS COADVISOR: CHAIYACHET SAIVICHIT, Ph.D., 56+xii pp., ISBN 974-17-5529-5

Mobile Ad Hoc Networks (MANETs) are infrastuctureless network. This can be deployed without existence of base station. Therefore, each node in the network must be capable of performing as host and router. One important problem of the ad hoc network is "routing". The network has to find appropriate paths from source to destination which has not been known yet. To satisfy today's requirements, ad hoc network should be capable of traversing multimedia applications. That is why the routing mechanism should also take into account the basic requirements of such applications. Jitter is one of most important metrics in real-time multimedia data transfer. Jitter should be kept as minimum as possible in order to get high quality multimedia transmission. Jitter control can be reduced by simple technique of buffering packet. In the multihop environment, the end-to-end jitter is a summation hop-by-hop jitter. Therefore, jitter control is applied to each intermediate node instead of at only the receiver. Multipath routing is another routing strategy in ad hoc network environment. Route dicovery process will find more than one valid route. Only one route is used for data transmission. The others are dedicated for backups and being monitored periodically to obtain jitter information. If there is a better path along data transmission process, it will be switched to the new path. By accomplishing this scheme, we can achieve ad-hoc multimedia communication routes with sufficiently low jitter.

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Last but not least, I would dedicate this work to my parents who always give me wonderful support, lifetime gentleness and kindness. The last, I devote all my greatest thanks to the God Almighty for giving me the incredible things.

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List of Symbol

$:=$	”is defined as”
$\in$	”belong to”
$\exists$	”there exists”
$\mathcal{P}$	”path”

CHAPTER I

INTRODUCTION

1.1 Background

The wireless communication has been experiencing exponential growth in the past decade. Many small wireless communication devices such as notebook computers, PDAs, and cellular phones have been part of our daily lifestyle. These kinds of devices offer many advantages such as portability, mobility, and efficiency in communication. The first generation of wireless communication required central node to manage and to control nodes in the network. However this scheme has some drawbacks. One of the most significant disadvantage is that communication will only exist if there is an infrastructure of the network. This network is sometime not suitable for certain situation. The next generation of wireless communication that can address that condition is mobile ad hoc networks (MANETs).

Mobile ad hoc networks (MANETs) are infrastructureless networks that can be deployed instantly without any forms of centralized administration or existing infrastructure. In this configuration, node can communicate with another one by means of either direct or multihop link. Therefore, each node involved in the network has to be able to act both as host and router. This kind of network can be very useful in the battle area, conference situation, or catastrophe condition in which it needs temporary network connection. In those kinds of situation, it is difficult to run infrastructured network communication. However, the basic problem in infrastructureless network is how to deliver data packets among nodes efficiently without predetermined topology or centralized control which is the main objective of ad hoc routing protocol.

Mobile ad hoc networks inherit the traditional problems of wireless and mobile communications, such as higher interference results in lower reliability, low bandwidth availability, highly variable network conditions, limited computing and energy resources, and limited service coverage. In addition, their multihop nature and the possible lack of fixed infrastructure introduce new research problems such as network configuration, device discovery, and topology maintenance, as well as ad hoc addressing and routing [1].

The infrastructureless and dynamic nature of ad hoc networks require a new set of networking strategies to implement in order to provide efficient end-to-end communication. Ad hoc networks employ traditional TCP/IP structure to provide end-to-end communication between nodes. However, due to their mobility and the limited resources of wireless network, each layer in the TCP/IP model requires redefinition or modification to function efficiently in ad hoc network [2].

MANETs should also be able to handle many kinds of application including multimedia softwares. Those require certain level of performance of the network. The performance of these applications will depend on the Quality of Service (QoS) that can be provided by the network. There are some metrics that are generally used for quantifying network QoS such as end-to-end delay, jitter, bandwidth, throughput, and delivery ratio.[3]

Among many metrics, jitter and delay have significant effect on multimedia application. In order to improve jitter and delay in ad hoc network, there must be a mechanism to do so. This research investigates the effect of jitter and delay in the multipath routing environment of mobile ad hoc network.

1.2 Motivation of Studying MANETs

Mobile Ad-Hoc Network is promising technology in the future. Compared to cellular network, it has advantage to run easily without existence any infrastructured networks. This new network configuration has been attracting many researchers since decades ago. However, this area still offers many challenging research objects.

The dynamic nature of mobile ad hoc network drives routing protocol to become the most active research area in which many researchers have been trying to improve efficiency in term of bandwidth, power, processing time and so on. Nowadays, many types of applications grow quickly along with . Routing protocol based on quality of service becomes important when ad hoc network is dedicated for multimedia transmission.

Delay and jitter should be handled carefully in order to get smooth multimedia communication. This research tries to investigate delay and jitter in mobile ad hoc network environment.

1.3 Research Objective and Scope

The objectives of the research are three-fold:

1. To improve jitter in the multipath routing of ad hoc network.
2. To evaluate system performance of jitter management in the multipath routing of ad hoc network.
3. To reduce routing discovery process by employing multipath scheme.

Scope of this research is confined by some factors as following.

1. This research is based on computer simulation.
2. The simulation tools that is used is OMNET++.
3. Linux operating system environment is chosen to get the stability and reliability.
4. Some mobility methods will be employed to the nodes movement.
5. Connectivity among nodes will include both MAC and physical layer.
6. Data fragmentation/defragmention procedure is not considered.
7. To get simplification, there is time synchronization in the system.
8. Source produces fix or variable rate of packets.

1.4 Thesis Organization

This thesis report is organized into six chapters. The first chapter is introduction which consists of background, motivation of studying MANETs, research objectives and scope, as well as chapter organization.

The next chapter explains theory background of mobile ad hoc networks (MANETs). Details about MANETs including routing protocol and mobility model will be elaborated. Existing routing algorithm is shown in briefly in order to save the space. Besides, jitter calculation is also presented in this chapter.

Chapter three describes problem statement and research methodology in which the way of research is elaborated in detail.

How to simulate the network scenario is shown in detail in chapter four. Simulation model in OMNeT++ is explained in this chapter. Finally, results of simulation obtained from many scenarios and summary are presented in chapter five and chapter six, respectively.

CHAPTER II

LITERATURE REVIEW

This chapter provides some backgrounds related to the work. Wireless ad hoc networks, routing protocols, and mobility models are elaborated in detail in the following sections. Wireless communication is presented firstly as introduction before describing all of those sections.

2.1 Wireless Communication

Wireless communication is generally defined as infra red or radio communication. Many types of wireless devices such as notebook computers, PDAs, and cellular phones spread in the market since years ago. First generation (1G) of wireless network was used for voice communication and had analog signal type. Advanced Mobile Phone System (AMPS), Nordic Mobile Telephone (NMT), and Total Access Communication System (TACS) are system example in that era [4].

Digital communication was applied for the first time in second generation (2G) wireless communication. Some data services via modem were also introduced to this 2G wireless network. Example system in this generation are Global System for Mobile communication (GSM) and DCS1900. Nowadays, 2G has been extended to 2.5G to provide better support for transmitting low-speed data up to 384 kbps.

Next generation which is known 3G offers some improvements that would follow a common global standard based on CDMA and provide international roaming capabilities. Higher speed of data communication is also the feature of this network generation. 3G networks provide increased bandwidth of 128 Kbps when mobile device is moving at higher speed, and 2Mbps in stationary applications making it possible to deliver video stream [4].

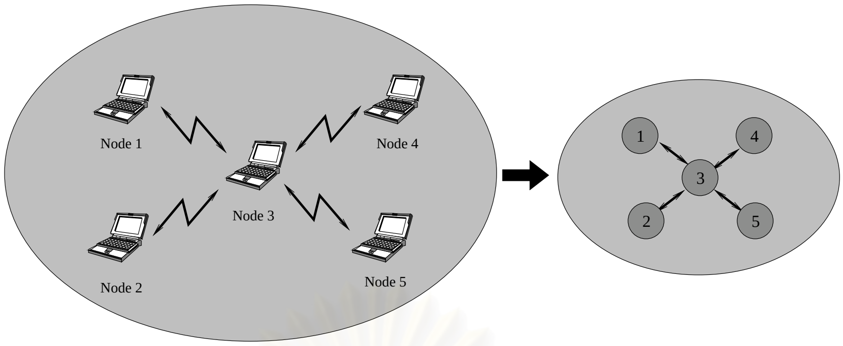


Figure 2.1: Mobile ad hoc network.

All above network generations are run in the infrastructured or managed environment. Whereas the next generation network which is known as 4G runs on both infrastructure and infrastructureless network configuration. Infrastructureless networks can be deployed instantly without any existence of base station. This network style is widely known as ad hoc networks.

2.2 Wireless Ad Hoc Network

The ad hoc network consists of collection of nodes which are equipped with wireless communication. Each node has to be able to act as router in which data is forwarded from one node to another node. In ad hoc network, wireless hosts can interact with each other without the existence of central node. This configuration gives advantage that it can be spread out in battle field, relief area, or conference. As shown in Figure 2.1, an ad hoc network is comprised of several home computing devices including notebooks, personal data assistance (PDA), portable phone, and so on. Nodes can communicate each other if they are in the same radio range. Therefore, communication between nodes can be performed by either direct link or multi-hop fashion.

2.3 Mobile Ad Hoc Network Routing Protocol

Mobile Ad Hoc Networks are dynamically formed by mobile nodes with no pre-existing and fixed infrastructure. In order to obtain end-to-end communication throughout the network, mobile node has to be capable of handling network function, such as routing of packet. In the real situation, each node which is involved in the network moves with its own mobility pattern. Recently, ad hoc routing protocol applies different strategies to accommodate such network dynamics. These strategies can be summarized into three categories: (1) proactive strategy; (2) reactive strategy; and (3) hybrid strategy.

Many routing protocols have been proposed and developed by researchers. In this work, only one routing protocol which is ad hoc on-demand routing protocol is presented in detail, whereas, some of those are explained briefly. The first routing class is proactive routing protocol in which each node in the network has to maintain routing table to another node in the network. Destination sequence distance vector (DSDV) [5] and wireless routing protocol (WRP) [6] are examples of proactive routing protocol. This scenario suffers overhead because there are many control packets in the network to keep routing update. However, the latency due to routing discovery process is not large compared to next category which is reactive routing protocol.

Destination sequence distance vector (DSVD) [5] routing protocol is similar to Bellman-Ford routing protocol from which it inherits. Distance vector feature is added to eliminate routing loop. Each node in the network maintains routing table. This table comprises of all of possible destinations within the non-partitioned network and the number of routing hops to each destination. By maintaining that routing table, route will always be ready whether it is needed or not. Therefore, this routing strategy suffers from a lot of control traffic in the network. That drawback is mitigated by applying two kinds of update mechanism. The first one is full dump in which all available routing information is carried. The second way which is only information that has changed since the last full dump.

Wireless routing protocol (WRP) [6] is distance-vector routing protocol which has loop free feature. For maintaining the connectivity, each node which is not sending data has to send HELLO message within a specified time period. Otherwise, the absent of message from the node may indicate the failure of that wireless and this can cause a false alarm. When the node receives HELLO message from new node, the new node information is added to the routing table. For the purpose of routing, a node mantains a *distance table* , a *routing table*, a *link-cost table*, and an *ack-status table*.

Routing table of node i is a vector with an entry for each known destination j which specifies:

- The destination's identifier
- The distance to the destination (D_j^i)
- The predecessor of the shortest path chosen toward $j(p_j^i)$
- The successor (s_j^i) of the shortest path chosen for j.
- A marker (tag_j^i) used to update routing table; it specifies whether the entry correspons to a simple path (tag_j^i = correct), a loop (tag_j^i = error) or a destination that has not been marked (tag_j^i = null).

The second routing strategy is on-demand. In the on-demand routing protocol scheme, routing discovery process is employed only when source requires to send data to destination. This method will reduce overhead in the network. The disadvantage of this protocol is the latency for building the routing. The example of this protocol are dynamic source routing (DSR) [7] and ad hoc on-demand distance vector (AODV) [8] which will be explained in detail in the next section.

Dynamic source routing (DSR) [7] is on-demand routing protocol which is based on the idea of source routing protocol. The protocol contains two mechanisms that are route discovery and route maintenance. They work together to allow nodes to discover and maintain source route to destination in the ad hoc network. The use of source routing allows packet routing to be trivially loop-free, avoids the need for up-to-date routing information in the intermediate nodes through which packets are forwarded, and allows nodes forwarding or overhearing packets to cache the routing information in them for their own future use. All aspects of the protocol operate entirely on-demand, allowing the routing packet overhead of DSR to scale automatically to only that needed to react to changes in the routes currently in use.

The last routing strategy combines those two routing protocols. This combination tries to alleviate the disadvantage in each previous routing strategies by maintaining an up-to-date topological map of a zone centered on each node. **Zone routing protocol (ZRP)** [9] is one example of the third routing protocol which is called hybrid routing protocol in which network area is divided into zones which can overlap.Each node acts as both cluster head and a member of other clusters. Proactive routing protocol is used in each zone area whereas reactive routing protocol is employed for zone interaction.

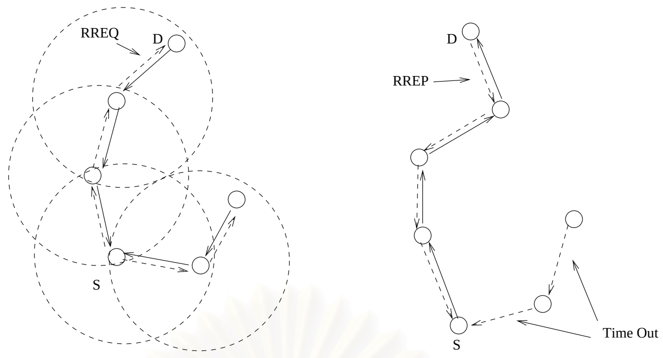
The number of nodes within zone can be be regulated by adjusting the transmission power of nodes. Lowering the power reduces the number of nodes within direct reach and vice versa.

2.4 Ad hoc On-demand Routing Protocol

Ad hoc on-demand routing protocol (AODV) is one of reactive routing protocol that is designed for ad hoc mobile networks [8]. It is based on hop-by-hop routing approach. It builds route only as desired by source node in which data need to route to destination. It maintains the routes as long as that is needed by source. Nodes which are not included in the routing process do not maintain any parameters related to routing process. The overhead of control packet of this routing is less than that of proactive routing protocol. Memory usage of this routing protocol process is also less than that of proactive one. Detail explaination of AODV in the following sections are based on [8].

2.4.1 Route Discovery and Route Maintenance

The path discovery will be initiated if source needs to send the data to destination for which it has no routing information in its table. Each node maintains two kinds of counter: a *node sequence number* and a *broadcast_id*. It broadcast route



(a) Reverse Path Formation (b) Forward Path Formation

Figure 2.2: Ad Hoc On-demand Routing Protocol.

request (RREQ) to its neighbors. The RREQ consists of the following field: $<$ *source_addr, source_sequence_#, broadcast_id, dest_addr, dest_sequence_#, hop_cnt* $>$

The pair $<$ *source_addr, broadcast_id* $>$ identifies a RREQ, $broadcast\_id$ is incremented when the source issues a new RREQ. Each neighbor either satisfies RREQ by sending route reply (RREP) packet back to the source or rebroadcast the RREQ to its neighbor after increasing hop_cnt. One node may receive multiple RREQ from its neighbor. If RREQ has the same $source\_addr$ and $broadcast\_id$ then it will be discarded.

At each intermediate node, when it receives RREQ the route to source is created as depicted in Figure 2.2(a). If receiving node is not the destination, and it has no route to the destination, it will rebroadcast RREQ. If receiving node is destination, or it has current route to destination, it generates route reply packet (RREP). A RREP contains the following information: $<$ *source_addr, dest_addr, dest_sequence_#, hop_cnt, lifetime* $>$

Route reply is unicast in a hop-by-hop manner to the source. Figure 2.2(b) represents the forward path as the RREP propagates, an intermediate node creates a route to the destination and can begin sending data. Nodes that are not along the path determined by RREP will time out and will delete the reverse pointer.

If there is a broken data flow, a route error (RERR) is sent to the source in the manner of hop-by-hop. As the RREP propagates towards the source, each intermediate node invalidates routes to any unreachable destinations. When the source of the data receives the RERR, it invalidates the route and re-initiates route discovery if necessary. Hello message may be used to detect and monitor links to neighbors. If hello messages are used, each active node periodically broadcasts a hello message. If node fails to receive hello message within a certain time from a neighbors, a broken link is detected.

2.4.2 Sequence Number and Loop Freedom

The important feature of AODV is its use of a destination sequence number for each route entry which is generated by the destination. Loop freedom can be achieved by employing destination sequence number. This is attached to all routing message which are used for determining the relative freshness between two routing message which have the same destination. The node with higher destination sequence number has the more recent routing information.

Routing update can be achieved from RREQ or RREP packet along with establishing of reverse path or forward path respectively. The routing update procedure can be elaborated as following.

if $(seq\_num_i^d < seq\_num_i^d)$ **or**

$((seq\_num_i^d = seq\_num_j^d)$ **and** $(hop\_count_i^d > hop\_count_i^d > hop\_count_j^d))$

then

$seq\_num_i^d := seq\_num_j^d;$

$hop\_count_i^d := hop\_count_j^d + 1;$

$next\_hop_i^d := j;$

Consider the tuple $(-seq\_num_i^d, hop\_count_i^d)$ where $seq\_num_i^d$ represents the sequence number of destination d at node i and $hop\_count_i^d$ respresents the hop count to destination d from node i. For any sequent node i and j on the valid route to destination, j is the next hop from i to d. Routing update procedure insists that $seq\_num_j^d$ is equal or larger than $seq\_num_i^d$, and if they are equal, $hop\_count_i^d$ is larger than $hop\_count_j^d$. That is $(-seq\_num_i^d, hop\_count_i^d) > (-seq\_num_j^d, hop\_count_j^d)$, where the $(-seq\_num_i^d, hop\_count_i^d)$ along any valid route implies loop freedom. The routing updating also ascertain loop freedom even in the presence of link failure because when the failure from node i to node j breaks a prior valid route from i to destination d, node i locally increments $seq\_num_i^d$ and sets $hop\_count_i^d$ to ∞. This prevents i from later establishing a route to d through a previously upstream node, thus making AODV loop-free at all times.

2.5 Multipath Routing

QoS routing protocol was initially proposed in [10], to find a route satisfying certain bandwidth and delay constraints. Even though, they only consider finding the route from source to destination in *uni-path* manner. These are on-demand routing protocols. Only when a node requires to transmit data packets, it searches a route to a destination node.

There is another approach of routing strategy that is *multi-path*[11], [12], [13], [14], [15]. In the process of discovering route, AODV will find more than one route from source to destination, though only one route will be considered and taken. Whereas, in multi-path route mechanism, more than one discovered path will be included in the data transmission process. The following subsections will explain in detail about Ad Hoc On-demand Distance Vector (AOMDV) routing protocol based on [11].

2.5.1 Protocol Overview

Some characteristics of AOMDV inherit from that of AODV. It employs the same manner in which distance vector and hop-by-hop routing are used. The important difference between those two is number of routes found in route discovery process. In AODV, RREQ which is flooded from source will be responded by both intermediate and destination to form multiple reverse path by which multiple forward path will be formed. In order not to contribute more overhead, the procedure of AOMDV will only give some extra fields in the packet header of AODV instead of forming special type of control packet.

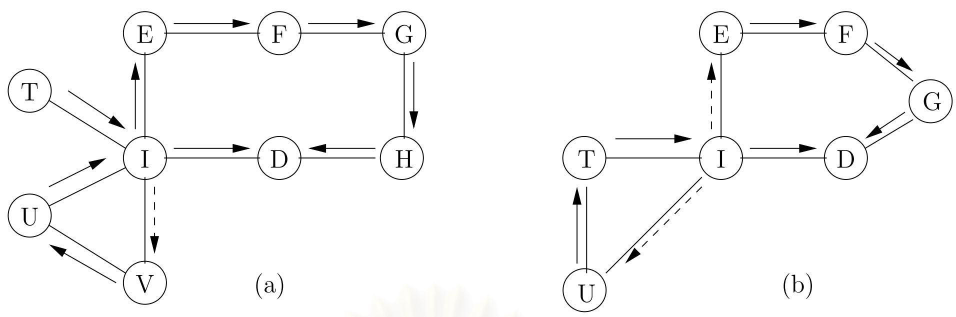


Figure 2.3: Routing loop scenario with multipath computation.

Loop Freedom

Similar to AODV, AOMDV should also be equipped with loop freedom routing capability. In order to guarantee that, some extensions of AODV routing update version are required. There are two interesting questions when we apply loop freedom in the multi-path environment. First, which one of the multiple paths should a node offer or advertise to others ? Since each of these paths may different hop counts, an arbitrary choice can yield loops. Second, which of the advertised paths should a node accept ? Accepting all paths may cause loops [11].

Figure 2.3 depicts example of routing loop problem. In Figure 2.3(a), node D is the destination and node I has two paths to D. The first path is a five hop that is $(I-E-F-G-H-D)$ and the second one is a one hop that is $(I-D)$. Consider that I advertises the path $(I-E-F-G-H-D)$ to node T and the path $(I-D)$ to node U. Then both node T and U has the route to destination with different hop count. After that, if node I has route information which is four hop $(V-U-I-D)$ from node V, node I cannot decide whether node V is upstream or downstream to itself since only hop count is included in the routing information. Therefore node I forms loop routing via node V. That is triggered because of advertising shorter path $(I-D)$to the destination by node I.

Another possible loop routing is also presented in the Figure 2.3(b). Node D is the destination. Node U has three hop path to node D which is $(U-T-I-D)$. Node E also has a three hop path to node D which is $(E-F-G-D)$. In this scenario, I cannot make a decision that E is downstream node because node U can also supply a four hop to D. Therefore, accepting a longer path after the node had shorter path to the neighbors can form routing loop.

Two above cases can be used for making routing procedure in which loop routing can be avoided. Three sufficient conditions for loop freedom can be elaborated as follows.

- *Sequence number rule*: Routing protocol will maintain only the highest known sequence number. If node received route advertisement with higher destination sequence number, all previous routes with older sequence number are discarded.
- *Route advertisement rule*: Never advertise shorter than already advertised.
- *Route acceptance rule*: Never accept a route longer than one already advertised.

AOMDV uses $advertised\_hop\_count$ to maintain multiple path for the same sequence number. Each node holds a variable called advertised hop count for each destination. This is set to the length of the longest available path for the destination at the time of first advertisement for particular destination sequence number. The advertised hop count remains unchanged until the sequence number changes. Using the longest path length permits more number of alternate paths to be maintained, while enforcing the route advertisement rule.

Disjoint Paths

In AOMDV disjoint path can also be guaranteed. There are two kinds of disjoint paths which are link disjoint and node disjoint. In link disjoint, all links in the different path does not share the same path, but it can have the same node other than source and destination. Whereas in node disjoint, only source and destination are common node. The example of disjoint path can be depicted in the Figure 2.4. In that scenario, node source S has three routes to node destination D. That picture also depicts both disjoint link and disjoint node. Route $(S-A-B-E-F-D)$

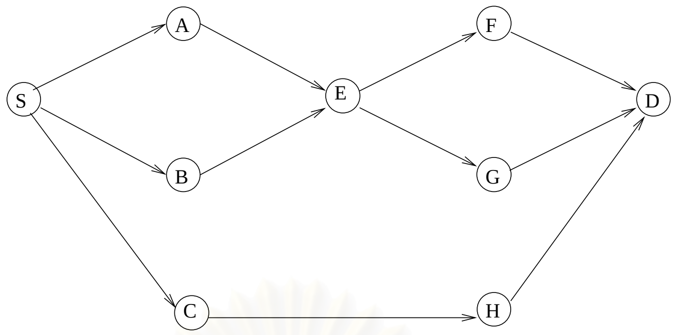


Figure 2.4: Disjoint path in multipath routing.

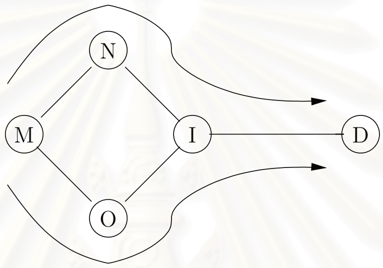


Figure 2.5: Routing path with only next hop information.

and route $(S-B-E-G-D)$ are link disjoint with one common node E. In contrast, route $(S-A-B-E-F-D)$ and route $(S-C-H-D)$ are node disjoint.

Distributed routing protocol forms path to destination based on path information form downstream neighbors towards to destination. To find the set of routing, AOMDV performs two-step process: (1) identifying a set of downstream neighbors having mutually link disjoint path to the destination, and (2) forming exactly one path via each of those downstream neighbors.

Next hop information in distance vector routing protocol is not enough to guarantee link disjointness which can be seen in the Figure 2.5. From the picture, node D is the destination. Node N has path to node D $(N-I-D)$. Similarly, node O has a path to node D $(O-I-D)$. Node M cannot determine whether path from node N and node O are link disjoint because node M does not know which node will be next hop for node N and node O.

Based on the above explanation, it is required additional information in the

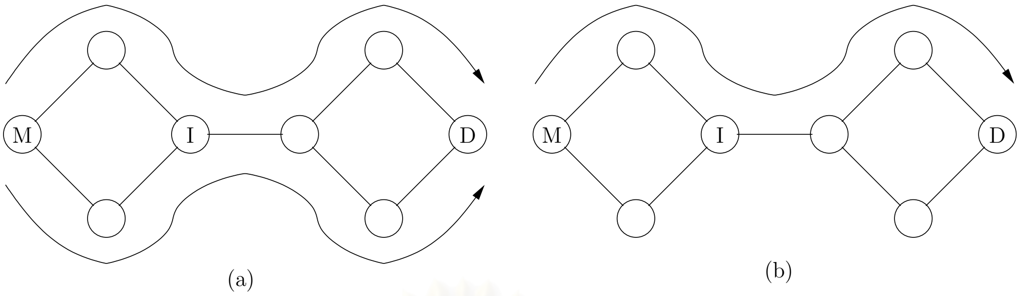


Figure 2.6: Disjoint Path Computation.

routing table to make sure that formed paths are disjoint. The one method of doing that is maintaining complete route information but this way can cause high overhead. Another mechanism that can maintain overhead not too high is adding last hop information for every path. The last hop of a path from node M to destination D refers to the node immediately preceding D on that path. For a single hop path, the next hop is the destination and the last hop is the source itself. For a two hop path, the next hop is also the last hop.

If two paths from a node M to a destination D are link disjoint, then they must have unique next hop as well as unique last hops. That statement is not always sufficient in converse. Consider Figure 2.6, the two paths shown from node M to D satisfy the differing next and last hop condition, bet they are not link disjoint. However, notice that the intermediate node I does not satisfy the condition.

If every node on a path ensures that all paths to the destination from that node differ in their next and last hops, the paths are link disjoint as depicted in the Figure 2.7. Therefore, in order to implement the idea, it is required to maintain the last hop information for every path in the routing table as shown . This information must be included in the RREQ and RREP packet.

2.5.2 Protocol Description

Routing protocol will be explained in detail in this subsection which is divided into three components: routing table structure, route discovery and route maintenance.

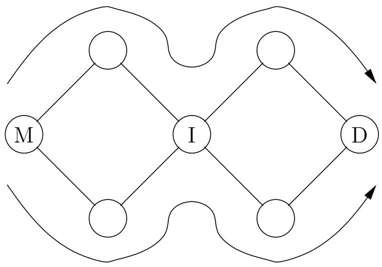


Figure 2.7: Link disjoint in multipath route.

destination	sequence number	hop couunt	next hop	expiration timeout

(a) AODV

destination	sequence number	advertised hop count

route list			
hop_count_1	$next\_hop_1$	$last\_hop_1$	$expiration\_timeout_1$
hop_count_2	$next\_hop_2$	$last\_hop_2$	$expiration\_timeout_2$
⋮	⋮	⋮	⋮

(b) AOMDV

Figure 2.8: Routing Table Structure in AODV and AOMDV

Routing Table

Routing table for Adhoc On-Demand Distance Vector (AOMDV) is slightly different from that of AODV from which the hop count is replaced by advertised hop count and the next hop is replaced by route list. Figure 2.8 depicts the distinction between both of them. It also maintain route list which includes information for each alternate path, however, AODV has only single path information.

The advertised hop count is invoke every sequence number updating time. Node i updates its advertised hop count for destination node d as follows.

$$\begin{aligned} advertised\_hop\_count_i^d &:= max_k\{hop\_count_k(hop\_count_k, next\_hop_k)\cdots \\ &\quad \in route\_list_i^d\}, i \neq d \\ &:= 0, otherwise \end{aligned}$$

Node will call the route update procedure when it receives route advertisement. That procedure also has capability of avoiding loop freedom and guaranteeing link disjointness. Update procedure in the AOMDV can be shown as following.

if $(seq\_num_i^d < seq\_num_j^d)$ **then** //enforce sequence number rule
$seq\_num_i^d := seq\_num_j^d;$
$advertised\_hop\_count_i^d := \infty;$
$route\_list_i^d := NULL$
if $j = d$ **then** // neighbor is destination
insert $(1, j, i)$ into $route\_list_i^d$
else
insert $advertised\_hop\_count_j^d + 1, j, last\_hop_{jk}^d)$ into $route\_list_i^d;$
endif
else if $((seq\_num_i^d = seq\_num_j^d)$ **and**
$(advertised\_hop\_count_i^d > advertised\_hop\_count_j^d))$
then // enforces the route acceptance rule
if $(j = d)$ **then** // neighbor is destination
if $((\exists k_1 : (next\_hop_{ik_1}^d = j))$ **and** $((\exists k_2 : (next\_hop_{ik_2}^d = i))$ **then**
// establishes uniqueness of next and last hops
insert $(1, j, i)$ into $route\_list_i^d;$
end if
end if $((\exists k_3 : (next\_hop_{ik_3}^d = j))$ **and** $((\exists k_4 : (next\_hop_{ik_4}^d = i))$ **then**
// establishes uniqueness of next and last hops
insert $(advertised\_hop\_count_j^d + 1, j, last\_hop_{jk}^d)$ into $route\_list_i^d;$
end if
end if

The node i will call the above procedure when it receives a route advertisement for a destination d from a neighbor j. The variables $seq\_num_i^d$, $advertised\_hop\_count_i^d$, and $route\_list_i^d$, represent the sequence number, the advertised hop count and the list of routes, respectively, for destination d at node $i(i \neg d)$. The variable $next\_hop_{ik}^d$

and $last\_hop_{ik}^{d}$ represent the next and last hops of k^{th} path (for some k) in the routing table entry for d at i, where $(hop\_count_{ik}^{d}, next\_hop_{ik}^{d}, last\_hop_{ik}^{d}) \in route\_list_{i}^{d}$.

Route Discovery

Route discovery process will be invoked if source needs to send data for mobile host to which it does not have valid routing table. Route request is sent to the neighbors by means of flooding through out the network which is the same way with AODV [8] does. By doing so, a node may receive some copies of the same RREQ. AODV will consider only first copy of RREQ by which reverse path is formed.

When intermediate node receives RREQ packet from the neighbor, it will check whether there is a route to the destination. If destination can be reached from this node, it replies back with RREP packet to the node from which it obtain RREQ packet. In the other case, intermediate node does not have valid route to the destination, it will forward RREQ immediately to the neighbor.

The similar process will also be run in the destination node which receives RREQ packet. It forms reverse path immediately. The destination generate RREP in response to every RREQ copy that comes via loop-free and disjoint path to the source.

Route Maintenance and Data Packet Forwarding

Route maintenance of AOMDV is performed in the same way as that of AODV. RERR packet is still used for detecting broken link. A node generate RERR packet for a destination when the last path to the destination breaks.

AOMDV also use time out mechanism similar to that in AODV. The important thing in this mechanism is determining the value of timeout.

There are two methods of utilizing multipath route. The first, all weighted route are used for sending data simultaneously. The other one, only one route will be used, and the rests are dedicated for backup. Routing discovery process can be minimized by employing multipath routing scheme. Therefore, latency of discovering process can be as minimum as possible. The discovery process is re-initiated only if all routes are broken.

2.5.3 Protocol Properties

This section explains proving of AOMDV protocol properties.

Loop Freedom [11]

In the loop freedom of AOMDV routing protocol, the following condition holds for any two successive nodes i and j on a valid path to a destination d.

$$(-seq\_num_i^d, advertised\_hop\_count_i^d) > (-seq\_num_j^d, advertised\_hop\_count_j^d)$$

This is quite similar to AODV except that advertised hop count replaces hop count.

Theorem 1. *A*OMDV route update mechanism generate loop free routes.

*P*roof. The proof is by contradiction.

Suppose that a loop size $m, (i_1, i_2, \ldots, i_m, i_1)$ forms in a route to destination d. Note that node i and j in the route update mechanism are two consecutive nodes in the route, and

$$seq\_num_i^d \leq seq\_num_j^d$$

Therefore, the following must be true among the nodes in the loop so formed.

$$seq\_num_{i_1}^d \leq seq\_num_{i_2}^d \leq \cdots \leq seq\_num_{i_m}^d \leq seq\_num_{i_1}^d$$

which implies

$$seq\_num_{i_1}^d = seq\_num_{i_2}^d = \cdots = seq\_num_{i_m}^d = seq\_num_{i_1}^d$$

This in turn implies the following condition holds.

$$advertise\_hop\_count_{i_1}^d > advertised\_hop\_count_{i_2}^d > \cdots$$
$$> advertised\_hop\_count_{i_m}^d > advertised_hop_count_{i_1}^d$$

Then,

$$advertised_hop_count_{i_1}^d > advertised\_hop\_count_{i_1}^d$$

Which clearly is impossible. Thus, routes formed by AOMDV are loop free.

Path Disjointness [11]

The prove of link disjointness of alternated paths in AOMDV is presented as following.

Theorem 2. *If all nodes is the network have unique identifiers (UIDs) and all nodes on a path from node X to destination D have identical destination sequence numbers, then alternate paths maintained by AOMDV from X to D are link disjoint*

Proof. It is sufficient to prove that a pair of paths from X to D are link disjoint. It can be applied to the every pair of paths between X and D to prove that all the alternate paths are link disjoint.

Consider two paths from X to D formed according to AOMDV route update rules. For ease of reference, let us call them $\mathcal{P}_1$ and $\mathcal{P}_2$. Paths are defined by the sequence of node identifiers from X to D. In the routing table of X, $\mathcal{P}_1$ and $\mathcal{P}_2$ are identified by the tuple$< D, next_hop, last_hop >$. Because of the update rules, $\mathcal{P}_1$ and $\mathcal{P}_2$ have different next and last hops.

It will be shown that $\mathcal{P}_1$ and $\mathcal{P}_2$ are link disjoint. By way of contradiction, suppose that $\mathcal{P}_1$ and $\mathcal{P}_2$ are not link disjoint. This means they have at least one common link. Let $I - J$ be such a link. By unique next hop condition, node I can have only one path to D via J in its routing table. This implies that I will propagate upstream only one path to D that goes through J, eventhough J may have more than one path to D each with a different last hop. This in turn implies that nodes upstream of I sharing the link $I - J$ cannot have more than one path. Since X is clearly upstream of I and has two paths, this presents a contradiction. Thus, the paths $\mathcal{P}_1$ and $\mathcal{P}_2$ must be link disjoint. [11]

There is an assumption that the node along each alternate path have the same destination sequence number because in AOMDV, whenever higher sequence number is received, it discards routes corresponding to the previously existing older sequence number.

From detail above explanation it can be summarized that multiple link-disjoint paths are computed from the source to destination through discovery process. The destination responds to only those unique neighbors from which it receives RREQ packet. Each node in the network maintains a list of alternate next hops that are sorted based on the hop count. If, during the routing, one of link between two nodes breaks, the immediate upstream node switches to the next node in its list of next hops. If this node does not have alternate route, it sends RERR to the upstream neighbor. In this routing protocols, paths that are computed during discovery process are not maintained during the data transfer. Therefore, paths can become stale and outdated by the time they are actually utilized.

In this research, similar process of multipath routing in [11] will be used. However, all the paths will be monitored to get the smallest value of jitter.

2.6 Mobility Model

In real circumstance, node moves from one position to another point randomly. We can approach this moving node by applying mobility model. There are some mobility models which are usually used for simulation. In mobility model, there two kinds of treating node which reach the boundary of simulation area. The first one, node will be reflected back with the same angle to the simulation area. The second one, node will appear to opposite boundary. Random walk and random way mobility model are expounded in the two following subsections.

2.6.1 Random Walk Mobility Model

Node moves from its initial point to new location by randomly choosing a direction and speed which are selected based on predetermined range. The interval of changing direction and speed can be based on either time or distance. If the node reach the boundary of simulation area, it bounces off the simulation border with an angel determined by incoming direction. The node then continues along this new track with the same speed as previously.

2.6.2 Random Way Point

Random way point mobility has similar characteristics to random walk mobility but it has pause times between changes in direction and/or speed. Node begins by staying in one location for a certain period of time. If the pause time expires, node will choose random destination and speed. The node then use the selected direction and speed to extend its movement. The same as previous random mobility model, this scheme is memoryless mobility which means it retains no knowledge concerning its past location and speed value.

2.7 Jitter Calculation

Jitter is defined as variation of delay of given packet. It should be considered carefully in the network dedicated for traversing multimedia application. For that purpose, the jitter should be kept as minimum as possible.

The jitter metric is defined as the difference in send and receive times between two packets, i and j. Let S_i is the send time of packet i and R_i be the receive time of packet i in the next hop. The difference $D(i,j)$, provide the jitter between any two particular packets as defined in the following:

$$D(i,j) = (R_j - S_j) - (R_i - S_i) = (R_j - R_i) - (S_j - S_i) \qquad (2.1)$$

In the multihop environment, the total jitter is the sum of the jitter at each of the intermediate nodes in the path from source, node s to the destination, node d. Thus the total jitter is given by

$$J_t = \sum_{s}^{d} \sigma_f(n) \qquad (2.2)$$

Where $\sigma_f(n)$ is jitter in each node n with the particular packet flow of f. Illustration of jitter phenomenon can be shown in the Figure 2.9.

To keep delay jitter as minimum as possible, there must be a delay jitter control scheme. Delay jitter can be alleviated by buffering at the receiver However, in the multihop environment, the amount of buffer in the receiver can be reduced if the

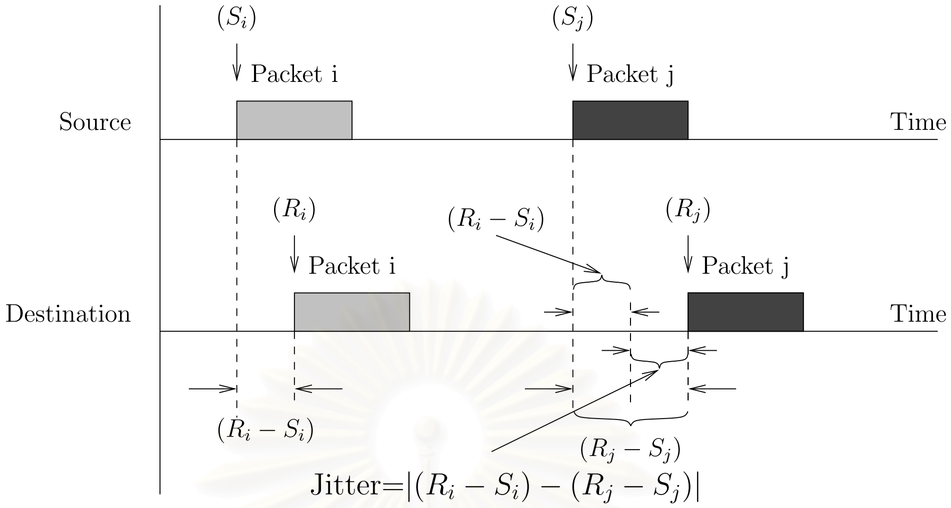


Figure 2.9: Jitter Phenomenon of Data Transmission.

network can guarantee jitter. In order to do that, jitter mitigation should be done on each node instead of only in receiver. The work in [16] is proposed jitter control in the wired network environment.

CHAPTER III

PROBLEM DEFINITION AND METHODOLOGY

Problem statement and methodology are described in this chapter. This work is based on AODV routing protocol which has been explained in the previous chapter. This routing protocol is chosen because it has some advantages compared to another one. It has lower overhead compared to proactive routing protocol. It is also one of the most developed routing protocol for mobile ad hoc networks.

3.1 Problem Definition

Routing protocol has important role in the ad hoc network by which data can be transfered from source to destination. Basic routing protocol will only consider of finding the destination in ad hoc network. It does not investigate quality of service of the link. Some applications that is run in the ad hoc network environment requires certain quality of service. Therefore, it is better if ad hoc network routing protocol is furnished QoS control mechanism.

In multimedia application, among many metrics, jitter and delay are the important factors. Jitter and delay should be kept as minimum as possible to satisfy the requirement.

Jitter and delay can also be contributed by routing process. Finding unknown destination node in reactive routing protocol takes some time because route list is not ready for using. In contrast, proactive routing protocol always has routing to any node in the network.

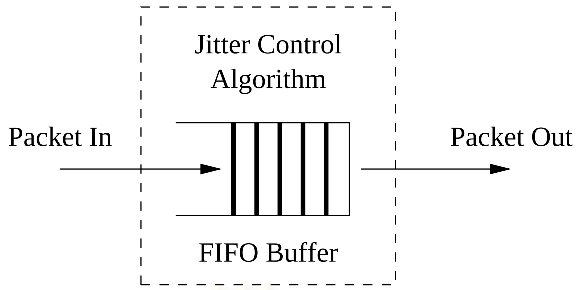


Figure 3.1: Buffer of jitter control.

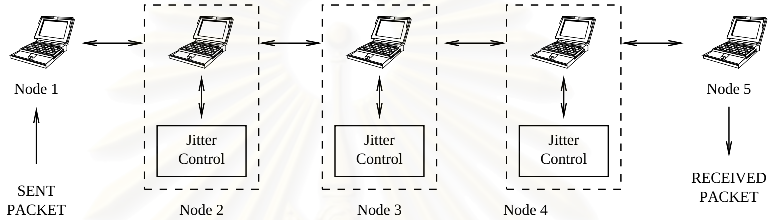


Figure 3.2: Jitter control configuration in ad hoc network.

3.2 Approach and Methodology

Jitter in the network can be alleviated by buffering incoming packet and sending with the correct interarrival time after the packet number in the buffer is satisfied. Buffering process can be depicted in the Figure 3.1. Packets in the buffer are released in FIFO (First In First Out) fashion. The time of packet release is regulated by jitter control algorithm. In the multihop environment, the amount of buffer in the receiver can be reduced if, not only the receiver, but the intermediate nodes also help to regulate the jitter. In order to do that, jitter control should be distributed on intermediate node instead of only in receiver as shown in the Figure 3.2.

Multimedia appplication may contain CBR (Constant Bit Rate) and VBR (Variable Bit Rate) data. Therefore, jitter control mechanism should be able to handle both of them. In the case of CBR, each intermediate node will try to arrange the interarrival time between packets in order to match the period of the CBR stream. After the arrangement, those packets are sent out to the next node. By doing this, the jitter of received packets in the next node can be minimized.

This simple jitter control for CBR with a slight modification can also be applied for VBR transmission. For VBR, each transmitted packet is assigned a piggyback information about the time this packet has to be sent out. Therefore, the time interval between packets can be maintained as close to the original stream as possible.

Jitter and delay contributed by routing process can be reduced by applying multipath routing. Routing protocol will find some routes along the process of finding the destination. At one time, only main routing protocol is used and the others are dedicated for backup. If the value of jitter of active route is under the threshold or the link is broken, data stream is switched to backup route. This mechanism is depicted in the Figure 3.3 By doing so, it is expected that jitter value can be maintained at certain level. Delay caused by routing process is also expected to be reduced.

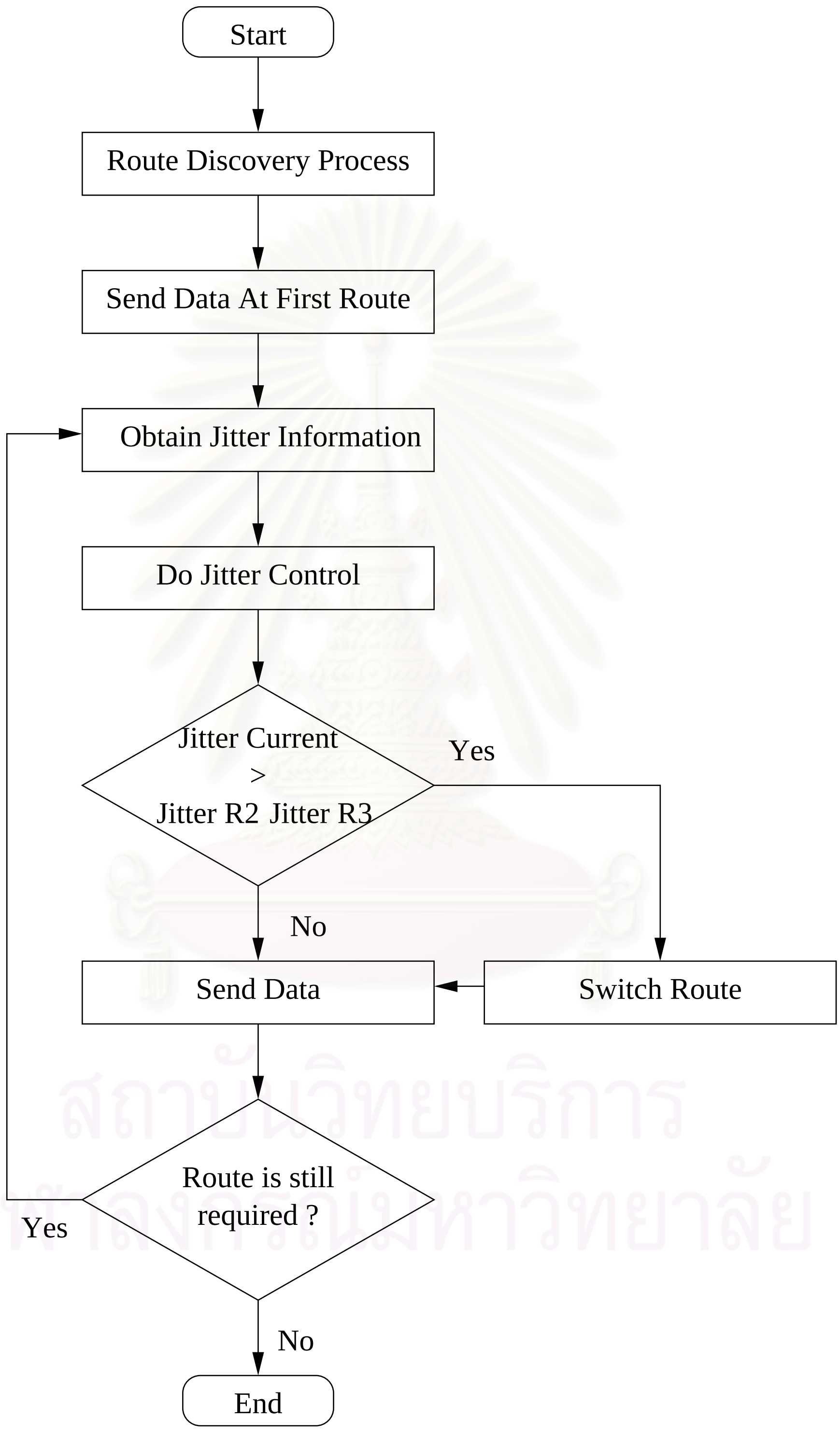


Figure 3.3: Path switching mechanism in multipath environment.

CHAPTER IV

SIMULATION MODEL

Building the real testbed for evaluating system performance of mobile ad hoc network is complicated and expensive. Therefore, running simulation is an alternative way to alleviate the drawbacks of running real testbed. However, simulation can not completely represent the real world because there are some assumptions. This chapter covers explanation of simulation experiment of this research. One of widely used simulation tool is Objective Modular Network Testbed in C++ (OMNeT++) which is discrete event simulation. Besides that, OMNeT++ is also able to generate some type of pseudo-random numbers, collecting simulation statistics, and configuring multiple simulation runs.

4.1 OMNeT++ Simulation Tool

OMNeT++ is capable of simulating communication networks, as well as complex IT system, queuing networks and hardware architecture [17]. The basic component of this simulation tool is module. It can be simple module or compound module which contains some modules. Modules can be connected each other using link from which propagation delay, bit error rate, and data rate parameters can be adjusted. Message is used to communicate between modules. Some advantages of this software can be elaborated as following.

- This simulation is based on C++ language, therefore no need to learn another language.
- OMNeT++ is fast enough. Based on the manual, the speed of OMNeT++ is only 1.5 slower than that of pure C++.
- There is a graphical user interface for convenient operation or presentation.

- OMNET++ offers many classes that can be used directly.
- It has clear and well-defined documents.

4.2 Simulation Model

This simulation is based on ad hoc simulation tool in OMNeT++ [17] and modified to fulfill the research requirement. In this simulation model is composed of some modules as following.

1. Top Level Module
2. Application Layer Module
3. Routing Layer Module
4. Link Layer Module
5. Physical Layer Module
6. Mobility Module

Module structure of the simulation is revealed in the Figure 4.1. Layers can communicate each other by sending and receiving message.

4.2.1 Top Level Module

In this simulation top module which is compound module consists of numbers of mobile nodes. Each mobile host is composed of application layer, routing layer, MAC layer, physical layer and mobility layer module. Adjacent nodes exchange message directly via physical module. Firstly, nodes are placed randomly. After that, their movement will depend on mobility model.

4.2.2 Application Layer

This layer is responsible for sending data. Only active nodes are able to send data to destination which is chosen by source randomly. Data is generated with the

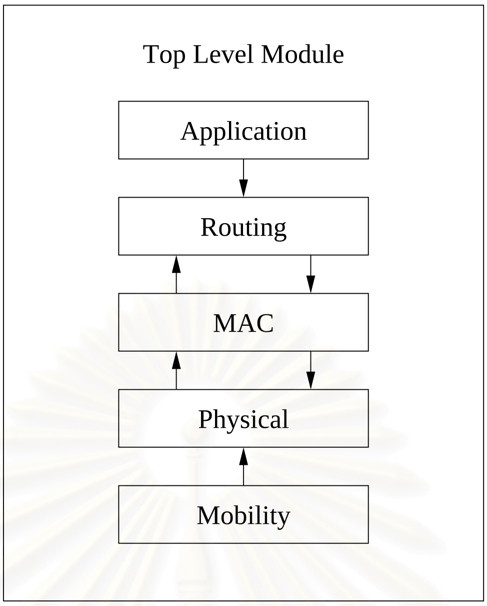


Figure 4.1: Layer structure of MANETs node.

constant bit rate and length. Those both parameters can be adjusted if it is required. This message is used to activate routing layer in which the path discovering process is run. Data is sent continuously during simulation time. Data lost is mostly due to link breakage or unreachable destination.

4.2.3 Routing Layer Module

Routing layer is ascendant part in MANETs because this layer is responsible for discovering the path for data transmission from source to destination. Jitter control mechanism is placed in this layer. Packet that will be forwarded is buffered in this layer. After exceeding certain number of packet in the buffer, the node forwards the packet to its neighbor. The minimum number of packets in the buffer is adjusted to get the optimum jitter alleviation and minimal end-to-end delay. As stated before, this research will use AODV routing protocol based on [8]

4.2.4 MAC Layer Module

The main function of the link layer is to handle the packet from network routing layer and physical layer. In this layer, data which is received from routing layer is forwarded directly to physical layer. Whereas, data from physical layer is queued with MM1 queue policy to simulate jitter.

4.2.5 Physical Layer Module

Connectivities among nodes are verified by maintaining its neighbors list. Message received from link layer is broadcast to neighbors node. Message from another node is delivered to higher layer which is MAC layer. Physical layer also receives message from mobility layer module from which position information that is used for updating position is obtained.

4.2.6 Mobility Module

The movement of each mobile host is determined by this module in which many movement algorithms can be applied in order to get different scenario of networks. Random way point and random walk mobility model will be used in this simulation. New position information is sent to physical layer.

4.3 Simulation Design

4.3.1 Performance Metric

Some performance metrics that will be investigated in this research are latency and jitter. Simulation will compare routing algorithm without to with jitter control.

4.3.2 Parameters

In order to get various results from simulation, some parameters are adjusted. The length of data is adjusted either 1 KBytes and 4 KBytes. Two mobility models which are random walk and random way point are used.

CHAPTER V

SIMULATION RESULT AND ANALYSIS

Results and analysis are presented in this chapter. Some simulation scenarios are run to yield many results with different parameters. Simulation consists of five scenarios which is elaborated in the following sections.

5.1 Simulation Results

For general scenario, message will be sent by only active node(s). However, in the case of movement scenario, random result can be gained from the simulation because the movement and chosen destination are random. Simulation time is based on kernel simulation time. The real time required by simulation directly depends on the complexity of scenario which is usually different from simulation time.

5.1.1 Static Node Scenario With Constant Bit Rate

The first scenario is run under static condition with AODV routing protocol. The simulation consists of five nodes as shown in Figure 5.1. One node acts as source from which packets stream are generated. Both variable and constant bit rate packets can be generated by source node. The rests can perform as either intermediate or destination nodes.

Each intermediate node has jitter control with three-packet buffer threshold. It means that the first packet that came to buffer will be released if the number of packets in buffer exceed four packets. This buffering mechanism will rearrange packet inter-arrival time which is equal to 0.25 second. Packet size for this scenario

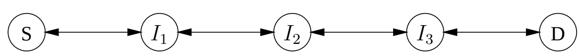


Figure 5.1: 4-hop ad-hoc communication.

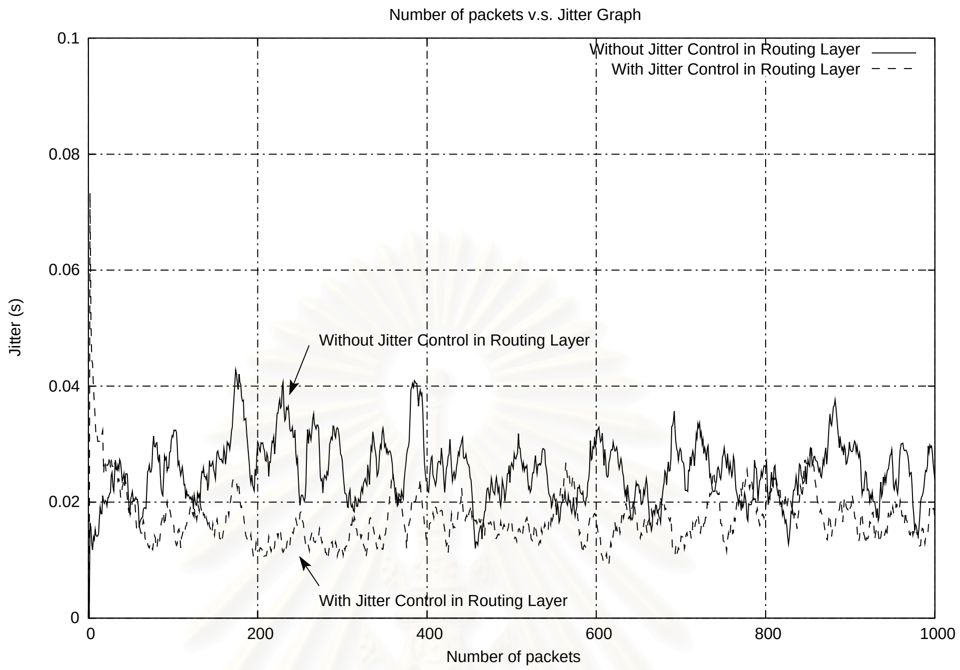


Figure 5.2: Jitter average in 2-hop communication.

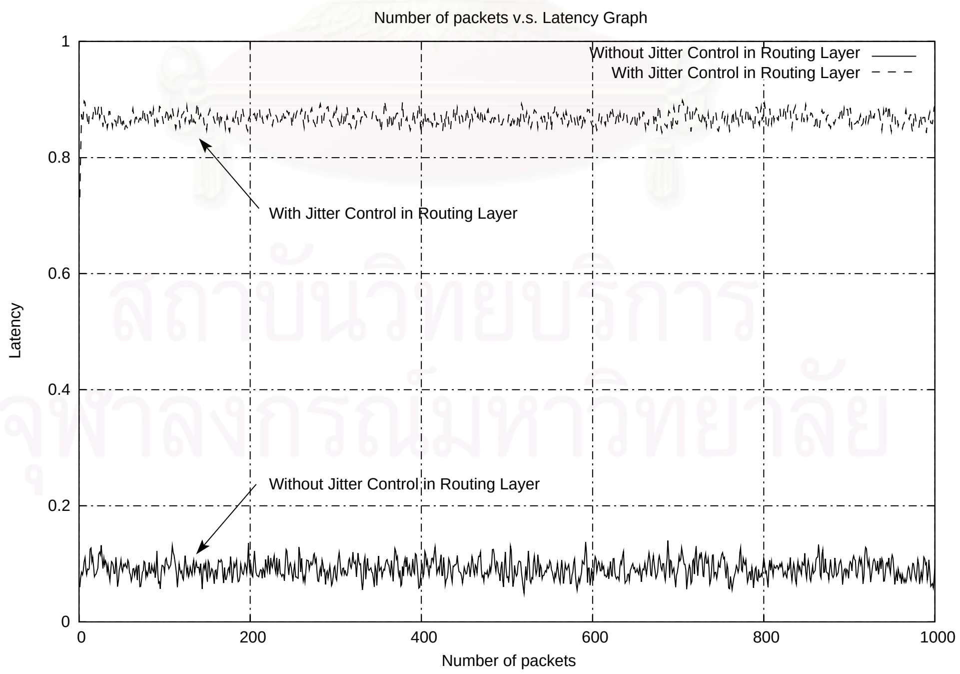


Figure 5.3: Latency in 2-hop communication.

is 1 KByte with constant bit rate. In order to obtain large number of packets that can reach to the destination, simulation is run in 5 minutes simulation time which take not more than 1 minutes of real time.

Jitter simulation is applied to MAC layer on each intermediate node. It is generated by uniform random distribution with the range of 0 to 0.05. By performing that, we hope that simulation can approach as close to the real jitter value as possible. In MAC layer, all simulation use 11 MBit/s channel data rate.

Figure 5.1 can be used for simulating 2-hop, 3-hop, and 4-hop communication. Two-hop communication consists of source node, intermediate node I_1, and I_2. In this case, intermediate node I_2 behaves as destination node in which jitter and delay value are recorded.

Jitter is measured by applying sliding average with window width is equal to 16. The formula to measured jitter is shown in the following equation.

$$J_{avg(n)} = \frac{J_n + J_{n-1} + \cdots + J_1}{w}; n \geq w \tag{5.1}$$

$$J_{avg(n)} = \frac{J_n + J_{n-1} + \cdots + J_1}{n}; n < w \tag{5.2}$$

Where w is window width and $J_{avg(n)}$ is jitter average at packet n. This formula can also be applied for measuring latency.

Jitter and latency of 2-hop communication are depicted in the Figure 5.2 and Figure 5.3, respectively. In the Figure 5.2, the solid line is jitter value without applying jitter control while the dashed line is jitter value with jitter control. The result shows that by buffering packet in the intermediate node and releasing with proper time interval can reduce jitter value.

In the Figure 5.3, latency of both with and without jitter control are presented. The solid line which is below graph is packet latency without jitter control while the other graphs is packet latency with applying jitter control.

Results of jitter and latency of three-hop ad hoc communication are presented in the Figure 5.4 and Figure 5.5, respectively. Any setting parameters of simulation between these results and the previous one are the same except number of hops. The jitter value without jitter control is represented by solid line in the Figure

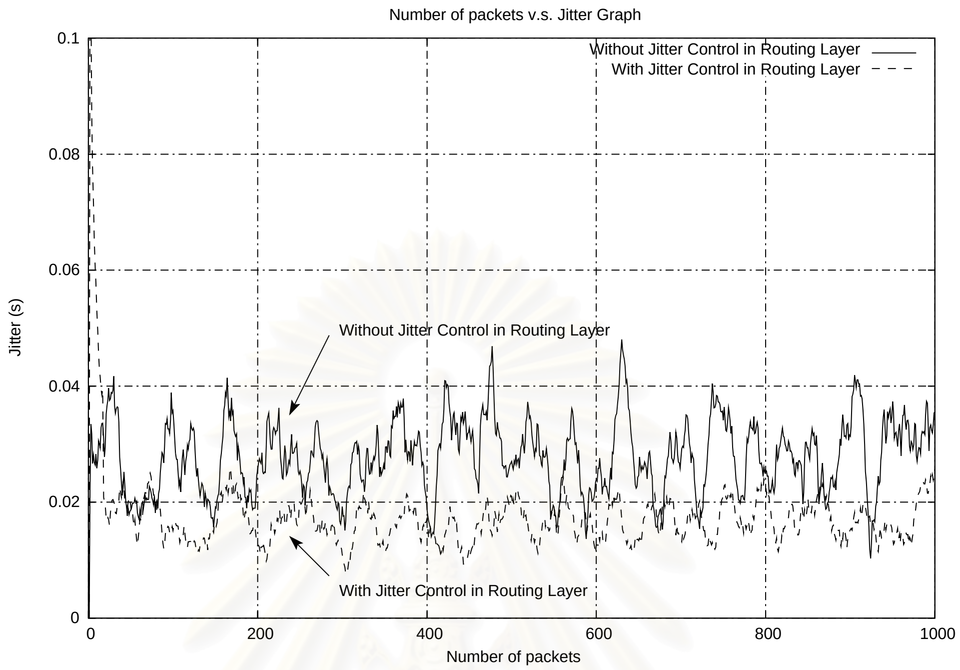


Figure 5.4: Jitter average in 3-hop communication.

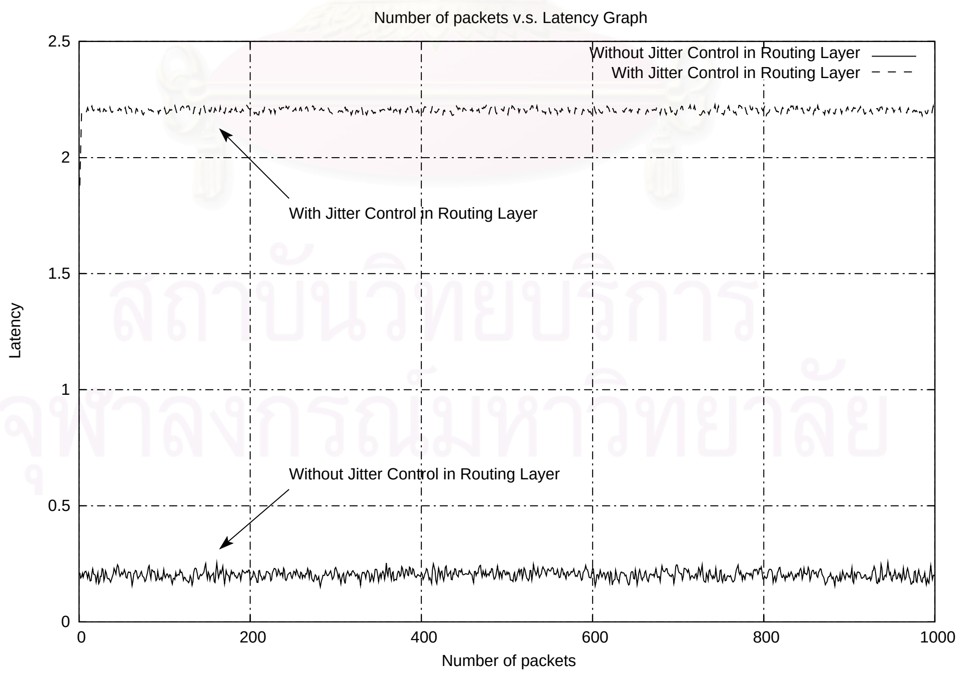


Figure 5.5: Latency in 3-hop communication.

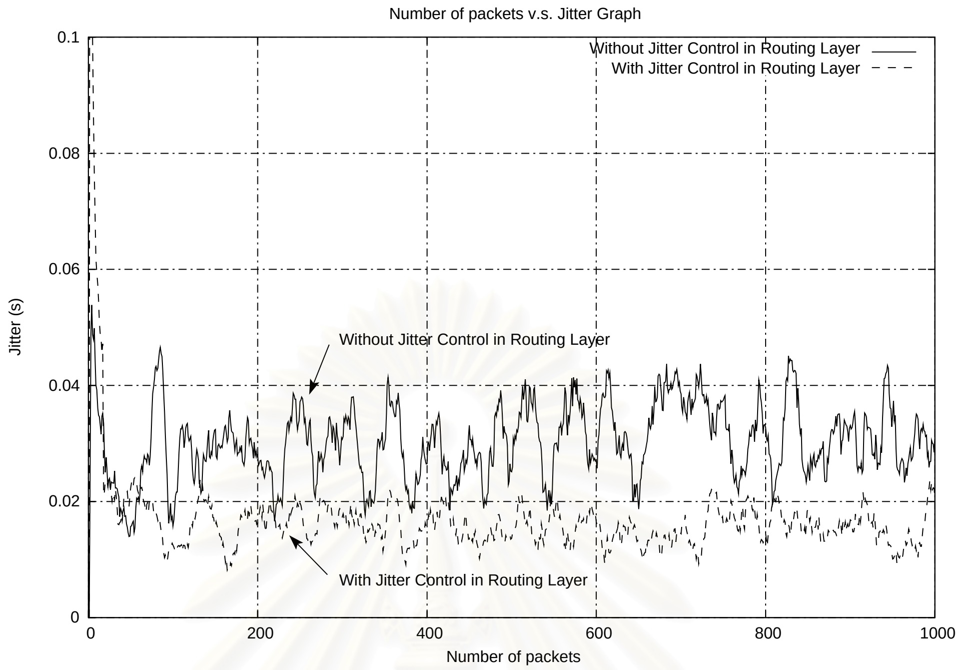


Figure 5.6: Jitter average in 4-hop communication.

5.4, whereas jitter value with jitter control is shown by dashed line. Jitter average without jitter control in this result is bigger than that in the previous result because higher number of hops. It agrees with the formula in Equation 2.2.

The same as in the result of two-hop scenario, latency of three-hop scenario without jitter control is depicted by solid line which is below graph of Figure 5.5. While latency with jitter control is shown by dashed line of the same figure. It is obvious that the more hops in communication, the more latency will be.

The last results of first scenario are shown in Figure 5.6 for jitter and Figure 5.7 for latency. The only difference between previous results and these results is number of hops. This simulation consists of four-hop communication.

5.1.2 Static Node Scenario With 4 KBytes Data Size

Jitter and latency are measured for only 4-hop communication. The only difference between first scenario and second scenario is the packet size which is 4 KBytes. Results of jitter and latency are shown in Figure 5.8 and Figure 5.9, respectively.

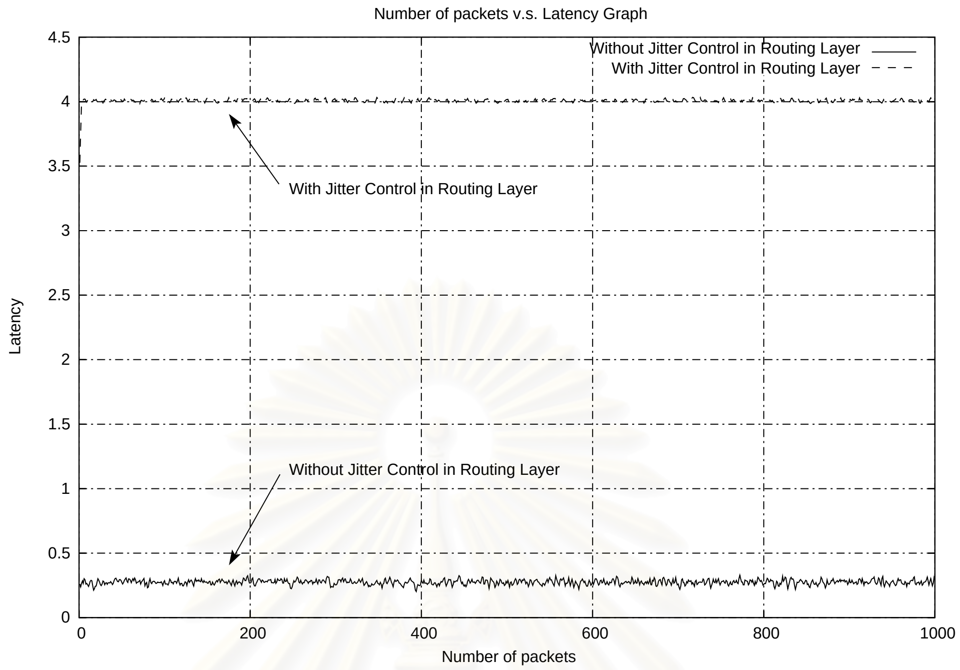


Figure 5.7: Latency in 4-hop communication.

Jitter trend and delay of this simulation is almost the same as that of previous simulation. It may be caused by the size difference of data size is not significant.

5.1.3 Variable Bit Rate Scenario

All previous simulations use constant bit rate data packet while in this scenario variable bit rate is performed to see the effect to jitter and delay. Jitter control is modified slightly as explained in the previous chapter in order to satisfy the variable bit rate. It is set randomly to be in the range 2 and 5 packets per second. To generate random bit rate, uniform random distribution is employed. Simulation time is set 10 minutes which is longer than previous simulation. It is intended to obtain the same number of packets which can reach to the destination. Result are shown in Figure 5.10 for jitter and Figure 5.11 delay.

Jitter trend of this simulation are almost the same as that of previous simulation. In delay characteristic there are suddenly delay changing on some places. It may be caused by bit rate change which is random.

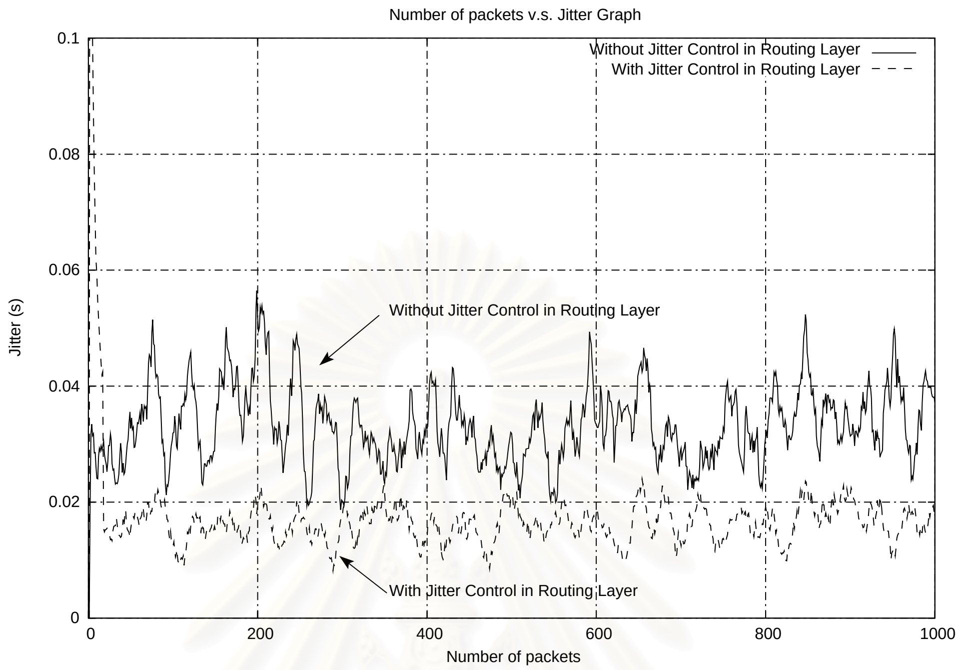


Figure 5.8: Jitter average in 4-hop communication (4 KB packet size).

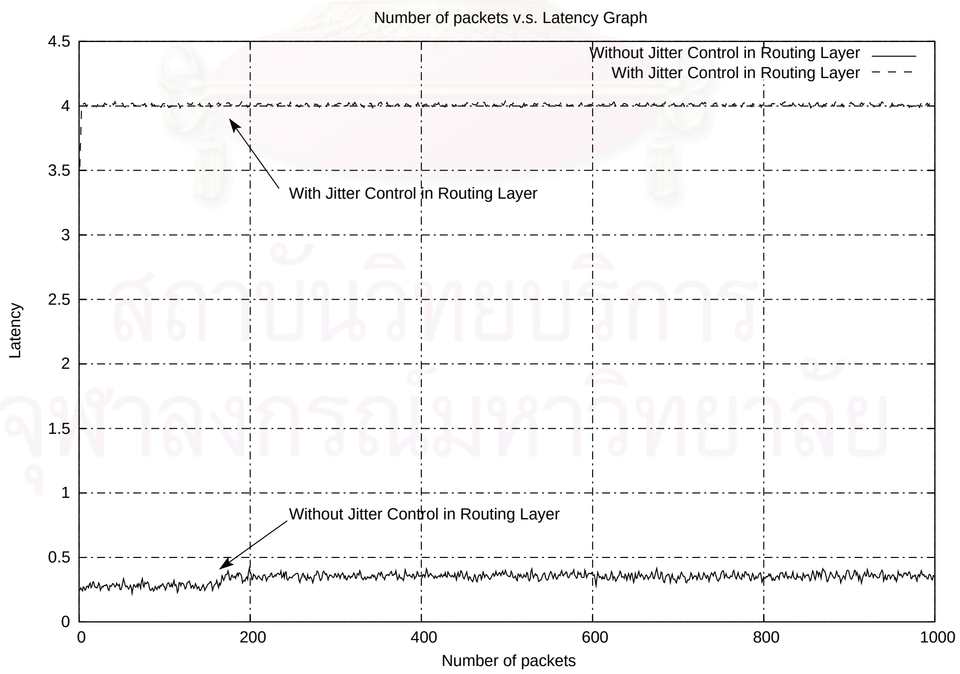


Figure 5.9: Latency in 4-hop communication (4 KB packet size).

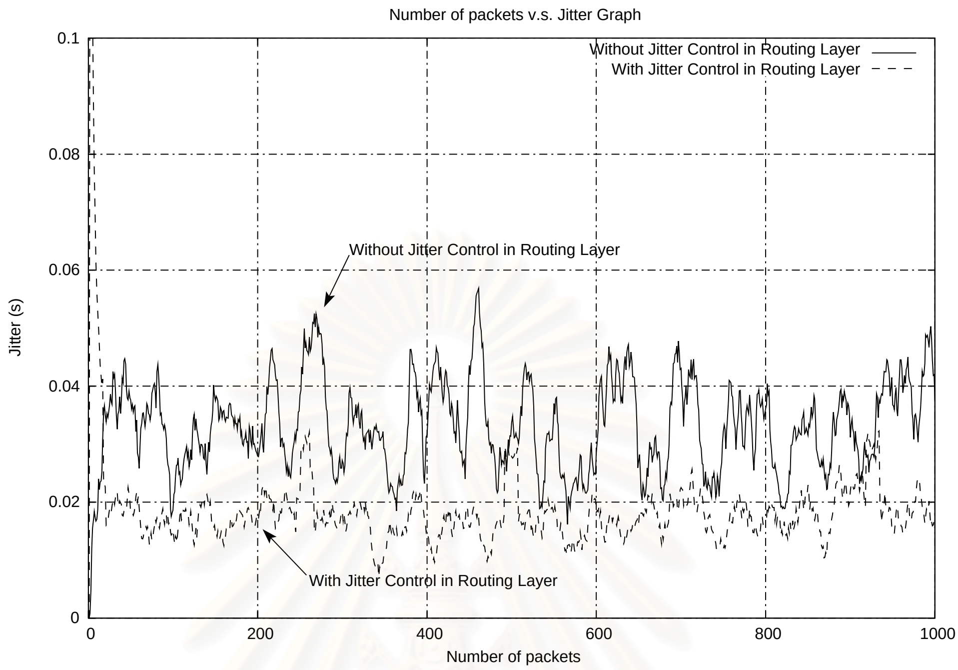


Figure 5.10: Jitter average in 4-hop communication (Variable Bit Rate).

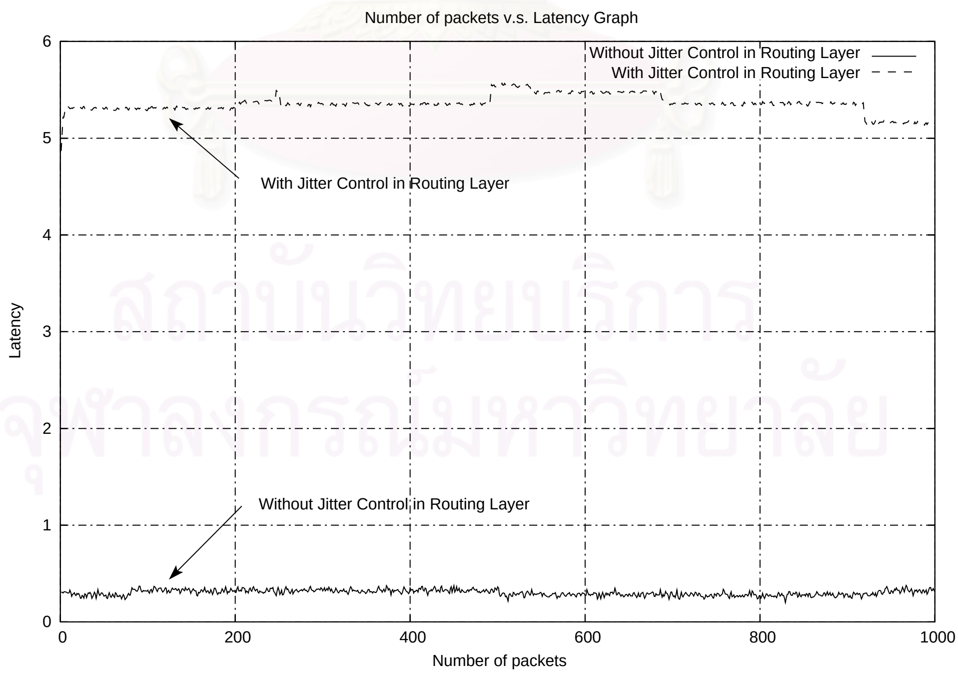


Figure 5.11: Latency in 4-hop communication (Variable Bit Rate).

5.1.4 Movement Scenario

First three simulation scenario is run under static environment which there is no movement. In this simulation, all nodes in the simulation area are moving. Two mobility models are employed. The first one is random way point mobility model and the other one is random walk mobility model. In both those model, nodes which exceed boundary of simulation area are reflected with the same angle. Results of both jitter and latency are collected from any nodes which act as destination.

Simulation area of this scenario is 900m x 600m. It containts 30 nodes which has 8 active nodes from which the packets are generated and sent to random destination. When simulation scenario is initialized, all nodes are spread on the simulation area randomly using uniform random distribution. Each active node choose its destination randomly with uniform random distribution. The number of communication hops can also be random.

Average jitter with random way point mobility model is shown in Figure 5.12. Figure 5.13 presents average jitter with random walk mobility model. Both graphs are generated from two-hop communication. In both mobility models, applying jitter control can reduce jitter.

5.1.5 Multipath Scenario

Multipath routing of the network will be employed to the network. This scenario is based on the flowchart in Figure 3.3. In order to evaluate in multipath routing environment, multipath network which consists of three paths as shown in the Figure 5.14 is presented. The switching mechanism will be evaluated by giving increasing value of jitter on each path. The variation of jitter on each part is simulated by changing the range parameter of uniform random distribution. The characteristic of jitter on each path is depicted in Figure 5.15, Figure 5.16, and Figure 5.17, respectively. Jitter is obtained from the following simulation settings: ad hoc network with stationary nodes, data rate of 4 packets/s (Constant Bit Rate), packet size of 1KByte, simulations time of 10 minutes, jitter threshold of 0.05s.

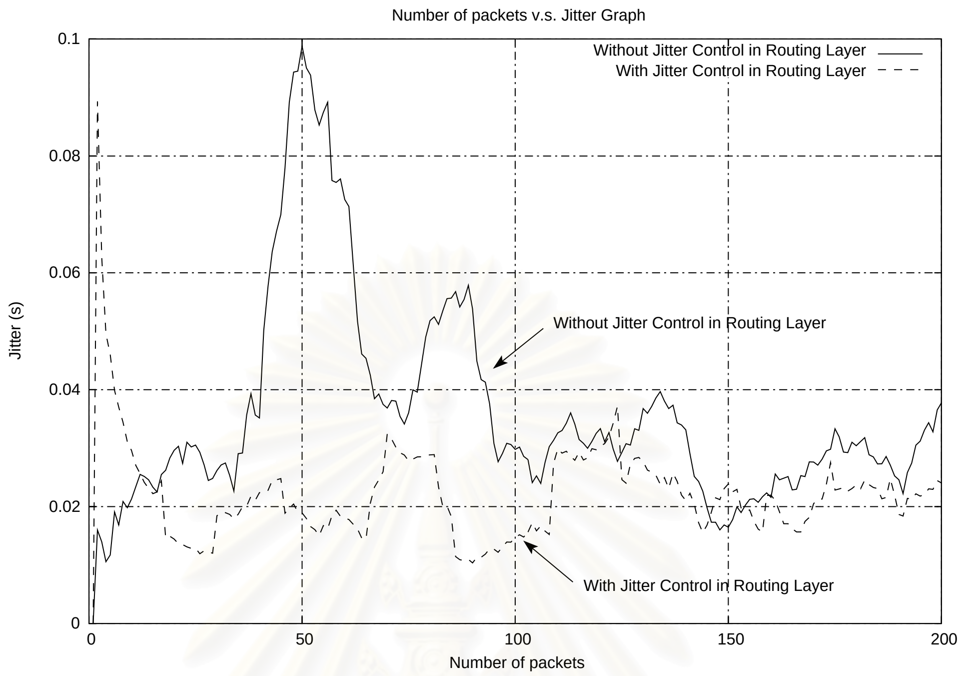


Figure 5.12: Jitter average in 2-hop communication with random way point mobility.

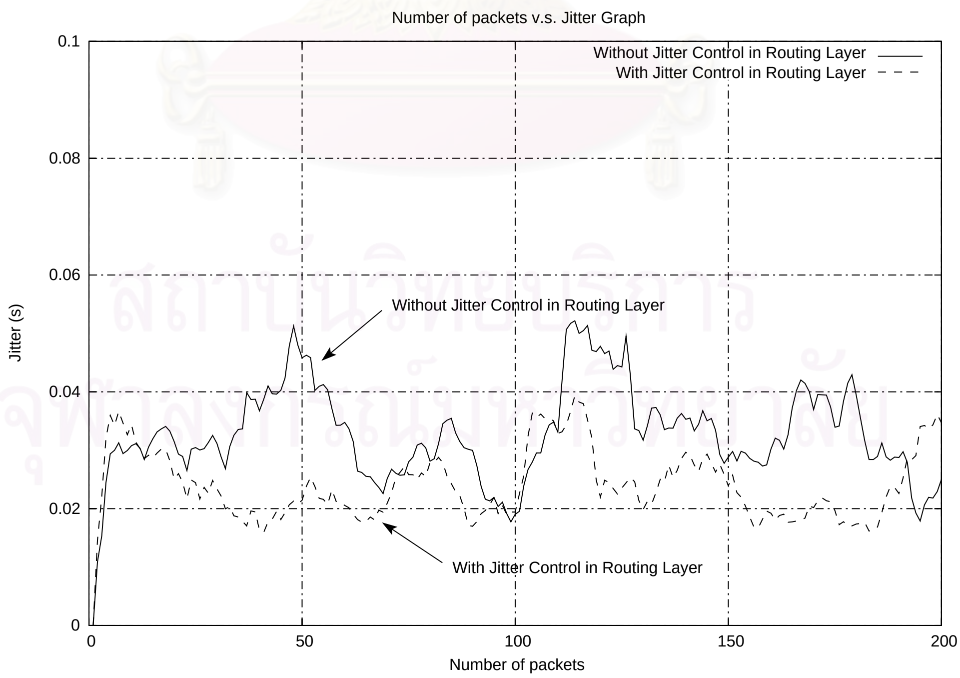


Figure 5.13: Jitter average in 2-hop communication with random walk mobility.

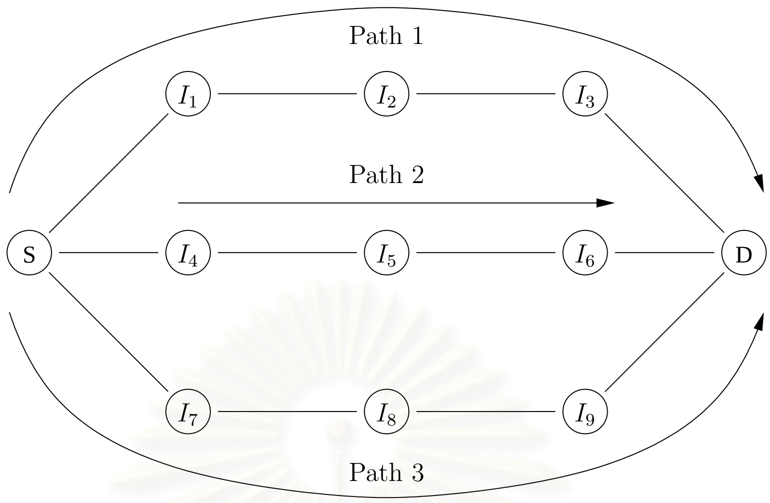


Figure 5.14: Simple multipath scenario.

Alternative paths which are not used for delivering data stream is monitored to obtain jitter by sending 1 KBytes packet every 10 seconds. Destination will return jitter information back to source through according path. This information is sent every 5 seconds. Decision is taken by source whether path is changed or not. It is done by comparing jitter information with jitter threshold.

If jitter from which destination informs to the source is greater than threshold, the data stream will be moved to the alternative path that was ready before. In the Figure 5.18, at the firs time, data is delivered through path one. This data stream suffers increasing jitter according to the jitter characteristic of path one. At packet number around 400, jitter threshold is exceeded then path is switch to path 2. Jitter at the receiver is improved according to jitter characteristic on path 2. At packet number around 1000 jitter exceeds threshold for the second time. Then, route is switched to path 3 which has lower jitter. Jitter threshold is reached for the third time at packet number around 1600. Again, path is switch to another path which is path 1.

Packet latency of this switching path mechanism is shown in the Figure 5.19. The average value of latency using multipath environment is better compared to previous buffering method. At the switching point, latency changes to better value according to the jitter characteristic of jitter of each path.

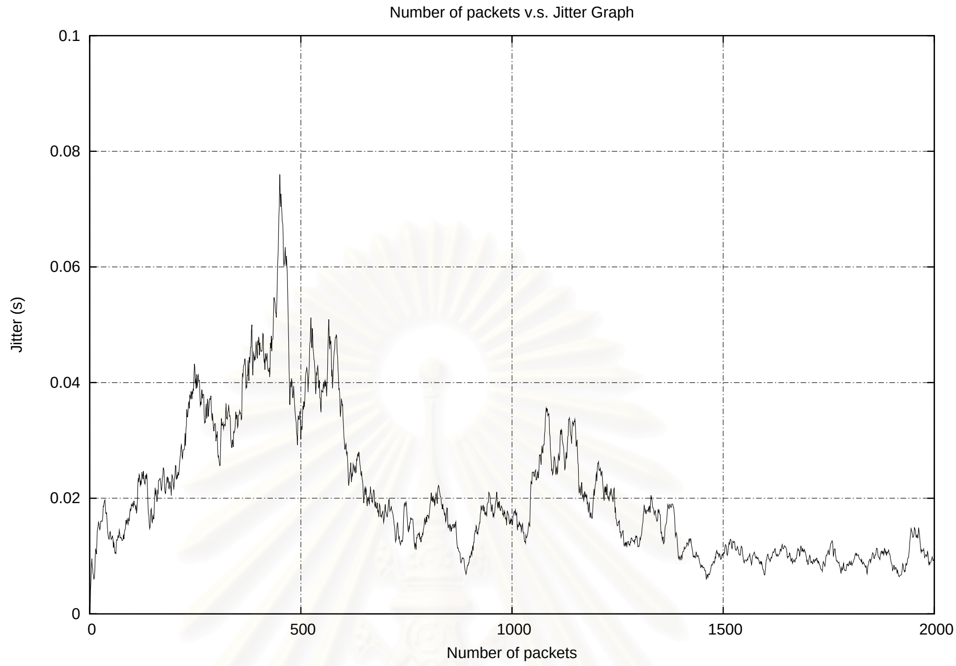


Figure 5.15: Jitter Characteristic of Path 1 of Figure 5.14.

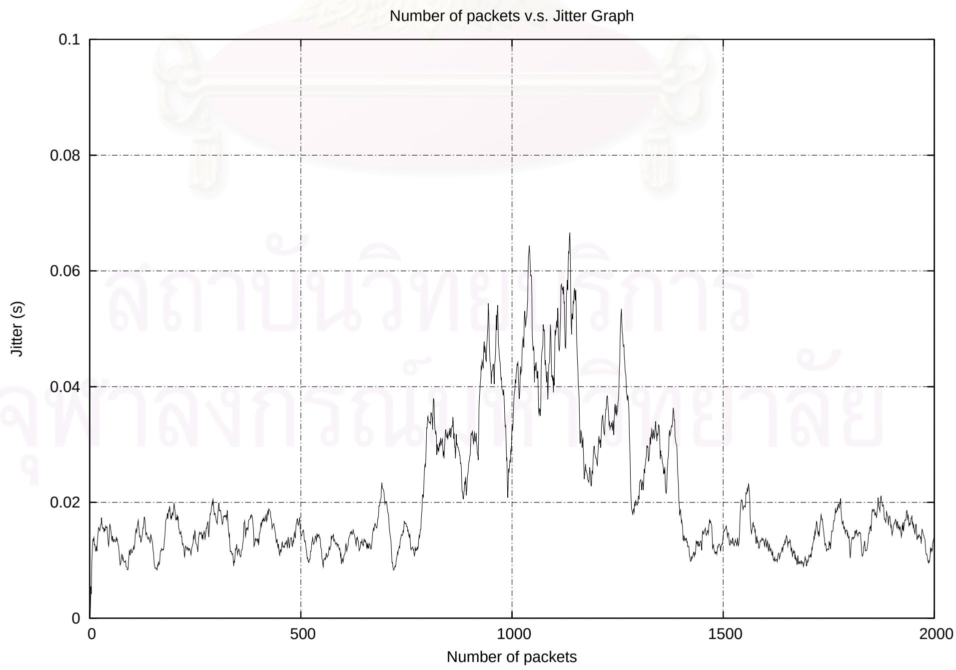


Figure 5.16: Jitter Characteristic of Path 2 of Figure 5.14.

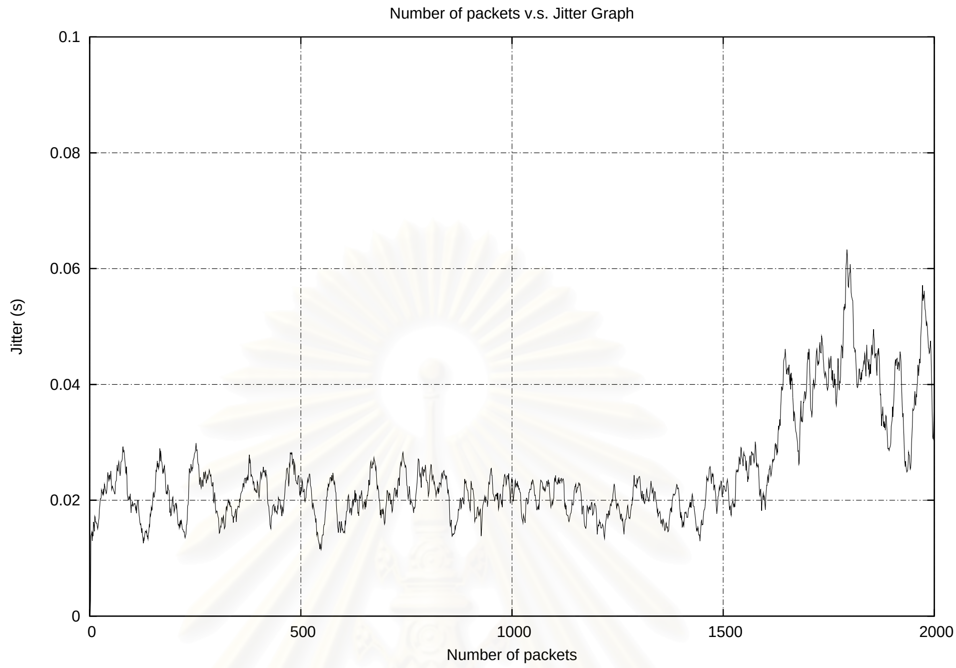


Figure 5.17: Jitter Characteristic of Path 3 of Figure 5.14.

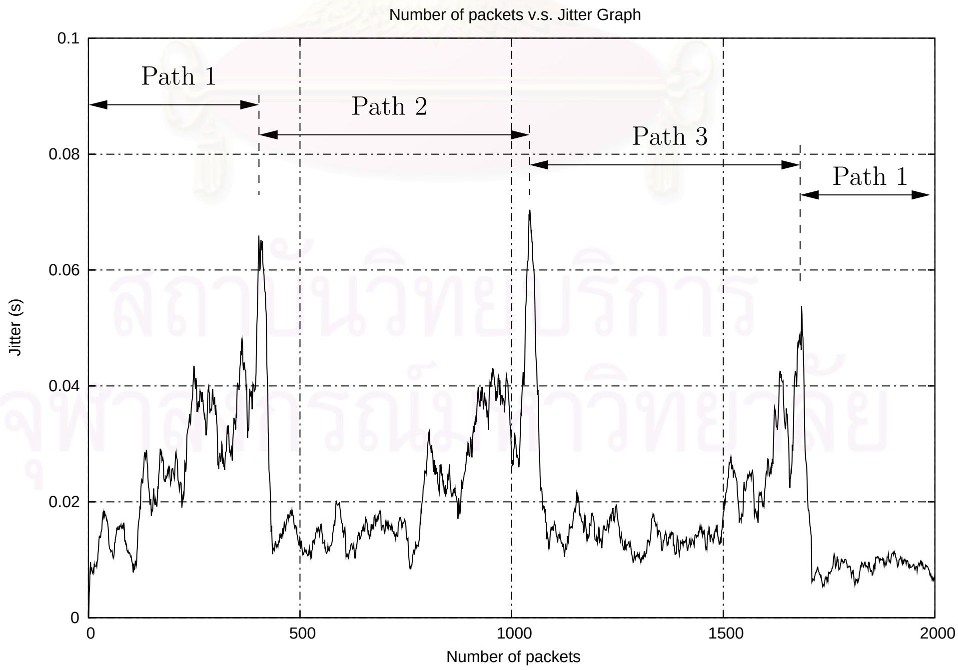


Figure 5.18: Jitter average with switching process.

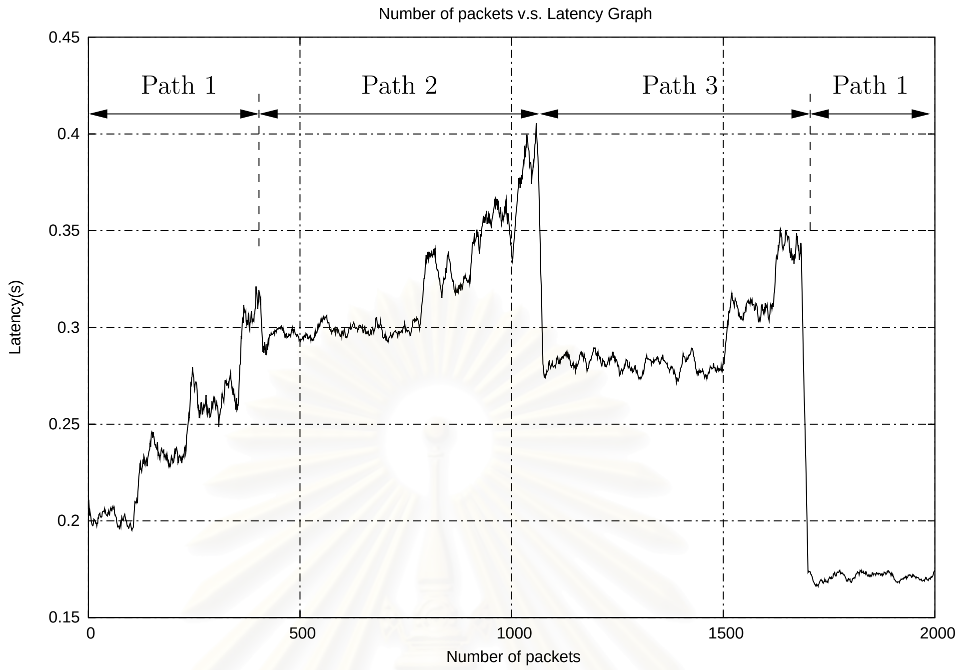


Figure 5.19: Latency average with switching process.

In this multipath environment that involves switching mechanism, there are two important factors that can affect the performance of system. The first one is frequency of test packet on backup route which is sent by source to destination and the other one is frequency of jitter information which is sent by destination to source. Setting to high frequency of those two can guarantee updated data eventhough it yields high over head and more fluctuation of jitter. In contrast, too low frequency produces outdated information of jitter.

Figure 5.20 and Figure 5.21 depict average jitter and latency on destination with every 20 second jitter information updating and every 20 second packet test. These two graphs and the following ones use 0.04s jitter threshold. Jitter fluctuation in this scenario is high. It is caused by long jitter information updating.

Figure 5.22 and Figure 5.23 show average jitter and latency on destination with every 1 second jitter information updating and every 20 second packet test. In this experiment jitter is relatively low compared to the previous and following experiment.

Figure 5.24 and Figure 5.25 present average jitter and latency on destination

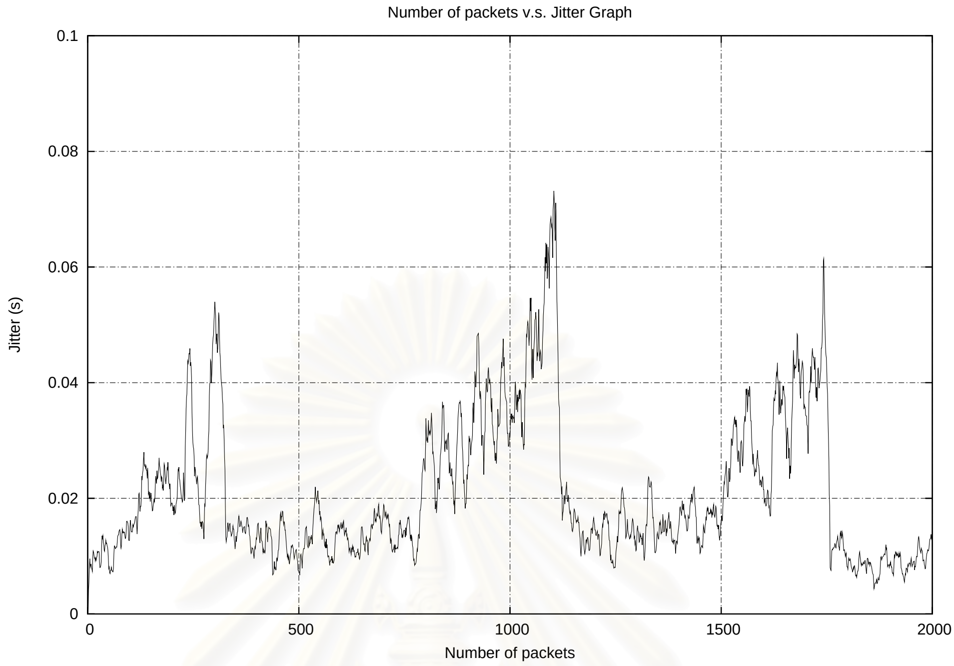


Figure 5.20: Jitter average in multipath environment with 20s jitter information updating.

with every 0.5 second jitter information updating and every 20 second packet test. By applying more frequency of jitter information updating, jitter fluctuation is also greater. This fluctuation is also contributed by data that bring jitter information from destination to source which use the same path.

5.2 Analysis

From the result in the first two scenarios, we can see that jitter control can work properly in the first scenario and second scenario. It is obvious that applying jitter control can contribute delay as depicted from the Figure 5.3, Figure 5.5 and Figure 5.7. This additional delay will not affect much to the non-interactive application such as video or audio streaming. In contrast, in the interactive application, high delay value quite disturbs user. Therefore, the buffering method is not dedicated to interactive multimedia application.

Various hops of communication are also presented. The results show that the greater number of hop, the more jitter value will be. It agrees to the Equation 2.2.

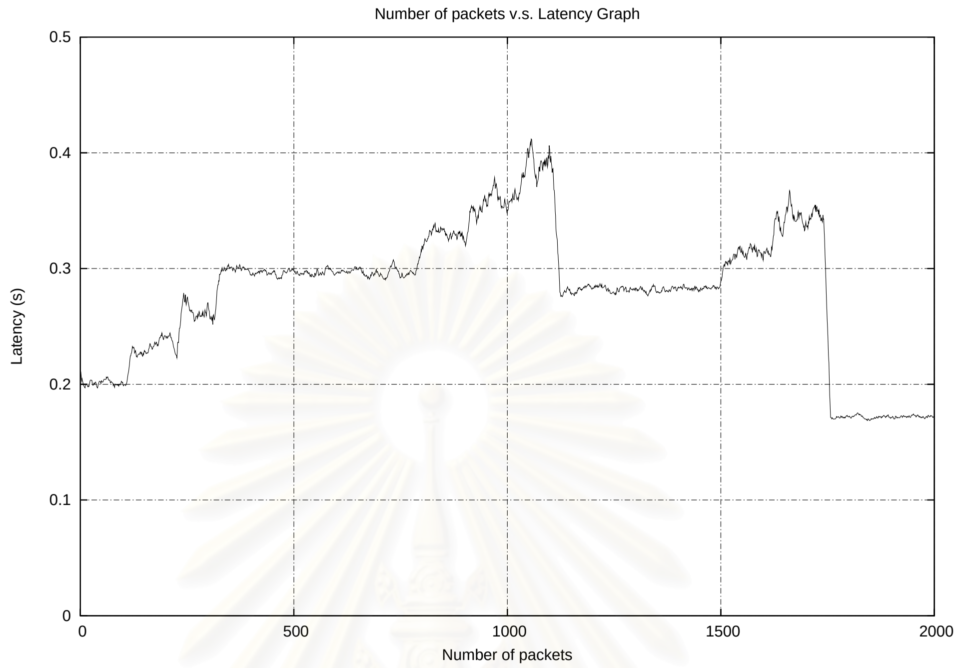


Figure 5.21: Latency average in multipath environment with 20s jitter information updating.

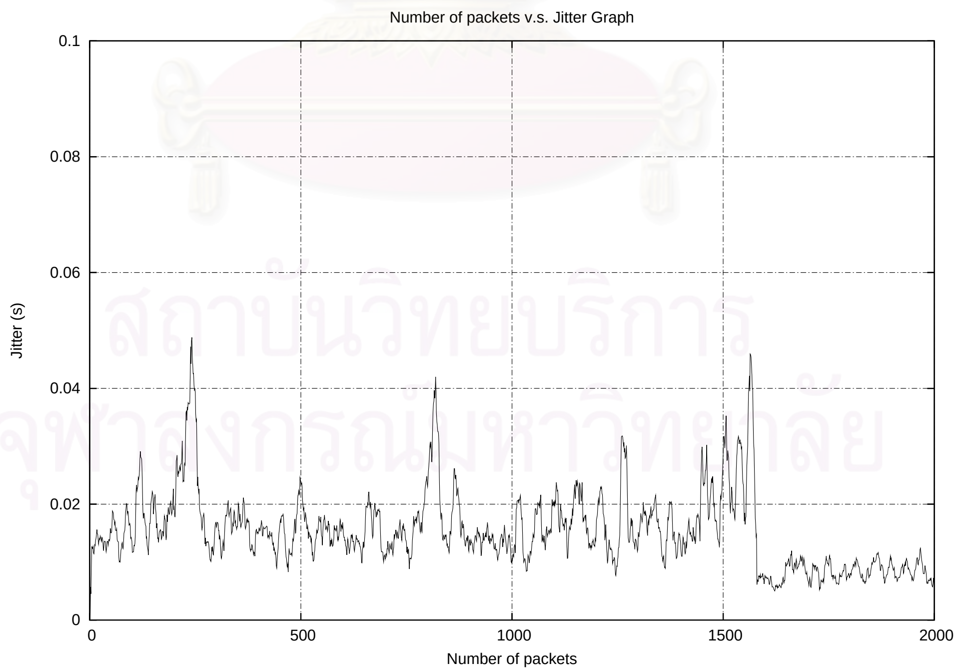


Figure 5.22: Jitter average in multipath environment with 1s jitter information updating.

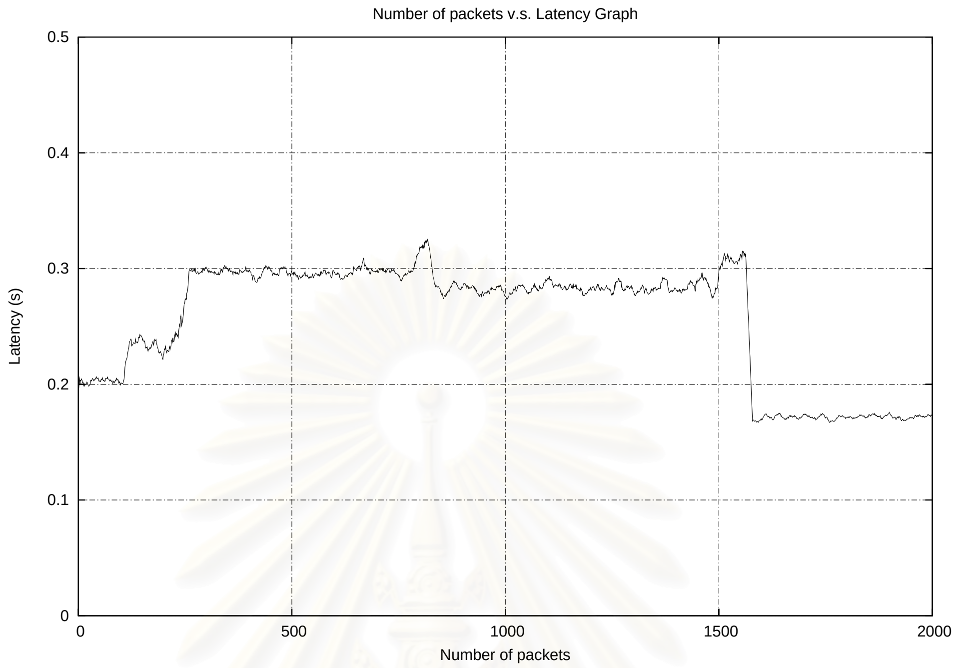


Figure 5.23: Latency average in multipath environment with 1s jitter information updating.

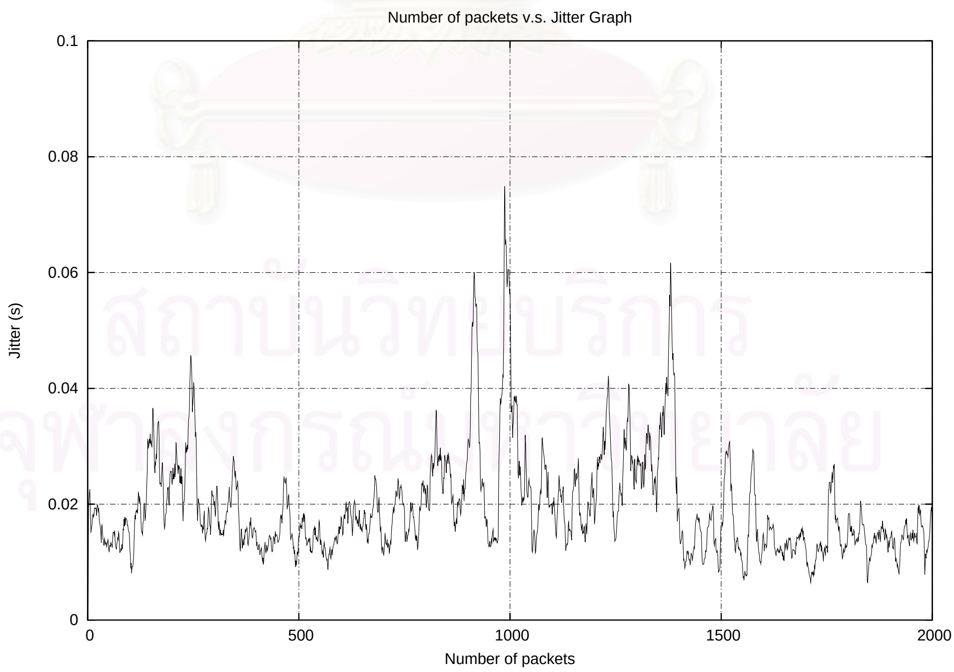


Figure 5.24: Jitter average in multipath environment with 0.5s jitter information updating.

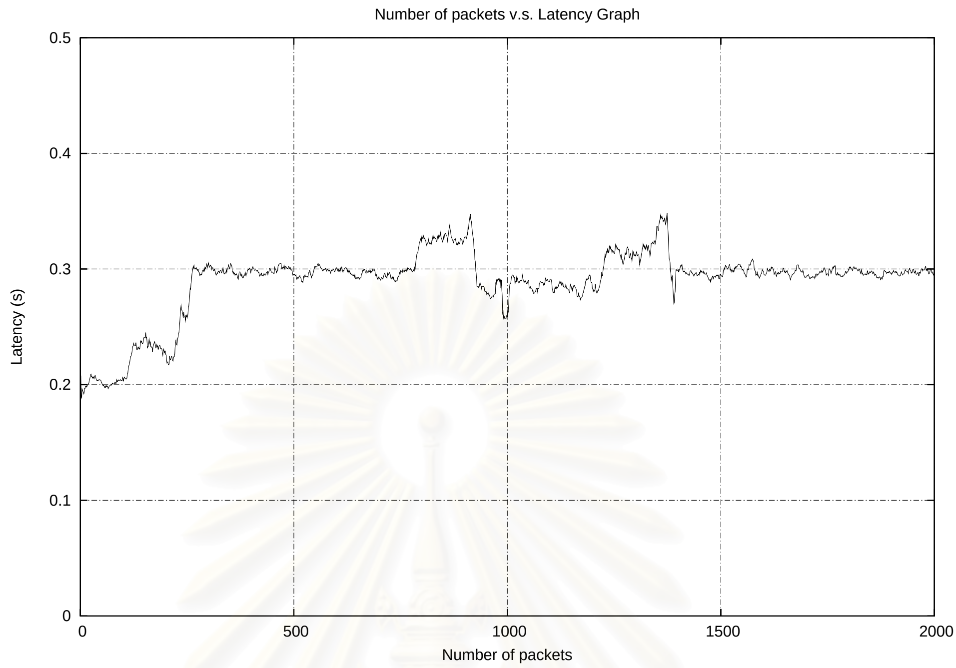


Figure 5.25: Latency average in multipath environment with 0.5s jitter information updating.

Both constant bit rate and variable bit rate are applied to the simulation. Figure 5.10 and figure 5.11 show the jitter and latency result, respectively. From that result, we can see that jitter control can handle variable bit rate data packet.

In the moving scenario, this simulation uses two mobility models which are random way point and random walk mobility model. Jitter control mechanism works properly on both of those mobility model as depicted in the Figure 5.12 and Figure 5.13, respectively.

Result of switching process in the multipath environment is presented in the Figure 5.18 and Figure 5.19. Jitter of data transfer is maintained as low as possible by choosing the paths which has lower one. That figure depicts when the jitter reaches the value around 0.05, the path is switched to the other one which has jitter value lower than 0.02. The performance of this method is affected by setting of how frequent jitter information updating is. Packet latency in this environment is not large which is suitable for interactive multimedia application instead of only non-interactive one.

Figure 5.20 to Figure 5.25 present jitter and latency with different jitter information updating frequency. Based on those results, the frequency of jitter information which is sent from destination to source should be considered carefully in order to get lowest jitter among available paths.

CHAPTER VI

CONCLUSION AND FUTURE WORK

6.1 Conclusion

In this research, we investigated jitter control and delay in the ad hoc network environment. The first proposed method is buffering packets on each intermediate node and rearranging packet inter-arrival time. The second method is switching the path in the multipath environment to find the best path among available path.

Based on the result in the previous chapter, jitter control can work properly in the ad hoc network environment with no movement. Both constant bit rate and variable bit rate data stream can also be tackled properly by jitter control. Jitter control can also be capable of handling jitter in the movement environment.

The disadvantage of applying jitter control by buffering method is that it will introduce additional delay to the packets which the value depends on the size of buffer threshold and number of hops. The greater value of buffer, the more delay will be suffered by packet stream. Besides, jitter will also increase if communication hop increases. Large delay is not suitable for traversing interactive application while it is still acceptable for non-interactive application such as audio or video on-demand.

In the multipath environment, jitter can also be controlled by keeping data transmission on the lowest jitter of provided paths. When the jitter on the active path exceeds the threshold, the transmission link is switched to use the alternative path. Applying multipath also has benefit that it is not required to flood route request again to find the path which has low jitter. However, this can not happen if all available paths don not have sufficient jitter for data transmission. Latency in this environment is not quite big which is suitable for interactive multimedia application. Compared to the buffering method, path selection in multipath environment is more promising method to reduce jitter in ad hoc network environment.

In this environment, we have to consider how frequent updating of jitter information and data test are. The higher the updating frequency, the larger the overhead will be. In contrast, low frequency updating can result wrong path selection which may yield large jitter.

6.2 Future Work

The work has shown that the performance of jitter control in the ad hoc network environment is quite promising. In order to upgrade the performance of jitter control, we can apply some improvements as following.

As explained in the previous chapters that applying jitter control in the system will affect to the delay. In the case of packet buffering method, choosing the buffer threshold is very important part of the whole process of jitter control. That critical part can be improved by using adaptive jitter control. The value of buffer threshold is controlled by the system depending on the predicted jitter value.

In the case of multi-path routing, this work only consider jitter metric on the path for selecting the best path. To upgrade the performance of path, additional metric such as delay and throughput can also be added.

In order to extend the functionality of jitter control in the ad hoc network environment, it can be applied to another routing algorithm such as, dynamic source routing, destination sequence distance vector, zone routing protocol, etc.

The work did not use real MAC simulation for simplicity. Therefore, to make closer to the real situation, it is better if the simulation process includes real MAC simulation.

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Biography

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