JIMMA UNIVERSITY

JIMMA INSTITUTE OF TECHNOLOGY

SCHOOL OF COMPUTING

LOAD BALANCING AND LINK EFFECTIVE COMMUNICATION TIME BASED IMPROVED AOMDV ROUTING PROTOCOL (LBLET-AOMDV) FOR SUPERSONIC SPEED FLYING AD HOC NETWORK

A THESIS

Submitted by

WERKNEH ESHETE YIFRU

In Partial Fulfillment of the Requirements for the Degree

of

MASTER SCIENCE IN COMPUTER NETWORKING

JIMMA, ETHIOPIA

January, 2018

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MAIN ADVISOR: SAMUEL ASFERAW (PHD)

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JIMMA, ETHIOPIA

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DECLARATION AND CERTIFICATION

This Independent Thesis entitled **"Load Balancing and Link Effective Communication Time Based Improved AOMDV Routing Protocol(LBLET-AOMDV) For Supersonic Speed Flying Ad Hoc Network"** has been read and approved as meeting the preliminary research requirements of the School of Computing in partial fulfillment for the award of the degree of master's in computer Networking, Jimma University, Jimma, Ethiopia.

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13/04/2018	

ACKNOWLEDGEMENT

I would like to express my gratitude to my advisor Dr. Samuel Asferaw for his guidance, support and his continuous enthusiasm and encouragement throughout this thesis work. I am also very grateful to extend my sincere thanks to my co-advisor Mr. Geletaw Sahle and other staff members of computer networking and operating system department for their cooperation. I also extend many thanks to my friends, who have helped and given me suggestions, supports and corrections during this study. Last but not the least, I want to express my grateful thanks for my beloved family, for their strong cooperation by standing with me throughout every step of my academic work.

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Acronyms

ABR	Associativity Based Routing protocol
AGT	Agent Type
AODV	Ad hoc on demand Distance vector routing protocol
AOMDV	Ad hoc on demand multipath Distance vector routing protocol
CBR	Constant Bit Rate Traffic
DSDV	Destination-Sequenced Distance-Vector Routing
DSR	Dynamic Source Routing protocol
EGM	Enhanced Gauss Markov mobility model
FANET	Flying Ad hoc Network
FSR	Fisheye State Routing protocol
GM	Gauss Markov model
HRP	Hybrid routing protocol
ISR	Intelligence, Surveillance, Reconnaissance
LAOR	Load-Aware On-Demand Routing
LBLET-AOMDV	Load Balancing and Link Effective communication Time based AOMDV
LET	Link Effective communication Time
M	Mach (1Mach=340meter/Second= 1,225 Kilometer/Second)
MANET	Mobile Ad hoc Network
MRP-LB	Multipath Routing Protocol with Load Balancing
NAM	network animator
NCW	Network Centric Warfare
OLSR	Optimized Link State Routing Protocol
OMNET	Objective Modular Network Test-bed in C++
OPNET	Optimized Network Engineering Tool
OTCL	Object Tool Common Language
QLB-AOMDV	QoS and Load Balancing AOMDV
QoS	Quality of Service
RET	Route Effective communication Time
RREP	Route Reply messages
RREQ	Route Request messages
RRL	route relying load
RRP	Reactive Routing Protocol
SHARC	Stability and Hop-Count based Approach for Route Computation
SMR	Split Multipath Routing
SSA	Signal Stability-Based Adaptive Routing Protocol
TORA	Temporarily Ordered Routing Algorithm
UAV	Unmanned Aerial Vehicles
UDP	User Data Gram Protocol
VANET	Vehicular Ad Hoc Network
ZRP	Zone Routing Protocol

Abstract

Mobile Ad-hoc Network (MANET) is a group of mobile nodes in which every node can communicate with each other without any fixed infrastructure. Ad Hoc network has an irreplaceable role and a broad application prospect in the field of battlefield communications. Currently in battlefield communications the flight speed of advanced cruise missiles, air defense missiles, fighter jets, unmanned reconnaissance aircraft, and other high-speed flight bodies can reach Mach 3-5 (about 1700m/s) which forms supersonic speed flying ad hoc network. Traditional routing protocols will not suit supersonic speed flying ad hoc network. For example, routing overhead incurred from route maintenance and route rediscovery when min-hop routing protocol try to recover broken link which is selected based on hop count metric without considering quality of link, make it unsuitable for supersonic speed flying ad hoc network. Specifically, on-demand routing is widely developed in highly dynamic mobile wireless ad hoc networks because of its effectiveness and efficiency. Most proposed on-demand routing protocols (such as in AODV and DSR) however, build and rely on single route for each data session and route rediscovery process when active path fail in single path routing will lead to extra overhead and latency and make under this highly dynamic network and make it unsuitable. On the other hand, LET based routing protocol and shortest path routing protocols repeatedly use a node and bandwidth around the best path respective of their metric which will create congested node and overloaded bandwidth around the path and leads to congestion and overwhelm the overall network performance. In addition to this, LET based routing protocol incurs additional end to end delay which make it unsuitable to support for QoS. Lastly, under bandwidth constrained wireless networks congestion commonly occurred which leads to longer end to end delay, packet loss and reduced network performance. Towards this, we have improved the routing protocol based on AOMDV by utilizing the idea of active communication time of link and load balancing strategy that splits the load among node disjoint multiple paths in round robin fashion to avoid congestion and to use network resources efficiently and make it support for QoS. Simulation results of the improved AOMDV using ns-2 shows its suitability for supersonic speed flying ad hoc network and the performance improvements in terms of the end to end delay, packet delivery ratio, and packet drop ratio in comparison with original routing protocol (AOMDV).

Keywords: MANETs, Supersonic Speed Flying Ad Hoc Network, Active Communication Time of Link, Load Balancing, Traffic Splitting, Multiple Route, Node Disjoint Path

Chapter 1
Introduction

1.1. Background

Mobile ad-hoc network(MANET) is a collection of wireless mobile nodes (or routers) dynamically forming a temporary network without the use of any existing network infrastructure or centralized administration. MANET is an emerging technology whose potential presents an opportunity to greatly improve warfighting capabilities [20]. The communities of military redefine the way wars will be fought in the future, evolving towards a Network-Centric Warfare (NCW) paradigm, where all elements of the warfighting apparatus are highly connected by electronic information networks down to the individual person or unattended sensor shown in Figure 1-1. Network Centric Warfare is an information-superiority enabled concept of operations that generates increased combat power by networking sensors, decision makers, and shooters to achieve shared awareness, increased speed of command, higher tempo of operations, increased survivability, and a degree of self-synchronization. The goal of NCW is to increase combat effectiveness through the increased awareness and knowledge throughout an organization, enabling through faster decision cycles. This means that the network and its infrastructure become a key enabler that promotes increased tempo and self-synchronization of operations [20]. Because, tactical-edge operations so often take place in locations where usable infrastructure is scarce, nonexistent, or unsuitable, MANET technology is attractive, as it would enable the creation of networks on demand as the need arises. Notionally, a MANET is constructed from a disparate set of participants who must interact in to complete an assigned mission.
Tactical warfighting apparatus currently consist of advanced cruise missiles, air defense missiles, fighter jets, unmanned reconnaissance aircraft and other high-speed flight bodies which have a speed that can reach Mach 3-5(about 1700m/s) [13]. This kind of networks will form supersonic speed flying ad hoc network which is the working environment for this research.

Though the advantage and applicability of NCW which enabled by MANET technology, there are many challenges for seamless deployment of MANETs in combat environment. As routing is the key solution under any network for forwarding traffic seamlessly with a good path the first challenge is selecting good routing strategies. Due to supersonic speed behavior link break is common. In addition to routing challenge, limited resources such as bandwidth under this network which leads to congestion should be considered to drive better QoS routing [65, 72].

QoS is nothing but the level of performance of particular routing protocol of service providing to network end users. Many real time applications especially multimedia programs having the QoS requirements which must be achieved. This application requires the underlying network to provide certain guarantees that are manifested in the support of several important QoS parameters such as throughput, delay, jitter, packet de-livery ratio, link stability, node buffer space, packet loss ratio etc.

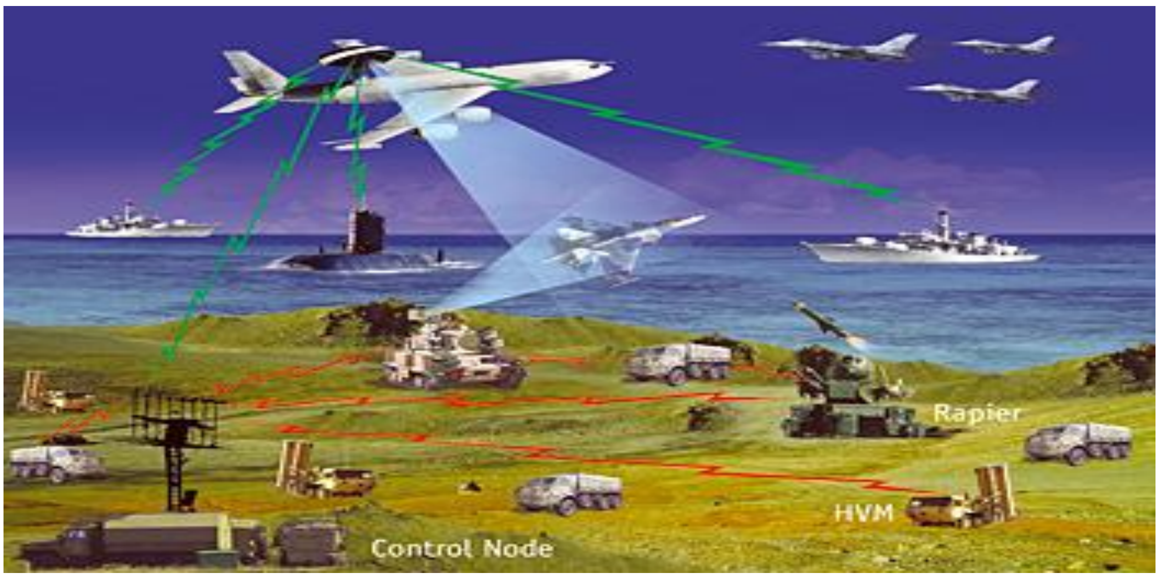

Figure 1-1: Network Centric Warfare

In this research to provide QoS routing for supersonic speed flying ad hoc network for enabling MANET-NCW we select to improve Ad Hoc On Demand Multipath Distance Vector Routing Protocol (AOMDV) [48] due to its efficient way of route cache management and its multipath property unlike Ad Hoc On Demand Distance Vector Routing Protocol (AODV) [35]. The proposed solution attempt to integrate 1) the knowledge of node mobility information done with link effective communication time calculation [13] so that we can predict where the aircraft will go in the future and enable as to select more stable link among available link unlike min-hop routing (minimum hop routing) and 2) the knowledge of load balancing so that we can efficiently use network resources under resource constrained network [65] and reduce the end to end delay incurred by tradeoff of between link effective communication time and network overhead from route re-establishment when the active route fail in single path routing. Efficient use of the resources in MANETs is of great importance to maintain the required quality of service. Till now there is no best routing protocol that well suites to this environment. Hence, we attempted to improve AOMDV to support for QoS and increase the performance of bandwidth limited ad hoc networks such as supersonic speed flying ad hoc network.

Therefore, this work proposes a better QoS routing algorithm which alleviates QoS routing problems like end to end delay, packet delivery ratio, packet drop ratio in supersonic speed flying ad hoc network to improve MANET-NCW application.

1.2. Statement of the Problem

Currently there are dozens of researches conducted on MANET routing with a node speed of 5-50 m/s which is appropriate for ground combat unit and fighting vehicles but NCW enabler in modern combat units also contain advanced cruise missiles, air defense missiles, fighter jets, unmanned reconnaissance aircraft, and other high-speed flight bodies that can reach Mach 3-5 (about 1700m/s), far exceeding the traditional protocol's velocity design. This combat unit will form supersonic flying ad hoc networks as pointed out in [13]. supersonic flying ad hoc network combat unit will cause frequent changes in network topology and the traditional principle of routing protocols in ad hoc networks is no longer applicable in this environment.

There are many problems to use traditional min-hop routing protocols directly for high-speed flying body network scenarios. There are two cases for this. The first one is, in this routing protocols, nodes on the shortest path will be more heavily loaded than others since they are frequently chosen as the routing path. Not only the node but also the bandwidth lying in the shortest path will be overloaded which needs special attention. This will create congested nodes and overloaded bandwidth at the center of the network which can lead to packet loss and buffer overflow, resulting in longer end-to-end delay, degradation in throughput, and loss of transport connections. Min-hop routing protocols use hop count metrics to select a best path without considering quality of link which make it unpleasant for supersonic speed flying ad hoc network because shortest path might contain weak link that will break soon before communication ends, and this is the second reason not to use min-hop routing to supersonic speed flying ad hoc network [13, 43, 29]. When the route breaks, min-hop routing protocols try to recover the connection either by repairing the route locally around the breakage or globally by informing the source node which then starts a completely new route discovery process. Each maintenance or route rediscovery is an additional overhead for the network. This overwhelms the whole network and the performance of the network will be decreased. Min hop routing can be reactive (on-demand) or proactive (table driven). The reactive or on-demand routing protocols determine a route only when required, using a broadcast query-reply cycle. Proactive routing protocols determine routes for every pair of nodes in the network, irrespective of the requirement. In dynamic scenarios, typical to that of MANETs, reactive on-demand routing protocols incur less overhead and exhibit better performance compared to the class of proactive routing protocols [69,70]. Hence, we restrict our attention to the on-demand routing protocols in this paper. However, on-demand approach is not without problems. In On-demand routing protocol, route discovery will often restart process due to dynamic nature of the network when active path is failed. This causes the network to be overloaded only by protocol control packets which spread all over the node. The network load causes a great burden on a node and a wastage of network resources. Most of the existing on-demand routing protocols (for example, Dynamic Source Routing (DSR) [15] and Ad hoc On-demand Distance Vector (AODV) [35] build and rely on single path for each data session. So, route recovery or rediscovery process is needed after each route failure, which causes to lose transmitted data packets and induce latency in such protocols. All the nodes in the table-driven routing protocol need to maintain the network static routing information at any time, and because the network state change frequently the routing table itself is difficult to update at any time, even if the update is completed, the maintenance of the information is not available (for example Destination-Sequenced Distance-Vector Routing (DSDV) [16] and Optimized Link State Routing Protocol (OLSR) [50]). It is precisely because the node’s high-speed movement caused by the network state change is violent, the above-mentioned agreement cannot be applied to the ad hoc network environment described in this paper.

In addition to this, supersonic speed flying ad hoc network has limited bandwidth resources [65] and hence congestion is possible which leads to longer end to end delay, packet loss, and reduced network performance. But, emerging multimedia applications require the underlying network to provide certain guarantees that are manifested in the support of several important QoS parameters such as throughput, delay, jitter, packet delivery ratio, link stability, node buffer space, packet loss ratio etc. [66]. Intelligence, Surveillance, and Reconnaissance (ISR) is a very critical and important operation in combat system which used to collect information about the enemy, terrain, weather, intentions of adversary and other aspects that will affect friendly combat operations. ISR systems ranges from satellites, to manned aircraft, to unmanned aircraft systems, and to human intelligence teams. The intelligence data provided by these ISR systems can be a video, image, sound and a short text and can take many forms, including optical, radar, or infrared images or electronic signals. Effective ISR data can provide early warning of enemy threats as well as enable military forces to increase effectiveness, coordination, and faster decision making at command and control center [75]. This is best example of multimedia application under this network. Resource constraints in MANET require the traffic to be properly distributed among the mobile hosts. Otherwise, heavily loaded hosts and bandwidth may cause congestion and large delay; even it may deplete energy quickly, which will lead to decrease in network performance and failure of application sessions. Though we will not consider the energy depletion as a problem in flying ad hoc network, because the on-board system of the internet will get power from the aircraft engine itself, the other MANET constraints also apply to Flying Ad hoc Network (FANET) [28]. Thus, there must be mechanism to cop up this problem in supersonic speed flying ad hoc network so that combat mission is conducted with high coordination, without any delay in transmission of data from sender to destination.

In extension to the above traditional routing algorithm many scholars and research institutions have proposed many routing algorithms for example, the well-known strategy in this environment currently is done in [13] using the idea of "effective communication time of link " on DSR routing protocol to solve the network changes caused by supersonic mobile nodes. Even though the algorithm still has a relatively strong feasibility and applicability, the mechanism they use increases the hop count in transmission which affects the performance of the network by incurring additional end to end delay and hence do not support for QoS [13, 68]. Due to its cache mechanism, DSR is not recommended for highly dynamic network [48]. Under highly dynamic network the path constructed most of the time is not used for long time due to high dynamicity of the network, which entails us to use efficient way of purging stale route from the cache. DSR however, does not apply any aging mechanism for cached route entries, and hence routes stored in the cache (either by the source or the intermediate nodes) may be stale [36]. Due to this DSR cannot maintain precise routes and drops more packets as nodes move more, and cannot be a good routing protocol for supersonic speed flying ad hoc network. In addition to link effective communication time strategy, signal strength based routing protocol (for example Signal Strength based Adaptive routing (SSA) [44]) is proposed in improving min-hop routing protocol. In contrast to link effective communication time based routing protocol, this routing protocol chooses the route if the receiving signal strengths of radio links along this route are larger than a threshold value. But as studies shows that [25] routing protocols which depend on signal strength as a routing metric cannot be used for airborne ad hoc network in general, because of the fact that signal strength will be bad in bad weather condition and all routing protocol will not get correct value of signal strength value to select best route. In addition to this, both signal strength based and link effective communication time based routing protocol tends to repeatedly use nodes and bandwidth lying on the stable path and hence creates congested node and overloaded bandwidth around the path and create unfair load distribution in the network which lead to congestion and lastly decrease overall network performance [68]. This needs a proper mechanism for distributing traffic throughout the network to ease congestion.

From the above discussion, we can observe that none of them are adequate routing protocol for supersonic speed flying ad hoc network for enabling modern NCW. Therefore, in this paper we propose an algorithm that combines prior research efforts in a novel way to achieve results not previously realized. To support for quality of service for multimedia communication in supersonic speed flying ad hoc network for network centric warfare, the proposed algorithm exploits the node mobility knowledge for forecasting link effective communication time between two links and the concept of load balancing that distribute traffic on multiple node disjoint path. Through load balancing, the proposed algorithm will decrease congestion incurred on a bandwidth constrained wireless network and congestion occurred due to repeatedly selecting a node and bandwidth lying on shortest path and stable path in min-hop routing and stability based routing protocol respectively. The proposed routing protocol also has effect on the end to end delay incurred due to using link effective communication time as routing metrics by using load balancing mechanism. Extra overhead incurred using single path at a time to transmit traffic decreases when multi path routing protocol and load balancing are used in the proposed improved routing protocol. Load balancing in MANET increases security, reduces end to end delay, enhance efficient use of network resources, increase communication speed, decrease the possibility of congestion occurrence, and by this it increases overall network performance and prepare routing protocol to support for emerging multimedia application demands [55].

Therefore, load balancing is important in mobile ad hoc networks because of the limited bandwidth between the nodes and limited energy resources (battery power) [73]. The multipath routing protocol determines multiple paths between source and destination. The multipath routing protocol could offer several benefits namely load balancing, fault-tolerance, higher aggregate bandwidth and lower end-to-end delay [48,73]. Thus, these new mechanisms enable us to integrate them to support QoS and suitable for supersonic speed flying ad hoc network.

1.3. Objectives of the Study

1.3.1. General Objective

The general objective of this thesis is making AOMDV routing protocol more suitable for highly dynamic combat environment for enabling modern network centric warfare by considering link effective communication time and load balancing.

1.3.2. Specific Objectives

Specific objectives of this work include:

- To review related works to have a conceptual understanding of the area and identify the state-of-the-art in highly dynamic environment and specifically supersonic speed flying ad hoc network
- Develop a model which considers load balancing and link effective communication time for highly dynamic combat environment
- Implement the algorithm using state-of-the-art simulation tool to analyze its performance

1.4. Scope and Limitation of the Study

In this study, we try to make AOMDV routing protocol more suitable by considering link effective communication time metrics and using node disjoint multiple path in round robin fashion for load balancing purpose.

This study is directing towards creating suitable routing algorithm for highly dynamic combat system by improving ad hoc on demand multipath distance vector routing protocol. In this research work environment interference or jamming that degrade network performance and battery powered tiny drone are not considered in the environment.

1.5. Methodology

In the first phase, intensive review and explorations are made on the areas related to MANET and FANET routing algorithm for highly dynamic environment, so as to have adequate understanding on the area and its situations at large. This was accomplished mainly through reading journal papers, proceeding papers, articles, IEEE papers, books and other reading materials that enrich the understanding of the subject area. More over suitable mechanisms are analysed for making routing algorithm suitable for highly dynamic combat ad hoc network which is very stable enough for passing combat information such as situational awareness to command and control and so on. In the second phase; which is in the design phase, proposed models and algorithms which are specified in the objective of this paper are designed. Literature review is the major input for this phase of the study for developing a model for making AOMDV routing protocol more suitable for highly dynamic combat environment. The model will include how load balancing and link effective communication time technique integrate for improving the traditional multipath routing algorithm (AOMDV). The algorithm describes how improved route request mechanism is processed in three kinds of node; source, intermediate and destination. In addition to this the algorithm also shows how the decision making is conducted to select the best paths at this node. Then, program for the algorithm is developed and implemented using NS2 simulator to see the effect and the result. We select this simulator because of its openness, a widely used network simulator in area of airborne ad hoc network, and because it is rich in user contributed model and modules. In addition to this Bonn motion [62] is used here for generating mobility for our network and Eclipse IDE used as C++ editor.

Finally, expensive simulation results of the proposed system is compared with the base protocol, where QoS parameters such as end to end delay, packet delivery ratio, and packet drop ratio are considered as evaluation metrics.

1.6. Contribution of the Study

This thesis combines prior research efforts in a novel way to achieve results not previously realized. In this research, we use a multipath routing algorithm(AOMDV) as an underline routing protocol to implement our new algorithm. This research uses

- Multiple node disjoint path for the purpose of load balancing concept and
- link effective communication time the which increases the performance of the network by decreasing the routing overhead needed for path rediscovery process when using single path routing algorithm and decrease end to end delay of using only link effective communication time which has a tradeoff relationship with hop count as well as for efficient use of resources under resource constrained network. Hence, make AOMDV routing protocol support for QoS.

1.7. Thesis Organization

An overview of the rest of the document is as follows:

- Chapter 2 presents a survey on the related literatures and background about MANET, FANET, combat environment, supersonic speed flying ad hoc network, routing protocols that include both traditional one and extended
- Chapter 3 provides an in-depth review on related work
- Chapter 4 describes the proposed algorithm
- Chapter 5 analyzes the results of the experiments conducted
- Chapter 6 provides conclusions, recommendations and future work

Chapter 2

Survey of Related Literature

2.1. Overview

An ad hoc network is a collection of wireless mobile nodes (or routers) dynamically forming a temporary network without the use of any existing network infrastructure or centralized administration. The nodes are free to move randomly and organize themselves arbitrarily; thus, the network's wireless topology may change rapidly and unpredictably. Such a network may operate in a stand-alone fashion or may be connected to the Internet. Highly dynamic mobility, large network size combined with congestion problem, bandwidth, and other constraints make the design of adequate routing protocols a major challenge. A new routing protocol is necessary in such an environment, because two hosts that may wish to exchange packets might not be able to communicate directly, as shown in Figure 2.1 [1, 2, 3].

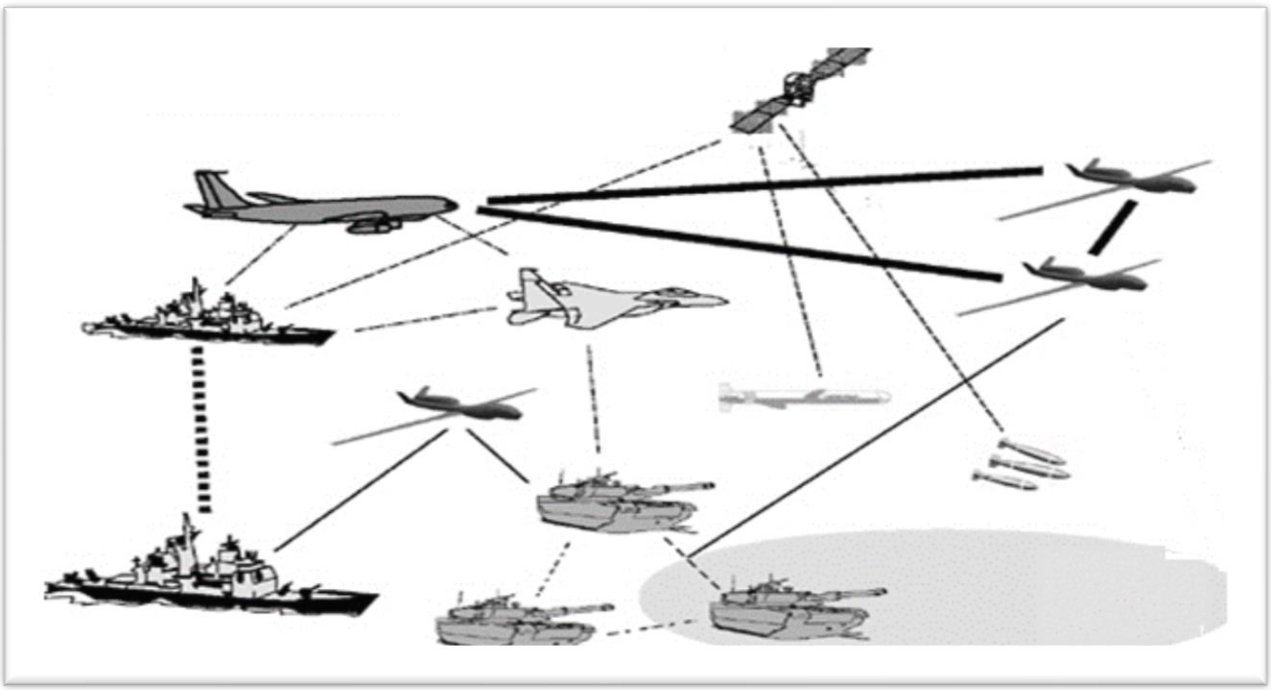

Figure 2-1: Mobile Ad hoc Network in modern battlefield

The rapid development of mobile wireless communications, such as wireless networks (IEEE802.11 series protocol, etc.) typically common cellular terminals communication systems, Bluetooth et al., brings a qualitative change in our lives.

They are, however, typically centrally controlled based on a pre-built network infrastructure. But for specific occasions, such as in war field rapid deployment, field investigation, natural disaster rescue, etc., the traditional technology can no longer meet the demand. The special features of Mobile Ad Hoc network in combat environment shown in Figure 2.1. MANET is a dynamic multi-hop wireless network that is established by a group of mobile nodes on a shared wireless channel and does not need to be dependent to the fixed network equipment of the base station which can set up fast and freely.

2.2. Application of Ad hoc Network

The field of wireless network emerges from the integration of personal computing, cellular technology, and the Internet. This is due to the increasing interactions between communication and computing, which are changing information access from "anytime anywhere" into "all the time, everywhere". At present, a large variety of wireless networks exists, ranging from the well-known infrastructure of cellular networks to non-infrastructure wireless ad hoc networks.

There are many applications that can benefit from MANETs such as [1]:

- ❖ Military tactical operations. A communication network that relies on a certain infrastructure is not desirable for military tactical operations, as it constitutes a soft spot in hostile environments. Elimination of the need for the hard/impossible to set up fixed infrastructure makes MANETs perfect candidates for such operations.
- ❖ Search and rescue missions. Oftentimes search and rescue missions are performed in remote locations with no communication infrastructure, such as the top of a mountain, the middle of a forest or inside a cave. MANETs are easy to use communication systems for such scenarios.
- ❖ Disaster relief. MANETs provide communication in environments where existing infrastructure is destroyed or left inoperable.
- ❖ Law enforcement. Law enforcement operations can be extended to include locations with no communication infrastructure. MANET systems provide fast and secure communication in such scenarios.
- ❖ Commercial use. MANETs can be used to support data exchange between people and applications in large meetings and conventions

2.3. Classification of Ad hoc Networks

Wireless ad-hoc networks can be further classified by their application into three broad categories as shown in Figure 2-2 and comparison is summarized in table 2-1. The first one is Mobile Ad hoc Networks (MANETs) which are self-configuring, infrastructure-less wireless networks of mobile devices. The second type is Vehicular ad hoc networks (VANETs). VANETs are a type of mobile ad-hoc network used for communication between vehicles and other roadside equipment. The last one is FANETs which are a special case of VANETs characterized by a high degree of mobility and frequent topology change. [4,5].

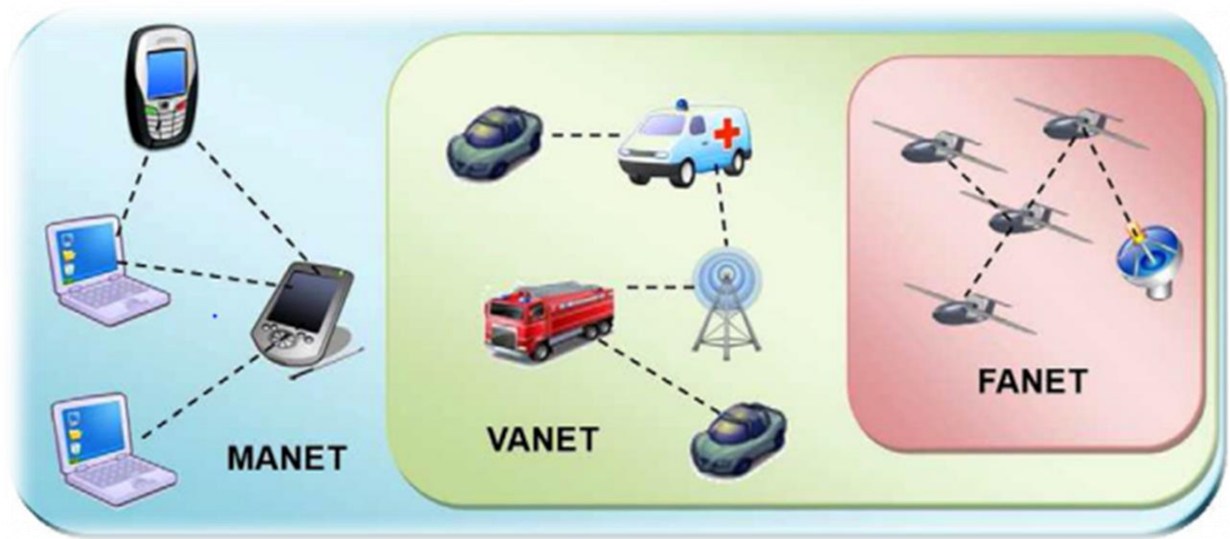

Figure 2-2: Classification of Ad hoc Network

Table 2-1: Comparison of FANET with Existing Ad-hoc Networks

	FANET	MANET/VANET
1.	High degree of node mobility	Medium to low node mobility
2.	Low node density	Higher node density
3.	Rapid topology change	Slow and steady topology change
4.	High above ground level; LoS accessible in most cases	Close to the ground; no LoS between sender and receiver in most cases
5.	Computational power of nodes is very large	Computational power of nodes is average/limited
6.	GPS, AGPS, DGPS, IMU used to provide geospatial localization	GPS sufficient to provide accurate geospatial localization

2.4. Routing and Routing Protocols in MANETs

Routing is the process of selecting paths in a network along which to send data packets. An ad hoc routing protocol is a convention, or standard, that controls how nodes decide which way to route packets towards its destination using most efficient path between computing devices in a mobile ad hoc network. There are different kinds of routing protocol in MANET and discussed briefly in the following section.

2.4.1 MANET Routing Protocols

Routing protocols in MANET are divided into three categories: table driven(proactive), reactive (on demand) and hybrid routing protocols [6-11].

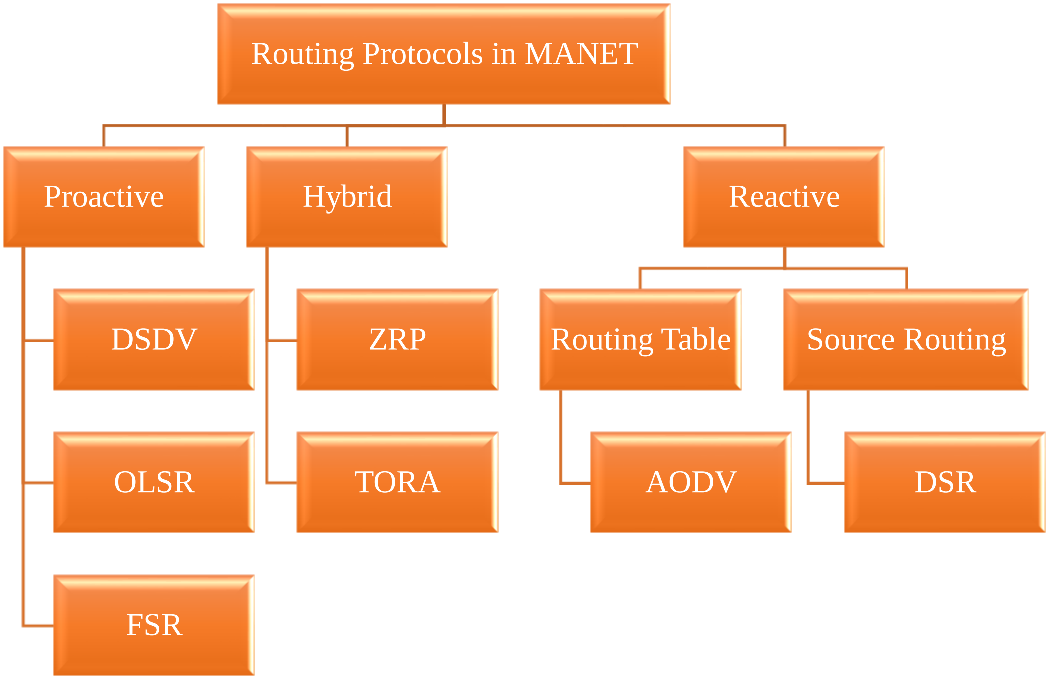

Figure 2-3: Classification of Routing Protocols in MANET

2.4.1.1. Proactive Routing Protocols

Proactive routing protocol is also called table-driven routing protocols. In this routing protocol, each node maintains one or more tables containing routing information to every other node in the network. All nodes update these tables so as to maintain a consistent and up-to-date view of the network. When the network topology changes, the nodes propagate update messages throughout the network in order to maintain a consistent and up-to date routing information about the whole network. Proactive protocols like DSDV [16], OLSR [50], and Fisheye State Routing protocol FSR [51], etc. provide fast response to topology changes by continuously monitoring topology changes and disseminating the related information as needed over the network.

2.4.1.2. Reactive Routing Protocols

Reactive Routing Protocol (RRP) is known as on demand routing protocol, which means if there is no communication between two nodes, there is no need to store a route between them. RRP is designed to prevail over the overhead problem of proactive protocols. There are two types of messages in this routing model: Route Request messages (RREQ) and Route Reply messages (RREP). The source node generates the Route Request Message and sends over the network then the destination node replies with Route Reply Message.

The communication begins after receiving the Route Reply. As a result, each node maintains only the routes that are currently in use. It is bandwidth efficient as there is no periodic messaging in this protocol. Also, high latency may appear during the route-finding process. Well known reactive routing protocols are AODV [35], AOMDV [48], and DSR [15].

2.4.1.3. Hybrid Routing Protocols

Hybrid routing protocol (HRP) is basically a combination of previous protocols and used to overcome the previous protocols limitations. It generally needs extra time in order to discover routes and overhead of control messages. HRP is suitable for large networks. A network must be divided into a number of zones and intra-zone routing uses the proactive method while inner-zone routing generally uses reactive method. Popular HRP are Zone Routing Protocol (ZRP)[52] and Temporarily Ordered Routing Algorithm(TORA)[53]. The following table shows a comparison of the three types of routing protocols.

Table 2-2: Comparison of MANET routing protocol

Protocol	Advantage	Disadvantage
Proactive	Latency is lesser information is readily available	Here Overhead is higher Routing Information Flood
Reactive	Overhead is bit lower in comparison and Free from loops Path available whenever needed	Latency is increased in the network
Hybrid	Suitable for larger network	It increased the complexity which leads to its disadvantage

2.4.2. Advanced Routing Protocols

These kinds of routing protocols are extended from original MANET routing protocol discussed above. Although there are many extensions made to traditional routing protocol we only focus on the most related extended routing protocols. This are multipath routing protocols, load balanced based routing protocols, and stability-based routing protocols. This are some of the extended routing protocols which we are dealing with in the following section.

2.4.2.1. Multipath Routing Protocols

Broadly, the existing routing protocols can be classified in two categories: single path routing protocols and multipath routing protocols. Single path routing protocols do not perform well in highly dynamic networks. In a single path protocol a new route is to be discovered whenever the only path from the source to the destination fails, it results in unnecessary flow of control packets and retransmission of data that adds congestion and latency in the network. Multipath routing protocols discover multiple paths between the source and the destination nodes in a single route discovery. In these protocols, a new route discovery is needed only when all these paths fail which avoids latency of rediscovery, additional control packets and retransmission of data.

All the routing protocols described above are uni-path routing algorithms and this is what earlier work has mostly focused on. However, when a route is broken, the nodes drop packets and launch a new route discovery. As many phenomenon's such as mobility, fading, interference, and collision can occur and create link failures, uni-path protocols are suboptimal for wireless ad hoc networks. Multipath using alternate routes can help to solve this problem, for each route discovery initiated, multiple routes can be discovered. In this way when the primary route disconnects, the source can still use alternate routes. Some results show that multipath reduces the route discovery latency and the overheads [48]. Although this is one approach to multipath routing, which is considering one primary route and other as alternate routes in case of a disconnection; another approach called downward demultiplexing uses multiple paths at the same time by splitting the traffic onto these multiple routes. Split Multipath Routing (SMR) [36] is one of this type. In both approaches the protocols aims to find disjoint paths. Disjoint paths can be link disjoint and node disjoint as shown in Figure 2-4 [74]. As shown in the figure node-disjoint protocol discovers completely independent paths, each path will fail independently but not the case in link disjoint protocols. Much research has focused on finding multiple disjoint paths for many purposes including minimizing energy, avoiding interferences, improving fault tolerance and security. For example, the impact of link failures is reduced when using multipath, eavesdropping also becomes more difficult as the attacker has to sniff multiple links. Some multipath routing protocols using one path at a time have been designed and they are in general extensions of uni-path routing protocols. Two of the on-demand protocols, DSR [15] and TORA [53] have built-in capability to compute multiple paths.

But each of them suffers from a different set of performance problems. DSR uses source routing, by virtue of which it can detect loops easily and can gather a lot of routing information per route discovery. However, aggressive use of route caching, lack of effective mechanisms to purge stale routes and cache pollution leads to problems such as stale caches and reply storms. These problems not just limit the performance benefits of caching multiple paths; they can even hurt performance in many cases [48]. TORA [53], on the other hand, builds multiple loop free paths without use of source routing and uses an interesting idea called link reversals to recover from link failures. Performance studies have shown that TORA suffers from high overheads of maintaining multiple paths [48]. Due to this reason to develop our algorithm we base an on-demand multipath protocol that provides the advantages of multiple paths without suffering from any additional overhead. This routing protocol is an extension of AODV [35] routing protocol and said to be Ad Hoc On-demand Multipath Distance Vector (AOMDV) routing protocol. Actually, DSR, TORA, and AOMDV are not multipath for data transmission, they just provide unipath with fault tolerance by containing some alternate paths. In other words, they distribute traffic on one connection at a time for each source-destination pair.

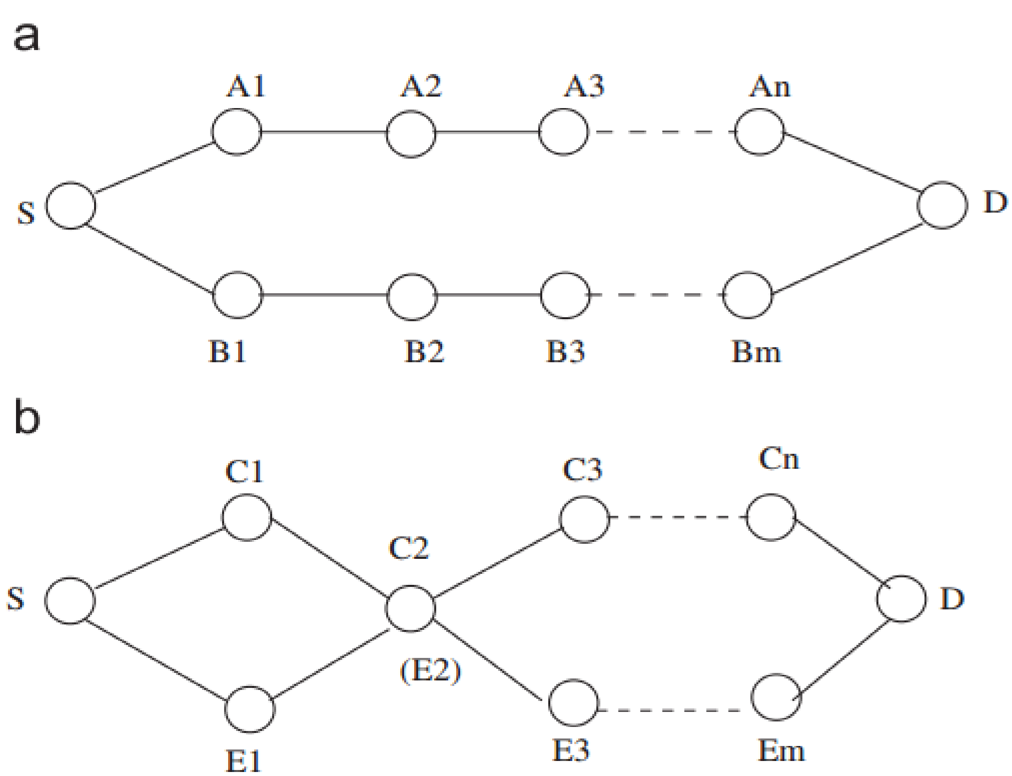

Figure 2-4 Node-disjoint paths (a) and Link-disjoint paths (b)

2.4.2.2. Load Balancing Based Routing Protocols

Load-balancing is another concept that allows a MANET node to take advantage of multiple best paths to a given destination. Load-balancing can work per destination, per packet, or per flow packet distribution. Per-destination load balancing means the node distributes the packets based on the destination address. Given two paths to the same network, all packets for destination 1 on that network go over the first path and all packets for destination 2 on that network go over the second path. Per-packet load-balancing means that the router sends one packet for destination1 over the first path, the second packet for destination1 over the second path. This allocation scheme is well known to work well in most ad hoc networks [36]. Research in wired networks has focused on minimizing the maximum utilization while supporting the same traffic demands. This can be achieved using multipath routing with load balancing. SMR [36] and Multipath Routing Protocol with Load Balancing (MRP-LB) are two best example of routing protocol of multipath routing with load balancing.

2.4.2.3. Stability Based Routing Protocols

Stability based routing protocols are routing protocols which uses different metrics rather than hop count as in traditional routing protocols discussed above. According to [42] there are two categories of stability based routing protocols. This are distance based and node mobility based routing protocols. In distance based protocols the basic idea is the longer route in term of the hop-count is chosen. Generally, the signal strength or the localization system is used for calculating this metric. From this category of routing protocol Signal Stability-Based Adaptive Routing Protocol (SSA) [44] is an example. Use of power of signals to determine relative node mobility should be avoided as power of signals may be subjected to atmospheric attenuation [25], especially in rainy weather for network formed in the air such as FANET. Node mobility based routing protocols considers the mobility parameters of nodes to estimate the link stability values, such as the direction of movement of nodes, their speed and their probability to remain in the vicinity for a long period. From this category of routing protocols Flow Oriented Routing Protocol (FORP) [43] is the one.

2.5. Dynamic Combat Environment

Modern war is called “Network centric war”. Multi-platform cooperative combat system is the current and future work of modern war. Multi - platform cooperative combat system in the combat unit not only includes the traditional ground combat system, also includes the sea combat system, air combat system and so on. Mobile Ad Hoc network has irreplaceable role in the field of combat communication. Battlefield communication system needs nodes that can be flexible and self-organized, as well as the network of high robustness, high stability, high reliability and other special needs. That means it needs independent ad hoc networks, self-organized ad hoc networks, no center-free base stations, dynamic topology, mobile and so on, to meet the specific needs of tactical communication [12].

At present, the flight speed of advanced cruise missiles, air defense missiles, fighter jets, unmanned reconnaissance aircraft and other high-speed flight bodies can reach Mach 3-5(1700m/s). Thus, a combat system consists of Ad Hoc Networks composed of supersonic flying body, a high dynamic network due to high-speed as specified above and thus which gives rise to frequent changes in network topology in which routing protocols for this environment should be adaptive to this speed.

The modern combat environment, whether it is high-speed flight attack missiles, or ground-to air interceptor missiles, or unmanned aerial vehicles (UAV) or other high-speed flying body, are a number of high-speed flying body constitute an air combat unit, and then perform combat mission which includes but not limited to detect or attack the target, intercept a launched missile, etc., as shown in Figure 2-5 adapted from [76]. In the air combat unit, the air combat unit is forming an ad hoc network on the sky while performing their mission given from command control station (C2). Once the combat unit launched from control station, it will become a closed, independent of the ground control system. The unit will complete the function of self-decision and self-cooperation and other functions. The flight of the mobile node in the most recent research [13] considered as it can maintain its state of motion constant, this algorithm still has a relatively strong feasibility and applicability.

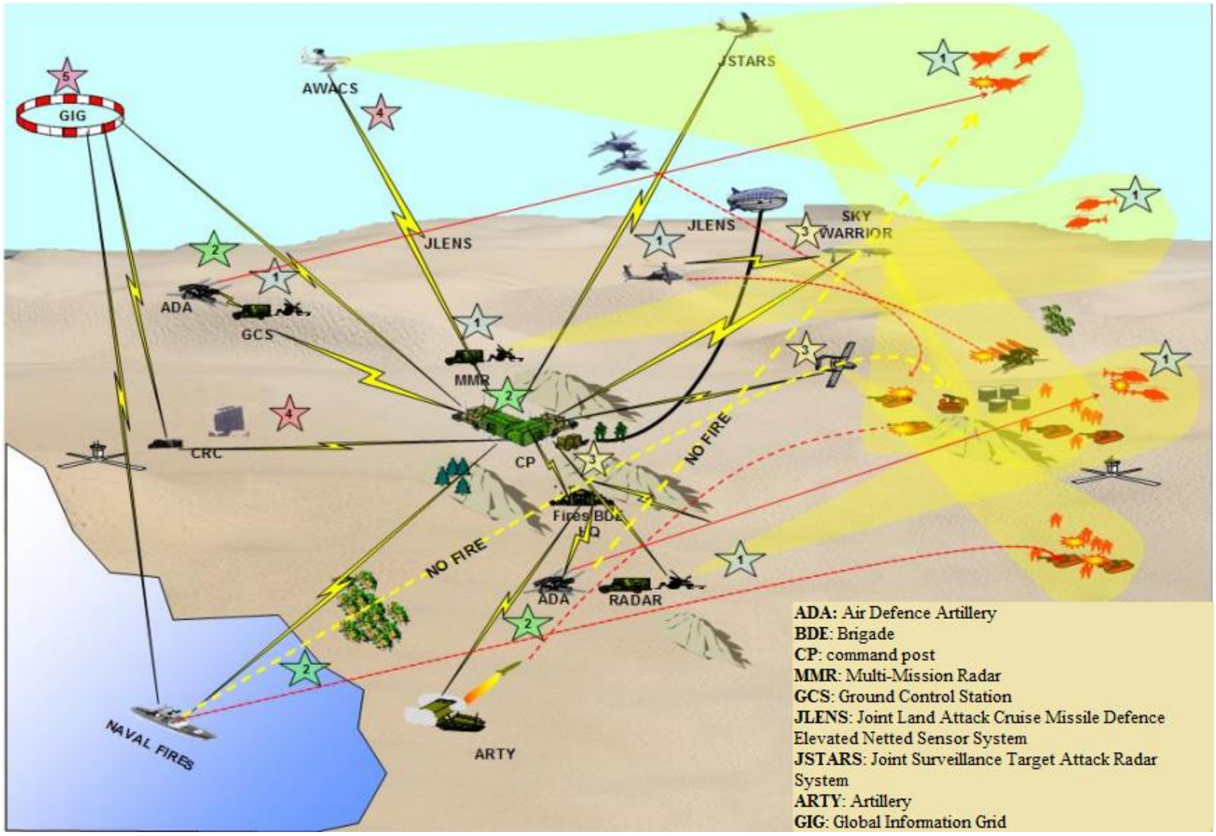

Figure 2-5: Air Combat Unit striking their Mission

In this paper, the air combat unit is taken as the research object, and the main research work is focused on performance improvement of routing in air high-speed combat unit ad hoc network. This paper designs a routing algorithm by merging the two most important metrics which are link effective communication time [13] and load balancing concept so that the performance will be improved.

2.6. A Comparison of Ground Combat Unit and High-Speed Flying Combat Unit

In the common ground combat weapon unit, multi-hop ad hoc network, the node speed is 25m / s (i.e. 90Km / h), where the routing link failure is usually very fewer occurrences within the link “effective communication time" [72]. It is precisely because movement speed is slow in the ground combat system unit, even if the node movement randomness again strong, it is difficult in a short time to move out of each other’s maximum communication radius d_{max}[13]. Correspondingly, the effective communication time between the two nodes of the whole network is maintained at a relatively stable and reliable within range.

Therefore, under the low-speed environment such as in the ground combat unit, the "effective communication time" between the nodes is relatively long, and the randomness of the nodes will not have too much impact on the overall routing performance of the network.

But the situation is completely different in the ultra-high-speed movement of the flying body. The flight node itself has the consistency of movement which determines the consistent state of the node, no randomness, and the process of change of flight speed and acceleration and other motion vectors, is also slow. But it is because of the flight node's super high-speed movement (1-5Mach, equivalent to 1700m / s) between the two nodes of any small state of motion differences are likely to lead to change in relative position of the node in the next short period of time, the node will even move quickly to the outside of maximum communication radius, so there is a very high probability of occurrence of communication link failure. The comparison between the two combat units is summarized below in Table 2-3.

Table 2-3 : Summarizes the Difference Between Ground Combat Unit and Supersonic Speed Flying Combat Unit

Ground Combat Unit	Supersonic Flying Combat Unit
speed is about 50m / s (i.e. about 90Km / h)	speed movement (1-5Mach, equivalent to 340m / s-3400m / s)
Relatively low link failure occurrences due to slow speed	Relatively high link failure occurrences due to supersonic speed
Node movement randomness is strong	Low randomness/acceleration
Sever change in network state	Have consistency in state
Not easy to move out of communication radius suddenly	move quickly to the outside of maximum communication radius
effective communication time between the nodes is relatively long	effective communication time between the nodes is relatively short
No frequent link failure as supersonic speed flying combat unit	frequent link failure occurs, on the one hand will lead to a large number of routing maintenance message this increases network load

2.7. Summary

Mobile ad hoc networks consist of wireless hosts that communicate with each other in the absence of a fixed infrastructure. They are used in disaster relief, conferences, and battlefield environments. There are different types of ad hoc network classified by network application areas namely (mobile ad hoc network (MANET), Vehicular Ad Hoc Network(VANET), and Flying ad hoc network (FANET). For efficient communication in this kind of network, routing protocol is needed and they are in three forms namely on demand or reactive, table driven or proactive, and hybrid. In addition to this there are many routing protocols in extension to this basic routing protocol. This extension includes making single path to multipath, making them to be aware of node mobility etc. Even though many research has been conducted in routing protocols for Mobile Ad Hoc Networks while traditional protocols cannot satisfy the demand of highly-dynamic combat environment which consists of a supersonic speed flying ad hoc network described in this paper.

Chapter 3
Review of Related Work

3.1. Overview

Following the invention of wireless network and ad hoc networks, the world is changing the way vital activities are done. From these activities network centric warfare is the one. To enable and improve this interesting technology in combat theater it is needed to create a best communication technology which includes a best routing protocol which select a best route to forward different data by avoiding faulty network paths. In recent years, there has been increasing demand in multimedia communication in MANET which demands certain guarantees from the underlying network that are manifested in the support of several important QoS parameters such as throughput, delay, jitter, packet de-livery ratio, link stability, node buffer space, packet loss ratio etc. Because wireless link capacities are usually limited, congestion is possible in MANETs [65]. Congestion leads to packet losses, bandwidth degradation, increased end-to-end delay and loss of energy which hinders support of QoS to multimedia application. There is a need of a different routing protocol that can either manage congestion or locate a better route and improve the quality of service (QoS) parameters. Load balancing is emerging as a key tool to better use MANET resources and improve MANET performance. Load balancing can be defined as a methodology to distribute or divide the traffic load evenly across two or more network nodes in order to mediate the communication and also to achieve redundancy in case that one of the links fails. With load balancing, MANET can minimize traffic congestion and load imbalance, as a result, end-to-end packet delay can be minimized, mobile node's lifetime can be maximized, and network energy consumption can be balanced. In addition to this using min-hop routing directly for highly dynamic network because shortest path is not always good path. Towards this there are different related research work. Some of the major work are listed and described as follows as in order of year of publication.

Ad-hoc On-demand Multipath Distance Vector Routing (AOMDV) [48] protocol is an extension to the AODV protocol for computing multiple loop-free and link disjoint paths. The routing entries for each destination contain a list of the next-hops along with the corresponding hop counts. All the next hops have the same sequence number. This helps in keeping track of a route. For each destination, a node maintains the advertised hop count, which is defined as the maximum hop count for all the paths, which is used for sending route advertisements of the destination. Each duplicate route advertisement received by a node defines an alternate path to the destination. Loop freedom is assured for a node by accepting alternate paths to destination if it has a less hop count than the advertised hop count for that destination. When a route advertisement is received for a destination with a greater sequence number, the next-hop list and the advertised hop count are reinitialized. AOMDV can be used to find node-disjoint or link-disjoint routes. To find node-disjoint routes, each node does not immediately reject duplicate RREQs. Each RREQs arriving via a different neighbor of the source defines a node-disjoint path. This is because nodes cannot be broadcast duplicate RREQs, so any two RREQs arriving at an intermediate node via a different neighbor of the source could not have traversed the same node. In an attempt to get multiple link-disjoint routes, the destination replies to duplicate RREQs arriving via unique neighbors. The trajectories of each RREP may intersect at an intermediate node, but each takes a different reverse path to the source to ensure link disjoints. The advantage of using AOMDV is that it allows intermediate nodes to reply to RREQs, while still selecting disjoint paths. But, AOMDV does not consider load balancing and node mobility characteristics which is very important under highly dynamic ad hoc network.

From family of stability based routing protocol Associativity Based Routing (ABR) [27] is the first routing protocol which consider node’s load and stability. ABR is a source-initiated on-demand routing protocol. It includes three phases: route discovery, route reconstruction, and route deletion. Load balancing is employed during the route discovery phase. A node desiring a route first sends a broadcast query (BQ) message in search of nodes that have a route to the destination. All intermediate nodes receiving the query append their addresses and associativity ticks with their neighbors along with the Route Relying Load (RRL) information into the query packet. In ABR, RRL is defined as the number of existing routes supported by a node. In this way the query packet arriving at the destination node contains associativity ticks and relaying load information of nodes along the route. The destination node thus knows, at an appropriate time after receiving the first BQ packet, all the possible routes and their qualities. ABR then considers acceptable routes with nodes that do not exceed the maximum allowable RRL. From among the acceptable routes, the destination node chooses the most stable route and sends a reply back to the source node via the route selected. In this way ABR avoids congested nodes; however, ABR did not consider the actual node’s load traffic because the number of active paths is not a true indicator of congestion. For example, let's consider two nodes, node **A** and node **B** in which node **A** has 10 active paths and node **B** has only 5. Node **B** is acting as a forwarder for heavy traffic such as video and sound of about 2 Giga bytes in total and node **A** is forwarding only web traffic of about 1000 Megabytes. Though the number of active path in the first node is greater than that of the second node the actual load of the two nodes are in reverse which is node **A** contains highest active link but comparatively small load and node **B** contains small number of active paths but heavy traffic than node **A**. Therefore, ABR will be deceived in selecting the second node to construct an end to end path between source and destination. On the other hand, the protocol must periodically send ticks to tell the neighbor's own stability which increases number of message in the network. When the node receives a lot of ticks from the same node, it indicates that the neighbor is stable at the node. This method is effective for slow or discrete motion, but for high-speed aerial motion, the nodes are in high-speed mobile state. The time between the two nodes as neighbors is very short, almost impossible to give the two nodes to send enough ticks to determine the stability of each other.

Signal Stability based Adaptive routing (SSA) [44], chooses the route if the receiving signal strengths of radio links along this route are larger than a threshold value; otherwise, the shortest path routing algorithm applies to find another route. In such protocols, traffic is not distributed into multiple paths; only one route is primarily used and alternate paths are utilized only when the primary route is broken. The use of power of signals [25] to determine relative node mobility should be avoided as power of signals may be subjected to atmospheric attenuation, especially in rainy weather. Therefore, according to this study, it is difficult to apply a routing protocol which depend on signal strength based in FANET.

Split Multipath Routing (SMR) is introduced by Lee and Gerla [36]. The main objective of SMR is to reduce the frequency of route discovery processes and thereby reduce the control overhead in the network. The protocol uses a per packet allocation scheme to distribute a load into multiple paths. When a destination node receives route request packets from different paths, it chooses multiple disjoint routes and sends replies back to the source. The basic route discovery mechanism of the DSR protocol is used in the SMR protocol, but an intermediate node is not allowed to reply from its route cache if it has some routes available to that destination. To avoid overlapped multiple paths, the author introduces a different route request forwarding scheme. In this scheme, instead of dropping a duplicate request message, an intermediate node forwards this request packet in a different incoming link other than the link from which the first request was received and whose hop count is not larger than that of the first request message. When a destination node receives a route request message, it selects two paths that are maximally disjointed. Between these two routes, the first one is the shortest path. The shortest path is chosen to minimize the route discovery time because it is the earliest discovered route. After processing the first request, for the second path selection, a destination waits for a certain duration of time to receive more requests and learns all possible routes. After this it selects a route from one of the alternative paths, which is maximally disjointed with the shortest path. A maximally disjointed path is the path that has the least number of common nodes compared to the shortest path. If there is more than one maximally disjointed path is available, the shortest hop path is selected among them. Another major difference from DSR protocol is that an intermediate node does not need to maintain a route cache. For this reason, a node has a smaller cache. Although the SMR protocol uses less frequent route discovery mechanisms compared to the DSR protocol, one of the drawbacks of SMR is the redundant overhead packets. Since an intermediate node is not dropping a duplicate request message, the frequency of route discovery process need to be reduced to curb the overhead. SMR did not consider mobility metric which is the most important metric in highly dynamic network.

K.N. Sridhar and M. C. Chan propose Stability and Hop-Count based Approach for Route Computation (SHARC) [32] in MANET that considers both the hop-count and stability metrics so that decreasing the effect of number of hop induced by stability to improve network performance in end to end delay. But their proposed algorithm uses simple histogram based estimator. This stability value of the path is the sum of all the residual lifetime divided by the length of the path computed as follows. Let l_i be the number of links with link duration i secs and R_a be the average residual link lifetime when the current link age is a. The full equation is shown below in Eq. 3-1.

$$R_a = \left(\sum_{i>a} (l_i * i) / \sum_{i>a} l_i\right) - a; \tag{3-1}$$

By considering only this parameter we cannot predict the highly movable combat environment with speed specified above [77]. Their proposed algorithm shows performance for node mobility ranging from 1-30 m/s which has a great difference with combat environment which has a speed of about up to 1700m/s. Their mechanism does not address load balancing for data transmission. In addition to this the stability value did not consider node's mobility metric which is very important for highly dynamic network.

Multipath Routing with Load Balancing and QoS in Ad hoc Network [55] was proposed by Mohamed Tekaya, Nabil Tabbane, and Sami Tabbane. In this article, by coupling a multipath routing protocol with load balancing mechanism according to some QoS, they presented a new protocol called QLB-AOMDV (QoS and Load Balancing AOMDV), a solution to achieve better load balancing with respect to the end-to-end QoS requirement. The simulation result shows the significant performance improvement of the network for the multipath routing protocol with load balancing and QoS. The proposed solution QLB-AOMDV work better than other protocols in terms of delay, capacity and load balance. First, they propose an extension to AOMDV protocol in order to support load balancing mechanism and technique to improve its performance, called it LB-AOMDV. LB-AOMDV can allow finding many routes between source and destination during the same route discovery procedure but use all of them at the same time unlike AOMDV which uses only one path to transmit data. When the source receives one or many RREP packets from many disjoint paths, it decides: If one RREP is received; therefore, only one route layout from source to destination is used to send data packets. If many RREP are received, the source distributes forwarding data packet to less congestion routes. The route maintenance is similar to AOMDV. In such protocols, link failures in the primary path, through which data transmission is actually taking place, cause the source to switch to an alternate path instead of initiating another route discovery. A new route discovery occurs only when all pre-computed paths break. To build the LB-AOMDV protocol, they redefine the structure of RREP packet by adding a new field called *buffer_size* which takes into account the traffic load on the route. This traffic load is expressed as the sum of *buffer_size* of intermediate nodes for each route between source and destination. When an intermediate node receives a RREP packet, it increments the new field with the size of occupation of its buffer. On the other hand, when the source receives RREP packet, it divides the value of the *buffer_size* field by the *hopcount* of each route between source and destination in order to have the congestion level. They add *buffer_size* in the *route_list* in the route table structure of original AOMDV. Each node sorts the *route_list* field by the descending value of buffer size. Each node sends data packets by using the route with the minimal buffer size. The LB-AOMDV protocol establishes three paths between source and destination nodes. The packets sent by source node are scheduled according to Round-Robin(RR) algorithm.

In addition, they add QoS to their proposal LB-AOMDV protocol which includes delay and throughput parameters. It takes advantage of the RREQ messages to exchange the essential information to achieve the QoS requirements. Enabling a QoS constrained from source to destination is the objective of their new protocol called QLB-AOMDV. Each node in the network estimates its quality of links with its one-hope neighbors. For this reason, they redefine the structure of RREQ message by adding two new fields which indicates the received time of the packet (Tr) and the transmission delay of the packet (Delay). To initiate QoS routing discovery, the source node sends the extended RREQ message. When an intermediate node N1 receives this RREQ message from the source node, it saves the time of this event in the (Tr1) field and forwards it to its neighbors. When a neighbor node (N2) receives the RREQ message from N1, it calculates the difference between the value of (Tr1) field and the current time (Tr2), which represents the measured delay of the link N1N2 and stores it in the (Delay) field. Each node sorts the *route_list* field that satisfied the end-to-end QoS requirement by the ascending value of delay. Each node sends data packets by using the route with the minimal delay. The QLB-AOMDV protocol establishes three paths between source and destination nodes. The packets sent by source node are scheduled according to Round-Robin(RR) algorithm. Though this algorithm is best regarding in load balancing they did not consider mobility metrics which are very important in highly dynamic speed flying ad hoc network.

In [13] presented an improved DSR protocol for highly dynamic environments (supersonic speed flying ad hoc network), In this work they try to make DSR routing protocol compatible to highly dynamic environment by using link life time for predicting link quality using Gauss Markov Mobility model. Their algorithm takes the entire communicating link's maximum lifetime into consideration. Compared to the original DSR protocol based 'minimum hops', their simulation results operated in Qualnet shows better performances of their improved protocol, especially in packet delivery ratio, received throughput, average end-to-end delay and average Jitter. Even though this improvement is done in the paper, their algorithm may increase the number of nodes in the transmission which have greater impact on routing performance. Some of the impact of many number of nodes in transmission includes excessive node interference and wastage of network bandwidth which yields poor performance in routing [35].

As stated in the paper the life time of a route which consists of several links in general should be calculated before sending the data on it and a route which have high link life will be the one which is selected for transmission than others. For instance, assume there is a path 's-1-2-d' consisting of node s, 1, 2, d in one sample network. This path is composed of link s-1, 1-2 and 2-d and then, calculate each link's lifetime LET (N_s, N_1), LET (N_1, N_2), LET (N_2, N_d). If any link of the path breaks, the path will also be invalid; therefore, the lifetime of the entire path is determined by the shortest lifetime of all links (the bottle neck), as shown in Eq. 3-2.

$$\text{LET}(N_s, N_d) = \min[\text{LET}(N_s, N_1), \text{LET}(N_1, N_2), \text{LET}(N_2, N_d)] \quad (3\text{-}2)$$

Where LET is Link Effective Communication Time which is the amount of the time two neighbor nodes will remain each other and defined by the following formula in Equation 3-3. Assume we have two mobile nodes N_1 and N_2 with in hearing range and they have equal transmission range *r*. Let (x_1, y_1) is a co-ordinate of node N_1 and (x_2, y_2) is a co-ordinate of node N_2. Also, v_1 and Θ_1 is the speed and angle of node N_1 and v_2 and Θ_2 is the speed and angle of node N_2. Then, (LET) are calculated as follows:

$$\text{LET} = \frac{-(ab+cd)+\sqrt{(a^2+c^2)r^2-(ad-bc)^2}}{a^2+c^2} \quad (3\text{-}3)$$

Where:

$a = v_1 \cos \Theta_1 - v_2 \cos\Theta_2$

$b = x_1 - x_2$

$c = v_1 \sin \Theta_1 - v_2 \sin \Theta_2$

$d = y_1 - y_2$

Therefore, based on this concept their algorithm selects those links which have maximum link life time. Since maximum link life time and hop count are tradeoff each other, a path having maximum link effective communication time have high number of nodes when compared with ordinary DSR routing protocols [13] which hinders support for QoS. In addition to this DSR is not selected as a best routing protocol in highly dynamic ad hoc network due to its aggressive use of route cache. Under supersonic speed network environment, a routing protocol should have good cache mechanism, but DSR do not have any one. This makes routing protocol to use stale route information which leads to packet drop and reduce network performance [48].

3.2. Comparison of Routing Protocols

Table 3-1: Comparison of Routing Protocols

Protocol	Base Protocol	Approach/Metric Used to Find Stable Routes	Stability Parameter	Disadvantage	Speed Support	Mobility Model	Load Balancing
Associativity Based Routing (ABR)[27]	DSR	Hello packet, Residual Lifetime	Association of neighboring nodes	Assume that older links are more stable which is not always correct, Node load detection that more active path is congested is not always correct and is not correct way of detecting load	2 m/s	random waypoint model under different mobility degree	No
Split multipath routing (SMR) [36]	DSR	Hop count only, like DSR	Not used	mobility metrics is not used	0-10 m/s	random waypoint model	Yes
Stability and Hop Count based Approach for Route Computation (SHARC) [32]	DSR	Hello packet, Simple Histogram Residual lifetime estimator	Hop count, stability of a path calculated using a simple histogram based estimator	Path stability depends on average value of residual lifetime which is not efficient	1-30 m/s	Random way point	No
LB-AOMDV/QLB-AOMDV [55]	AOMDV	Delay, throughput, buffer size of a node	hop count	Did not consider node mobility metrics	10m/s	Random way point	Yes
An Improved Routing Protocol Based on Gauss-Markov Model In Ad Hoc Networks Utilizing Prediction of Link Quality [13]	DSR	Link Effective Communication Time	Communication Range, distance, GPS position, Relative Velocity, and Direction	Increases the number of hop in transmission	3-5 Mach	Gauss Markov Mobility model	No
LBLET-AOMDV (our proposed algorithm)	AOMDV	Link Effective Communication Time and load balancing	Communication Range, distance, GPS position, relative velocity, Direction, load balancing, LET	Increase probe packet size	3-5 Mach	Gauss Markov Mobility model	yes

3.3. Summary

MANET is becoming common and preferred technology for different disciplines. For example, combat network. Currently combat system includes supersonic speed flying nodes. Under this highly dynamic network if multimedia traffic is a vital traffic passing through this network the need of the reliable routing protocol is very important. MANET is resource constrained network such as bandwidth which needs proper utilization. Load balancing is emerging as a key tool to better use MANET resources and improve MANET performance. With load balancing, MANET can minimize traffic congestion and load imbalance; as a result, end-to-end packet delay can be minimized and improved. The nodes in supersonic speed flying ad hoc network are moving in supersonic speed and needs a robust routing protocol to have good communication. Traditional hop count based routing protocol cannot satisfy this network since shortest path is no longer always good. Therefore, there must be a mechanism in which to predict future movement of the node and base this prediction when selecting best path. Only this solution is not enough because stability-based routing protocol has a tradeoff relationship with hop count and hinders to support QoS for emerging multimedia communication. In addition to this, since wireless network has scarce resources, load balancing which is a mechanism which enables to use network resource efficiently has to be considered. Therefore, routing protocol under this highly dynamic network should consider these parameters to be better routing protocol which supports QoS.

Chapter 4
Load Balancing and Link Effective Communication Time Based Improved Routing Protocol Algorithm Design for Supersonic Speed Flying Ad hoc Network

4.1 Overview

In this paper, we propose to improve AOMDV routing protocol by considering load balancing concept and link effective communication time for supersonic speed flying ad hoc network in objective of improving routing in NCW. The proposed routing protocol takes AOMDV [48] routing protocol as a baseline protocol and exploits the advantage of load balancing and link effective communication time prediction to cope up highly dynamic ad hoc combat network. To achieve our objective, we mainly based on concepts of two metrics, which are at the basis of our approach: load balancing and link effective communication time based strategy. This will improve the network performance by utilizing the resource efficiently such as bandwidth, buffer space, and node energy. Following this overview, in the rest of sections we describe the details about the techniques and the model developed for the proposed solution. In Section 4.2, we describe and present our proposed model architecture and mobility model comparison and selection. In Section 4.3, we describe modules which are used for the successful communication of two nodes. Summary about the chapter is described in Section 4.4.

4.2. Model

4.2.1. Proposed Model

In proposed system model both load balancing and link effective communication time (LET) is used to support for QoS for emerging multimedia communication in supersonic speed flying ad hoc network. Load balancing should be aware of stability of the path or the link to be better routing protocol for supersonic speed flying ad hoc network. Therefore, in the proposed model the source node has responsibility to choose *n* disjoint paths having maximum link effective communication time. Then, the source will distribute the traffic along *n* replied path ordered by Route Effective Communication Time (RET) using per-packet scheme as shown in the diagram below in Figure 4-1 by this load balancing and link effective communication time is achieved.

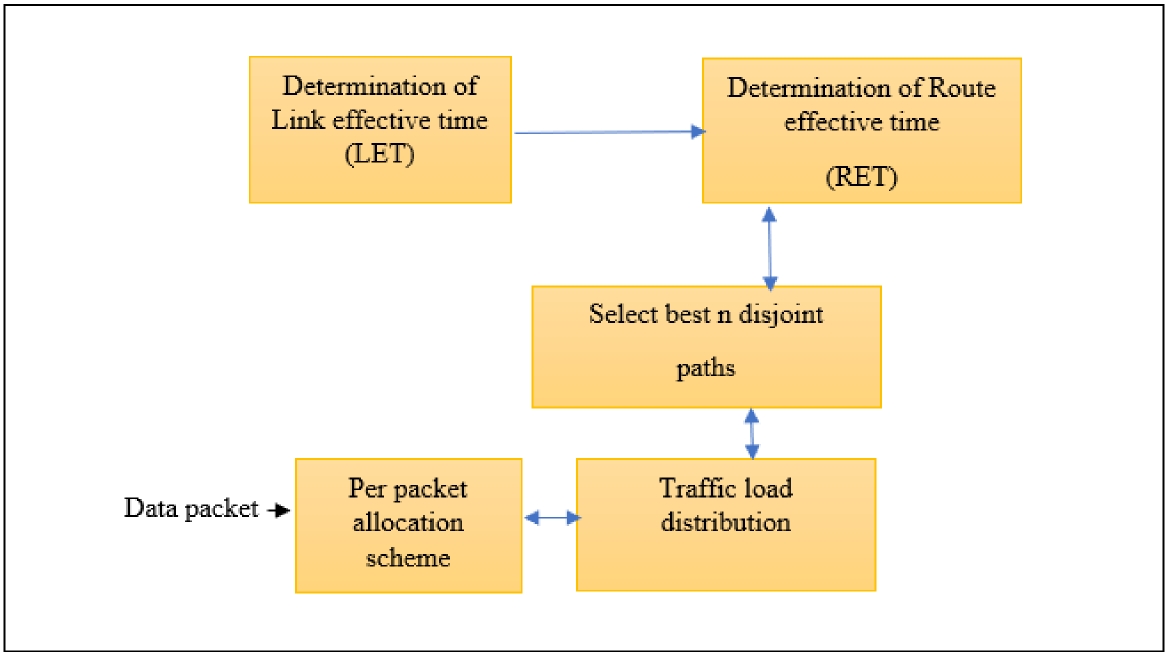

Figure 4-1: Proposed model of link Effective communication time and load balanced based routing model

4.2.2. Mobility Model

Mobility model represents the movement of mobile nodes and how their location, velocity and acceleration changes overtime. Selecting best mobility model that correctly mimic the movement of flying ad hoc network is a necessary task because when we select more accurate mobility model more it fits to the real-life scenario and the more realistic results will be produced.

There are different mobility models already built in some simulation tools, including random direction 2D, random walk 2D, random waypoint, constant velocity, constant acceleration, and constant position. Each model has its own characteristics, working capacity and limitations.

In constant velocity, nodes proceed along their initial velocity vector for the duration of the simulation as shown in Figure 4-2a. There are no geographic boundaries in this model.

In random walk 2D, each node is given a random trajectory (speed and direction) and travels on that trajectory for a fixed period of time or a fixed distance as shown in Figure 4-2b. When nodes reach the limits of the 2-dimensional boundary, they bounce off in a new direction mirroring the previous direction and velocity. Figure 4-2c shows an example of the random direction model, in which nodes travel on a random trajectory until they reach the 2D boundary, at which time they pause for a random period of time and head off in a new random direction and speed. In the random waypoint model, as illustrated in Figure 4-2d, each node travels to a random waypoint (x, y coordinate), pauses for a period of time, and then heads off to another waypoint. The waypoints, node speeds, and pause times are modeled as uniformly distributed random variables.

Some of the challenges faced by combat environment networks include high mobility, limited bandwidth, limited transmission range, and intermittent connectivity. The path of a flying node will not be completely random, but its position at any point in time will be dictated largely by its previous position and velocity vector [47]. Therefore, the mobility model must have memory. The mobility models mentioned previously are all memoryless. One characteristic of a memoryless mobility model is the existence of very sharp and sudden changes in direction and speed. Thus, these characteristics have a noticeable effect on routing performance as shown by literature [47]. Airborne nodes are highly dynamic and require 3-dimensional models. The fundamental problem with many synthetic mobility models is their random, memoryless behavior. Simulations using these mobility models exhibit unnatural movements with abrupt and often extreme changes in velocity and direction, uncharacteristic of highly-mobile flying nodes. These mobility models are insufficient in simulating a highly-dynamic flying ad hoc combat network. They also lack support for 3-dimensional position allocation, relative velocity between nodes in 3D space, and realistic flight behavior. To solve this problem two mobility model is proposed namely Gauss Markov mobility model and Enhanced Gauss Markov mobility model. The former mobility model shown in Figure 4-2e has slightly sharper corner than the improved one which is more realistic as shown in Figure 4-2f [47].

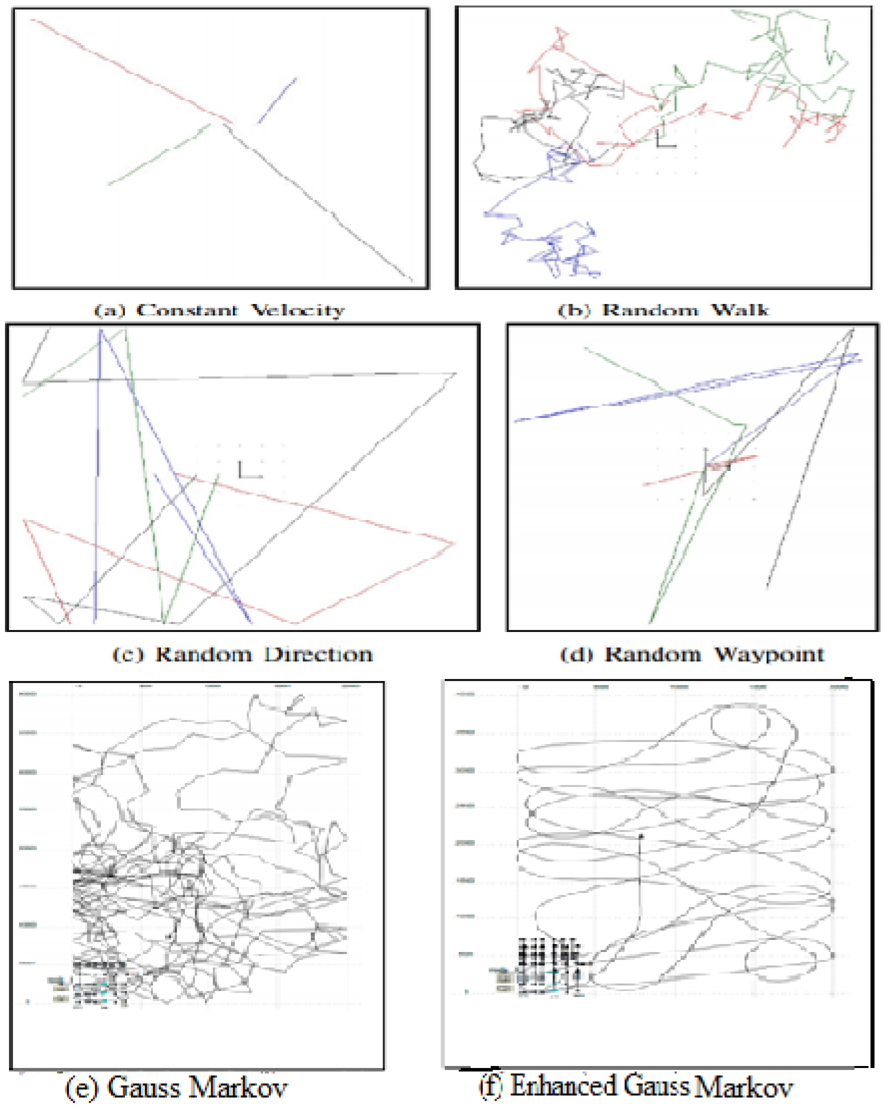

Figure 4-2: Mobility Models

The following table, Table 4-1 describes mobility model characteristics so that one can easily select appropriate mobility model for the proposed target environment.

Table 4-1: Mobility Model Study for Proposed Target Environment

Mobility Characteristics	Memory based Mobility Models (Gauss Markov mobility model and Enhanced GM)	Memory less Mobility model (Random way point, random direction, random walk, constant velocity, constant acceleration, constant position etc.…)
Random ness	Not sharp random	Sharp random
Memory	Memory based	Memory less
Sharp corner for velocity and direction	Have not sharp change (enhanced one have better corner)	They have sharp corner for velocity and direction
Uncharacteristic of mobile airborne network	They mimic highly dynamic combat environment specially Enhanced GM	They do not
3D position allocation	They represent nods in x, y, z coordinate	They represent in x, y coordinate only
Relative velocity between nods in 3D space	they represent nods relative velocity in x, y, z	They do not

Because the movement of high-speed aircraft is characterized by memorability, continuity, and smooth turn, the EGM motion model describes it accurately. Therefore, we recommend selecting it as a mobility model for any ad hoc network having flying body. Unfortunately, since EGM is not implemented in NS2. We did not used it as a mobility model, instead we used Gauss Markov mobility model which is implemented in NS2 from Bonn motion [62].

4.3. Load Balancing and Link Effective Communication Time Based Improved AOMDV Routing Algorithm

The proposed routing algorithm uses node mobility factor [13] and load balancing together so that improve current routing protocol for supersonic flying ad hoc network for improving routing in NCW.

4.3.1. Link Quality Prediction

In air communication, link life time or expiration time is the time that two aircraft in the air with high-speed movement stay together without being out of each other's communication range. Due to the direction of movement and speed of the two-aircraft, displacement will continue to change and due to the attenuation of electromagnetic waves, two nodes will be affected by the distance of communication. When the distance between the two aircraft reaches the maximum communication distance, the communication link between the two machines will be disconnected. To solve this problem, the link lifetime is proposed and analyzed in previous research [13] and the calculation flow is shown in Figure 4-3.

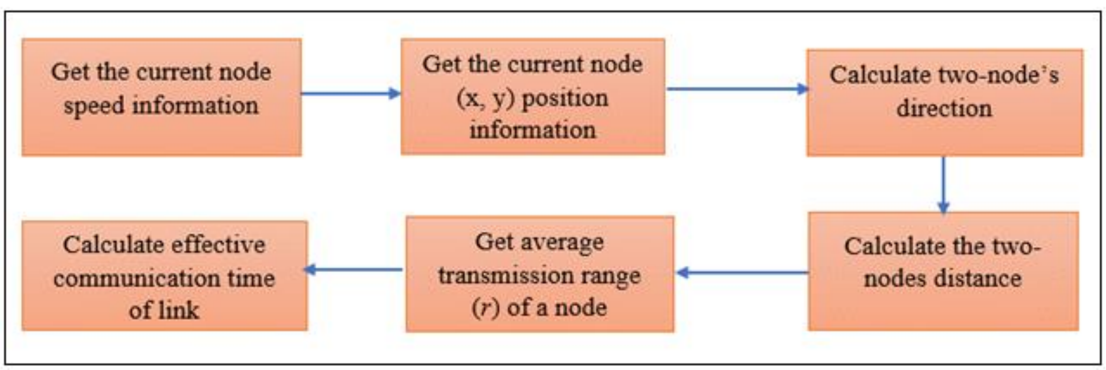

Figure 4-3: Link Effective Communication Time Calculation Steps

The relative velocity is the root cause of the change in the relative displacement between the two bodies with different speeds and directions which results frequent link breakage due to the speed of two communicating nodes, they will be out of each other's transmission range soon. The effective communication time calculation method of the simple link is solved by the Equation 3-3 [13].

In mobile Ad Hoc networks, several neighboring nodes are connected to form a valid path [1]. While the link between two adjacent nodes there is an " link effective communication time ". The communication between the source node and the destination node depends on every two-neighboring node's connectivity and stability. Due to the high-speed motion of the nodes, the connectivity between the nodes changes very rapidly. The failure of any link between adjacent nodes will cause the probe packet or data packet to be sent will be dropped and the entire route will fail and the packet will have to be resent which decreases the overall network performance by increasing the overhead.

Therefore, the shortest "effective communication time" between the two neighboring nodes in all the route will be the maximum effective communication time of the whole route, and the maximum effective communication time of the link "1 - n" is calculated as Equation (4-1) shows:

$$LET(link_{1\text{-}n}) = \min (LET(link_{1\text{-}2}), LET(link_{2\text{-}3}), \ldots, LET(link_{n\text{-}1\text{-}n})) \quad (4\text{-}1)$$

If there are *m* paths between node 1 to node *n* at the same time, then select the largest of all path lifetime, as shown in Equation (4-2).

$$LET(1\text{-}n) = \max (LET_1, LET_2, \ldots, LET_m) \quad (4\text{-}2)$$

4.3.2. Load Balancing

The function of load balancing method of proposed algorithm is done in source node. The source waits for wait period to accept all possible routes. After this the source node orders *n* disjoint paths according to the value of RET of each route in descending order. Then the sender distributes the traffic in per packet allocation scheme using round robin fashion on the chosen routes. This means that each packet for each source and destination pair will follow different paths. This is the way how load balancing is done at source node.

4.3.3. Proposed Algorithm RREQ Packet Format

To perform this improvement in AOMDV routing protocol we need to change the original RREQ format of AOMDV routing protocol. The additional fields are shown in the Figure 4-4.

….	X.Pos	Y. Pos	Speed	Direction	LET

Figure 4-4: Proposed RREQ Packet Format

where:

- X.Pos, Y. Pos: The (X, Y) coordinates of a node.
- Speed: The speed of the mobile node.
- Direction: The angle or direction of the moving node.
- LET: Link Expiration Time

In the proposed routing algorithm if the source node wants to obtain the reachable path to the destination node, the source node first initiates the RREQ packet. The whole improved routing algorithm follows the following step to select the best route:

Step 1: Source node ***Ns*** broadcasts a RREQ packet to its neighboring nodes that are within the transmission radius. It adds its ID, the link expiration time, and mobility metrics such as velocity, moving direction, and current coordinate position to the RREQ packet. Here, initially link expiration time is ∞.

Step 2: When RREQ packet reaches to the intermediate node (***Ni)***, it calculates LET between RREQ sending node and itself. Then, it compares the value calculated and LET in RREQ and put minimum value in RREQ. After this it checks weather it has high destination sequence number than in RREQ known by RREQ originator node that initiate RREQ packet and also checks weather it has better LET value for the same sequence number. If so, it has a fresh and stable route to the destination and prepare and send RREP to the RREQ originator. If not, it rebroadcast the RREQ packet with minimum LET value with its mobility information by replacing the mobility metrics of RREQ sending node. In addition to this intermediate node will insert a reverse path to the source in its routing table with LET value. If a node receives two or more RREQ packet for the same destination with the same destination sequence number, then it compares all RREQ packets with LET value and propagate a RREQ packet having maximum

LET further. In addition to this, if intermediate node receiving one or multiple RREP packet or packets have one or more reverse path to the source, it will unicast RREP along the reverse path having highest value of effective communication time.

Step 3: When destination node D receives a RREQ packet, it computes LET between RREQ sending node and itself and put min value in RREQ. After this it performs a reverse path towards the sender. After this it copy the value of LET in to Route Effective Communication Time (RET) field of RREP shown in Figure 4-6. Then, it replies to *k* copy of RREQ packet to source node.

Step 4: After receiving multiple RREP, the source node orders the routes using RET value. Then distribute the traffic among selected *n* disjointed paths using per-packet allocation scheme in round robin fashion. The whole process is depicted as follows in the Figure 4-5.

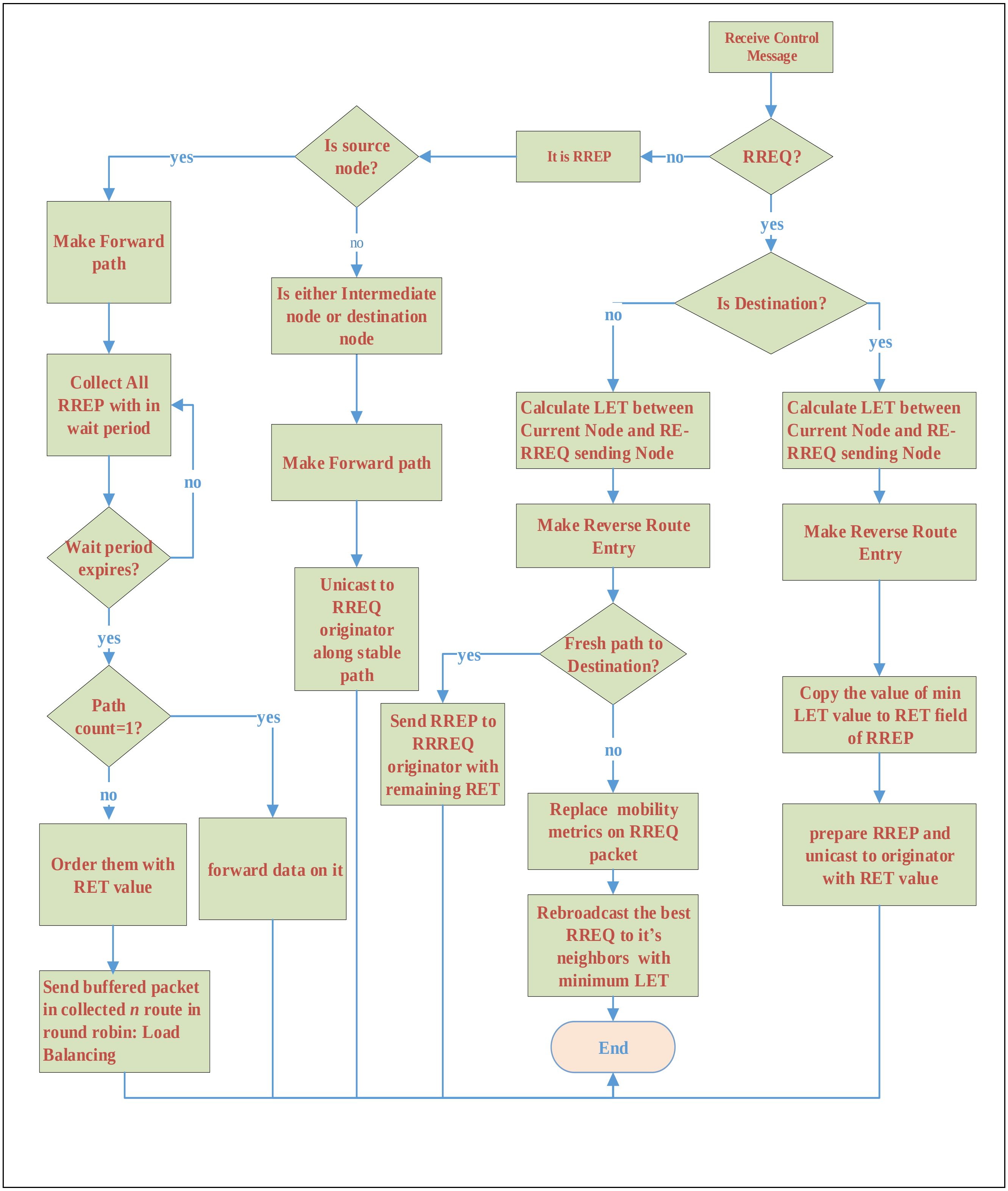

Figure 4-5: Route Discovery Process Flow Chart

4.3.4. Proposed Algorithm RREP Packet Format

When a destination receives different RREQ packet first it calculates the link effective communication time and put the minimum value in RREQ. Since it is the destination of RREQ packet, it is expected to reply a RREP. To do that it copies the value of link effective communication time from RREQ in to route effective time field of RREP shown below in Figure 4-6. Then after making reverse path to source it unicasts the RREP packet directly to the source nod. To accomplish this, it requires to re structure the RREP packet of original AOMDV routing protocol by adding additional field for route effective communication time (RET) field.

SA	DA	Sequence number	Hop count	timeout	RET

Figure 4-6: Proposed Routing Algorithm RREP Packet Format

Where:

SA: Contains sender address

DA: contains destination address

Sequence number: contains destination sequence number

Hop count: contains hop count from DA to current RREP receiving node

Timeout: contains ages of a routing entry

RET: contains route effective communication time value

4.3.5. Proposed Algorithm Routing Table Entry Structure

The new structure of routing table entries is shown in Figure 4-7. We add another additional field effective communication time in the route_list of original AOMDV routing protocol to hold path effective communication time.

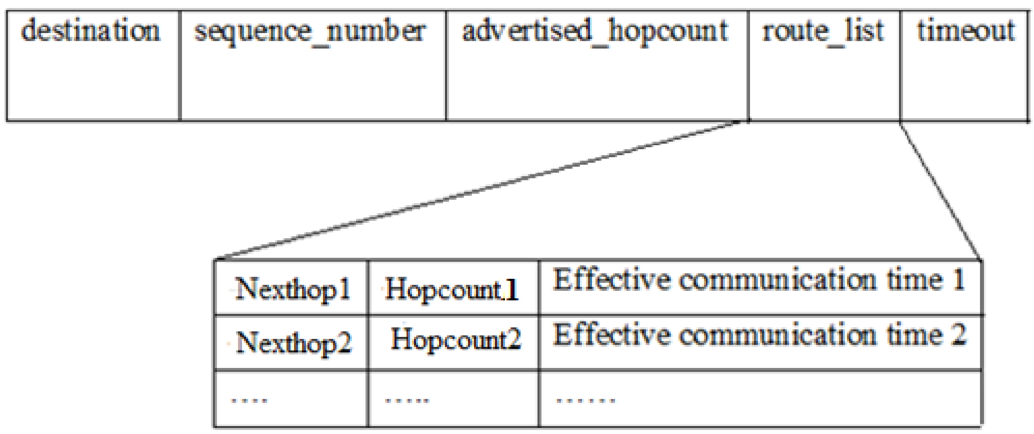

Figure 4-7: Proposed Route Table Entry Structure

Where:

destination: This attribute stores destination node address

sequence_number: This attribute stores sequence number which specify how fresh the route information is

advertised_hopcount: This attribute stores maximum hop count for multiple paths for the destination

route_list: This attribute store path information in form of (nexthop, hopcount) tuples

timeout: This attribute stores age of a route entry

Nexthopn: next hop to source or destination at n^{th} list in route_list

Hopcountn: hop count from source or destination at n^{th} list in route_list

Effective communication time n: Route effective communication time at n^{th} list in route_list

4.3.6 Proposed Algorithm

In the algorithm let ***Ns, Ni,*** and ***Nd*** be sender node, intermediate node, and destination node respectively. Then, the procedure for source node is described in the following algorithm number one. In order to limit the interference[48, 36], the number of **N** is limited to three in our experiment.

Algorithm 1: For source node(Ns)

```
int path_count; /* Existing known and active paths in Ns */
If (no route to destination)
       Initialize RREQ packet with Ns's speed, direction
           and LET with max value, and x, y coordinate;
       Initiate route discovery;
End if
While (wait period)
 Collect All RREP;
End while
If (RREP received)
path_count++;
End if
If (path_count==1)
     Forward data packet to specified route;
 else /* N routes are known and active (where N is >=2) */

     orders the path with RET value in descending order;
     distribute traffic per packet base in N routes;
 End if
```

The second algorithm i.e. Algorithm 2 is the procedure for intermediate node(***Ni***). This algorithm shows the prcedure when intermediate node accepts RREQ packet and RREP packet. Here, intermediate node may receive two RREQ packets for the same destination with the same sequence number, in that case the node(***Ni***) will compare the LET values of each RREQ packet and select one RREQ having highest number of LET value to propagate to it's neighbor. In addition to this, if intermediate node receiving one or more RREP packet or packets have one or more reverse path to the source, it will unicast RREP along the reverse path having highest value of effective communication time.

Algorithm 2: For Intermediate node(Ni)

```
if (it receives RREQ packet)
 calculate LET between current node and RE: RREQ sending node;
 Make reverse route entry for that source node with minimum
 LET value;
  If (no path to destination is known)
       Replace speed, direction, x, y coordinate in RREQ;
       RE Broadcast best RREQ message to all its Neighbours
       with minimum LET value;
  Else
      Prepare RREP and send RREP to Source;
  End If
Else if (it receives RREP packet)
   Insert forward entry for the destination with RET value
   Unicast RREP towards the source node along stable reverse
   route;
End if
```

The last algorithm shows the procedure of destination node when it replies to a request.

Algorithm 3: For Destination node(Nd)

```
If (it receives RREQ packet)
  calculate LET between current node and RE: RREQ sending
  node;
  Make a reverse route entry;
  Write the minimum LET value in RET field of RREP;
  Reply to source node;
End if
```

4.5. Summary

In this chapter our proposed system's: flow chart, model and algorithm are described. Moreover, improvements made on the original routing protocol (AOMDV) data structure and packet format, i.e. LET and load balancing components of the proposed improved AOMDV routing protocol are illustrated. In the chapter, mobility models are also discussed and compared. According to the comparison, Enhanced Gauss Markov mobility model describes the air movement (FANET) well. Since EGM is not implemented in NS2, we used GM mobility model as a mobility model in our simulation.

Chapter 5

Implementation and Performance Evaluation

5.1. Overview

In this section, first we compare network simulation tools and describe the reason why we choose network simulator 2 (NS2). After this we describe our simulation parameter setting. Following this we mention how our mobility is generated. Then, we conduct simulation experiment to evaluate the performance of our proposed improved routing protocol based on AOMDV, using NS2 [60]. We took end to end delay, packet delivery ratio, and packet drop ratio to compare with existing routing protocol.

5.2. Simulation Tools

At present, there are four most commonly used network simulation softwares. These are Optimized Network Engineering Tool(OPNET) series [56], QualNet series [58], OMNET++ series [59], and ns series [60]. OPNET is a commercial software, so the interface is very friendly, powerful, easy to operate, and the main changes to the node is the modification of its attributes [56]. From OPNET series, the current highest version is 17.5, and OPNET 14.5 version is free and its package available online for download [57]. Though OPNET 14.5 are available on line freely we will not recommend for student to do with it because there is no free support online when technical difficulties arrive unless one can pay for it. Moreover, its the interface is not flexible; the physical layer of modeling is not very accurate [13], and takes long time to learn as NS series.

QualNet [58], as a typical event triggering model, has a strong inter-layer relationship and a strong portability. It is a commercial simulator with expensive prices (hundreds of thousands of dollars) to its users concentrated in large commercial companies and research institutes. College teachers and students rarely uses it, so this determines the amount of its customers is very small and there is much less information about QualNet on the Internet. But QualNet has friendly interface, the interface is particularly flexible. We can take QualNet as Windows, and OPNET as Mac [13]. Multi-system co-simulation is very convenient, the physical layer of modeling can be achieved by means of MATLAB.

OMNET++ [59] provides a component based hierarchical, modular and extensible architecture. Components are programmed in C++ which consists of the simulation kernel and utility classes for statistics collection and topology discovery. Both NS series and OMNET++ series are freely available online. It takes relatively short time to learn than NS series and OPNET series. Though it is not good as OPNET and QualNet, it has graphical user interface unlike NS series. Although OMNET++ has this advantage, it has less modules and user contributed code online compared with NS series.

NS's biggest advantage is its open source and free online support. But NS simulation needs high user programming ability, difficult at entry level, and learning time takes long period. NS series has many users and many documents available online compared to other simulator. Specially, compared to NS3, NS2 is rich in user contributed models and modules on the Internet. Due to this reason we select it as a simulation software for evaluating our improved routing protocol for supersonic speed flying ad hoc network.

The network simulator NS-2 is discrete event simulation software for network simulations. NS-2 began as a variant of the REAL network simulator (REAL Network Simulator) in 1989 [60]. We use latest version, ns-allinone-2.35, which supports our base protocol which is AOMDV and other routing protocols for ad-hoc wireless networks such as AODV, TORA, DSDV, DSR, and extra. NS-2 is written in C++ programming language and Object Tool Common Language (OTCL). Although NS-2 can be built on various platforms, we chose a Linux platform (UBUNTU 16.04 LTS) for this thesis, as Linux offers a number of programming development tools that can be used along with the simulation process.

To run a simulation with NS-2, the user must write the simulation script in OTCL, get the simulation results in an output trace file, and analyze the results by using the *awk* command, Perl scripts, or any other trace analysis available program. Our simulation script written in OTCL is shown in Appendix A and output trace file is shown in Appendix B. For this thesis, we developed an improved routing protocol based on ad hoc routing protocol AOMDV and analyzed its NS-2 trace files to calculate average end to end delay, packet delivery ratio, and packet drop ratio metrics that we use for the evaluation of the improved routing protocols. NS-2 also offers a visual representation of the simulated network by tracing nodes' movements and events and writing them in a network animator (NAM) file. To edit original AOMDV first we clone the protocol and rename it, and the general procedure taken from online [61].

5.3. Simulation Parameter Setting

The test simulation parameters are shown in the following table, Constant Bit Rate traffic (CBR) is selected in the simulation scenario which generate user data gram protocol (UDP) data flow. The simulation experiment is carried out for 20, 40, 80, and 100 high-speed moving nodes in the square area of 20km * 20km, each simulation was performed by varying simulation seconds starting from 60 sec and average values are taken. In the simulation, the node speed ranges from 1Mach(M) to 5Mach(M) i.e. from 340-1700 in m/s. Gauss-Markov mobility model is taken with the memory parameters of 0.85. We set the node maximum transmission distance of 1500m. The remaining parameters are shown in Table 5-1:

Table 5-1: Parameter Settings

Parameter type	Parameter value
Mission Area	20km * 20km
Packets	UDP
Traffic type	CBR
Packet size	512 bytes
Node Transmission Range	1500 m
Simulation time	60 s
Node Speed Range	1M, 2M, 3M, 4M, 5M
Mobility Model	Gauss Markov Mobility model (GM)
Number of Nodes	20, 40, 80, and 100
MAC Protocol	802.11
Packet rate (Mbps)	1, 2.5, 5.5, and 11

5.4. Mobility Scenarios Generation

NS-2 requires node movements to either be defined in the OTCL script or to be read from an external file. In this thesis, we used the Bonnmotion-1.3 software [62], developed at the University of Bonn, to create mobile-node movement scenarios. The Gauss Markov mobility model [62] is a mobility model in which mobile nodes move based on history in the simulation area. This model correctly mimics the movement of flying body as study shows that in [13]. The movement speed of node is randomly chosen from range given as maximum speed and minimum speed as a parameter to the model. The type of parameters that can be used for the generation of the GM mobility scenario is explained in Table 5-2.

Table 5-2:GM parameters in Bonnmotion-1.3

Gauss Markov model (GM) Parameters	
-n	Number of mobile nodes
-d	Simulation duration
-x	Simulation area width
-y	Simulation area height
-z	Simulation area depth
-h	Max. speed
-m	Min. speed(default=0)
-g	Gaussian parameters
-u	force uniform speed distribution

To generate a Gauss Markov model mobility scenario, the user should write the following command shown in line number 1. After the generation of scenario named fanetGmvt, we should type the command in line 2 to transform fanetGmvt into a file that can be read by NS-2.

```
1. . /bm -f fanetGMmvt GaussMarkov -n 10 -d 60 -x 20000 -y 20000
   -h 1700 -m 340 -g 0.85
2. ./bm NSFile -f fanetGMmvt
```

Figure 5-1 shows the nodes in the NAM console at specific time of the simulation.

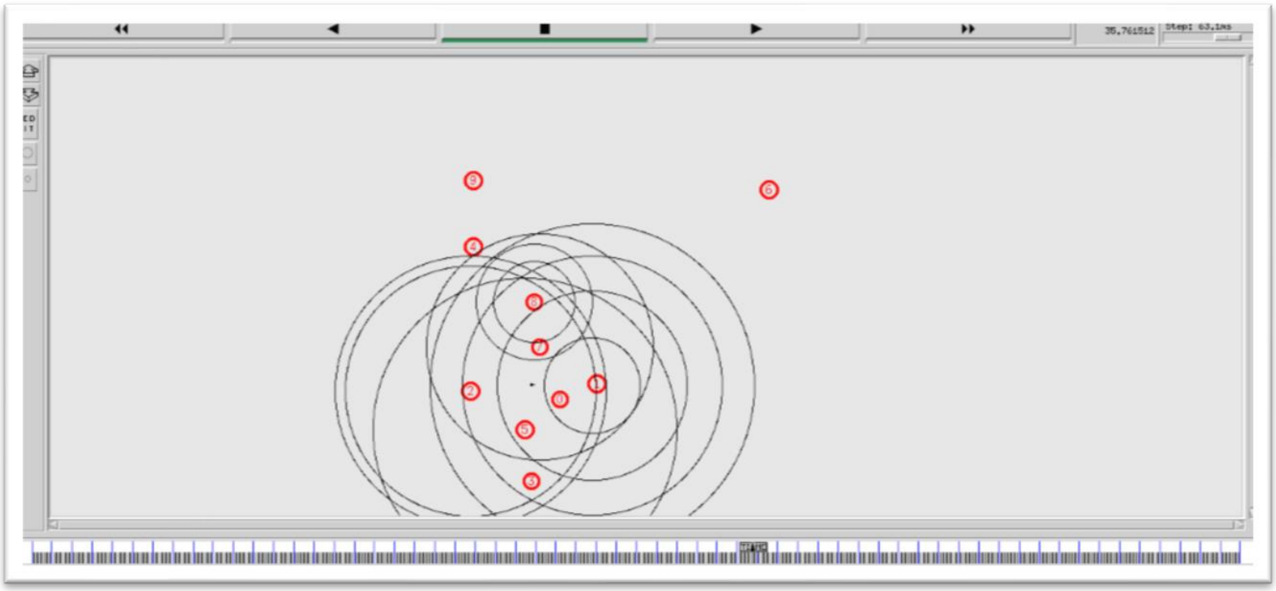

Figure 5-1: Supersonic Speed FANET Model in NS2

5.5. Setting Transmission Range

Transmission range is the maximum distance or coverage area at which a node can send data to another node that is within range. If a node is not with in communication range or transmission range of a node multi hop concept is applied so that it will forward to the intermediate node and the intermediate node will forward to the intended receiver node. MANET is working using this multi hop concept. In NS2 we cannot directly assign transmission range in terms of distance [67]. To set transmission range we need to set transmit power `(Pt_)` and receiver signal threshold `(RXThresh_)` variables on our OTCL script and shown in appendix A. NS2 has an inbuilt mechanism to calculate the distance for certain communication range using the `threshold.cc` file in `~ns-2.35/indep-utils/propagation/` folder**.** To use this file to find important variable for configuring transmission range we will use `./threshold` command shown below. Since, this paper describes the environment for the air supersonic-speed flying objects of the ad hoc network, we choose to use free space propagation model and specify it using -m option. We put the transmission range of 1,500 in order to decrease the adverse effect of supersonic speed behavior of our environment. Then after this, `threshold.cc` will output what `Pt_`, `RXThresh_`, and other variable should be for this distance.

```
./threshold -m FreeSpace 1500
```

After inputting this command followed by return, we will get the following result which are similarly shown in Appendix A.

```
1. distance = 1500
2. propagation model: Free Space
3. transmit power: 0.381838
4. frequency: 9.14e+08
5. transmit antenna gain: 1
6. receive antenna gain: 1
7. system loss: 1
8. Receiving threshold RXThresh_ is: 1.42681e-12
9. transmit power      Pt_ is: 0.381838
10. channel frequency (Hz) freq_ is: 9.14e+08
11. Carrier Sensing threshold CSThresh_ is: 1.559e-11
12. capture threshold CPThresh_ is: 10.0
```

So, we will use this result in to our OTCL script as follows which also shown in Appendix A in our whole OTCL script:

```
1. Phy/WirelessPhy set CPThresh_ 10.0      ;#capture threshold in Watt
2. Phy/WirelessPhy set CSThresh_ 1.559e-11 ;#Carrier Sensing threshold
3. Phy/WirelessPhy set RXThresh_ 8.5457e-11;# receiver signal
   threshold
4. Phy/WirelessPhy set freq_ 9.14e+08      ;# channel frequency (Hz)
5. Phy/WirelessPhy set Pt_ 0.381838        ;# transmit power
```

5.6. Evaluation Metrics

In this paper, the performance metrics such as packet delivery ratio, average end-to-end delay, and packet drop ratio were calculated and evaluated for AOMDV and our proposed protocol Load Balancing and LET based AOMDV(LBLET-AOMV).

5.6.1. Packet Delivery Ratio

It is the ratio of the number of data packets received successfully at the destination and the total number of data packets actually transmitted by the source. Packet delivery ratio can also be used to measure the quality of discovered routing path. The packet delivery ratio is given as

Packet delivery ratio= ((Number of packets received)/ (Number of packets sent))*100 (5-1)

5.6.2. Average end-to-end Delay

The average end-to-end delay gives the average time it takes for a data packet sent by a source node to the time it delivered to the destination. The delay measures the performance of the flows. The average end-to-end delay can be calculated as

Average end-to-end delay

$$= \sum ((\text{Packet received time - Packet sent time}))/ (\text{Number of packets})) \qquad (5\text{-}2)$$

5.6.3. Packet Drop Ratio

Packet drop ratio is the ratio of the number of packets dropped during the routing and the number of packets sent by the source. This is used to measure the quality of routing path. The packet drop ratio is measured as

Packet Drop Ratio

$$= (((\text{Number of packets sent - Number of packets received}))/ (\text{Packet sent}))) \qquad (5\text{-}3)$$

5.7. Trace Analysis

The *awk* script program is used to analyze the NS-2 trace files and to calculates the values of the above three quantitative metrics. This program is shown in Appendix C. In this section, we explain how to get those values from the NS-2 trace file.

To calculate Average End to End delay from NS-2 trace files, for every packet in the sentPktList, we search its sequence number in the rcvPktList and store the transmission time. For each successful matching, we extract the receiving time of that packet and calculate the end-to-end delay. Then, we sum all the delays and divide by the number of packets.

To calculate Packet Delivery Ratio from NS-2 trace files, we build two lists, one of received and one of sent CBR packets with the agent type AGT. In NS-2 a data packet is delivered at the destination node only if there is a receive event with the same packet sequence number associated with the agent type AGT. For the sentPktList, we store values for transmission time and packet sequence number. In the same way, we store the receiving time and the sequence packet number in the rcvPktList. Two counters, named rcvPkts and sentPkt, are used to calculate the packet delivery ratio.

Lastly to calculate Packet Drop Ratio from NS-2 trace files, sentPktList and rcvPktList are used to compute Packet Drop Ratio.

5.8. Simulation Result

There are two set of experiments conducted using NS2. The first set of experiment compares the performance of the AOMDV and LBLET-AOMDV routing protocol by increasing the packet rate from 1Mbps to 11Mbps, while maintaining the node speed in range of [340m/s, 1700m/s] and no pause time at all. The second set of experiments compare the performance of AOMDV and LBLET-AOMDV routing protocol by increasing the number of nodes in network from 10 to 100, while maintaining the node speed in range of [340m/s, 1700m/s] with no pause time.

In all our experiments, 10 runs were executed per recorded value. Figure 5-2 through Figure 5-7 show the performance of AOMDV and LBLET-AOMDV with varying packet rate and number of nodes. From the results shown in Figure 5-2 through Figure 5-7, we can see that the performance of the two protocols decreases as the packet rate and number of nodes increases in the network because of the limited wireless link capabilities.

Figures 5-2 and 5-3 shows the average end to end delay with varying packet rate and number of nodes in the networks respectively. From this, the average end to end delay of the LBLET-AOMDV protocol is much lesser than AOMDV. The reason is that LBLET-AOMDV uses all the discovered best route having highest amount of RET value at the same time to transmit data which leads to increase in speed of transmission and this decreases the delay. In addition to this, load balancing method adopted in proposed routing protocol avoids congestion under constrained bandwidth and by this decreases packet drop. Moreover, in AOMDV, when the link breaks due to supersonic speed behavior of the network, packets are buffered and sent later on the new route discovered. In such a case, packets are delayed in reaching the destination. Whereas LBLET-AOMDV uses LET to select stable path avoids frequent route breakage and hence results in lesser delay.

From Figure 5-2, we can see that the delay of the two protocols increases as the load increases because high loads can deplete constrained bandwidth resources, it can lead to packet loss, buffer overflow and degradation in throughput. So, it results in a longer end-to-end delay. However, LBLET-AOMDV outperforms AOMDV because of adopting load balancing by traffic distribution over multiple paths.

Load balancing in MANET increases security, reduces end to end delay, enhance efficient use of network resources, increase communication speed, enhance efficient utilization of bandwidth, decrease the possibility of congestion occurrence, and by this it increases overall network performance and support for QoS. The next figure, Figure 5-3 shows the average end-to-end delay of AOMDV and LBLET-AOMDV for the different number of supersonic speed mobile nodes. From Figure 5-3, we can see that the average end-to-end delay increases as the number of nodes in the network increases for the two protocols. The average end-to-end delay of the data packet includes waiting time in the nodes, queue delay for the transmission/retransmission at the MAC layer and waiting time in the buffer during route recovery due to a route failure. The selection of a more stable path and load balancing in LBLET-AOMDV significantly reduces and controls the end-to-end delay of the data packets. So, from the Figure 5-2 and 5-3, it can be seen that the average end-to-end delay of the LBLET-AOMDV outperforms AOMDV routing protocol.

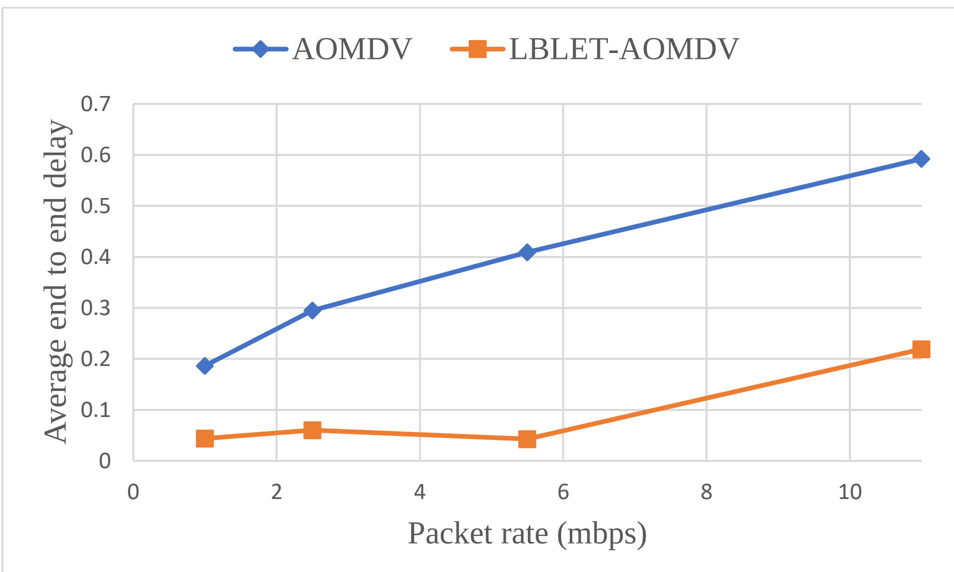

Figure 5-2: Average End to End Delay Varying Packet Rate

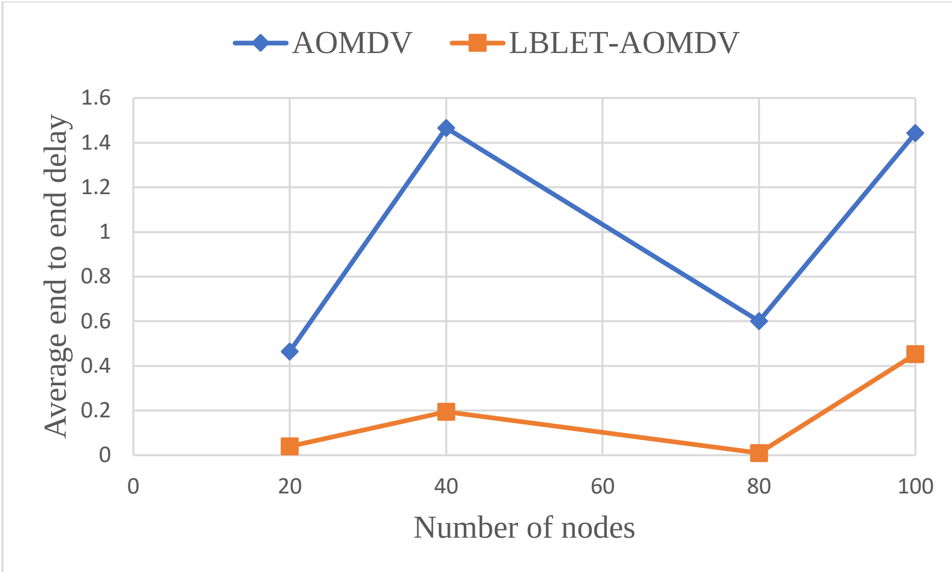

Figure 5-3: Average End to End Delay Varying Network Size

Figure 5-4 and 5-5 shows packet delivery ratio under different packet load and number of nodes. As it can be seen from the figure LBLET-AOMDV performs better than that of AOMDV. The reasons for this are:

1. LBLET-AOMDV uses load balancing and link effective communication time method to find the most stable multiple paths between the source and destination in highly dynamic network and distribute traffic over multiple path using round robin manner.
2. The congestion incurred due to constrained bandwidth resources which leads to longer end to end delay, packet loss, and reduced network performance are controlled by load balancing mechanism adopted in LBLET-AOMDV through distributing the traffic over multiple paths.
3. Load balancing adapted in LBLET-AOMDV for supersonic speed flying ad hoc network increases security, reduces end to end delay, enhance efficient use of network resources, increase communication speed, enhance efficient utilization of bandwidth, decrease the possibility of congestion occurrence, and by this it increases overall network performance and support for QoS.

4. LET allows LBLET-AOMDV to select more stable path and avoids frequent route rediscovery and hence maintenance packet and other protocol control packet will not induce overload in the network and do not overwhelm the network performance as AOMDV.
5. There is a greater wastage of network resources such as bandwidth in AOMDV when shortest active route failed because of dynamic nature of the network and when AOMDV frequently restart route rediscovery packet and route maintenance packet in the network which will consume the bandwidth available and result high overhead in the network.
6. The protocol predicts the link breakage and finds stable link from available link so the packets loss due to breakages are prevented. This contributes to higher number of packets delivered at the receiver end.
7. Repeatedly selecting a node on shortest path in AOMDV leads to buffer overflow at specific node which leads to packet loss

So, the packet delivery ratio is higher in LBLET-AOMDV than in AOMDV, which relays only on single stable path with no load balancing technique.

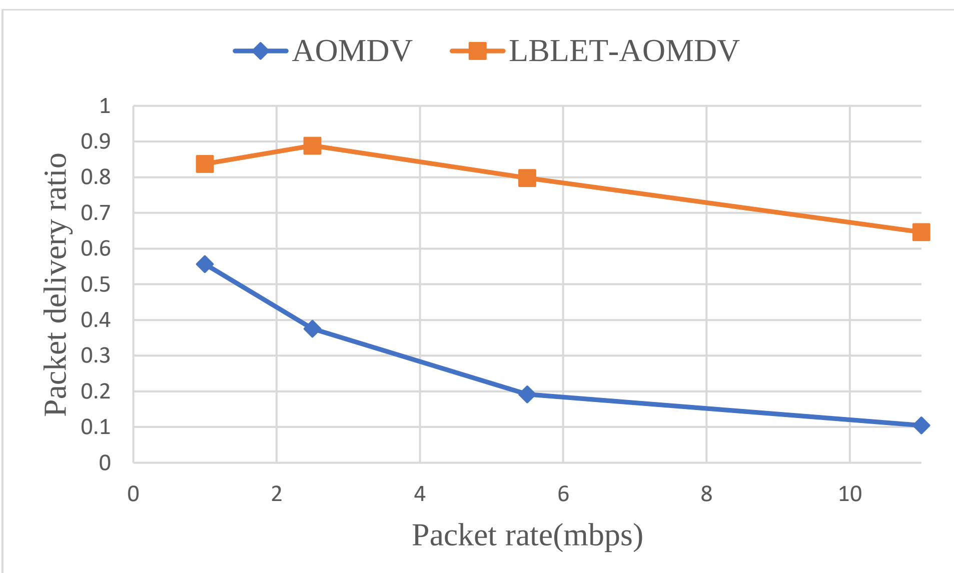

Figure 5-4: Packet Delivery Ratio Varying Packet Rate

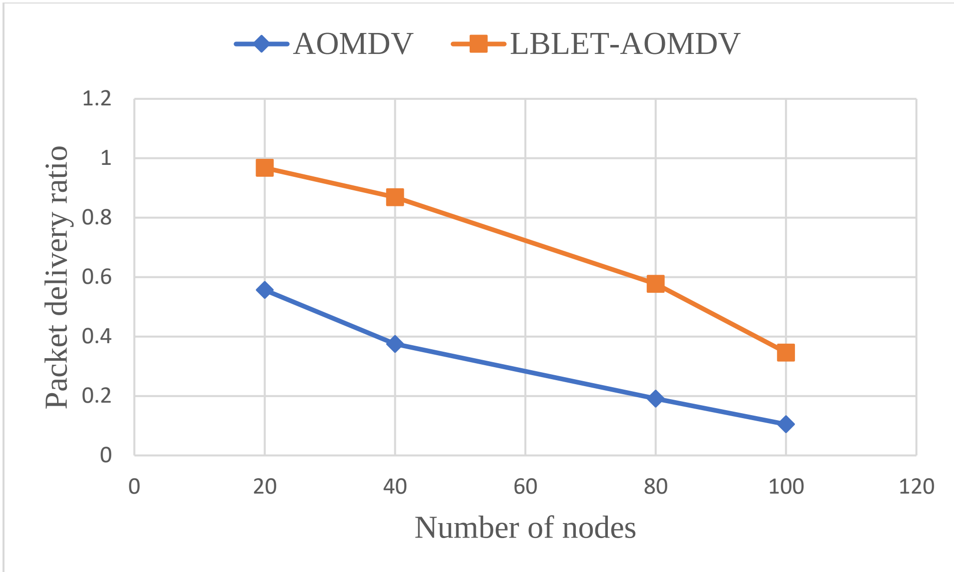

Figure 5-5: Packet Delivery Ratio Varying Network Size

Figures 5-6 and 5-7 shows the simulation results of the packet drop ratio of the LBLET-AOMDV and AOMDV routing protocols with varying load and number of nodes respectively. From Figure 5-6 and 5-7, we can see that the packet drop ratio increases as the load increases and number of nodes increases in the network. LBLET-AOMDV outperforms AOMDV, especially in Figure 5-7 the performance difference is more significant. The reasons are as discussed above.

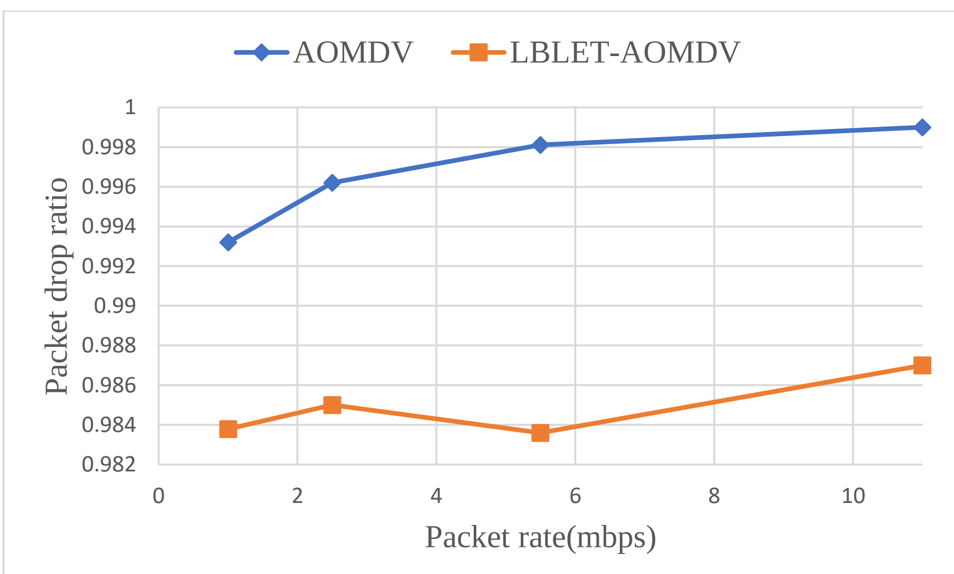

Figure 5-6: Packet Drop Ratio Varying Packet Rate

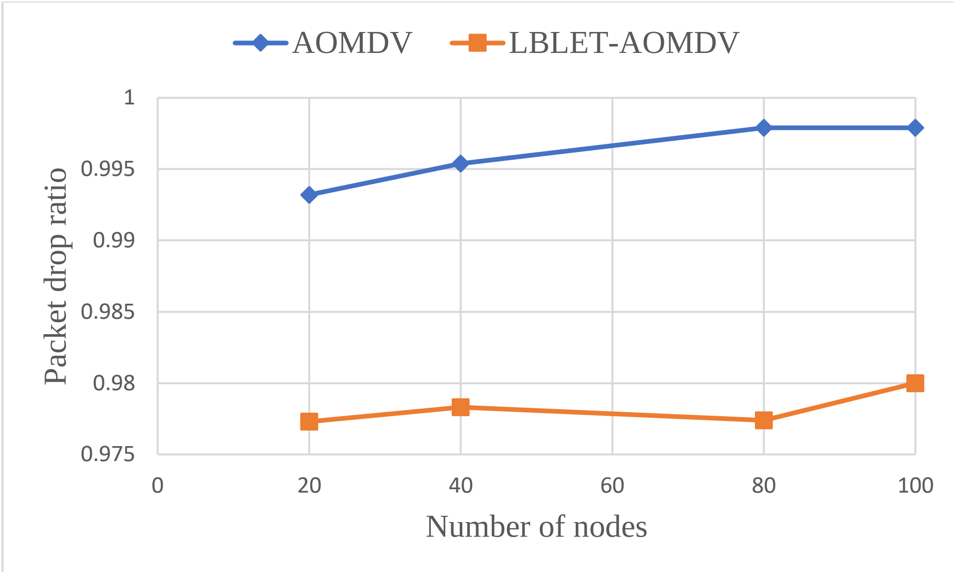

Figure 5-7: Packet Drop Ratio Varying Network Size

5.9. Summary

In this thesis an improved routing protocol (LBLET-AOMDV) for supersonic speed flying ad hoc network is proposed and tested using the well-known simulator of NS-2.35. The proposed improvement is added towards adapting AOMDV routing protocol for supersonic speed flying ad hoc network through using constrained bandwidth efficiently in the network, decreasing effect of LET-hop count tradeoff effect (end to end delay); as well as, towards decreasing congestion occurred due to bandwidth constrained supersonic speed flying ad hoc network. This makes the proposed routing protocol support QoS for emerging multimedia communication in supersonic speed flying ad hoc network. Multimedia communication demands from underlying network minimal delay, minimal delay variance (jitter) and minimum packet loss rate [66]. To fulfil this the improved routing algorithm uses load balancing and link effective communication time together to use the advantage of both. By exploiting these two advantages remarkable and significant results have achieved as shown in analysis part of this chapter.

Chapter 6

Conclusion and Recommendation for Future Work

6.1. Conclusion

We have proposed an improved routing protocol LBLET-AOMDV for supersonic speed flying ad hoc network which integrates load balancing and link effective communication time on AOMDV. LBLET-AOMDV efficiently balance the traffic load in the network, decreases end to end delay, increase packet delivery ratio, and decrease packet drop ratio. Here, the selection of the path is performed by using link effective communication time and the load is distributed along a path having highest value of RET so that it decreases the need of route rediscovery and congestion by selecting most stable paths in supersonic speed flying ad hoc network. It also decreases end to end delay by using multiple paths at the same time in round robin fashion to send data. The source node selects *n* useful disjoint paths and efficiently distributes the traffic load using per-packet allocation scheme which is well known to work well in most ad hoc networks [36]. Simulation results, under the network simulator-2 (NS-2), show that LBLET-AOMDV improves the performance of AOMDV in terms of average delay, packet delivery ratio, and packet drop ratio.

6.2. Recommendations for Future Work

As a future work, some interference control mechanism can be implemented in LBLET-AOMDV to control interference when using multiple path at the same time. In addition to this packet distribution can be performed with respect to the value of RET of the path, and evaluate the proposed algorithm using EGM mobility model. Per flow allocation mechanism can also be adapted to make this improved routing protocol more suitable and to coexist with TCP communication so that remove the drawback of this scheme which is out of order delivery and re-sequencing burden on the destination. We believe, however, that cost-effective reordering buffers are easily implementable.

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Appendix A: OTCL script

```
#-----------------------------------------------------------------
# Definition of the physical layer
#-----------------------------------------------------------------
#remove-all-packet-headers                                        ;# removes all except common
#add-packet-header IP LL Mac AODV AOMDV ATR DSDV DSR OLSR UDP TCP CBR FTP   ;# needed headers
Mac/802_11 set CWMin_                31
Mac/802_11 set CWMax_                1023
Mac/802_11 set SlotTime_             0.000020                     ;# 20us
Mac/802_11 set SIFS_                 0.000010                     ;# 10us
Mac/802_11 set PreambleLength_       144                          ;# 144 bit
Mac/802_11 set ShortPreambleLength_  72                           ;# 72 bit
Mac/802_11 set PreambleDataRate_     1.0e6                        ;# 1Mbps 1
Mac/802_11 set PLCPHeaderLength_     48                           ;# 48 bits
Mac/802_11 set PLCPDataRate_         1.0e6                        ;# 1Mbps 1
Mac/802_11 set ShortPLCPDataRate_    2.0e6                        ;# 2Mbps
Mac/802_11 set RTSThreshold_         300                          ;# bytes 0
Mac/802_11 set ShortRetryLimit_      7                            ;# retransmissions
Mac/802_11 set LongRetryLimit_       4                            ;# retransmissions
Mac/802_11 set newchipset_           false  ;# use new chipset, allowing a more recent  packet to be correctly received in place of the first sensed packet
Mac/802_11 set dataRate_ 11Mb                          ;# 802.11 data transmission rate
Mac/802_11 set basicRate_ 1Mb                          ;# 802.11 basic transmission rate
Mac/802_11 set aarf_ false                             ;# 802.11 Auto Rate Fallback
#--------------------------------------------------------------------------------
# Defining options
# --------------------------------------------------------------------------------

set val(chan)         Channel/WirelessChannel
set val(prop)         Propagation/FreeSpace
set val(ant)          Antenna/DirAntenna
set val(ll)           LL
set val(ifq)          Queue/DropTail/PriQueue
set val(ifqlen)       200
set val(netif)        Phy/WirelessPhy
set val(mac)          Mac/802_11
set val(nn)           10
set val(x)            20000
set val(y)            20000

set val(energymodel)  EnergyModel
set val(n_ch)         chan_1
#-----------------------------------------------------------------
# Scenario parameters
#-----------------------------------------------------------------
set val(rp) LBLETAOMDV                                ;# routing protocol
set val(end) 60.0                                          ;# simulation
```

```
time [s]
set val(mobility) /home/nwengr/fanetmob/fanetGMmvt.ns_movements ;# mobility model
set val(minSpeed) 340                               ;# movement minimum speed [m/s]
set val(maxSpeed) 1700                              ;# movement maximum speed [m/s]
set val(minPause) 0.0                               ;# movement minimum pause time [s]
set val(maxPause) 0.0                               ;# movement maximum pause time [s]
set val(traffic) Node-UDP ;# data pattern
set val(dataStart) 5.0
set val(dataStop) [expr $val(end) - 5.0]
set val(seed) 1 ;# general pseudo-random sequence generator
set val(macFailed) true                     ;# ATR protocol: ns2 MAC failed callback
set val(etxMetric) true                             ;# ATR protocol: ETX route metric
set val(throughput) 5.4 ;# CBR rate (<= 5.4Mb/s)
set val(flow) 100       ;# number of concurrent data flow for FLOW-**P data pattern
set val(nodes) $val(nn);# number of concurrent nodes for NODE-**P data pattern

# ------------------------------------------------------------------------------
# Channel model
# ------------------------------------------------------------------------------
Phy/WirelessPhy set CPThresh_ 10.0                  ;# capture threshold in Watt
Phy/WirelessPhy set CSThresh_ 1.559e-11                     ;# Carrier Sensing threshold
Phy/WirelessPhy set RXThresh_ 8.5457e-11                    ;# receiver signal threshold
Phy/WirelessPhy set freq_ 9.14e+08                           ;# channel frequency (Hz)
Phy/WirelessPhy set Pt_ 0.381838

# ------------------------------------------------------------------------------
# Pseudo-random sequence generator
# ------------------------------------------------------------------------------
# General pseudo-random sequence generator
set genSeed [new RNG]
$genSeed seed $val(seed)
set randomSeed [new RandomVariable/Uniform]
$randomSeed use-rng $genSeed
$randomSeed set min_ 1.0
$randomSeed set max_ 100.0
# Data pattern: node
set genNode [new RNG]
$genNode seed [expr [$randomSeed value]]
set randomNode [new RandomVariable/Uniform]
$randomNode use-rng $genNode
$randomNode set min_ 0
$randomNode set max_ [expr $val(nn) - 1]
# Data pattern "Random": flow start time [s]
set genStartData [new RNG]
$genStartData seed [expr [$randomSeed value]]
set randomStartData [new RandomVariable/Uniform]
```

```
$randomStartData use-rng $genStartData
$randomStartData set min_ $val(dataStart)
$randomStartData set max_ $val(dataStop)
# Data pattern "Full: flow start time [s]
set genStartDataFull [new RNG]
$genStartDataFull seed [expr [$randomSeed value]]
set randomStartDataFull [new RandomVariable/Uniform]
$randomStartDataFull use-rng $genStartDataFull
$randomStartDataFull set min_ 0
$randomStartDataFull set max_ [expr ($val(nn) * ($val(nn) - 1)) - 1]
# Data pattern: flow end time [s]
set genEndData [new RNG]
$genEndData seed [expr [$randomSeed value]]
set randomEndData [new RandomVariable/Uniform]
$randomEndData use-rng $genEndData
$randomEndData set min_ 0.0
$randomEndData set max_ [expr $val(end) - $val(dataStart) - 10]



set ns [new Simulator]
set tracefd [open letaomdv.trc w]
$ns trace-all $tracefd
$ns use-newtrace
set namtrace [open sim3.trc w]
$ns namtrace-all-wireless $namtrace $val(x) $val(y)

set topo [new Topography]

$topo load_flatgrid $val(x) $val(y)

create-god $val(nn)
#Create channel
set chan_1 [new $val(chan)]

$ns node-config  -adhocRouting $val(rp) \
-llType $val(ll) \
-macType $val(mac) \
-ifqType $val(ifq) \
-ifqLen $val(ifqlen) \
-antType $val(ant) \
-propType $val(prop) \
-phyType $val(netif) \
-topoInstance $topo \
-agentTrace ON \
-routerTrace ON \
-macTrace ON \
-movementTrace OFF \
-channel $chan_1   \

for {set i 0} {$i < $val(nodes)} { incr i } {
set node_($i) [$ns node]
$node_($i) random-motion 0
$node_($i) color red
$ns at 0.0 "$node_($i) color red"
$ns initial_node_pos $node_($i) 200
```

```
}

puts "Loading scenario file..."
source $val(mobility)

# -------------------------------------------------------------------------------
# Data communication
# -------------------------------------------------------------------------------

if {$val(traffic) == "Node-UDP"} {
for {set i 0} {$i < $val(nodes)} {incr i} {
set udp($i) [new Agent/UDP]
$ns attach-agent $node_($i) $udp($i)
set dest [expr round([$randomNode value])]
while {$dest == $i} {
set dest [expr round([$randomNode value])]
}
set monitor($dest) [new Agent/LossMonitor]
$ns attach-agent $node_($dest) $monitor($dest)
$ns connect $udp($i) $monitor($dest)
set cbr($i) [new Application/Traffic/CBR]
$cbr($i) attach-agent $udp($i)
$cbr($i) set packetSize_ 512
$cbr($i) set random_ false
$cbr($i) set rate_ 100Kb
#       $cbr($i) set rate_ [expr $val(throughput) / [expr $val(n) * sqrt($val(n))]]Mb
#       $cbr($i) set rate_ [expr $val(throughput)]Mb
$ns at [expr $val(dataStart) + [$randomSeed value]] "$cbr($i) start"
$ns at $val(dataStop) "$cbr($i) stop"

#       $ns at [expr [$randomStartData value]] "$cbr($i) start"
#       set endData [expr [$randomStartData value] + [$randomEndData value]]
#       if {$endData > $val(dataStop)} {
#             set endData $val(dataStop)
#       }
#       $ns at $endData "$cbr($i) stop"
}
}

proc finish {} {
global ns tracefd namtrace

$ns flush-trace
close $tracefd
close $namtrace

exec nam sim3.trc &
exit 0
}


for {set i 0} {$i < $val(nn) } {incr i} {

$ns at $val(end) "$node_($i) reset";
```

```
}
$ns at $val(end) "finish"
puts "Starting Simulation..."
$ns run
```

Appendix B: Sample Trace file

```
1. r -t 21.549957748 -Hs 0 -Hd -2 -Ni 0 -Nx 3265.00 -Ny 3722.25 -Nz 0.00 -Ne -
   1.000000 -Nl MAC -Nw --- -Ma 0 -Md ffffffff -Ms 2 -Mt 800 -Is 2.255 -Id -1.255 -
   It LBLETAOMDV -Il 44 -If 0 -Ii 0 -Iv 1 -P lbletaomdv -Pt 0x1 -Ph 0 -Pd 2 -Pds 6
   -Pl 4.000000 -Pc HELLO
2. r -t 21.549959117 -Hs 8 -Hd -2 -Ni 8 -Nx 3657.92 -Ny 3431.45 -Nz 0.00 -Ne -
   1.000000 -Nl MAC -Nw --- -Ma 0 -Md ffffffff -Ms 2 -Mt 800 -Is 2.255 -Id -1.255 -
   It LBLETAOMDV -Il 44 -If 0 -Ii 0 -Iv 1 -P lbletaomdv -Pt 0x1 -Ph 0 -Pd 2 -Pds 6
   -Pl 4.000000 -Pc HELLO
3. r -t 21.549959325 -Hs 4 -Hd -2 -Ni 4 -Nx 4129.52 -Ny 3695.00 -Nz 0.00 -Ne -
   1.000000 -Nl MAC -Nw --- -Ma 0 -Md ffffffff -Ms 2 -Mt 800 -Is 2.255 -Id -1.255 -
   It LBLETAOMDV -Il 44 -If 0 -Ii 0 -Iv 1 -P lbletaomdv -Pt 0x1 -Ph 0 -Pd 2 -Pds 6
   -Pl 4.000000 -Pc HELLO
4. r -t 21.549959472 -Hs 7 -Hd -2 -Ni 7 -Nx 3307.17 -Ny 3200.88 -Nz 0.00 -Ne -
   1.000000 -Nl MAC -Nw --- -Ma 0 -Md ffffffff -Ms 2 -Mt 800 -Is 2.255 -Id -1.255 -
   It LBLETAOMDV -Il 44 -If 0 -Ii 0 -Iv 1 -P lbletaomdv -Pt 0x1 -Ph 0 -Pd 2 -Pds 6
   -Pl 4.000000 -Pc HELLO
5. s -t 21.549964704 -Hs 9 -Hd -2 -Ni 9 -Nx 2750.01 -Ny 2479.32 -Nz 0.00 -Ne -
   1.000000 -Nl AGT -Nw --- -Ma 0 -Md 0 -Ms 0 -Mt 0 -Is 9.0 -Id 3.2 -It cbr -Il 512
   -If 0 -Ii 14915 -Iv 32 -Pn cbr -Pi 14915 -Pf 0 -Po 0
6. r -t 21.549964704 -Hs 9 -Hd -2 -Ni 9 -Nx 2750.01 -Ny 2479.32 -Nz 0.00 -Ne -
   1.000000 -Nl RTR -Nw --- -Ma 0 -Md 0 -Ms 0 -Mt 0 -Is 9.0 -Id 3.2 -It cbr -Il 512
   -If 0 -Ii 14915 -Iv 32 -Pn cbr -Pi 14915 -Pf 0 -Po 0
7. s -t 21.549964704 -Hs 9 -Hd 3 -Ni 9 -Nx 2750.01 -Ny 2479.32 -Nz 0.00 -Ne -
   1.000000 -Nl RTR -Nw --- -Ma 0 -Md 0 -Ms 0 -Mt 0 -Is 9.0 -Id 3.2 -It cbr -Il 532
   -If 0 -Ii 14915 -Iv 30 -Pn cbr -Pi 14915 -Pf 0 -Po 0
8. r -t 21.549982748 -Hs 0 -Hd -2 -Ni 0 -Nx 3264.98 -Ny 3722.27 -Nz 0.00 -Ne -
   1.000000 -Nl RTR -Nw --- -Ma 0 -Md ffffffff -Ms 2 -Mt 800 -Is 2.255 -Id -1.255 -
   It LBLETAOMDV -Il 44 -If 0 -Ii 0 -Iv 1 -P lbletaomdv -Pt 0x1 -Ph 0 -Pd 2 -Pds 6
   -Pl 4.000000 -Pc HELLO
9. r -t 21.549984117 -Hs 8 -Hd -2 -Ni 8 -Nx 3657.94 -Ny 3431.46 -Nz 0.00 -Ne -
   1.000000 -Nl RTR -Nw --- -Ma 0 -Md ffffffff -Ms 2 -Mt 800 -Is 2.255 -Id -1.255 -
   It LBLETAOMDV -Il 44 -If 0 -Ii 0 -Iv 1 -P lbletaomdv -Pt 0x1 -Ph 0 -Pd 2 -Pds 6
   -Pl 4.000000 -Pc HELLO
10. r -t 21.549984325 -Hs 4 -Hd -2 -Ni 4 -Nx 4129.49 -Ny 3695.01 -Nz 0.00 -Ne -
   1.000000 -Nl RTR -Nw --- -Ma 0 -Md ffffffff -Ms 2 -Mt 800 -Is 2.255 -Id -1.255 -
   It LBLETAOMDV -Il 44 -If 0 -Ii 0 -Iv 1 -P lbletaomdv -Pt 0x1 -Ph 0 -Pd 2 -Pds 6
   -Pl 4.000000 -Pc HELLO
11. r -t 21.549984472 -Hs 7 -Hd -2 -Ni 7 -Nx 3307.19 -Ny 3200.90 -Nz 0.00 -Ne -
   1.000000 -Nl RTR -Nw --- -Ma 0 -Md ffffffff -Ms 2 -Mt 800 -Is 2.255 -Id -1.255 -
   It LBLETAOMDV -Il 44 -If 0 -Ii 0 -Iv 1 -P lbletaomdv -Pt 0x1 -Ph 0 -Pd 2 -Pds 6
   -Pl 4.000000 -Pc HELLO
12. d -t 21.549989704 -Hs 9 -Hd 3 -Ni 9 -Nx 2750.01 -Ny 2479.29 -Nz 0.00 -Ne -
   1.000000 -Nl IFQ -Nw --- -Ma 0 -Md 3 -Ms 9 -Mt 800 -Is 9.0 -Id 3.2 -It cbr -Il
   532 -If 0 -Ii 14915 -Iv 30 -Pn cbr -Pi 14915 -Pf 0 -Po 0
13. s -t 21.550395791 -Hs 9 -Hd -2 -Ni 9 -Nx 2749.97 -Ny 2478.87 -Nz 0.00 -Ne -
   1.000000 -Nl MAC -Nw --- -Ma 4da -Md 3 -Ms 9 -Mt 0
14. s -t 21.550723222 -Hs 9 -Hd -2 -Ni 9 -Nx 2749.94 -Ny 2478.54 -Nz 0.00 -Ne -
   1.000000 -Nl AGT -Nw --- -Ma 0 -Md 0 -Ms 0 -Mt 0 -Is 9.0 -Id 3.2 -It cbr -Il 512
   -If 0 -Ii 14916 -Iv 32 -Pn cbr -Pi 14916 -Pf 0 -Po 0
15. r -t 21.550723222 -Hs 9 -Hd -2 -Ni 9 -Nx 2749.94 -Ny 2478.54 -Nz 0.00 -Ne -
   1.000000 -Nl RTR -Nw --- -Ma 0 -Md 0 -Ms 0 -Mt 0 -Is 9.0 -Id 3.2 -It cbr -Il 512
   -If 0 -Ii 14916 -Iv 32 -Pn cbr -Pi 14916 -Pf 0 -Po 0
16. s -t 21.550723222 -Hs 9 -Hd 3 -Ni 9 -Nx 2749.94 -Ny 2478.54 -Nz 0.00 -Ne -
```

```
  1.000000 -Nl RTR -Nw --- -Ma 0 -Md 0 -Ms 0 -Mt 0 -Is 9.0 -Id 3.2 -It cbr -Il 532
  -If 0 -Ii 14916 -Iv 30 -Pn cbr -Pi 14916 -Pf 0 -Po 0
17. d -t 21.550748222 -Hs 9 -Hd 3 -Ni 9 -Nx 2749.93 -Ny 2478.51 -Nz 0.00 -Ne -
  1.000000 -Nl IFQ -Nw --- -Ma 0 -Md 3 -Ms 9 -Mt 800 -Is 9.0 -Id 3.2 -It cbr -Il
  532 -If 0 -Ii 14916 -Iv 30 -Pn cbr -Pi 14916 -Pf 0 -Po 0
18. r -t 21.550751027 -Hs 3 -Hd -2 -Ni 3 -Nx 3693.95 -Ny 2253.79 -Nz 0.00 -Ne -
  1.000000 -Nl MAC -Nw --- -Ma 4da -Md 3 -Ms 9 -Mt 0
19. s -t 21.550761027 -Hs 3 -Hd -2 -Ni 3 -Nx 3693.94 -Ny 2253.79 -Nz 0.00 -Ne -
  1.000000 -Nl MAC -Nw --- -Ma 3a0 -Md 9 -Ms 0 -Mt 0
20. d -t 21.551068261 -Hs 9 -Hd -2 -Ni 9 -Nx 2749.90 -Ny 2478.18 -Nz 0.00 -Ne -
  1.000000 -Nl MAC -Nw STA -Ma 3a0 -Md 9 -Ms 0 -Mt 0
21. s -t 21.551481741 -Hs 9 -Hd -2 -Ni 9 -Nx 2749.86 -Ny 2477.75 -Nz 0.00 -Ne -
  1.000000 -Nl AGT -Nw --- -Ma 0 -Md 0 -Ms 0 -Mt 0 -Is 9.0 -Id 3.2 -It cbr -Il 512
  -If 0 -Ii 14917 -Iv 32 -Pn cbr -Pi 14917 -Pf 0 -Po 0
22. r -t 21.551481741 -Hs 9 -Hd -2 -Ni 9 -Nx 2749.86 -Ny 2477.75 -Nz 0.00 -Ne -
  1.000000 -Nl RTR -Nw --- -Ma 0 -Md 0 -Ms 0 -Mt 0 -Is 9.0 -Id 3.2 -It cbr -Il 512
  -If 0 -Ii 14917 -Iv 32 -Pn cbr -Pi 14917 -Pf 0 -Po 0
23. s -t 21.551481741 -Hs 9 -Hd 3 -Ni 9 -Nx 2749.86 -Ny 2477.75 -Nz 0.00 -Ne -
  1.000000 -Nl RTR -Nw --- -Ma 0 -Md 0 -Ms 0 -Mt 0 -Is 9.0 -Id 3.2 -It cbr -Il 532
  -If 0 -Ii 14917 -Iv 30 -Pn cbr -Pi 14917 -Pf 0 -Po 0
24. d -t 21.551506741 -Hs 9 -Hd 3 -Ni 9 -Nx 2749.86 -Ny 2477.73 -Nz 0.00 -Ne -
  1.000000 -Nl IFQ -Nw --- -Ma 0 -Md 3 -Ms 9 -Mt 800 -Is 9.0 -Id 3.2 -It cbr -Il
  532 -If 0 -Ii 14917 -Iv 30 -Pn cbr -Pi 14917 -Pf 0 -Po 0
25. s -t 21.552240259 -Hs 9 -Hd -2 -Ni 9 -Nx 2749.79 -Ny 2476.97 -Nz 0.00 -Ne -
  1.000000 -Nl AGT -Nw --- -Ma 0 -Md 0 -Ms 0 -Mt 0 -Is 9.0 -Id 3.2 -It cbr -Il 512
  -If 0 -Ii 14918 -Iv 32 -Pn cbr -Pi 14918 -Pf 0 -Po 0
```

Appendix C: awk script

```
BEGIN {
        sends = 0;
        receives = 0;
         routing_packets = 0;
         end_to_end_delay = 0;
         highest_packet_id = 0;
}

{action=$1;

if(action == "s" || action == "r" || action == "f")
{
   # parse the time
   if($2 == "-t")
         time = $3;

   #paarse the packet_id
   if($40 == "-Ii")
         packet_id = $41;

   #calculate the sent packets
   if(action == "s" && $19 == "AGT" && $35 == "cbr")
         sends++;

   #find the number of packets in the simulation
   if(packet_id > highest_packet_id)
         highest_packet_id = packet_id;

   #set the start time, only if its not already set
   if(start_time[packet_id] == 0)
         start_time[packet_id] = time;

   #calculate the receives and end-end delay
   if(action == "r" && $19 == "AGT" && $35 == "cbr")
      #if(action == "r")
         {
               receives++;
               end_time[packet_id]= time;

         }
         else end_time[packet_id] = -1;

               #calculate the routing packets
   if(action == "s" || action == "f" && $19 == "RTR" && $35 == "AOMDV" || $35 == "LBLETAOMDV"  || $35 == "LETAOMDV" || $35 == "message")
         routing_packets++;
}
}
END {

   #calculate the packet duration for all the packets

   for(packet_id = 0; packet_id < highest_packet_id; packet_id++)
   {
         packet_duration = end_time[packet_id] - start_time[packet_id];
```

```
        if(packet_duration > 0)
              end_to_end_delay = end_to_end_delay + packet_duration;
  }

  #calculat the average end-end packet delay
  avg_end_to_end_delay = end_to_end_delay / receives;

  #calculat he packet delivery fraction
  pdfraction = (receives / sends) * 100;
        #calcuate packet drop ratio
        packet_drop_ratio=(sends - receives) / sends;

   printf "cbr s:%d r:%d, f:%d \n", sends, receives, routing_packets;
   printf "avg_end_to_end_delay: %.4f\n", avg_end_to_end_delay;
   printf "Packet Delivery ratio: %.4f\n", pdfraction;
   printf "Packet Drop ratio: %.4f\n", packet_drop_ratio;

}
```

Declaration

I, the undersigned, declare that this thesis work is my original work, has not been presented for a degree in this or any other universities, and all sources of materials used for the thesis work have been duly acknowledged.

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Signature: _____________

Place: Jimma, Ethiopia

Date: ________________

This thesis has been submitted for examination with my approval as a university advisor.

Name: Dr. Samuel Asferaw Demilew

Signature: 

Place: Debre Birhan University, Debre Birhan, Ethiopia

Date: 13/04/2018

The End