Delay Reduction in Hybrid Wireless Optical Broadband Access Network

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Approval

It is certified that the contents and form of the thesis entitled **"Delay Reduction in Hybrid Wireless Optical Broadband Access Network"** submitted by **Aima Awais** has been found satisfactory for the requirement of the degree.

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Dedication

This thesis is dedicated to my Family specially my Parents and siblings who encouraged me, supported me, pushed me for tenacity during the whole journey of MS and longed to see this achievement come true.

Certificate of Originality

I hereby declare that this submission is my own work and to the best of my knowledge it contains no materials previously published or written by another person, nor material which to a substantial extent has been accepted for the award of any degree or diploma at NUST SEECS or at any other educational institute, except where due acknowledgement has been made in the thesis. Any contribution made to the research by others, with whom I have worked at NUST SEECS or elsewhere, is explicitly acknowledged in the thesis.

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Abstract

The hybrid wireless-optical broadband-access network (WOBAN) is a promising architecture for future access networks. The front end is wireless network and the back end is optical network. Recently, the wireless part of WOBAN has been gaining increasing attention due to number of challenges. However, there still remain several challenges which need to be addressed. One of the major challenges identified is network delay. Capacity mismatch between the optical and the wireless network and congestion are the reasons for delay. A number of routing protocols are proposed to address the problem of delay in wireless part of WOBAN. The routing protocols which are proposed so far are either reactive or proactive. All the protocols are designed on some routing metric like minimum hop, throughput requirement and capacity etc. We also outlined the problem of delay minimization in WMN. We proposed a hybrid routing algorithm combining the features of reactive and proactive routing approaches for reducing end to end delay. In our proposed approach, network is divided into zones and each node has its own zone. RARA is used between the zones and CADAR is used inside the zones. Capacity and delay are calculated for each zone and minimum delay paths inside all the zones is calculated for efficient. The simulation results show that our proposed algorithm, when compared with RARA and CADAR, is able to minimize delay especially at higher load regions. Moreover, due to the hybrid nature of algorithm, the overhead of maintaining routing tables and control packets is also decreased. As a future work, it can be interesting to consider a real network scenario. Furthermore, in this work, we considered static topology; it is worth to test the proposed algorithm on a dynamic scenario.

Chapter 1
Introduction

Chapter 1 is intended to provide a comprehensive overview and motivation of our thesis work which is based on delay reduction in Hybrid-Wireless Optical Broadband Access Network. Our main focus is on wireless mesh part. We briefly state our aims for the thesis and define the scope. This chapter concludes with the details regarding the structuring of thesis work and by highlighting the goals of each chapter.

1.1 Hybrid Wireless Optical Broadband Access Network: Background

In current years, the rapid growth of bandwidth hungry applications expedites the requirement to design "last mile" broadband access network having flexibility and high capacity. Today, as an influential access technology, Passive Optical Networks (PON) is considered as a suitable solution because of its eminence in high bandwidth capacity and scalability. However, PON requires significant cost of maintenance and deployment. Simultaneously another dominant access solution, wireless networks like WiMAX and Wi-Fi are acquiring more popularity due to easy deployment and flexibility. However, the limited spectrum extremely bounds the bandwidth capacity of the wireless networks. Hybrid wireless-optical broadband access network (WOBAN) which is integration of both optical and wireless technologies serves the end users to access internet in a high capacity and flexible manner. The Architecture of WOBAN consists of many segments composed of PON at the backend and Wireless Mesh Network (WMN) at the front end. Optical Network Unit (ONU) acts as an interface between the optical and wireless network. Thus, apart from the ability to receive and transmit optical signal, all the ONUs in WOBAN can also receive and transmit wireless signal and have the capability of converting optical signal into wireless signal and vice versa. End users send packets to the most adjacent wireless router for upstream communication in WOBAN. The packets travel through multiple hops and finally reach the Optical Line Terminal (OLT) and routed to rest of the Internet. Likewise, for downstream communication, packets are routed from the OLT to WMN and finally reach the end users. Delay in the access network can be noteworthy as packet travels multiple hops before reaching the destination. Moreover, due to the capacity mismatch between the wireless and optical network, delay is experienced at the wireless side. In addition, some links may be under-utilized while others over-utilized, which results in inefficient routing [1].

1.2 Problem Statement

Inefficient routing is one of the challenging problem in WMN of WOBAN. Delay is experienced in WMN which can be due to congestion, capacity mismatch between the wireless network and optical network etc. Our main focus is to enhance the performance of WOBAN using a hybrid technique which combines the reactive and proactive algorithm.

1.3 Purpose

The main purpose of this research is to study the factors which can reduce delay. How effective is the combination of reactive and proactive algorithm in reducing delay. We make zones in the network to make reactive and proactive algorithm work together and check how zone radius can effect delay.

1.4 The Scope

The scope of the research is limited to wireless mesh part of WOBAN, optical part is not under consideration.

1.5 Objectives

Our proposed scheme meets the following objectives

- Effect of zone radius on delay.
- Delay reduction in wireless mesh network of WOBAN using the hybrid of reactive and proactive routing algorithm.
- To check performance of proposed algorithm using different traffic loads.
- To check control packet overhead and routing table overhead and their comparison with previously proposed algorithms.

1.6 Thesis Outline

The remaining thesis document is organized as follows:

- Chapter 2 is intended to provide the overview of basic wireless technologies and photonic technologies. The basic components of hybrid wireless optical broadband access network, architecture, motivation and challenges.

- Chapter 3 addresses the routing protocols which have been proposed in the existing literature for reducing delay. In order to give a clear picture we divide this chapter into three major sections. The first section discusses the main categories of routing protocols, the second section discusses the traditional routing approaches and their working while the third part deals with explanation of state of the art routing protocols.

- Chapter 4 gives the detailed overview of our proposed scheme that we have used in our thesis work. We have studied two benchmark routing algorithms namely Zonal Routing Protocol and Landmark Routing Protocol. We selected zonal routing protocol and used some of its major concepts in our proposed methodology. We have combined two routing algorithms namely CADAR which is proactive in nature and RARA which is reactive in nature to achieve our thesis objectives, since each routing algorithm follows a different procedure and is suitable for particular scenario. This chapter presents the details about the working of our algorithm, motivation and major design goals.

- Chapter 5 presents the results of our thesis evaluation. We have divided this chapter into two sections. The first section deals with the simulation setup and gives the clear description of the simulation topology. The second section deals with the result of our simulations.

- Chapter 6 presents the summary of our research findings and concludes by stating the future research directions of our thesis. It highlights the essential research problems in the domain of Hybrid Wireless Optical Networks that are still needed to be resolved particularly the issues related to delay. First, we summarize our research contributions made in this and then, a conclusion of our major findings. Lastly, this chapter explains some of the future research prospects of this thesis.

Chapter 2
Theoretical Background

This chapter is intended to provide the overview of the basic wireless technologies and photonic technologies. The basic components of hybrid wireless optical broadband access network, the basic architecture, motivation and challenges of WOBAN

2.1 Introduction to WOBAN

Wireless broadband Access Network (WOBAN) has been introduced as a next generation access solution to provide high data rates to the end users. As the number of users are increasing so is the demand for high speed, mobility, QOS and ubiquity. To provide all these features to the end users a hybrid architecture which is a combination of photonic and wireless technologies was introduced. Long transmission links and high bandwidth are supported by the photonic technologies while the wireless technologies are not well suited for providing QOS at long distances to the end users. The integration of optical and wireless technologies is used to serve the end users optimally and in a cost effective manner. Point to Point and star are two main optical access topologies. Active Optical Network (AON) and Passive Optical Network (PON) can be implemented using a star topology. High bandwidth provision and cost effectiveness are the main features of PON. With the help of Wavelength Division Multiplexing (WDM) PON the bandwidth can be further increased. LTE, WiMAX and WiFi are some of the common designs of wireless network to reach end users **[2]**.

2.2 Basic Technologies of Access Network

Home run and star are the two common topologies for the access networks. Further the star topology based is classified into two groups PONS and AONS. TDM, WDM or the Hybrid of both technologies can be used in PON [3].

Point to Point (Home Run)

This topology has dedicated links of subscribers to the central office which provides great QOS and high bandwidth to the users. Home run topology is shown in figure 1. This kind of topology needs a large numbers of connectors, fibers and splices, point to multipoint are introduced to cope up with the disadvantages of home run [4].

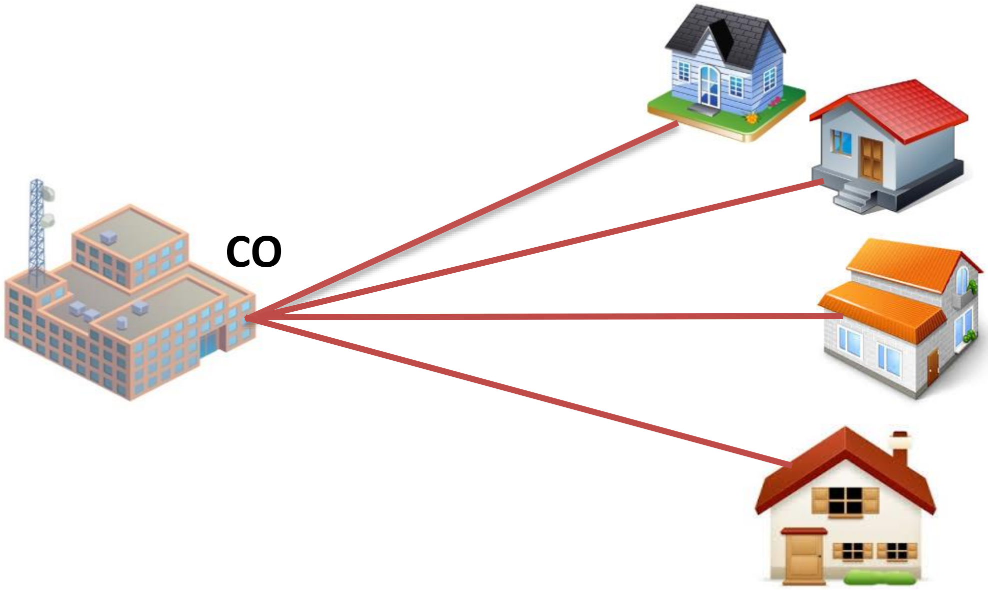


Figure 1 Point to Point Topology [4]

TDM PON

In TDM PON different time slots are allocated to the ONUs dynamically. The data is 1st multiplexed and with the help of passive optical splitter the data is sent to all the ONUs in the downstream direction. In the same way when the data has to be sent in the upstream direction each ONU sends it data in the allocated time slot. TDM PON can be further divided into many types for example Gigabit PON and Ethernet PON [5] [6]. Figure 2 shows the architecture of TDM PON.

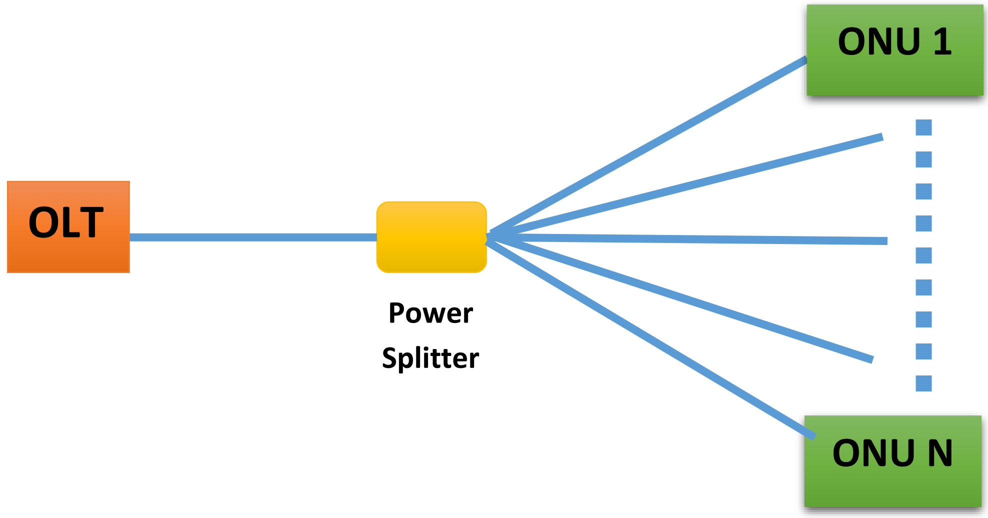


Figure 2 Architecture of TDM PON [5]

WDM PON: In WDM PON there is a dedicated wavelength for each ONU to send data in the downstream direction. Passive Coupler is used so that each ONU could get its desired wavelength. WDM PON ensures its privacy. Each ONU has different wavelength so each ONU gets only its own data but it's costly. WDM PON systems provide high QOS (quality of service) and large bandwidth. 1, 2.5, 4 and 10GB/s are the upstream and downstream bitrates offered by WDM PON. The splitting ratio is dependent upon the type of WDM PON. For coarse WDM PON (CWDM PON) the splitting ratio is 1:8 and for arrayed waveguide grating (AWG) its 1:40 [7]. The Architecture of WDM PON is shown in figure 3.

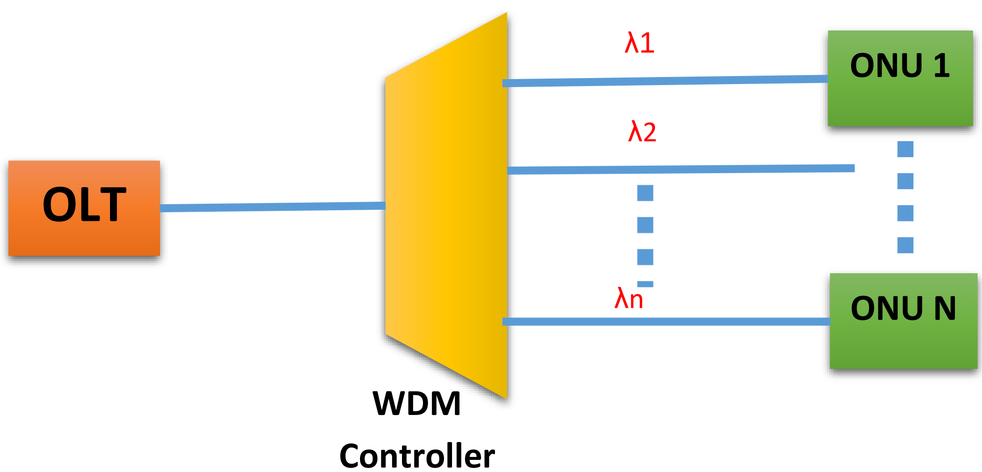


Figure 3 Architecture of WDM PON [7]

OFDMA PON and AON (Active Optical Network) are also the types which are out of scope of our research.

2.3 Basic Technologies of Wireless Network

Wireless became necessary technology in the time period of late 19th century. There are many wireless technologies like WiMAX, Wi-Fi and LTE.

Wi-Fi: Radio Waves are used in Wi Fi for providing wireless access to the computing devices. All the standards of 802.11 come under Wi Fi. For example 802.11a, b, g, n etc. 802.11a, and 802.11g have OFDM based transmissions and has the channel bandwidth of 20MHz. This is used for higher bitrate and for using the spectrum more efficiently. Wi Fi has many access points which are used for delivering services to the end users. A user can connect to the nearby access point which lies in the range. A service set identifier is broadcasted periodically after every 100ms. 54Mbps is the downstream and upstream bit rate of 802.11g. 45-91m is the maximum distance supported by Wi-Fi for indoor. The advanced versions of Wi-Fi have better performance like for example 802.11n has the operating frequency of 2.4GHz and 5GHz. It has wider bandwidth and supports longer distances i.e. for indoors 70m and for outdoor it supports 250m [8] [9].

WiMAX: For providing broadband access in large areas WiMAX is used. It has two main IEEE protocols namely 802.16m and 802.16e. 802.16m is the improvement of 802.16e and it provides better handover techniques. OFDMA is used in WiMAX for multi user access and also for multiple input and multiple output (MIMO) for increasing the bitrate. WiMAX supports a wide spectrum for operating frequencies like 450-470MHz to 3.4-3.6 GHz respectively. For every channel almost 20MHz bandwidth is available. According to the 802.16 standard WiMAX supports point to multipoint (PMP) and mesh operation mode. In (PMP) mode there is one base station and many subscriber stations, it is also known as the infrastructure mode. In the mesh mode multi hop adhoc network is formed by the subscriber station. Better flexibility is provided by the mesh mode. Bit rate of WiMAX is 134Mbps for both upstream and downstream and it supports maximum distance of 5km [10] [11].

LTE: The redefinition of cellular radio access networks incorporating packet switching for providing better quality of service in terms of low delay and greater bandwidth are the main features of LTE. The protocols of LTE are TCP/IP based. Many different QOS classes are also defined. For managing the power consumption a sleep mode is defined as well. LTE is best for serving a large number of users at moderate speed which makes large delays and frequency selective fading. For coping up with channel imperfections and for increasing the bitrates

OFDM is used by LTE and for giving multi user access OFDMA is used. LTE also uses MIMO for taking advantage in multipath components of wireless transmissions which helps in increasing the bit rates. 1Gbps bit rate is supported by LTE Advanced with a greater bandwidth. In LTE advanced 80 MHz of OFDM bandwidth is available having subcarrier separation that is of 15 KHz and QPSK 16 and 64 QAM modulations. In Europe LTE is deployed since 2009 and in United States it's been deployed since 2010. LTE was deployed for commercial use in 2011 by AT&T and Verizon which are the major US Carriers [12].

2.4 Components of WOBAN

WOBAN has following main components. First three components are of fiber which is used on backend of WOBAN and other three components are of Wireless which are used at the front end [13] :

1. OLT
2. ONU
3. Gateways.
4. Wireless Routers.
5. User nodes.

2.5 Architecture of WOBAN

Capturing best of both optical and wireless network WOBAN Architecture can be employed. It has great features that are very high capacity, reliability and robustness because of the optical network and flexible and low cost because of the wireless network. The front end of WOBAN is supported by the wireless network whereas the back end of WOBAN consists of Passive Optical network [14]. Figure 4 shows the architecture of WOBAN.

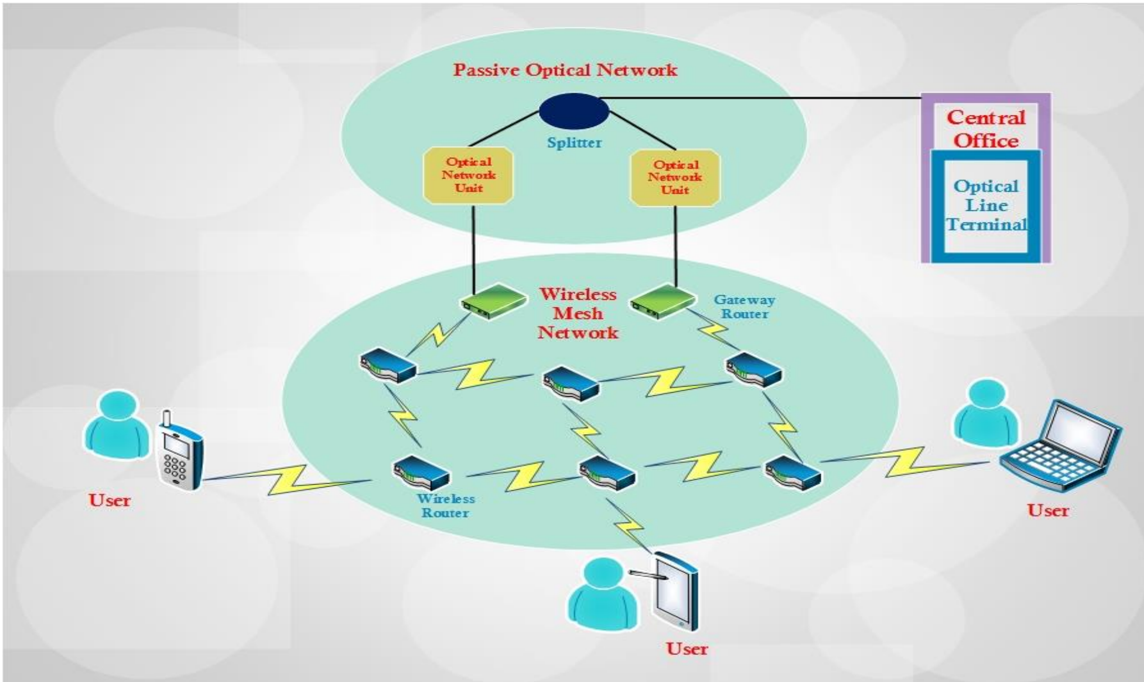


Figure 4 Architecture of Hybrid Wireless Optical Broadband Access Network [14]

There is a CO (Central Office) in which OLT (Optical line Terminal) resides and PON segment radiate away from the CO. The tail end of PON is supported by ONU (Optical Network Unit). The ONUs are connected with wireless routers namely the gateway routers. The Gateway routers are further connected to many other routers. The users connect themselves to the nearest possible router. The Gateway routers basically help in connecting the optical network to the wireless network. The front end of WOBAN basically forms a mesh network of wireless routers for managing the network efficiently. The Wireless portion has technologies like WiFi and WiMAX being employed in it. The users may be scattered in a geographical region. The end user who wants to send data to the specific destination communicates with the neighbor router which is part of the mesh network. The data packet after travelling multiple hops reaches at the gateway router and is sent to the OLT. In the upstream direction that is from the user to the ONUs the network is anycast which means that data reaches to the ONU from any of the gateway and in optical network from ONU to OLT it is multipoint media access network, all the ONUs are installed in tree network in connection with the OLT. The ONUs competes for a shared bandwidth. In the downstream direction that is from the ONU to the user the network is unicast which means that the packet would be only sent to the specific destination. In the optical part from OLT to ONU the network is broadcast that is data is broadcasted to all ONUs but only the destination ONU process the data. Data received by all other ONUs is discarded. The Fig 2.6 below shows the transmit modes of Wireless and Optical parts of WOBAN [15].

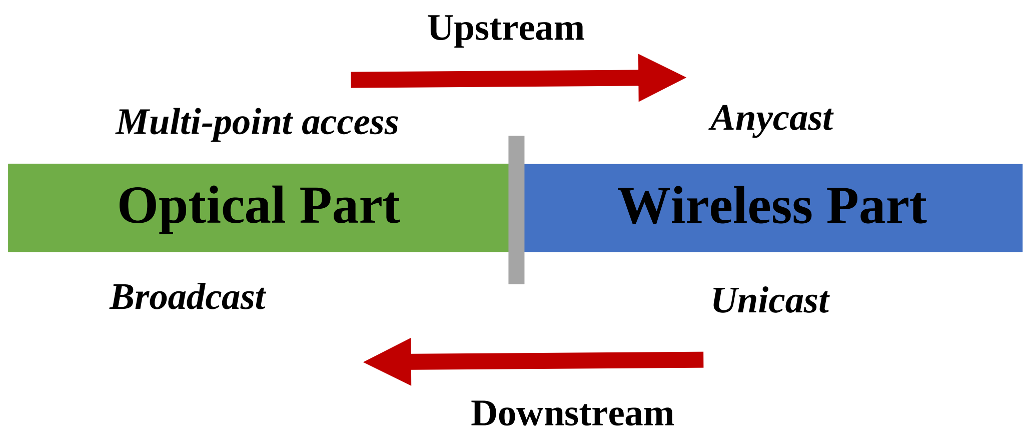


Figure 5 Transmit modes of optical and wireless [15]

2.6 Motivation behind WOBAN

The motivation behind WOBAN can be summarized as follow:

1) **Cost Effectiveness:** Expensive FTTH connectivity is not needed in case of WOBAN as there is no need of installing fiber to user's premises. Users can connect to ONU with the help of the wireless mesh network. The data after being received by the ONU can be sent to the OLT.
2) **Flexibility:** The wireless part of WOBAN is multi hop network in which users can connect to any of the nearby router. If any of the routers fails, data still can be transferred with the help of other router in the mesh. This provides great flexibility as compared to optical access network. WiMAX can also be used in place of Wi-Fi at front end. WiMAX can give more bitrate.
3) **Robustness:** WOBAN is more robust as compared to the optical network. If the connection of any of the ONU breaks from the OLT, data would not be transferred. At wireless side due to the mesh topology the data can be still be transferred by finding the ONU which is alive and sending data through it. The ONU will communicate with another OLT which resides in the CO.
4) **High Capacity**: Wireless network has a very low capacity but optical network has a very high capacity. As WOBAN is the integration of wireless and optical network so it has a high capacity due the high capacity optical trunk.
5) **Reliability and Better Load balancing:** WOBAN is considered more reliable as compared to the wireless network. There is very less chance of information loss and congestion as the wireless part has a mesh topology. User can even communicate with

any of the ONU which lies in its vicinity in case of ONU failure. This helps in load balancing and more reliability.

6) **Self-Organizing:** WOBAN is considered self-organizing because it is fault tolerant, robust and has load balancing features [15].

2.7 Challenges of WOBAN

WOBAN faces a number of challenges.

- One challenge is optimal placement of access network. Such algorithm must be proposed for the designing the WOBAN which focus on multi hop wireless connection between different subscribers. This algorithm must give the optimal position of ONU as well as the shortest path between users [16].
- Another major challenge in the network is placement of equipment in WOBAN, so it can reduce cost as well as energy consumed. Network element can be managed in such a way that if some of the elements are underutilized then switch off that element according to the traffic demand [17]
- Survivability is one of the major issues in WOBAN as the failure of single segment causes huge loss of data i-e when all the ONU’s in single element failure disconnect from the OLT [17]
- Efficient Routing is also considered one of the most important problem. Many Routing protocols are proposed which are either reactive or proactive [15].

Chapter 3
Literature Review

This chapter addresses the routing protocols which have been proposed in the existing literature for reducing delay. In order to give a clear picture we divide this chapter into three major sections. The first section discusses the problem of delay and its types, the second section discusses the main categories of routing protocols and their working while the third part deals with the explanation of state of the art routing protocols.

3.1 Main Categories of Routing Protocols

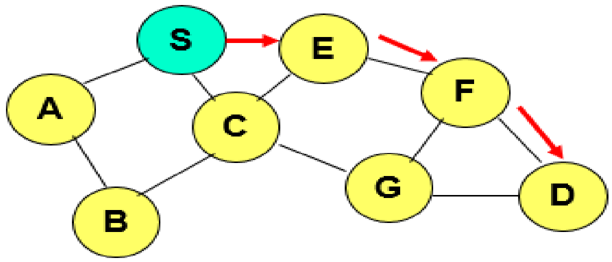
Routing protocols define how routers exchange information with other routers in a network. They help in determining the optimum path for communication between source and destination node. Routing Protocols can be divided into three major categories [18]

1) Proactive
2) Reactive
3) Hybrid

Proactive Routing Protocols

In proactive routing, each node keeps up to date information of the entire network. The paths are already maintained and whenever request for any route is initiated, the packets are immediately transferred. For larger networks proactive schemes are not suitable as each node has to maintain the routing table for all the paths in the network. This leads to bandwidth wastage and over head of routing tables. On the other hand for small networks, proactive schemes are suitable as low latency is experienced due to predefined routes.

Working of Proactive Routing



Source	Destination	Path
S	D	S-E-F-D
Routing Table For Node S		

Figure 6 Working of Proactive Routing Algorithm

Table 3.1: Routing table of Node S

Source Node (S) wants to send data to destination (D).Paths are already stored in the routing table. Data transfer starts using shortest delay path stored in the routing table as shown in figure 6.

Reactive Routing Protocols

In reactive routing, the route discovery is initiated on demand whenever a node wants to send packet. This has high latency as compared to proactive routing because routes are not already defined. The process of flooding occurs for route discovery and route request messages are sent to the entire network. This leads to control packet overhead, but bandwidth is not wasted [18].

Working of Reactive Routing

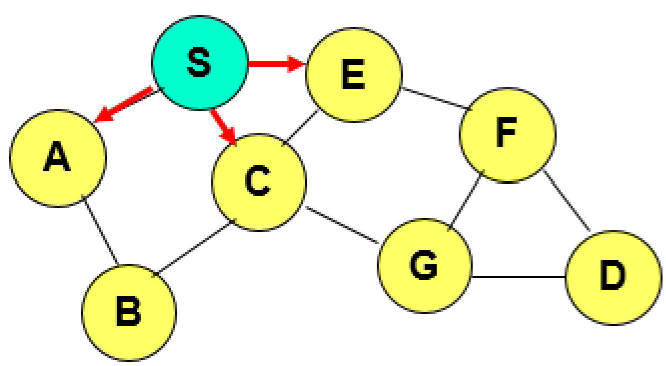


Figure 7 Working of Reactive Routing Algorithm step 1

Source Node (S) floods route request in the network for destination (D). Reverse paths are formed when a node hears a route request as shown in figure 7.

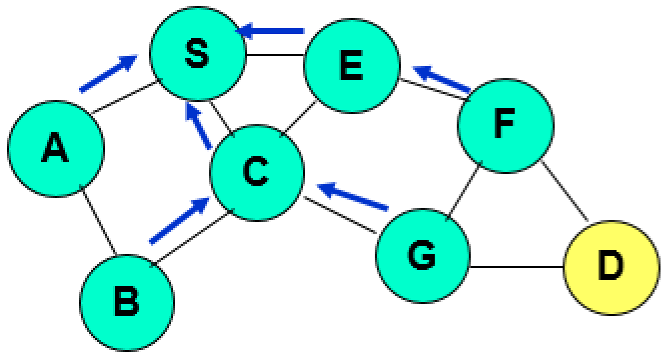


Figure 8 Working of Reactive Routing Algorithm step 2

Hop-by-hop routing is used. The route request is sent to the nodes until destination is found. Reverse paths are formed when a node hears a route request as shown in figure 8.

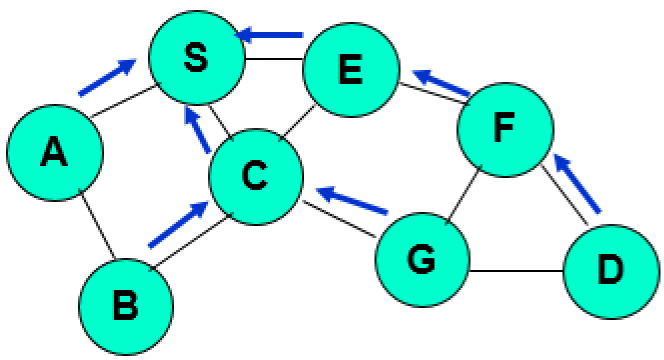


Figure 9 Working of Reactive Routing Algorithm step 3

Route reply forwarded via the reverse path. Data transfer starts as shown in figure 9.

Hybrid Routing Protocols

Hybrid Routing is the combination of reactive and proactive routing. Proactive routing needs more bandwidth for maintaining routing information whereas reactive routing experiences more delay for route determination. The merits of reactive and proactive routing are combined to overcome the demerits. Best features of both reactive and proactive routing are used in hybrid routing protocols [18].

3.2 Routing Protocols for Delay Reduction

Traditional Routing Approaches for WOBAN

Minimum Hop, Shortest Path Routing and Predictive Throughput Routing Algorithms (MHRA, SPRA and PTRA)

MHRA and **SPRA** are the traditional approaches used for WOBAN. In MHRA link metric is set as unity [19]. In SPRA the link metric is inversely proportional to link capacity. These algorithms work on the principle of shortest path [20]. Traffic is not taken into consideration so various routing limitations are experienced by MHRA and SPRA like adverse load balancing, more delay and congestion on a link or on multiple links. These limitations can become even more intense due to wireless channel's limited speed. **PTRA** on the other hand does not work on the principle of shortest path. It works on the basis of link state and throughput requirement. Measurement samples are taken periodically for link rates of the wireless links. For any user-gateway pair, available paths are computed which fulfil the throughput requirement. The path having the highest throughput is selected by PTRA. The major issue in PTRA is that packet delay is not taken into account so a packet may travel longer in mesh network than expected. For delay sensitive traffic, PTRA is not suitable as throughput criteria is only considered even if the path is longer [21].

3.3 State of the Art Routing Approaches for WOBAN

In order to reduce delay, many routing protocols are proposed in literature. All the routing protocols work either reactively, proactively or in a hybrid manner. Figure 10 sums up the protocols proposed and the categories to which they belong.

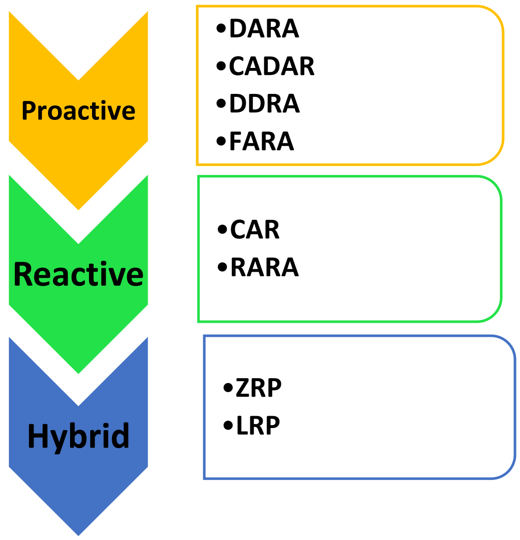


Figure 10 Classification of Routing Algorithms

Capacity Aware Routing (CAR)

The basic parameter for any routing protocol is its routing metric. Expected Transmission Count (ETX) is a routing metric which was proposed by De Couto et al. This metric deals with the loss rate of broadcast packets for each link. The path with least number of packet transmissions (including the retransmissions) which is required to deliver a packet successfully to reach the final destination is computed by ETX. Another routing metric known as "Weighted Cumulative ETT (WCETT)" was proposed by Richard Draves et al. which works on channel diversity and the expected time for end-to-end packet transmission. This metric does not consider the traffic on link, thus load balancing cannot be achieved among links, so for tackling the load balancing issue a new metric known as "Bottleneck link capacity (BLC)" was introduced. The main aim of BLC is to increase system throughput, and to resolve the issue of load balancing among links.

Capacity Aware Routing is introduced as a reactive routing protocol with BLC incorporated in it. On the basis of flow paths are discovered. The path having highest residual capacity is selected and the nodes are considered static equipped with NICs. Two tables are maintained by each node i.e. BusyPeriod and ResidualAirTime. BusyPeriod basically refers to the total busy time of sending and receiving periods of a link for predefined time. ResidualAirTime refers to the free-to-use air-time on a specified channel. BLC basically estimates the expected busy time for transmission of a packet successfully on a link. If a route is needed, route request (RREQ) packet is flooded on control channel for discovering the route.

The route request has traffic information which consists of channel map and residual air time table. It also has the path information. When a RREQ packet is received by a node, it checks the discovered partial path to see if the identification of that specified node appears. If so, the packet is discarded otherwise the channel is determined that is common to the previous node and itself. The path capacity is made maximal that is the resulting partial path has the normalized BLC maximal. The destination learns all routes after waiting for a specific time. The route with the maximum residual capacity is selected and Route Reply (RREP) is unicasted to source node. The channel is known by the intermediate nodes receiving RREP packet for communicating with next and the previous hops. Reverse and forward paths are established accordingly. The routing entry is deleted from routing table if data packet of intended flow is not received. Data transmission starts as soon as the source node receives first RREP packet. Better path is selected and updated in the routing table if more than one RREP are received by source node with greater BLC value. BLC is compared with WCETT and Hop count, it has less queuing delay at intermediate nodes as compared to the other metrics because it selected the routes which are less congested [22] .

Redundancy Aware Routing Algorithm (RARA)

RARA is reactive algorithm which reduces end to end delay. It computes multiple disjoint paths just like Adhoc on Demand Multipath Distance Vector (AOMDV). It route packets to the path which has less delay. First the hello packets are exchanged between nodes and traffic information is achieved from MAC layer which is forwarded with the help of control packets. On the basis of load information capacity is assigned to each node. When a RREQ is initiated the accumulated delay field is set to zero, and as the delay is calculated for each node it is added into the accumulated delay field. The accumulated delay for the whole path is sent to destination path. The source receives multiple paths from which it selects two paths having least delay. When the routing table gets updated, routing takes place from primary path having minimum delay and secondary path is used as a backup. RARA is compared with CADAR. RARA performs better than CADAR at higher loads and at low loads both show same performance [23].

Delay Aware Routing Algorithm (DARA)

DARA is proactive in nature which considers end to end packet delay. End to end packet delay means the delay at front end of WOBAN from source to gateway router and vice versa. System time (Q) or packet transfer delay depends upon queuing delay, slot synchronization delay and transmission delay. Packet arrival follows Poisson distribution having exponential inter arrival time. The length of packets is independent and exponentially distributed. In an asymmetric manner capacity is assigned. Then delay for each link is calculated [24]

Capacity and Delay Aware Routi.ng Algorithm (CADAR)

CADAR is a proactive routing algorithm which works by assigning link weights and radio capacities to the nodes on the basis of received LSA .This helps in reducing the end to end delay of the network. On the basis of assigned capacities delay is calculated and shortest path is computed [25].

Delay Differentiated Routing Algorithm (DDRA)

In DDRA traffic is divided into two types, DTS (delay to the server) in sensitive and DTS sensitive. For fast transmission of DTS sensitive traffic to the server, external buffers are introduced for wireless mesh part where insensitive data is stored temporarily under high load conditions. The stored data is transmitted when link leading to gateway are available. For improving the delay performance, paths are computed for both DTS sensitive and DTS insensitive flows. Significant delay occurs at the adjacent routers to the gateways, so for better performance external buffers are incorporated in routers having direct link with gateways. Traffic like Instant mobile messaging, mobile VOIP and mobile IPTV is considered DTS sensitive where as large file being uploaded to server are considered as DTS-insensitive. If the delay requirements of flows is deducted, it can be organized into two categories after comparison with DTS threshold. Value above threshold is considered DTS sensitive, and path from ingress router leading to gateway is computed for transmitting the traffic. For DTS insensitive traffic path from ingress router leading to any external buffer is computed. The status of external buffer's connected router will be monitored for checking the availability of gateway link. If link is available the stored data is forwarded to server. This helps in load balancing and reduces queuing delay of DTS sensitive traffic. DDRA is applied on 43 node topology of Wildhorse are Davis, CA and is compared with DARA and SPRA. When load is less than 2.5Mbps on every node, DDRA shows same performance as DARA and SPRA for DTS sensitive flow. As the load increases DDRA shows better performance as compared to DARA and SPRA and can support 1.2 times more load. At 5Mbps the performance of DARA and SPRA degrades. On the other hand, DDRA performs still better. DDRA works even better if there is more DTS insensitive flow [26].

Fault Aware Routing Algorithm (FARA)

FARA is a proactive routing algorithm which helps in load balancing and provides network resiliency. It has two basic steps; path computation and path maintenance. Expected Transmission Count is used as routing metric because channels conditions are considered when link weight is computed. In path computation phase, ETC value is computed for each node by

transmitting a test packet to neighbor node. The number of packets that are received by each node are found in the test packet. As soon as the test packet is received by the neighboring node, link success rate is computed. This success rate is computed for all the nodes in the network. Link state advertisement (LSA) help in advertising the success rate value to all links. Then three paths are selected with highest ETC value. One path is primary, other two are backup-path1 and backup-path2. This completes the 1^{st} phase then path maintenance phase starts. In this phase no new paths are computed only the status of computed paths is monitored.
Delay of three paths computed by each node is calculated and then primary and secondary paths are assigned. No new paths are computed until the less delay is experienced than the threshold delay of network. Maintenance of paths takes place for routing. However, if network delay threshold exceeds, new paths are computed and maintained for routing of packets. Delay is calculated only for the computed paths, this has advantages in terms of bandwidth utilization as LSAs are not required frequently. Secondly, link failure or congestion status of paths can be estimated, if delay of paths exceeds the maximum threshold. Delay Comparison of DARA and FARA is done. For low load values DARA performs better as compared to FARA, but at high loads FARA performs better because it has load balancing property. The threshold of delay is set at 2.0ms and the improvement is of 0.15ms which is 7% of threshold value [27].

Zonal Routing Protocol (ZRP)

Zonal Routing Protocols as the name implies works on the concept of zones. The zones are defined on the basis of number of hops. Within the zone, proactive routing algorithm that is intra zone routing protocol (IARP) works. Globally reactive routing algorithm that is Inter-zone routing protocol (IERP) works. The information with in the zone is maintained by IARP and route discovery outside the local zone is offered by IERP. The route is discovered by checking if the destination is within the zone. If it's not present in the zone, route request message is broadcasted until destination is found. Route reply message is sent back to the source node. There are certain advantages of zonal routing protocol. It reduces the control traffic produced by periodic flooding of routing information packets. It reduces the wastage of bandwidth and control overhead compared to reactive schemes [28] [29].

Landmark Routing Protocol (LRP)

Landmark routing protocol is basically designed for adhoc networks. The main aim of the protocol is to reduce the routing table size without increasing path length. Some routers are selected as landmarks, then a hierarchy of landmarks is constructed with increasing radius at each level. The routers are named according to their proximity of landmarks.

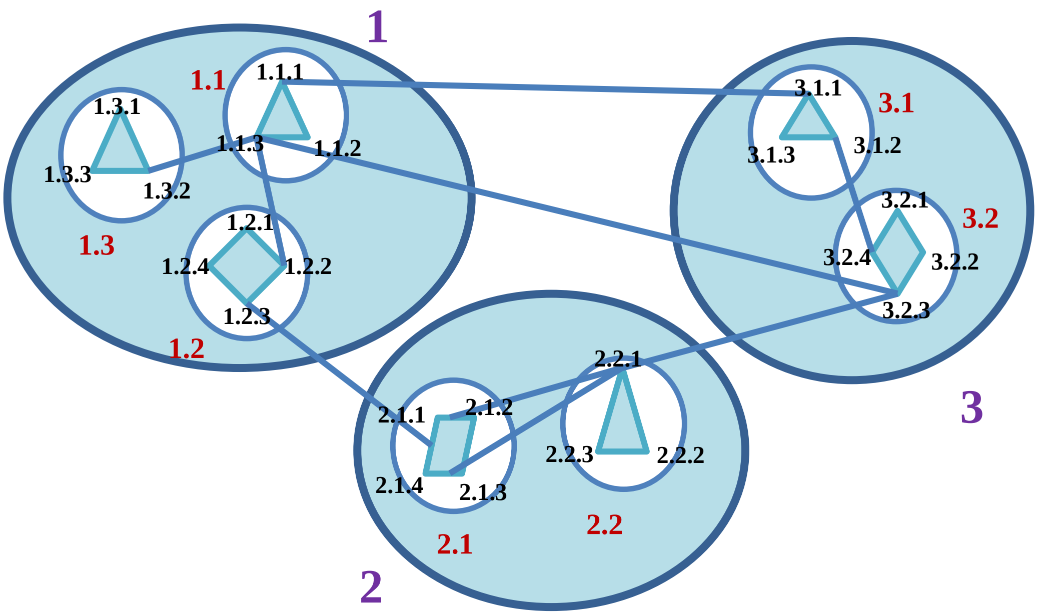


Figure 11 Routing regions of LRP

As shown in the figure 11, the whole network is divided into regions, and each router knows the full topology of its region. For example router in region 2.2 knows the full topology of 2.2. Router also knows the existence and regions of border router. Router in 2.2 knows region 2.1, region 1, and region 3 exist, and how to reach them. Each node knows only a limited amount of topological information. It has certain benefits like routing table size is decreased and number of updates are less. The disadvantage is that routers does not know that a shorter path exists due to the limited topology information stored at a given node [30].

Chapter 4
Proposed Methodology

This chapter gives the detailed overview of our proposed scheme that we have used in our thesis work. We selected zonal routing protocol and used some of its major concepts in our proposed methodology. We have combined two routing algorithms namely CADAR which is proactive in nature and RARA which is reactive in nature to achieve our thesis objectives since each routing algorithm follows a different procedure and is suitable for particular scenario. This chapter presents the details about the working of our algorithm, motivation and major design goals.

4.1 Motivation of Our Proposed Scheme

Generally, the current routing protocols can be categorized into proactive and reactive Proactive routing protocols keep up to date information of routes, so that route can immediately be used when a packet needs to be forwarded. Delay is less as paths are already stored in the routing table. However, to keep the routing information up to date, a lot of network capacity is used. On the other hand, reactive routing protocols initiate route discovery process on demand. Thus, for route determination, global search is required. This involves excessive control traffic and long delays [28].

In WOBAN, all routing protocols that are previously proposed are either reactive proactive. What is required is an algorithm that starts route discovery process on demand, but at less search cost. Our propose algorithm is an example of such hybrid scheme. We created zones for limiting proactive scope of a node only to its zone instead of network. The global search is done in an efficient manner without querying all network nodes. This reduces control traffic and routing table overhead. The capacity of network is utilized in an effective way and maintenance of routing table information is easier. Further, the amount of routing information that is never used is minimized. Nodes farther away still can be reached with reactive routing.

4.2 Choice of Reactive for inter-zones and Proactive for intra-zone

Zone are made in the entire network for making reactive and proactive routing algorithm work together. A zone can be defined as a collection of nodes, whose distance from node under consideration is not greater than a parameter referred as zone radius. Zone radius is defined in terms of no of hops and is denoted by ρ. Routing zone for each node is defined individually and zones may overlap the neighboring zones.

A node proactively maintains routes to destinations with in its local neighborhood known as intra-zone. The choice of proactive routing algorithm to work inside the intra-zone reduces proactive scope of a node relative to the entire network. Whereas, in inter-zone reactive routing works which reduces the control traffic by sending RREQ messages to selected nodes instead of querying all the network nodes. If proactive routing is applied in inter-zones, the proactive scope will increase leading to bandwidth wastage. Therefore, we applied the concept of ZRP in making zones [28].

We selected CADAR which is proactive in nature to work inside a routing zone i.e. intra-zone. It distributes the radio capacity of a single-radio wireless node among its outgoing links, performs delay-aware routing and supports higher loads. It has the best performance in terms of delay as compared to previously proposed proactive routing algorithms. Link State Advertisements (LSAs) are exchanged among nodes for advertising the states of outgoing links. Based on traffic of each node, capacity and delay is calculated. Each node then stores the optimum paths, having less delay in its routing table for all the nodes in its zone. Outside the zone i.e. inter-zone, data is sent using reactive algorithm. We selected RARA because it minimizes end to end delay, increases reliability and provide robustness. Capacity Aware Routing Algorithm (CAR) and RARA are the only two routing algorithms proposed so far in literature for WOBAN. RARA performs better in terms of lower delays, so for our proposed scheme we selected algorithms which show improved performance as compared to other routing algorithms.

Zone Sizing

Zone radius is configurable and every network has an optimal zone size. This vary according to the network type. For mobile network optimal zone size may be different as topology changes frequently. If, for any network optimum zone size is selected, the control traffic can be reduced and efficiency of the network can be increased. For determining the optimal zone size, it is important to understand the factors that may affect the zone size. The factors that affect zone size are number neighboring routers per node and size of the network. In [28] it is proposed that zone size should change according to change in network topology. In our case, topology is static, so we kept static zone radius. In [29] they suggested that for large networks large zone size is suitable whereas for small networks, small zone size is suitable. Our network is small having 25 wireless routers, so we kept zone radius=2hops.

How zones are created?

Zones are created on the basis of TTL (time to live) value. For zone creation proposed algorithm broadcasts a node discovery packet with TTL value= ρ. This TTL value decrements at each hop and source gets a node reply message from the node where TTL value becomes zero. This is how source will maintain its routing table and results in creation of zone. Consider topology in figure 12-15. As the start of the algorithm, S creates its zone by sending node discovery packet to B, C and E. TTL value is decremented at each node and zone is created.

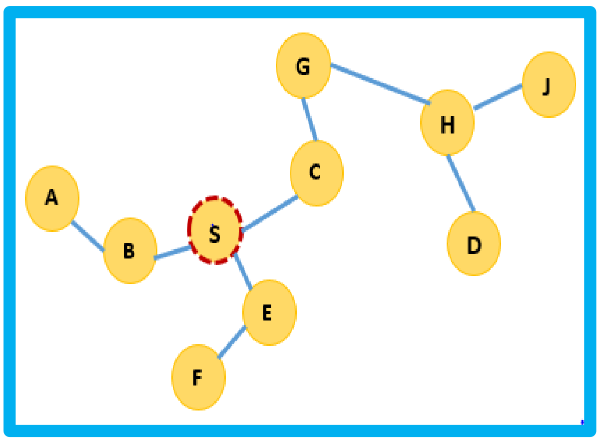


Figure 12 Example Topology for zone creation of node S

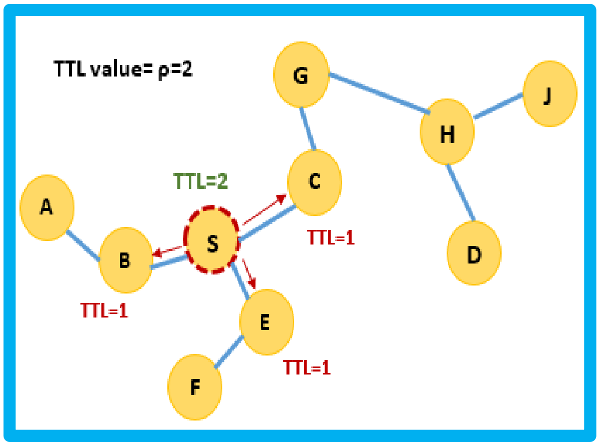


Figure 13 TTL value=2 at node S

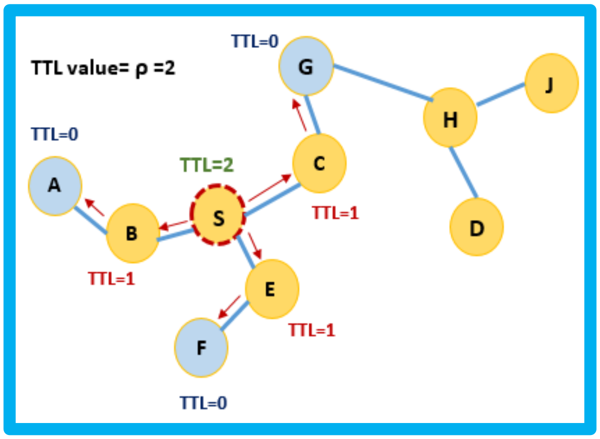


Figure 14 TTL value decremented by 1 at B, C and E

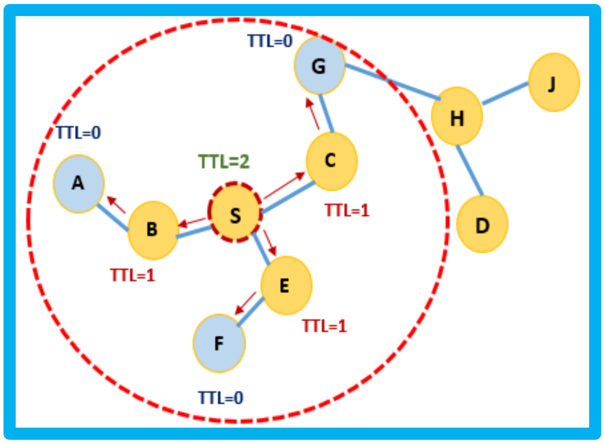


Figure 15 TTL value decremented from 1 to 0

Routing zone of node 1 is shown having node 2, 3, 4, 5, 6 and 9 in it. The zone does not include node 7, 10, 11, 13, 14 and 15. Zone is depicted with a dotted circle. Zones are defined on the basis of number of hops not physical distance. Example of zone creation is shown in figure 16

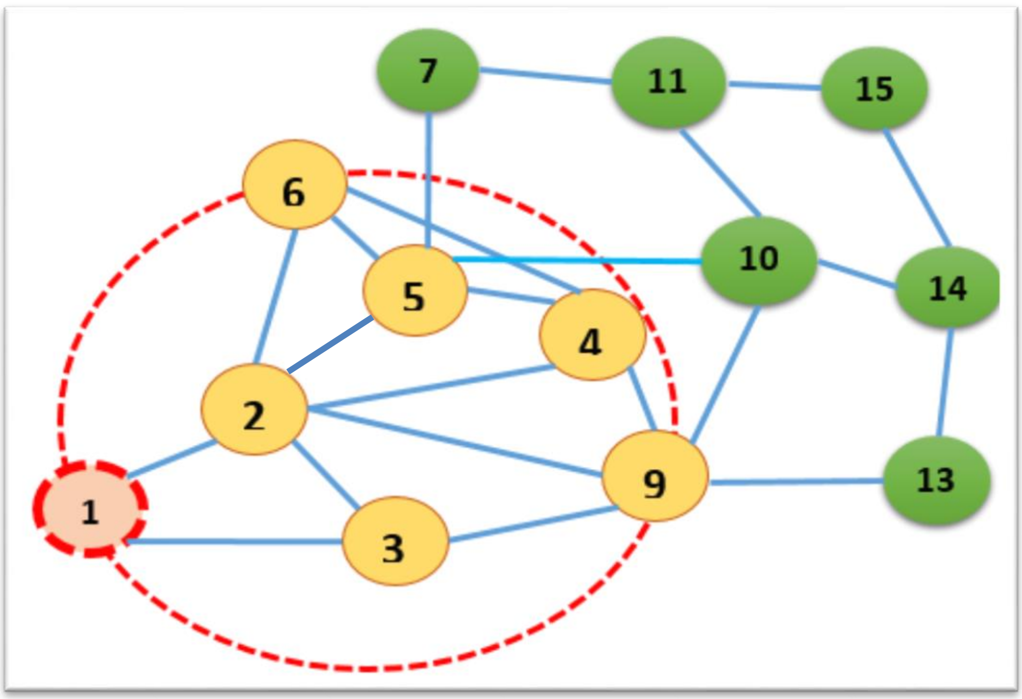


Figure 16 Zone creation example with ρ=2

All nodes in the zone are at most two hops away from node 1. However, nodes in the zone can be reached using more than one path having length more than 2 hops but, the shortest path is equal or less than zone radius. In this way all the zones are made with in the network. The nodes of each zone are categorized into two types' internal nodes and end nodes. In case of node 1's zone, the end nodes are 9, 4 and 5 whereas node 2, 3 and 6 are internal node because they are not connected to other zones.

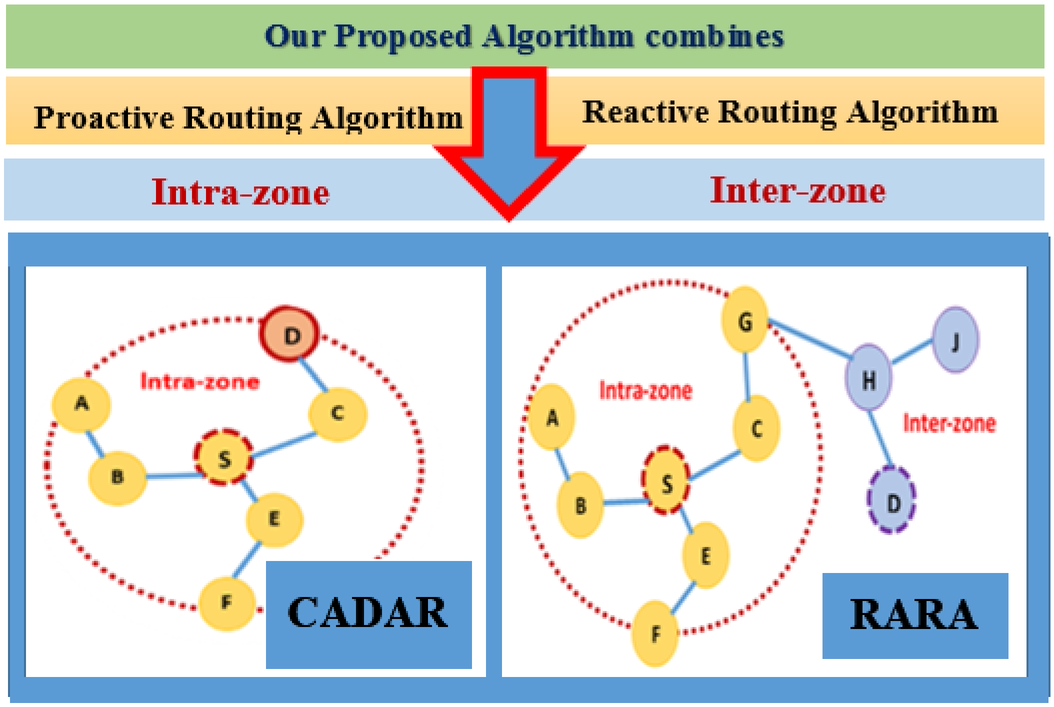


Figure 17 Basic Architecture of proposed scheme

4.2.1 Intra-Zone Routing

As stated earlier, inside a routing zone, CARAR works. The basic steps involved in intra-zone routing are capacity calculation which takes place just after traffic distribution in the network, followed by delay calculation and finally routing. Intra-zone routing steps are shown in figure 18.

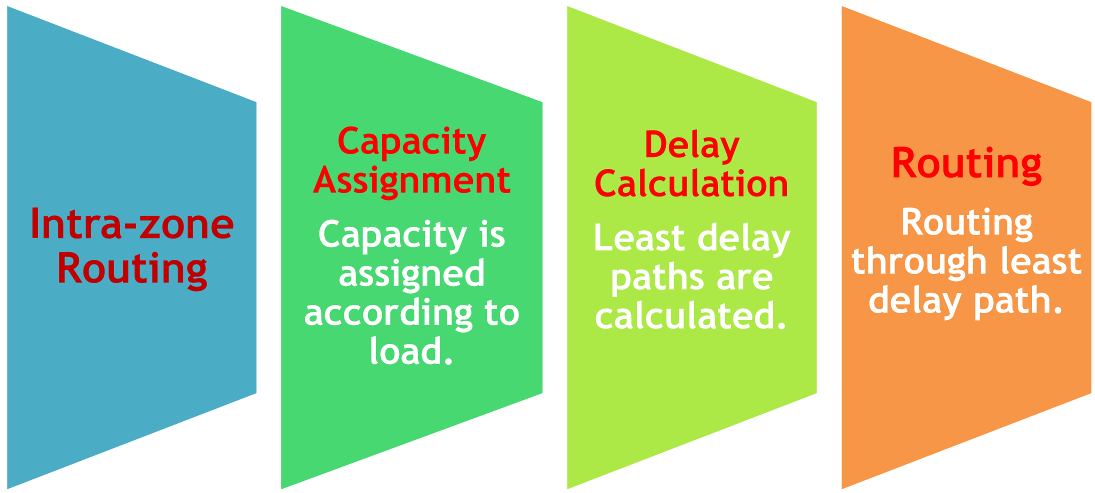


Figure 18 Main steps of intra-zone routing

Capacity Assignment

In telecommunication networks, Time Division Multiple Access (TDMA) is a famous multiplexing technique, so it's a reasonable choice for WMN of WOBAN for communication to take place between the wireless nodes. In a TDMA frame, time slots depends upon number of adjacent nodes. Time slot duration may be different for each link depending on the current traffic which is obtained from Link state advertisement (LSA).Links originating from a node have different timeslots durations depending upon the load node which ultimately translates to assignment of dynamic capacity on each link. Fraction of radio capacity that must be assigned to each link is determined in order to reduce network delay. The sum of capacities assigned to each link must be equal to the total capacity of node. Assignment of time slots and their durations is dynamic [25].

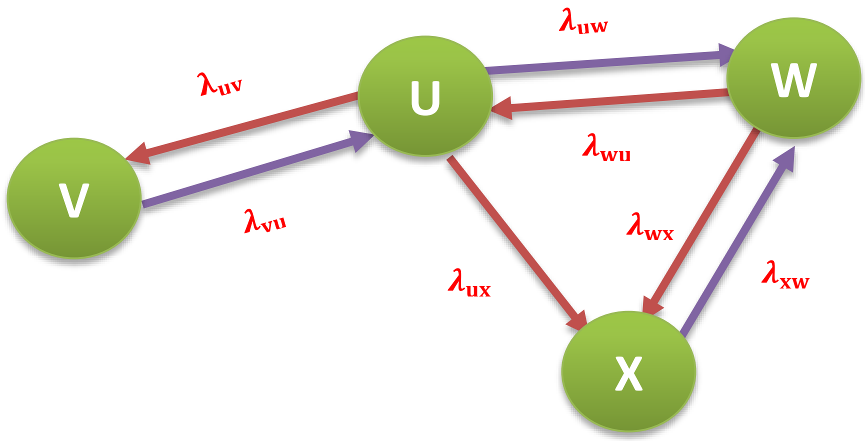


Figure 19 Wireless links with their traffic flows [25]

Figure 19 shows an example of wireless links and their respective traffic flows where node *(u)* has three adjacent links *(w)*, *(x)* and *(v)*. Traffic load on *(w)*, *(x)* and *(v)* may be different. For delay minimization, the radio capacity of node *(u)* must be distributed in an efficient manner to links (*uw*), (*ux*) and (*uv*) bases on their traffic load. Thus, Capacity on links C(*uv*), C(*uw*) and C(*ux*) is assigned based on their respective loads λ(uv), λ(*uw*) and λ(*ux*) and can be calculated using equation no 1 [25].

$$Cuv = \frac{\lambda_{uv}}{\mu} + \frac{(\delta(u) - \sum(v)\frac{\lambda_{uv}}{\mu})\sqrt{\lambda_{uv}}}{\sum(v)\sqrt{\lambda_{uv}}} \qquad (1)$$

Where λ is the load on the link, δ(*u*) is the radio capacity of a node *(u)* and μ is the packet size. The formula in equation 1 is used to assign capacity to nodes in a zone.

Delay Calculation

In wireless mesh network routing takes place either from a gateway to the router or vice versa. Routing in wireless mesh mainly deals with two parts:

1) The connectivity of a user to its closest router in its vicinity
2) The optimal path from the ingress router to an appropriate gateway

A user needs to choose which router it should connect with itself before packet transmission. If there is only one router in its vicinity, that specific router is selected for sending packets. If there are multiple routers and the nearby router is congested, the user can select the next nearby router. Single hop communication delay between a user and connected ingress router is insignificant as compared to delay in wireless mesh. The reason for significant delay in mesh is because a packet could likely travel multiple hops before it reaches a gateway [25].

The packet delay in mesh network is composed of four categories:

1) Propagation Delay
2) Transmission Delay
3) Slot Synchronization Delay
4) Queuing Delay

Propagation Delay

Propagation delay is the time required for a packet to travel from a source to the destination. It’s the ratio between the total distance and propagation speed for any specific medium. In wireless mesh the routers are very close to one another so propagation delay is insignificant.

Transmission Delay

Transmission delay is the time required to push all the packet bits to the medium. This delay depends upon the packet length and effective link capacity. If there is high link capacity the delay would be low. Transmission delay between two nodes *u* and *v* can be calculated using the formula $\frac{1}{\mu C_{uv}}$. ($\frac{1}{\mu}$ is the packet size.)[25].

Slot Synchronization Delay

Time division multiplexing is used in wireless channels in which time slots are allocated to each router. Each router sends the packet in the time allocated to it. Slot synchronization delay is experienced because as the packet arrives, it requires to synchronize to the allocated time slot for data transfer with the neighboring wireless node. Slot synchronization delay between any two nodes *u* and *v* can be calculated using the formula $\frac{1}{2\mu C_{uv}}$ [25].

Queuing Delay

Queuing delay is the delay experienced when a packets waits in queue until it is processed. It is the major component in network delay. It depends upon the packet arrival rate and the service rate of router. Higher the traffic, slower the service rate of router and more queuing delay will be experienced. If packet travels multiple hops before it reaches gateway router, queuing delay is experienced which accumulates as packet traverses through mesh. Queuing delay between two nodes *u* and *v* can be calculated using the formula $\frac{\lambda_{uv}}{\mu C_{uv}\,(\mu C_{uv}-\lambda_{uv})}$[25].

Total Delay (D) for any wireless link (*uv*) can be calculated using equation 2 [25].

$$\text{Duv} = \frac{1}{\mu C_{uv}} + \frac{1}{2\mu C_{uv}} + \frac{\lambda_{uv}}{\mu C_{uv}\,(\mu C_{uv}-\lambda_{uv})} \qquad (2)$$

The overall network delay can be calculated using equation 3 [25].

$$T = \frac{1}{\gamma}\sum_{u=1}^{n}\sum_{v=1}^{n}\frac{\lambda_{uv}}{\mu C_{uv}-\lambda_{uv}} \qquad (3)$$

The equation 3 is used to calculate the overall link delay of nodes in a zone.

Routing

In intra-zone, routing process initiates as soon a packet arrives. Packet contains the destination address field and next hop field and hop count field as shown in figure 20.

Destination Address
Next Hop Address
Hop Count

Figure 20 packet format

The field description of packet format are stated below:

Destination Address: It’s the address to the destination where packet is to be forwarded.

Next Hop Address: It the address of the next hop host to the destination.

Hop Count: Length of the route to the destination host, which is measured in terms of hops.

The node which receives a packet checks its routing table which is proactively maintained, to see if destination address matches any entry in its routing table. Routing table contains routes only for nodes in its zones. The format of routing table is shown in figure 21. Routing table entries include host field, route to the destination and destination address. If destination address is found in routing table, data transfer starts immediately using the stored path.

Host Id	**Route to Destination**				**Destination Address**
	Next Hop	Hop Count	Next Hop	Hop Count	

Figure 21 Routing table format

The field description of routing table entries are stated below:

Host Id: The source node is basically the host which has a unique id.

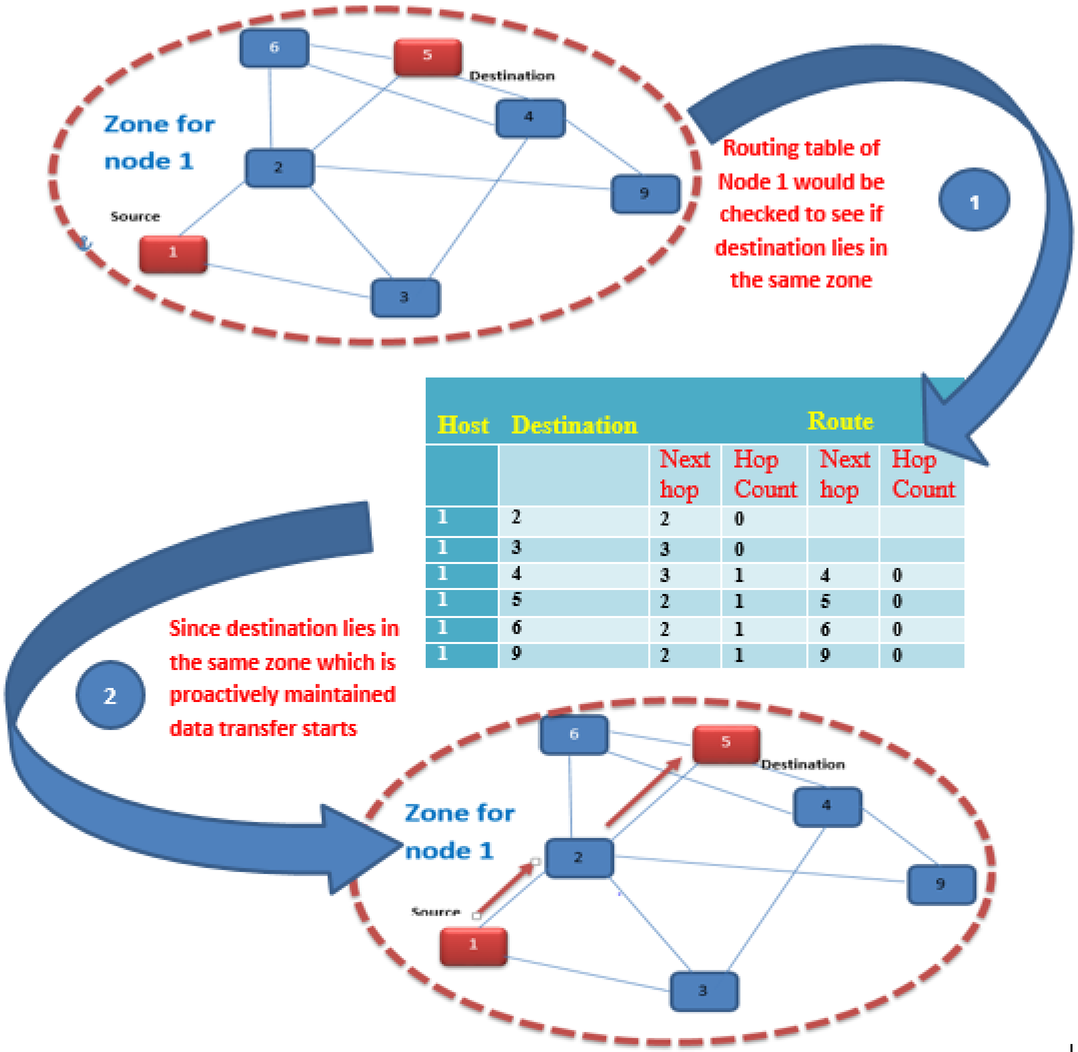
Route to destination contains:

Next Hop: It’s the address of next hop in the stored path.

Hop count: This refers to the number of hops from source to destination.

Destination Address: The destinations stored in routing table.

We have shown an example of intra-routing in figure 22 which shows that node 1 wants to send data packet to node 5. Node 1 which is the source node, checks its routing table to see if destination address is present in the routing table. As the address of node 5 is present in the routing table which resides inside zone of 1. Data transfer starts using the stored path. Path address is stored in terms of next hop and hop count. When hop count becomes 0, that means destination is reached. Hop count is decremented at every hop.



Host	Destination	Route			
		Next hop	Hop Count	Next hop	Hop Count
1	2	2	0		
1	3	3	0		
1	4	3	1	4	0
1	5	2	1	5	0
1	6	2	1	6	0
1	9	2	1	9	0

Figure 22 Intra-zone routing example

To give a clearer picture of intra-zone routing, the flow chart is shown in figure 23.

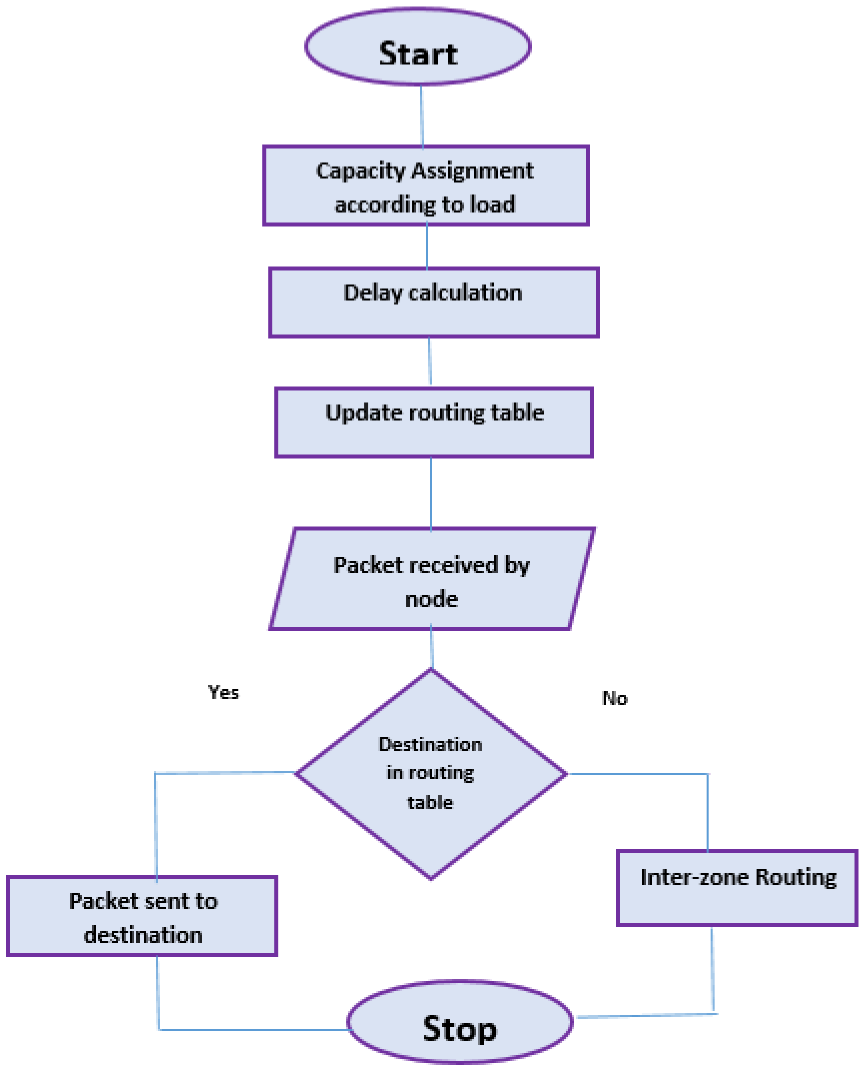


Figure 23 Flow chart of intra-zone routing

Inter-zone Routing

Inter-zone routing process starts in case destination node is not found in routing table. The process starts by sending route request messages to the end nodes of a zone. Route request (RREQ) messages contain the source address, destination address and accumulated delay field. The format of RREQ message is shown in figure 24

Source Address	Destination Address	Accumulated Delay

Figure 24 RREQ message format

The field description of RREQ message is stated below:

Source Address: Address of source node

Destination Address: The address where packets need to be transferred.

Accumulated delay: This is 0 in the start, the delay along the path is added in it.

As soon as the RREQ message reaches the end nodes of the source node, the routing table of end nodes is checked. If destination is found in routing table of end nodes, it will directly send route reply (RREP) message to the source and data transfer starts. RREP message contain source address, destination address, and accumulated delay field. The format of RREP message is shown in figure 25

Source Address	Destination Address	Accumulated Delay

Figure 25 RREP message format

The field description of RREP message is stated below:

Source Address: Address of source node

Destination Address: The address where packets need to be transferred.

Accumulated delay: The delay is added along the path and sent back to the source in RREP message.

In case, destination is not found in routing table of end nodes, the RREQ messages is again sent to end nodes until RREP message is received. However, it should be noted that when RREQ messages reaches end nodes, it means RREQ has entered in new routing zones. As we are dealing with mesh network, it is possible that a destination may be part of more than one zone, so more than one RREP can be received by source node. Source node will only the path having minimum delay. In order to explain inter-routing process we have shown an example where Node 1 wants to send data to node 17 as shown in figure 26. Node 1 checks its routing table to see if node 17 lies in it routing table. Since destination does not lies in the same zone which is proactively maintained, so now reactive search would start and routing table of node 3, 9, 4, 5 and 6 would be checked. The routing table of node 9 contains node 17, so data transfer starts.

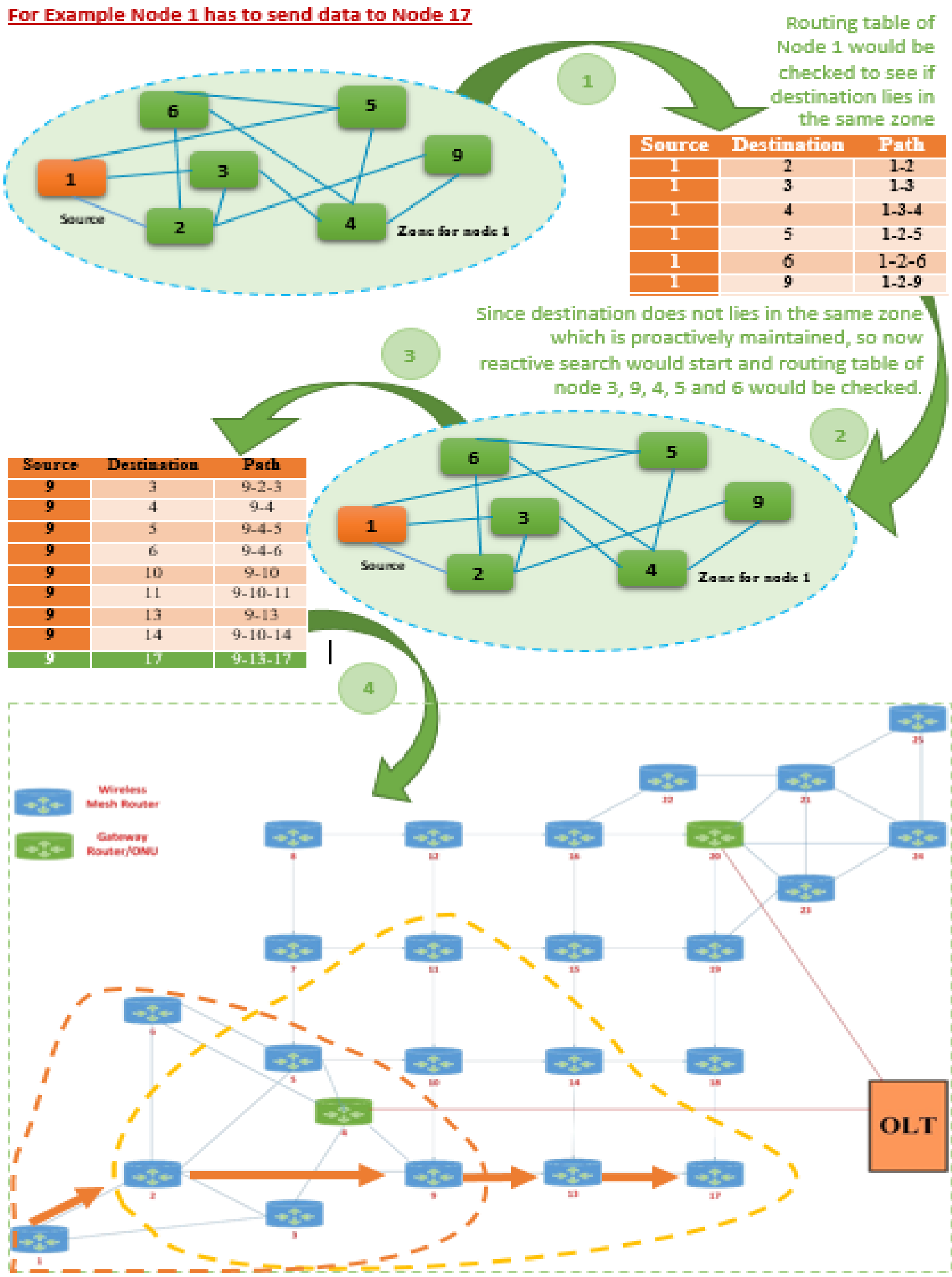


Figure 26 Example of inter-zone routing

To give the clear picture of inter-zone routing, the flow chart is shown in figure 27.

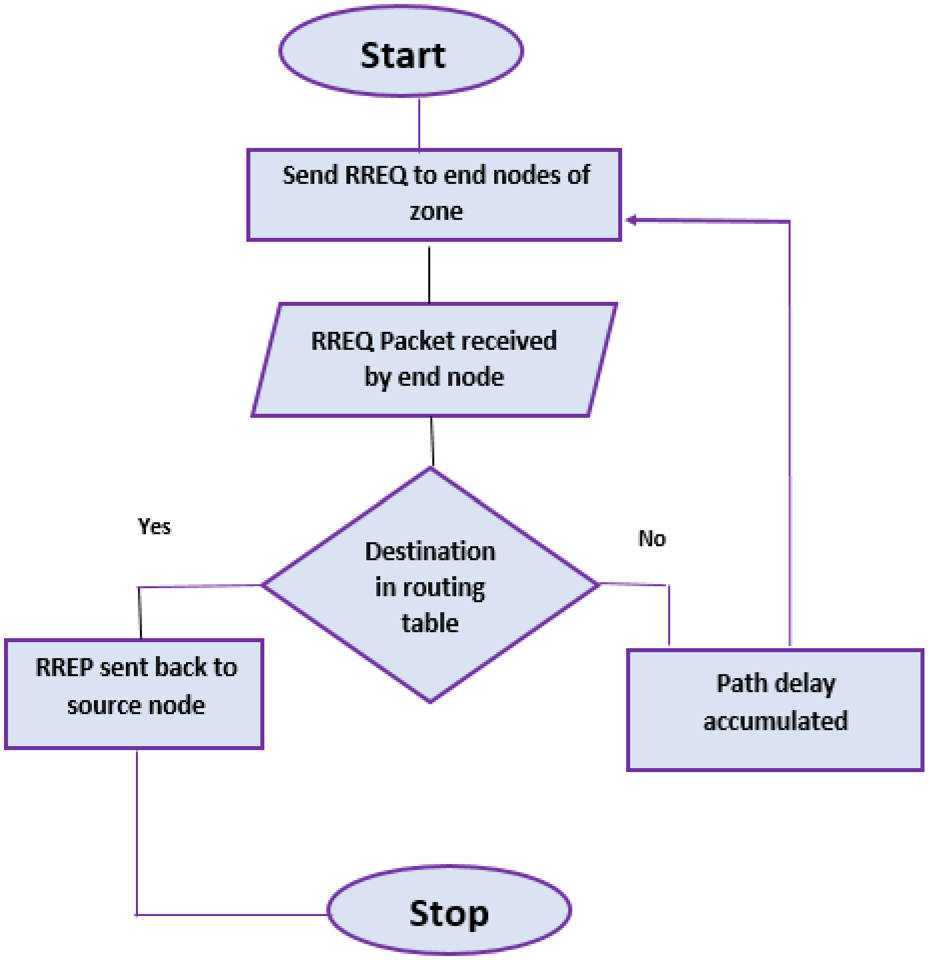


Figure 27 Flow chart of inter-zone routing

Chapter 5
Results

This chapter presents the results of our thesis evaluation. We have divided this chapter into two sections. The first section deals with the simulation setup and gives the clear description of simulation topology. Second section deals with result of our simulations.

5.1 Simulation Setup

For checking the performance of proposed algorithm, we did simulations on a topology of 25 static wireless nodes. In our topology we considered 2 gateway routers, connected to the OLT. We have programmed a simulator in C# which is event driven. According to 802.11g nodes have the capacity of 54Mbps. However, in our case downlink traffic is only considered, so capacity is dropped down to 25Mbps. Packet size is 64 bytes. We used Poisson distribution traffic model in our simulations. Proposed algorithm is compared with RARA and CADAR. Table.1. shows the simulation parameters. The topology is shown in the figure 28.

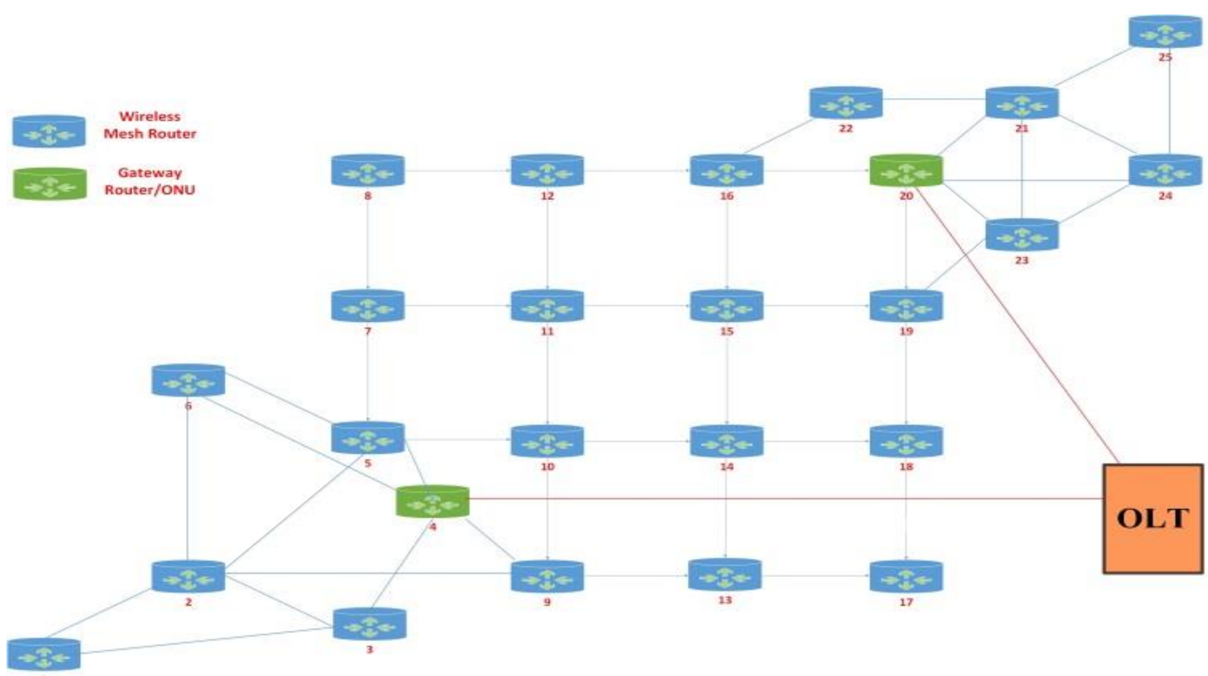


Figure 28 Simulated Topology.

Capacity of Nodes	25 Mbps
Wireless Standard	802.11g
Packet Size	64 bytes
Traffic Model	Poisson Distribution

Tab. 2: Simulation Parameters

On the basis of optimum zone radius, we have calculated the overall end to end delay of network. We then calculated the control packet and routing table overhead for evaluating the performance of our algorithm. Finally, we defined a parameter gamma which is used for calculating the overall performance of network having 50% delay weightage and 50% control packet overhead weightage. The results with detailed description are explained in section 5.2.

5.2 Results

5.2.1 Optimum Zone Radius Selection

Zone radius is configurable and every network has an optimal zone size. If for any network optimum zone size is selected, the control traffic can be reduced and efficiency of the network can be increased. For determining the optimal zone size, it is important to understand the factors that may affect the zone size. The factors that affect zone size are number neighbouring routers per node and the size of the network. Figure 29 shows zones delay at $\rho=2$, $\rho=3$ and $\rho=4$. The load values in Mbps are plotted on x-axis and delay in (sec) is plotted on y-axis. We observe that as the size of the zone increases delay also increases. This happens because with the increase in size, delay between all the nodes is accumulated. Delay at $\rho = 2$ is less, when compared to $\rho=3$ and $\rho=4$. The reason for less delay at $\rho=2$ is that, in our case network is of 25 nodes, so in a smaller zone the accumulated delay would be less compared to a zone with bigger zone radius. If zone radius is large, maximum nodes in a zone would be covered, algorithm behaves same as proactive routing algorithm. Therefore, in our case, radius of 2 hops is suitable for calculating end to end system delay.

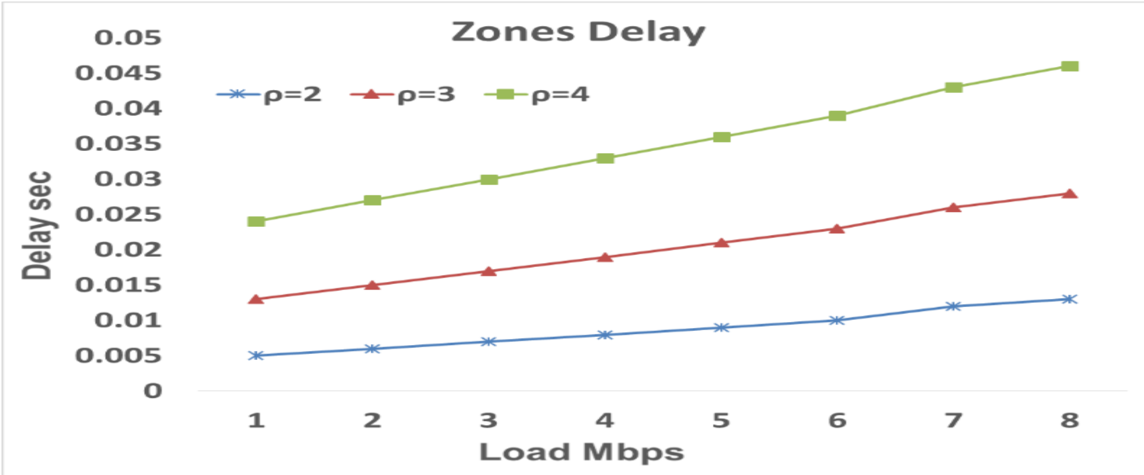


Figure 29 Zones Delay at ρ=2, ρ=3 and ρ=4

5.2.2 End to End link Delay

We kept zone radius= 2hops for calculating the end to end system delay of our proposed algorithm. We compared it with CADAR and RARA. Delay (in msecs) is plotted on y-axis and load (in Mbps) is plotted on x-axis as shown in figure 30. We will refer the load values from 0-5 Mbps as low load regime whereas from 5-8 Mbps as high load regime. The results depict that proposed algorithm show improved performance when compared to RARA and CADAR. In low load regime it shows almost same performance as RARA and CADAR but as the load increases proposed algorithm shows better performance in terms of lower delays.

We have considered the end to end delay which is the combination of slot synchronization delay, queuing delay and transmission delay. We have not considered the delay of routing table maintenance which is experienced at the start because it is insignificant.

Proposed algorithm has less delay as compared to RARA and CADAR because our algorithm efficiently utilizes the benefits of reactive and proactive. We have used intra and inter routing to decrease the system delay. RARA is purely reactive in nature, it floods the entire network with control messages. Whereas, CADAR is purely proactive in nature, it has routes for all destinations in its routing table but utilizes more bandwidth due to large routing table size. We combined the two routing algorithms for better performance by making zones. CADAR works in intra-zone only, instead of working in the entire network. Whereas, RARA works in inter-zone, in case destination is not found in intra-zone. Delay in querying all the network nodes is reduced by limiting the scope of RARA. Limited nodes are queried for route determination.

This reduces the control traffic which in turn reduces delay. On the other hand, in a limited zone it's easy to maintain routing information. Each node keeps information of its zone members, instead of keeping information of the complete topology. This helps in reducing the capacity wastage and improves efficiency of the network.

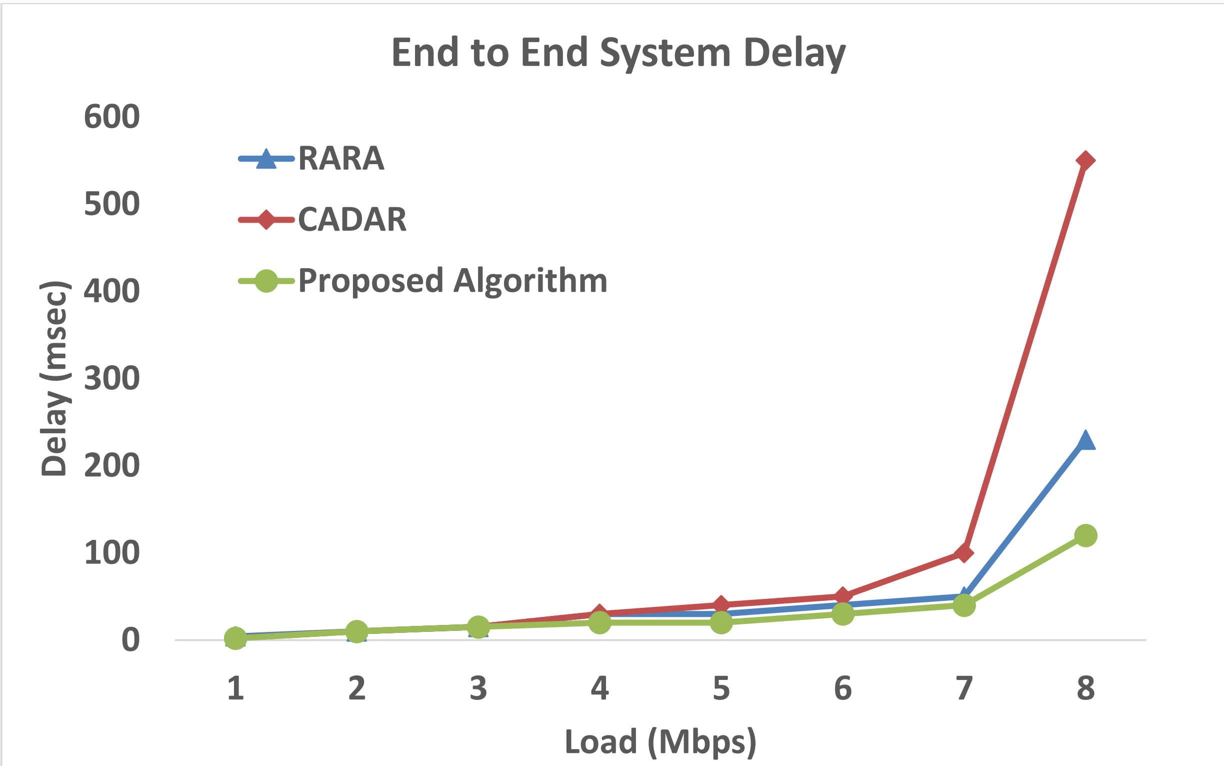


Figure 30 Comparison of our proposed scheme with RARA and CADAR for system delay at different load values

5.2.3 Transmission Delay

Figure 31 shows the transmission delay for RARA, CADAR and Proposed Algorithm. Delay in (secs) is plotted on y-axis against load in (Mbps) plotted on x-axis. Transmission delay is calculated using the formula in section 4.3. The graph clearly depicts that proposed algorithm has less delay compared to RARA and CADAR at all the load values. Transmission delay depends on packet size and capacity of the node. Packet size is constant in our case but, it divides capacity in such a way that it reduces transmission delay.

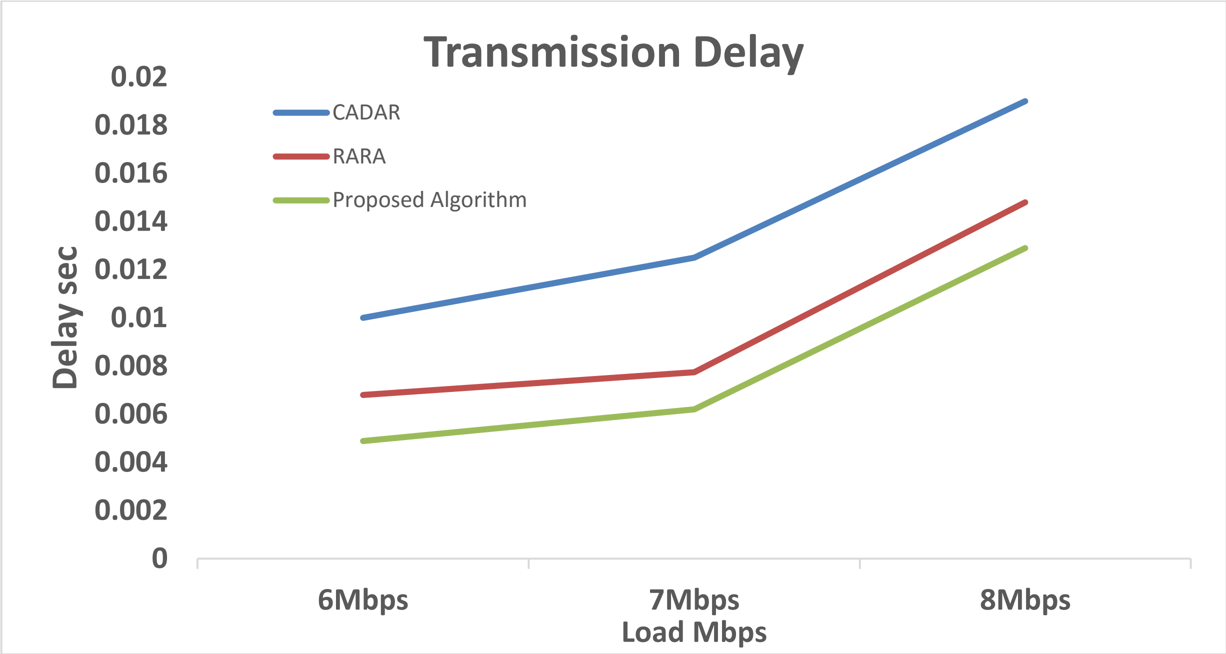


Figure 31 Comparison of our transmission delay of our proposed scheme with RARA and CADAR

5.2.4 Control Packet Overhead

Figure 32 shows the control packet over head for RARA, CARAR and our proposed algorithm. The percentage of overhead is plotted against load. The highest percentage of overhead is for RARA as it is reactive in nature, RREQ messages are exchanged between the nodes whenever nodes need to send data to one another. RARA has only information of its neighboring nodes. The rest of the topology is not known to it, so for finding path, it needs to send RREQ messages to the nodes for data transmission to the destination node.

On the other hand, CADAR is proactive in nature, it has routing table maintained, but at the start for maintaining the table information it sends control packets for getting aware of the topology. If any route request message is received, it simply checks it routing table for destination and immediately transfers the packet. Once the paths are stored in routing table, there no need of frequent control packet exchange, as our topology is static.

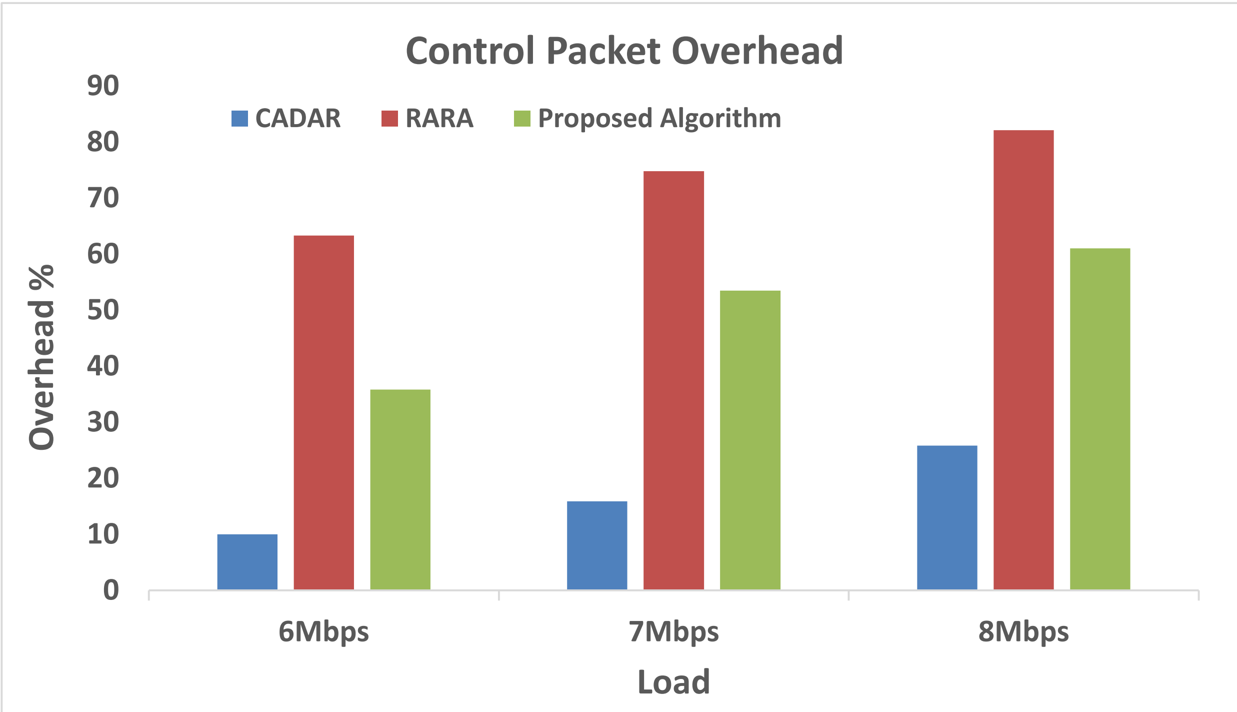


Figure 32 Comparison of our proposed scheme with RARA and CADAR for percentage of control packet overhead

Our proposed algorithm is the combination of RARA and CADAR, so in our case the control packet over head is moderate when compared with RARA and CADAR. Zones only keep information of zone members. If route request arrives for a node which resides outside the zone, then control packets are exchanged for finding the destination, but they are not as much as in case of RARA and they are not as less as of CADAR.

The trend of bars clearly depict that RARA has the highest control packet overhead at all load values. CADAR has the least overhead, where as our proposed algorithm lies in the middle. As the load increases, overhead also increases, the reason for this increase is that, more traffic leads to more exchange of control packets for finding the path, in case of RARA. In case of CADAR even after more traffic there is less overhead due to the already maintained paths which are stored in the routing table. In case of our proposed scheme, zones are proactively maintained, so there is exchange of control packets only in case if destination is not found in the routing table.

5.2.5 Overall Performance Evaluation

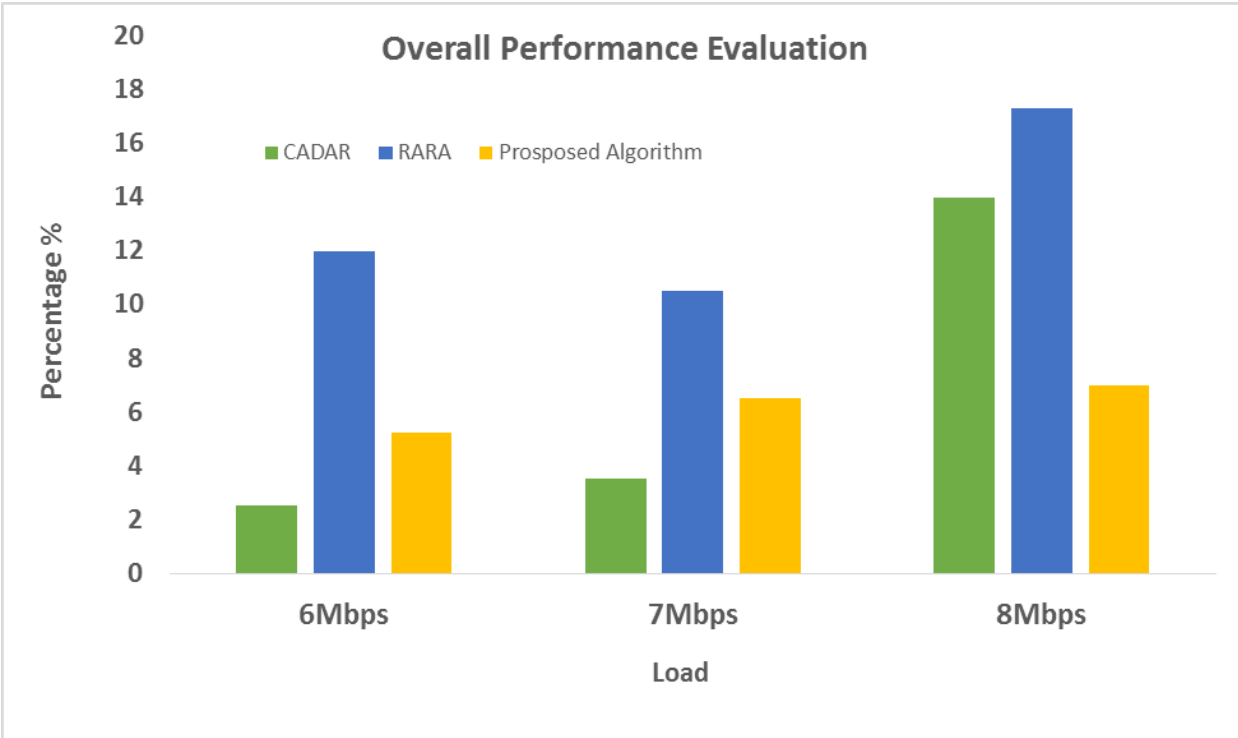


Figure 33 Comparison of our proposed scheme with RARA and CADAR for overall performance evaluation

We have taken a new parameter gamma for checking the overall performance of our proposed algorithm as shown in figure 33.

γ = accumulative delay (packet transmission delay + control packet overhead)

50% weightage of control packet overhead and 50% weightage of packet transmission delay is plotted for calculating the percentage overhead which is plotted against load. We have taken load values 6Mbps, 7Mbps and 8Mbps. The results show that our proposed algorithm has the lowest overall overhead at 8Mbps. The reason is that, delay comparison of CADAR and RARA with our proposed algorithm at 8 Mbps shows a significant improvement in terms of lower delay. 50% weightage of delay and 50% weightage of control packet overhead combine to give the overall overhead of 6%. RARA has the highest over head at all the load values. The reason is that RARA is a reactive routing algorithm it has the highest control packet overhead because the paths are not already maintained. CADAR performs better at 6Mbps and 7Mbps when compared with RARA and our proposed algorithm. The reason for showing better performance is that it has the least control packet overhead and at loads 6Mbps and 7Mbps there is no significant improvement in terms of delay. So when 50% weightage of delay and 50% weightage of control packet overhead is plotted for CADAR it has the worst overall performance.

5.2.6 Routing Table Overhead

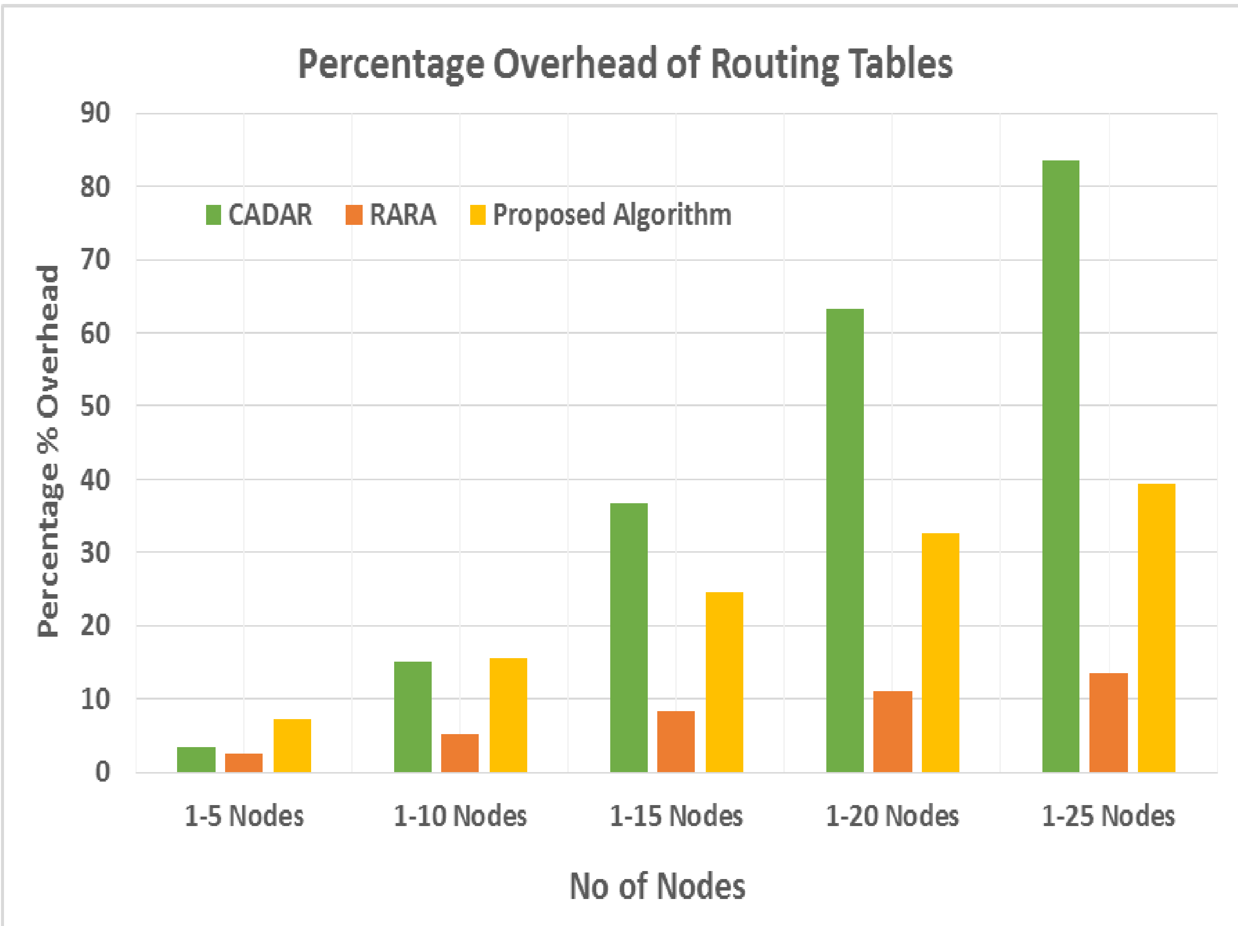


Figure 34 Comparison of our proposed scheme with RARA and CADAR for percentage overhead of routing tables.

We have plotted bar chart for percentage overhead of routing tables as shown in figure 34. We have varied the number of nodes. On the x-axis no of nodes is plotted and on the y-axis percentage overhead is plotted. The green bar is for CADAR, orange for RARA and yellow for our proposed algorithm. The results show that RARA has the least routing table overhead, even if the size of the network increases. The reason is that it is a reactive routing algorithm. It has the routing information of only the directly connected neighbors. CADAR has the highest overhead as it the information of the whole topology. Our algorithm has medium overhead as it has the information of only the zones. Each node only keep the information of the nodes which lie in its zone which reduces the routing table overhead.

Chapter 6
Conclusion & Future Directions

This chapter presents the summary of our research findings and concludes by stating the future research directions of our thesis. It highlights the essential research problems in the domain of Hybrid Wireless Optical Networks that are still needed to be resolved particularly the issues related to delay. First, we summarize our research contributions made in this and then, a conclusion of our major findings. Lastly, this chapter explains some of the future research prospects of this thesis.

6.1 Thesis Contributions: A Summary

We have carried out research for minimizing delay in Hybrid-Wireless Optical Broadband Access Networks (WOBAN). We targeted only the wireless mesh part of WOABN because a significant delay is introduced at wireless side due to the capacity mismatch between the wireless network and optical network. As a result, our key goals achieved so far are summarized below:

1. As our first contribution, we have performed in depth literature survey to explore the vast domain of WOBAN. The rationale behind this research was that for delay reduction, many routing algorithms have been proposed until now claiming to offer less delay but they are either reactive or proactive. However, as to the best of our knowledge there exist no Hybrid routing algorithm for reducing delay. As a result, we propose a hybrid routing algorithm which aims at reducing the end to end delay by combining the best features of reactive and proactive routing approaches.

2. In our next contribution, we have studied two bench mark routing protocols namely Zonal Routing Protocol and Landmark Routing Protocol. After deep

analysis, we set Zonal Routing Protocol as the basis for our proposed routing algorithm and used the concept of zones. Zone Radius which has an impact on delay was analyzed by varying the zone size. After performing simulations by varying zone radius by 2, 3 and 4 hops, we came to the conclusion that 2 hop radius is most optimal in our scenario.

3. As our last contribution, we have designed and implemented the hybrid routing algorithm. Our Proposed Algorithm works by combining the best features of RARA which is reactive in nature and CADAR which is proactive in nature in order to reduce delay.

6.2 Conclusion

In current years, the rapid growth of bandwidth hungry applications expedites the requirement to design "last mile" broadband access network having flexibility and high capacity. Hybrid wireless-optical broadband access network (WOBAN) which is integration of both optical and wireless technologies serves the end users to access internet in a high capacity and flexible manner. Delay in the access network can be noteworthy as packet travels multiple hops before reaching the destination. Moreover, due to the capacity mismatch between the wireless and optical network, delay is experienced at the wireless side. In addition, some links may be under-utilized while others over-utilized, which results in inefficient routing. We addressed the problem of delay minimization in WMN. We proposed a hybrid routing algorithm combining the features of reactive and proactive routing approaches. Network is divided into zones and each node has its own zone. After performing experiments, value of zone radius is kept 2. The simulation results show that our proposed algorithm, when compared with RARA and CADAR, is able to minimize delay especially at higher load regions. Moreover, due to the hybrid nature of algorithm, the overhead of maintaining routing tables and control packets is also decreased.

6.3 Future Directions

To validate our simulation this work must be done on actual system. In our case the nodes are static it should be tried on mobile nodes as well because this hybrid technique can even work better in mobility scenarios.

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