ROHC-MPLS TUNNEL ARCHITECTURE FOR WIRELESS MESH

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ROHC-MPLS TUNNEL ARCHITECTURE FOR WIRELESS MESH NETWORK

by

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DEDICATION

I dedicate my thesis to my Father and late Mother

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3G	3^{rd} Generation (telecommunication technology)
3GPP	3^{rd} Generation Partnership Project
3GPP2	3^{rd} Generation Partnership Project 2
4G	4^{th} Generation (telecommunication technology)
ACK	Acknowledgement
ACMP	Adaptive Core based Multicast Routing
ACMRP	Adaptive Core Multicast Routing Protocol
ADMR	Adaptive Demand-Driven Multicast Routing
AG	Anonymous Gossip
AMRoute	Ad-hoc Multicast Routing Protocol
AMRIS	Ad-hoc Multicast Routing
ANP	Analytic Network Process
AODV	Ad-hoc On-Demand Distance Vector
AOMDV	Ad-hoc On-Demand Multipath Distance Vector Routing
ARQ	Automatic Retransmission Request
BATMAN	Better Approach To Mobile Adhoc Networking
BATMAN-Adv	Better Approach To Mobile Adhoc Networking – Advance
BCHP	Backup Cluster Head Protocol
BGAN	Broadband Global Area Network
BGP	Border Gateway Protocol
BODS	Bandwidth Optimized Delay Sensitive

BTS	Base Transceiver Station
CALM	Communications, Air Interface, Long & Medium range
CAMP	Core Assisted Mesh Protocol
CARMEN	CARrier grade wireless MEsh Network
CBRP	Cluster based Routing Protocol
CBT	Core-based Tree
CD-ROM	Compact Disc Read Only Memory
CG-WBN	Carrier-grade Wireless Back-haul Network
CG-WMAN	Carrier Grade Wireless Metropolitan Area Network
COLT	cell on light truck
COW	Cell on Wheels
CR-LDP	Constraint-based Routing Label Distribution Protocol
CQMP	Consolidated Query packets Multicast routing Protocol
CRTP	Compressed Real Time Protocol
CTCP	Compressed Transmission Control Protocol
DCMP	Dynamic Core based Multicast Routing Protocol
DDM	Differential Destination Multicast
DRN	Disaster Response Network
DSDV	Destination-Sequence Distance Vector
DSR	Dynamic Source Routing
DVB	Digital Video Broadcast
DYMO	Dynamic MANET On-demand
ECRTP	Enhanced Compressed RTP
ECV	Emergency Communication Vehicle

EHMRP	Efficient Hybrid Multicast Routing Protocol
ESP	Encapsulating Security Payload
EV-DO	Evolution Data Optimized
eWLER	Engress Wireless Label Edge Router
E-ODMRP	Extended On-Demand Multicast Routing Protocol
FC	Full Context
FEC	Forward Error Correction
FGMP	Forward Group Multicast Protocol
FRR	Fast ReRoute
FO	First Order
FSM	finite state machines
GloMoSim	Global Mobile Information System Simulator
GSM	Global System Mobile
HSPA	High Speed Packet Access
HVDB	Hypercube-based Virtual Dynamic Backbone
ICT	Information and Communication Technology
IDHOCNET	ID Centric Architecture for Ad Hoc Network
IEEE	Institute of Electrical and Electronics Engineer
IETF	Internet Engineering Task Force
IP	Internet Protocol
IPHC	IP Header Compression
IPv4	Internet Protocol version 4
IPv6	Internet Protocol version 6
IR	Initialization/Refresh

ISO	International Organization for Standards
iWLER	Ingress Wireless Label Edge Router
LAM	Lightweight Adaptive Multicast algorithm
LAN	Local Area Network
LDP	Label distribution protocol
LSB	Least Significant Bits
LER	Label Edge Router
LSR	Label Switch Router
LSP	Label Switch Path
LTE	Long Term Evolution
MAC	Media Access Control
MAMR	Mobile Agents Aided Multicast Routing
MANET	Mobile Ad Hoc Network
MANSI	Multicast for Ad Hoc Networks with Swarm Intelligence
MAODV	Multicast Ad-hoc On-Demand Vector
MCEDAR	Multicast Core Extraction Distributed Ad-hoc Routing
MPGC	Multicast Power Greedy Clustering protocol
MPLS	Multi-Protocol Label Switch
MTU	Maximum Transmission Unit
MZRP	Multicast Zone Routing Protocol
NC	No Context
NDR	National Disaster Recovery
NERV	Network Emergency Response Vehicle

NGO	Non-Governmental Organization
NRK	NetHope-Relief-Kits
NSMP	Neighbour-Supporting Multicast Protocol
NS-2	Network Simulator-2
NS-3	Network Simulator-3
ODMRP	On-Demand Multicast Routing Protocol
OFDMA	Orthagonal Frequency Division Multiple Access
OLSR	Optimized Link State Routing protocol
OPHMR	Optimized Polymorphic Hybrid Multicast Routing protocol
OSPF	Open Shortest Path First
OSPF-TE	Open Shortest Path First - Traffic Engineering
O-mode	Optimistic-Mode
PCE	Path Computation Element
PDCP	Packet Data Convergence Protocol
PDR	Packet delivery ratio
PHS	Payload Header Suppression
PMRP	Power-aware Multicast Routing Protocol
PUMA	Protocol for Unified Multicasting through Announcements
P-REMiT	Probability for Refining Energy Efficiency of Multicast Tree protocol
QoS	Quality of Service
QualNet	QualNet Communications Simulation Platform

RALM	ReliAble, congestion-control Led Multicast
RBM	Reservation-Based Multicast
RDG	Route Driven Gossip
RIP	Routing Information Protocol
RMA	Reliable Multicast Algorithm
RMDP	Reliable Multicast Protocol
ROHC	RObust Header Compression
ROHCv2	Robust Header Compression version 2
ROMANT	Robust tree-based Multicast Ad-hoc Networks
RSVP	Resource ReSerVation Protocol
RSVP-TE	Resource ReSerVation Protocol – Traffic Engineering
RTP	Real-time Transport Protocol
R-mode	Reliable Mode
R-ODMRP	Reliable On-Demand Multicast Routing Protocol
SC	Static Context
SIP	Session Initiation Protocol
SNR	Signal to Noise Ratio
SO	Second Order
ST	Shared Tree
SRMP	Source Routing-based Multicast Protocol
STAMP	Shared Tree Ad-hoc Multicast routing Protocol
TacOps	Tactical Operations
TCP	Transmission Control Protocol
TE	Traffic Engineering

TSF	Telecom Sans Frontier
UDP	User Datagram Protocol
UE	User Equipment
UDP-Lite	User Datagram Protocol – Light
UMTS	Universal Mobile Telecommunications System
UNC	University of Northern Carolina
UTRAN	UMTS Terrestrial Radio Access Network
U-mode	Unidirectional Mode
VANET	Vehicle Area Network
VJHC	Van Jacobson Header Compression
VoIP	Voice over IP
VSAT	Very Small Aperture Terminal
WAVE	Wireless Access for Vehicular Environment
WiBACK	Wireless Backhaul
WiFi	Wireless Fidelity
WiMAX	Worldwide Interoperability for Microwave Access
WirelessMAN	Wireless Metropolitan Area Network
WLSP	Wireless Label Switch Path
WLSR	Wireless Label Switch Router
WMN	Wireless Mesh Network
WSN	Wireless Sensor Networks
W-LAN	Wireless Local Area Network
W-LSB	Windows-based least significant bits

SERI BINA TEMBUSAN ROHC-MPLS UNTUK RANGKAIAN JEJARING TANPA WAYAR

ABSTRAK

Bencana alam atau buatan manusia adalah peristiwa tidak dijangka yang boleh menyebabkan kerosakan ketara, terutama kepada infrastruktur komunikasi rangkaian. Dalam kejadian ini, penggunaan sistem komunikasi rangkaian yang pesat diperlukan untuk menyampaikan atau menerima komunikasi dalam kalangan orang-orang di kawasan bencana untuk menjalankan usaha membantu dan menyelamat. Rangkaian jejaring tanpa wayar telah muncul dan diakui potensinya untuk penempatan pantas dan liputan terakhir dari infrastruktur rangkaian yang sangat sesuai untuk pengurusan tindak balas kecemasan. Walaupun rangkaian jejaring tanpa wayar ini mempunyai ciri-ciri yang bermanfaat, ia juga memperkenalkan beberapa masalah penting. Semasa penghantaran data, masa pemulihan laluan adalah lebih tinggi dan boleh menyebabkan kehilangan data, jika berlakunya kegagalan nod dan pautan. Walaupun pemampatan teguh kepala ROHC dapat mengurangkan kos penghantaran paket secara ketara, ia juga memperkenalkan isu-isu skala, paket data yang tidak teratur dan masa lengah hujung ke hujung tambahan disebabkan oleh mekanisme pemampatan / penyahmampatan pada setiap langkah. Cadangan terowong ROHC-MPLS untuk rangkaian jejaring tanpa wayar mempunyai fungsian lapisan-silang untuk membolehkan konfigurasi diri, meningkatkan kecekapan jalur lebar, mengurangkan masa lengah hujung ke hujung dan menyokong pemulihan diri dalam masa yang minimum. pemampatan teguh kepala ROHC dapat mengurangkan saiz kepala paket dan mengurangkan secara dramatik kegunaan jalur lebar rangkaian tanpa wayar. Terowong MPLS dapat membolehkan penghantaran data pantas dan pemulihan diri secara pensuisan paket berdasarkan kejuruteraan lalulintas berbanding dengan penghalaan berasaskan IP tradisional. Seni bina lapisan-silang cadangan dinilai secara menggunakan tapak ujian masa nyata berdasarkan peranti Raspberry Pi, daripada segi masa lengah hujung ke hujung, ratio kehilangan paket dan truput, serta masa pemulihan laluan, berbanding dengan pendekatan bukan berlapisan-silang sedia ada. Seni bina terowong ROHC-MPLS menunjukkan peningkatan prestasi ketara dalam masa lengah hujung ke hujung dan ratio kehilangan paket dan truput sebanyak 42% dan 15%, manakala mengurangkan truput sebanyak 1.6% sahaja berbanding dengan kaedah pemampatan kepala langkah demi langkah. Mekanisme pemulihan laluan mengurangkan masa pemulihan sebanyak lebih daripada 50% berbanding dengan pendekatan bukan berlapisan-silang sedia ada.

ROHC-MPLS TUNNEL ARCHITECTURE FOR WIRELESS MESH NETWORK

ABSTRACT

Natural or human-made disasters are sudden events that can cause significant damage, especially to the network communication infrastructure. In these events, a rapid deployment of network communication systems is required in order to relay or receive the communication among the people in the disaster areas to conduct relief and rescue efforts. Wireless mesh networks have emerged and has been recognised for its potential for rapid deployment and last mile coverage of network infrastructure, which is highly suitable for emergency response management. While wireless mesh networks have beneficial attributes, it also introduces some crucial problems. During data transmission, the path recovery time is significantly higher resulting in the loss of data if node and link failures occur. Although Robust Header Compression (ROHC) can significantly reduce packet overheads, it introduces scalability issues, out-of-sequence data packets and importantly, additional end-to-end delays due to compression/decompression mechanism on every hop. The proposed ROHC-MPLS tunnel architecture for wireless mesh network has cross-layer functionality to enable self-configuration, improve bandwidth efficiency, minimise end-to-end delay and support self-healing in minimum time. ROHC header compression reduces the packet header sizes, dramatically saving wireless bandwidth. MPLS tunnelling enables fast

data forwarding and network self-healing using traffic engineering-based packet switching as compared to traditional IP based routing. The proposed cross-layer architecture was evaluated using a real-time test-bed based on Raspberry Pi embedded devices, in terms of the end-to-end delay, packet loss ratio and throughput, as well as the path recovery time, compared against existing non-cross-layer approaches. The ROHC-MPLS tunnel architecture showed significant improvements in performance of end-to-end delay and packet loss ratios of 42% and 15% respectively, while minimising the decrease in throughput to 1.6% compared to hop-by-hop header compression. The path recovery mechanism reduces the recovery time by up to 50% better as compared to existing non cross-layer header compression approaches.

CHAPTER 1

INTRODUCTION

1.1 Introduction

The Internet is essential for every human being for their social and educational purposes. During the last decade, there was a rapid advancement in terms of the multimedia applications as well as wireless communication network which is evolving continuously in standards. However, there is a need for an effective delivery of robust transmission of multimedia over wireless communication networks. Therefore, communication infrastructure and attractive facilities have been established to accommodate the needs of community in urban areas. The limitation of single hop wireless local area network created a new era of communication which is known as mesh networking. The robust and effective communication infrastructure which are capable of providing multimedia service to the rural remote location is possible by using newly emerged paradigm wireless mesh networks. In the passage of time, wireless mesh network (WMN) have evolved and is suitable for extending the last mile communication network in the remote rural areas. It has its ability of self-configuration, self-healing, self-management and characteristics such as resilient, easy and quick deployment, fault-tolerant, lower maintenance and operational cost which makes it very suitable for rural remote areas where lack of infrastructure.

Recently, the usage of multimedia-based service have grown in an alarming rate. With the evolution of wireless network infrastructure and rapid advancement of mobile application technology makes it possible to have effective deployment of wireless mesh networks not only in resourceful metropolitan cities as well as remote locations, disaster effected region and even war battlefield to have effective multimedia based application transmission. The mesh-based routing protocol has high robustness as compared to tree-based routing protocol especially in case of high mobility (Yuan et al. 2014). The mesh based routing protocol design depends on the mesh architecture, network application, and deployment scenario. A mesh architecture can be flat, hierarchal or hybrid depending on the requirements. The wireless mesh network is relatively static or has limited mobility which leads the router backbone can increase the routing efficiency. The formation of mesh-like backbone in the wireless mesh network can be optimised with some important attributes such as throughput and scalability of mesh nodes.

1.2 Background

Natural or human-made disasters are sudden phenomenon that can cause significant damage, especially to the network communication infrastructure. A rapid deployment of network communication systems is crucial for effective communication among disaster-affected victims for relief and rescue purposes. The wireless mesh network has been emerged to have a rapid deployment of network infrastructure that can provide immediate civil applications services such as monitoring, surveillance and disaster response network. At the same time, the wireless mesh network is useful for disaster response network because of it has the rapid and cost effective deployment at any place with easier scalability and powered by a battery with autonomous path selection based on network resources, especially in the remote areas. The mesh networks have multiple paths which increase the reliability of network that is critical in the network recovery and fault tolerance, especially in disaster response network. Moreover, it can be integrated at any time of network range from Cellular and Satellite as backhaul that highly suitable for disaster response based communication systems purposes. The core requirements for disaster response network are based on the rapid deployment of wireless networks with self-organization and self-configuration features. Moreover, for communication quality, Quality of Service (QoS) is an important factor that can be affected by link robustness, communication reliability, and network coverage for the communication quality. An immediate response is required followed by the occurrence of a disaster to resume the communication among the victims to conduct rescue efforts. Satellite communication can take place anywhere without consideration of area but requires costly deployment and high maintenance. An alternative to satellite communication in disaster recovery mechanism is wireless mesh network that is a subcategory of wireless ad hoc networks.

With the attributes and requirements discussed earlier, the wireless mesh network are highly suitable to be deployed in disaster effected areas for conducting relief efforts (Chenji et al. 2011)(Chenji et al. 2012)(Wu et al. 2011)(Kanchanasut, Tunpan, Awal, Wongsaardsakul, et al. 2007)(Kanchanasut, Tunpan, Awal, Das, et al. 2007), systems that helps to monitor environment (Wu et al. 2011), rural IT services (Backens et al. 2010)(Backens et al. 2010) etc. There are number of applications that can be benefit from wireless mesh networks such as remote medical care (Takahashi et al. 2007), traffic control system (Lan et al. 2007), public services (Bernardi et al. 2008), integration with sensor monitoring systems (Wang et al. 2008), (Wu et al. 2011) and DUMBONet (Kanchanasut, Tunpan, Awal, Das, et al. 2007), (Murugeswari &

Radhakrishnan 2014), (Dilmaghani & Rao 2008b), (Iqbal et al. 2009) to broaden coverage and penetrate deep into remote areas where destroys the telecommunication infrastructure. There were numerous work have been proposed to utilise the capabilities of wireless mesh networks in disaster response network. As the rate of occurrences of natural disasters increases, the public safety and restoration of communication network becomes vital.

1.3 Motivation and Research Problem

In general, the wireless networks face issues such as frequent disconnection, signal weakness, limited connectivity for more users that directly effect the ongoing multimedia communication which is sensitive and heavily dependent on Quality of Service (QoS) matrices. The tolerance of data loss is different in voice communication and multimedia communication where the later demand stringent QoS matrices. The main purpose of disaster response network is to provide immediate communication system after existing infrastructure gets down with minimum cost and deployment time. The wireless mesh network is well-establish network paradigm, especially when provided low cost and rapid network deployment in disaster relief areas, military battlefield and metropolitan areas (Wang et al. 2005). Wireless mesh network is relatively static or limited mobility making the router backbone can increase the routing efficiency. A formation of mesh-like backbone within the wireless mesh network can optimise important wireless network parameters like quality of the channel and throughput that effects the QoS. The routing protocol design is formed based on the routing information and maintenance such as reactive and proactive approach. The research was pursued with the fact that with author's knowledge there are few literature available that highlighted the multimedia enabled services for disaster response network along with packet and path recovery attribute in wireless mesh network. The multimedia transmission over the wireless network requires strict quality of service requirements to have better services for end users. Another key research motivation is work on reducing Internet Protocol (IP) packet header overhead that will significantly reduce the bandwidth utilisation in the wireless network (Mobin 2013). Moreover, effective method of end-to-end packet delivery will solve the packet-reordering mechanism. The minimal time for path recovery is a challenge as well as main motivation of this research (Hansen et al. 2008)(Mobin 2013). If path loss takes place during ongoing multimedia communication, the ideal time to reroute the packets to have minimal delay will be 50 milliseconds. To the author knowledge, none of the vast literature of wireless mesh routing protocol addresses the issue of fast reroute in case of path loss.

A reliable and efficient communication is vital in the disaster response network where the cellular and wireless local area network system infrastructure will be highly affected. The situation becomes more concerning when the area of disaster is in the remote location. The shortcoming of traditional communication technology for emergency response and disaster response network are range from integrity of heterogeneous communication network, high setup cost, time consuming deployment, complex network routing, inadequate bandwidth resources of multimedia data intensive communication, slow configuration and recovery time (Koskela et al. 2016). The wireless mesh network is the best alternative to make a rapid communication infrastructure in the disaster response network. However, the existence in the form of simulated and real time research work was proposed to address the efficiency and effectiveness of disaster response network through wireless mesh network. At the same time, there are also lack of functional and performance requirement.

This research identifies problems, limitation and deficiency in the existing work as highlighted below:

- Existing disaster response network which enables wireless mesh network routing protocol are complex and less efficient.
- Existing wireless mesh network which enables disaster response network is not optimised to use resource efficiently as it involve high bandwidth utilisation.
- Existing wireless mesh based routing protocol in disaster response network does not support the efficient link recovery mechanism for ongoing data transmission.
- Existing wireless mesh based routing protocol disaster response network does not address the functional and performance requirements.

1.4 Research Objectives

The objectives of this research thesis are:

1. To design robust wireless mesh based architecture for disaster response network that reduce IP packet header overhead for bandwidth utilization

2. To design an end-to-end tunnel method to hop by hop header compression that reduce end-to-end delay
3. To develop wireless mesh based architecture that supports optimization of real time efficient path failure recovery mechanism for disaster response network
4. To evaluate the proposed routing protocol in terms of end-to-end delay, packet loss, throughput and path recovery

1.5 Research Contributions

The research proposes wireless mesh based tunnel architecture for disaster response network that enables rapid deployment of communication infrastructure. The contributions for this research presented as follows:

- **Efficient bandwidth utilization:** The ROHC-MPLS (Robust Header Compression-Multiprotocol Label Switching) tunnel architecture for wireless mesh based disaster response network provides ROHC header compression for efficient bandwidth utilisation and effective throughput.
- **MPLS tunnel architecture:** The ROHC-MPLS tunnel architecture uses MPLS tunnel for end-to-end compression and decompression mechanism that address the per hop compression/decompression issue with reducing end-to-end delay.
- **Efficient Path Recovery:** The ROHC-MPLS tunnel architecture uses MPLS enables traffic engineering that utilises Fast Reroute for efficient path recovery

mechanism. The traditional scheme uses routing table for alternative path lookup that consumes more time as compared to MPLS based Fast Reroute.

1.6 Research Scope

The research proposes ROHC-MPLS tunnel architecture for wireless mesh network in disaster response network which is capable to do network discovery, path optimisation for end-to-end packet delivery, IP packet overhead reduction through header compression for efficient use of network bandwidth, end-to-end tunnel to leverage the network traffic priority based on type of data service and fast path rerouting in case of path loss in a minimal time to maintain best QoS metrics. The research scope of this these are as follows:

- Unicast routing protocol for WMN
- WMN communication of IP version 4 (IPv4) based packets
- Multi-hop WMN topology based on stationary mesh points
- Research evaluation based on quantitative data from QoS parameters namely throughput, packet loss ratio, end-to-end delay and path recovery time
- Evaluation of results on in the metropolitan area where other networks exist instead of real disaster network with no communication network

1.7 Research Methodology

The research design refers to the methodology of the research project. A successful research must undergo few stages that involve identification of problem until the stages of analysis and findings presentation. In this research, there are four stages were followed as shown in Figure 1.1.

Problem identification: This researcher identified the limitation of wireless mesh network paradigm by applying of header compression in the wireless mesh network and its implications. Lastly, the researcher also identified the lack of path recovery mechanism in the wireless mesh network.

Literature review: The literature review covers the classification of wireless mesh network routing protocol and its current deployed status along current status of header compression, MPLS tunnelling architecture. The literature review also covers the current disaster response network and its communication technologies. At the end of the section, the researcher has discussed the comparative analysis of literature review by highlighting the problems and solution.

Proposed research methodology: The proposed research contains the integration of wireless mesh network, the header compression scheme, MPLS tunnelling architecture to work together to address efficient bandwidth utilisation and effective path recovery mechanism suitable for disaster response network.

Implementation design and testing scenarios: This research presents the framework architecture design and algorithm of its components. The section highlights the number of hardware involved along with specifications and routing libraries. The implementation details are presented by means of network emulation and real-time test-bed implementation details. The section concludes with detail explanation of the experiment design and number of scenarios used for the experiments.

Results and discussion: The research was evaluated using quantitative research evaluation with experiments data presented by comparison of end-to-end delay, packet loss, throughput and path recovery time duration. Proceeding section shows detail discussion and evaluation of gathered result along with justification

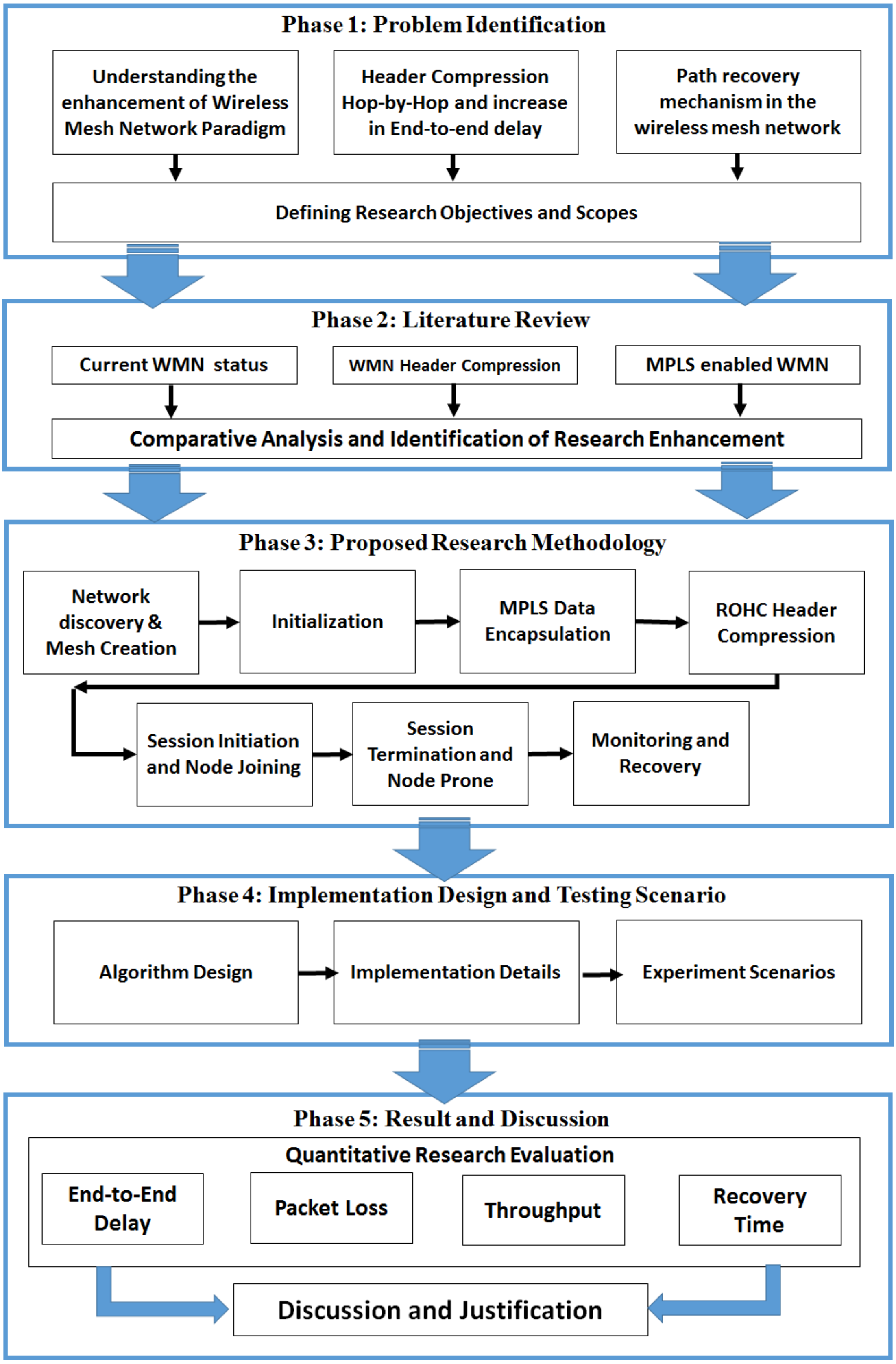

Figure 1.1: Research methodology

1.8 Outline of Thesis

There are six chapters in this thesis as explained below:

Chapter 2 covers the current literature review in wireless mesh routing protocols, header compression research field and MPLS technology in wireless networks. Moreover, the research has conducted critical analysis by reviewing the improvement in routing. Moreover, the literature review also covers the current work in the disaster response network. Lastly, the conclusion of the section contains an explanation on conducting the comparative study of the literature review.

Chapter 3 covers the methodology discussion on how the proposed architecture framework has designed. In this phase, the research presents proposed research methodology design and routing protocol along with algorithmic details. Apart from that, the research also highlighted a method of ROHC header compression integration in routing protocol and its benefits especially bandwidth saving which is scarce in wireless network is highlighted. Packet switching is efficient as compared to packet routing. This efficiency is critical in case of path failure occurs in an ongoing transmission. MPLS is well-known and widely deployed technology in telecommunication sector around the world. Lastly, the research conducted thorough and in-depth study in the possible use of MPLS technology in the resource constraint wireless mesh network.

Chapter 4 presents the implementation design of proposed architecture in the form of algorithm design, emulation and real-time test bed of wireless mesh network was presented. The section further elaborates the implementation details of proposed architecture and states emulation along with real-time implementation parameters, pre-requisites and specifications.

Chapter 5 focuses on the results, research evaluation and discussion. The first section contains the experimental results categorised into qualitative and quantitative research evaluation based on experimental results with QoS performance metrics. In the second section, the research discussion with justification has presented based on the comparison and evaluation of proposed work with related work.

Finally, **Chapter 6** summarise the research finding, contributions, evaluation and possible future work of the proposed research.

In the **appendix**, the library installation details and source code used throughout the research thesis has included in the appendix section.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

With the evolution of wireless network infrastructure and rapid advancement of mobile application technology, it is possible to have an effective deployment of wireless mesh networks not only in resourceful metropolitan cities, but in remote locations, disaster-affected regions and even in war battlefield in order to have an effective multimedia based application transmission. Over the past decade, researchers have proposed numerous routing protocols for wireless mesh network in order to address the QoS problems and efficient transmission (dos Santos 2007)(Kretschmer et al. 2009). Path distribution of mobile node is one of the most well-known methodology to distinguish mobile ad hoc networks (MANETs) protocols that are categorised into tree-based, mesh-based and hybrid (Uludag et al. 2012). The mesh-based routing protocol have high robustness as compared to the tree-based routing protocol especially in the case of high mobility (Yuan et al. 2014). During the last decade, an interactive multimedia (such as video conferencing systems, video streaming etc.) becomes evolves with immense growth of Internet. This section will establish mesh-based routing protocol that have been proposed by the researchers and covers the thorough and technical review.

The literature review of this research, the overview section highlights the background in Section 2.1.1, classification of the wireless mesh network routing protocol in Section 2.1.2, routing phases of the wireless mesh network in Section 2.1.3 and current wireless network status in Section 2.1.4. The following Section 2.2 discusses the current research and industrial work on disaster response network that covers DRN over wireless multi-hop ad hoc networks and narrow down to wireless mesh networks. The Section 2.3 projects the IP Header Compression specifically Robust Header Compression (ROHC), its architecture, ROHC enabled application over communication networks and focus on the ROHC over the wireless mesh network literature. In Section 2.4, discusses the MPLS based wireless mesh network both as backhaul network and in wireless mesh network domain after an extensive discussion on header compression. In the last section of literature review, comparative analysis of ROHC header compression integrated with MPLS architecture over wireless mesh network has discussed for disaster response networks. The discussion also presented a comparative study of ROHC header compression, MPLS architecture and wireless mesh network in the form of tabular form.

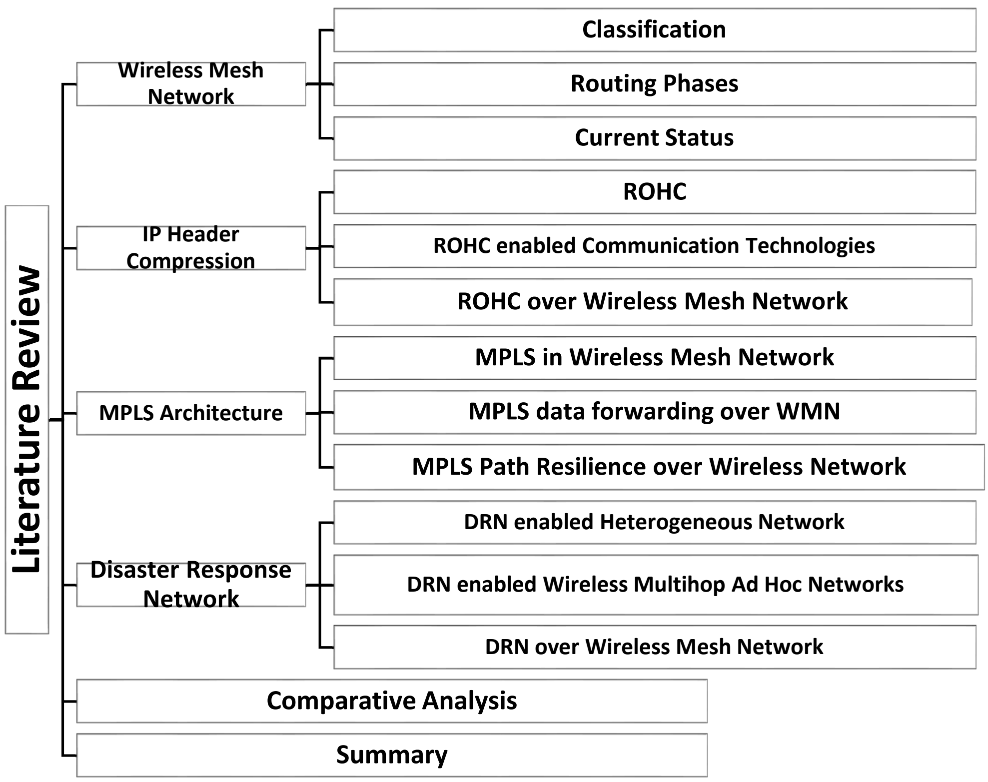

Figure 2.1: Taxonomy of literature review

2.2 Wireless Mesh Network Paradigm

This necessity of robust and effective communication infrastructure that is capable of providing multimedia service to the rural remote location is possible using newly emerged paradigm wireless mesh networks. WMN have evolved with the passage of time and it is well suitable for extending the last mile communication network in the remote rural areas. The ability of self-configuration, self-healing, self-management and characteristics as resilience, easy and quick deployment, fault-tolerant, lower maintenance and operational cost make it well suitable for rural remote areas which are lacking infrastructure. Recently, the usage of multimedia-based service has grown at an alarming rate. Figure 2.2 presents the overview of this section.

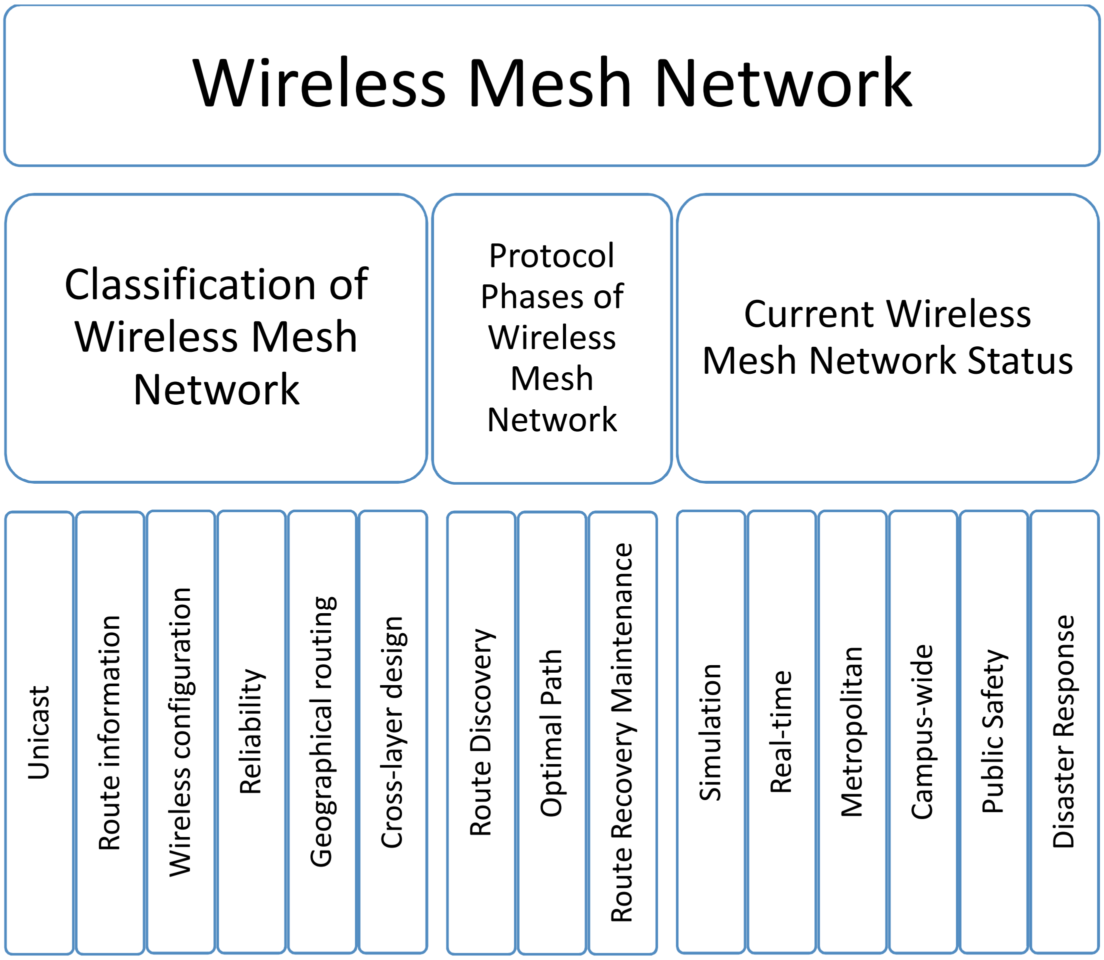

Figure 2.2: Detailed classification of Wireless Mesh Networks

2.2.1 Classification of Wireless Mesh Networks Routing Protocol

Wireless mesh routing protocol is responsible for nodes discovery, initialization, advertisement, multicast traffic flow, adding or leaving new node (scalability), recovery mechanism etc.

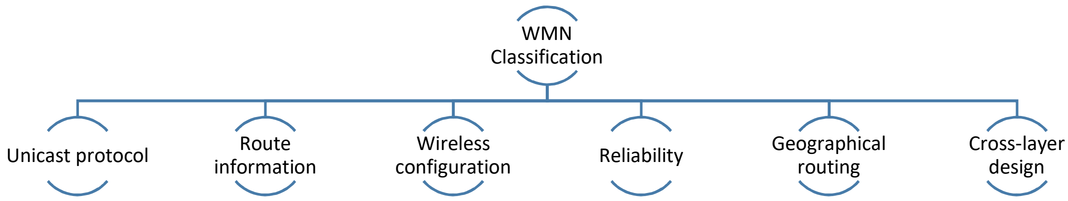

Figure 2.3: Classification of wireless mesh routing protocols

2.2.1.1 Protocol based on unicast protocol

The key success factor of this approach is to design and support multicast and unicast routing protocols concurrently. The protocol lies in this category are either unicast-dependent or unicast-independent. The unicast-dependent multicast routing protocol can be categorised further by multicast protocols that only work with a certain unicast protocol for instance CAMP (Garcia-Luna-Aceves & Madruga 1999), MCEDAR (Sinha et al. 1999) and LAM (Ji & Corson 1998),while the other sub-category of multicast routing deals with any unicast routing protocol for their working such as AMRoute and DDM. The dependent protocol suffers from the control message overhead that wastes the bandwidth of a network, resulting in decrease network overall performance.

2.2.1.2 Protocols based route information gathering

In MANET, there are generally two approaches for route information gathering namely proactive approach and reactive approach. In proactive (table driven approach), each participating node will evaluate all possible available routes for nodes by discovering all routes immediately. In this way, the routes are up-to-date and have consistent view of network topology in case of any topology changes. These updates on network routes are dynamically carried by control messages that handles changes in network. On the down side, the usage of control message increases the network overhead with unnecessary information stored in the routing table. Some notable examples are Better Approach To Mobile Adhoc Networking (BATMAN) (Neumann et al. 2008), Optimized Link State Routing (OLSR) protocol (Clausen et al. 2003) etc. In contrast, reactive approach uses on-demand routes that does not result the network overhead unlike proactive approach that uses extensive control message to maintain the network topology. In this way, if any node want to send data it then discover the fresh network route. This makes the reactive approach more scalable. On the downside, on-demand approach introduce delay upon discovery process. Ad hoc On-Demand Distance Vector (AODV) (Perkins et al. 2003) and Dynamic Source Routing (DSR) (Johnson & Maltz 1996) are protocol for reactive approach. Apart from reactive and proactive routing protocol, there exist the hybrid routing protocol which is the combination of proactive and reactive together. Some notable examples are HWMP (Seth et al. 2010) and HSLS (Koltsidas et al. 2005).

2.2.1.3 Protocol based on wireless configuration

The wireless mesh network routing protocol utilises the capability of hardware to connect with nodes and form mesh. These nodes interact with each other with antenna and wireless channels. Some protocols can use of single antenna while other uses multiple antennas. Some WMN routing protocols for single antenna are AODV, OLSR, HWMP while notable routing protocols for multiple antennas LQSR (Draves et al. 2004a), DYMO (Sommer & Dressler 2007)(Kum et al. 2010). Moreover some routing protocols support both single and multiple antenna such as OLSR, AODV

2.2.1.4 Protocol based on reliability

Reliability is an important factor in the wireless network especially in case of MANET environment where the ad-hoc nature is more fragile in the error-prone environment. Some important deployment where reliability is the main factor is the military-based infrastructure where the packet delivery is an important and guaranteed requirement. There are the three main mechanisms with regards to the MANET routing protocol based on the reliability that are (1). Automatic Retransmission Request (ARQ) such as RMA (Gopalsamy et al. 2002), R-ODMRP (Klos & Richard III 2005), ReAct (Rajendran et al. 2004) and RALM (Tang et al. 2002) (2) Gossip based AG (Chandra et al. 2001) and RDG (Luo et al. 2003) (3) Forward Error Correction (FEC) (Chen et al. 2009) RMDP (Rizzo & Vicisano 1998) etc.

2.2.1.5 Protocol based on geographical routing

The geographical routing protocol are different than topology based protocol as they forward the packets to the wireless nodes based on their geographical location

(Akyildiz et al. 2005). They are based on single path greedy algorithm where decision of packet forwarding is considered on the current location of node and its neighbouring nodes. The downside of this approach is their increase in communication overhead while losing the stateless property (Frey 2004). This issue was addressed along with guarantee packet delivery on (Bose et al. 2001)(Datta et al. 2002). The geographical routing for wireless mesh network is still open for advancement and research.

2.2.1.6 Protocol based on cross-layer design

Traditional network layer routing protocol discussed earlier worked on their layer without considering upper layers protocols. Although they are transparent to each other with simple and scalable process but they might not necessarily gives optimum wireless network solution (Akyildiz et al. 2005). Wireless mesh network have challenges as it needs to consider physical and MAC layer limitation on multi-hop environment, routing and transport protocol (Akyildiz et al. 2005). All these layers should have to good collaboration which leads to cross-layer design protocol. The cross-layer protocols are different from traditional routing protocols in two ways. Firstly by performance improvement of protocol layer and secondly optimization among the interaction of cross layers leading significant improvement (Bhatia & Kodialam 2004)(Chiang 2004)(Kozat et al. 2004). On the down side, it have complex maintenance and management (Kawadia & Kumar 2005).

In the following section, routing phases of wireless mesh network will be discussed in details with focus on route discovery, optimal path from source to destination and route recovery mechanism in case of wireless network disconnection.

2.2.2 Routing Phases of wireless mesh network

There are important phases on the wireless mesh network that leads to the discovery of mesh nodes, the formation of mesh nodes to wireless mesh, optimal path search from source to destination, data packet routing and importantly path recovery with maintenance mechanism.

2.2.2.1 Route Discovery

Among the phases of wireless mesh network routing protocols, the route discovery and route maintenance are two most critical phases. The route discovery enables any host in the wireless mesh network to discovery any other host dynamically. The route discovery can be either sender-initiated in which sender act as an initiator by broadcasting advertisement and the interested receiver accepts the request and join. Better Approach To Mobile Adhoc Networking (BATMAN) (Neumann et al. 2008), Optimized Link State Routing (OLSR) protocol (Clausen et al. 2003) are the sender-initiated routing protocols. Second type of route discovery is receiver initiated where receiver desired to discover sender in order. Ad hoc On-Demand Distance Vector (AODV) (Perkins et al. 2003) and Dynamic Source Routing (DSR) (Johnson & Maltz 1996) are protocol examples for.

2.2.2.2 Optimal Path

The routing protocol plays an integral role in the sustainability of the deployment that starts from network discovery to route the packet in the less congested path and importantly reroute the packet in case of path loss. The routing is an integral part of communication protocol that diverges the traffic on the suitable path from source to destination avoiding network congestion and path reroute in case of a path failure. Some of the well-known testbed deployment in this category are Mobi-Mesh (Capone et al. 2007), SMesh (Amir et al. 2010), MeshDVNet (Iannone et al. 2006), Carleton U. Testbed (Anon 2015p), Auburn Univ. Testbed (Anon 2015m), SwanMesh (Iqbal et al. 2009), ReMesh (Passos et al. 2006), OR State U Testbed (Edmonds et al. 2008), ScaleMesh (Anon 2015c), Purdue MAP (Anon 2015g), RoofNet (Anon 2015d), CUWiN (Anon 2015b), Umic Mesh Net (Anon 2015o), Berlin RoofNet (Anon 2015j) and etc.

2.2.2.3 Route Recovery Mechanism

In the traditional routing protocol, the route recovery maintenance is a part of network discovery protocol with route gets checked and update by continuous transmission of control packets. These periodic messages will utilise network resources and are considered costly. The wireless networks have scarce resources as compared to the traditional wired network making them unreliable in nature. (Kanchanasut, Tunpan, Awal, Das, et al. 2007; Shibata et al. 2009; Calarco et al. 2010; Ajayi et al. 2014; Kobel et al. 2013) are notable works on path recovery in WMN.

2.2.3 Wireless Mesh Network Trends and Status

During the last decade, there were quite much research works have been conducted in the Wireless Mesh Network with a primary research focused by (Akyildiz and Wang 2007) on media access control (MAC), routing protocols, channel assignment strategies, QoS provisioning and interference avoidance. Since the advent of the wireless mesh network, the researchers are proposing innovative routing protocol that addresses the better QoS provisions to the user, especially in terms of scalability, efficiency and robustness. The unicast enabled research of the wireless mesh network can be categorised into three (3) sections namely:

2.2.3.1 Simulation

The real-time implementation of the wireless mesh network is complex and sophisticated in terms of equipment cost, difficulty in implementation, time duration, professional expertise for the deployment of the infrastructure and etc. the researchers are using open-source or commercial simulation software that helps to understand the characteristics of the deployed mesh, performance evaluation and other techniques in order evaluate the wireless mesh network research work in a fast and un-costly manner. . Some of the simulations that are widely adopted are NS-2 (Mccanne & Fall n.d.), NS-3 (George F. Riley 2010), QualNet (Anon 2015h), GloMoSim (Zeng et al. 1998), Riverbed Modeler (formerly OPNET simulation) (Anon 2015i) respectively.

2.2.3.2 Real-time Implementation

Over the passage of time, the wireless mesh based network infrastructure has been improved to be utilised in more effective and efficient manner, especially in the remote or disaster-affected locations. The challenges occur in the remote rural environment that have a high density of trees and irregular terrain that affects the wireless signal strength due to non-line of sight and long distance and irregular cell coverage. (Hincapie et.al 2007) mentioned that Wireless Mesh Network (WMN) addresses these problems of remote rural environment that is self-configured, scalable and easy to be deployed. The wireless mesh network (WMN) is evolving during a period of time with more improvement in order to provide robust and last mile effective communications. Around the globe, there are many deployment of WMN-related to academic research like MIT Roofnet (MISSING:2005-MOBICOM-Architectureandevaluation 2018; Aguayo et al. 2004), Berlin RoofNet (Sombrutzki et al. 2006), Heraklion MESH (Delakis et al. 2008), WiLDNet (Patra et al. 2007), Orbit project (Raychaudhuri et al. 2005), Microsoft Research (Draves et al. 2004a; Draves et al. 2004b), QuRiNet (Wu et al. 2011) and etc. Some project like WiBACK architecture (Kretschmer et al. 2013) was inspired by EU FP7 CARrier grade wireless MEsh Network (CARMEN) (Banchs et al. 2008), (Azcorra et al. 2009) project based on cross-layer concepts low-level layers operating below the Network Layer. The WiBACK project has a centralised self-management approach that does not rely on the IP network but extends the IEEE 802.21 standard with MPLS based traffic engineering. Based on the experimental result of wireless mesh network deployment in the research, the WMN has been deployed in the rural network (Africa 2009) and environmental monitoring applications (Hartung et al. 2006) with large-scale distance up to 10 km to 100 km quite recently. While commercial mesh based projects Meraki (Li et al. 2007), Open Mesh (Anon 2015e), Firetide (Firetide 2015) were deployed in various places.

According to ((Uludag et al. 2012), the wireless mesh network deployment testbeds can be categorised in terms of routing protocol, mobility, throughput and importantly, Quality of Service (QoS) UCSB Testbed (Lundgren et al. 2006), UCLA Testbed (Chavoutier et al. 2007), Dublin IT Testbed (Anon 2015a), Intel Res. Testbed