Performance Evaluation of VOIP over Multi Radio Multi channel Network

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***Abstract*— Wireless mesh network is an advanced form of wireless network. A wireless mesh network provides a better solution to problems that often arise in cellular and WLAN. Wireless mesh networks (WMNs) are receiving increasing demand as an effective solution to deploy ISP's wireless last mile access, such as wireless enterprise backbone networks and other applications. Wireless mesh networks (WMNs) provide a unique architecture and extend the connectivity of mobile devices by using multiple access points connected to the internet and other networks. Wireless mesh network (WMN) is a key technology that supporting several application scenarios. Recently, WMN evolves towards multi-radio multi-channel (MR-MC) WMN architecture, which can improve performance by using multiple radio interfaces with each node and by using multiple non-overlapping channels. This evolution creates new challenges on network design. Performance analysis of VoIP over multi radio multi channel (MR-MC) network is essential in order to meet the network performance. In this paper, we presents a study of real time voice communication QOS in terms of packet loss, throughput, (mean opinion score) MOS and end to end delay. Instead of using single radio network, we use multiple radios to increase throughput, bandwidth, and capacity. We have also implemented and compare the results of single radio multi channel (SR-MC) with multi radio multi channel (MR-MC) WMNs by using QUALNET simulator.**

***Keywords*— Throughput, Packet loss, (mean opinion score) MOS and End to End Delay.**

1. Introduction

A wireless mesh network (WMN) is a communications network made up of radio nodes that are organized in a mesh topology. Wireless mesh networks are consisting of mesh clients, mesh routers and gateways. The examples of mesh clients are laptops, cell phones and other wireless devices while the mesh routers forward traffic to and from the gateways which may, but do not connect to the Internet. The coverage area of the radio nodes working as a single network is sometimes called a mesh cloud. Access to this mesh cloud is dependent on the radio nodes working in harmony with each other to create a radio network [1]. The main advantages of mesh network are reliable and offer redundancy. When one node can no longer operate, the rest of the other nodes can still communicate with each other, directly one or more intermediate nodes. The architecture WMNs is a first step towards providing cost effective and dynamic high-bandwidth networks over a specific coverage area. Like traditional WLAN access points, WMNs is built up of peer radio devices that don't have to be cabled to a wired port. The other common advantage of mesh architecture that sustains signal strength by breaking long distances into a series of shorter hops. Intermediate nodes not only boost the signal, but cooperatively make forwarding decisions based on their knowledge of the network through routing. Such architecture carefully designed by high bandwidth, spectral efficiency, and economic advantage over the coverage area. Multi-radio mesh refers to a unique pair of dedicated radios on each end of the link. This means there is a unique frequency used for each wireless hop and thus a dedicated CSMA. This is a true mesh link where you can achieve maximum performance without bandwidth degradation in the mesh and without latency. This result, voice and video applications work just as they would on a wired Ethernet network. In 802.11 networks, there is no concept of a mesh. There are only Access Points (AP's) and Stations. A multi-radio wireless mesh node will dedicate one of the radios that act as a station, and also connect to a neighbour node AP.

MR-MC WMNs

In MR-MC WMNs, each mesh router is equipped with multiple NICs and each NIC can operate on multiple frequency channels. The MR-MC solution has more demandable with the advantages of reduction in interference and improvement in network scalability. This implies that various logical links may be assigned to the same channel. In this type of cases, interference occurs if these logical links are close to each other, and results the interfering links cannot be active simultaneously. Furthermore, the number of available NICs is also very limited, and results some logical links in a router need to share a NIC to transmit and receive the data packets. When two logical links in a router share a NIC, they are required to operate over the same frequency channel, and cannot be active simultaneously. And results it reduces their effective capacity. The effective link capacity can be increased by removing some of the links from the logical links. However, when some of the links are not activated, the number of hops through some routing paths may be increased, and the logical topology may not even be connected. Therefore major factors to be considered in MR-MC networks how many logical links should be assigned between neighbouring routers, the allocate interfaces and channels, and through which logical links packets should be forwarded. Multi-Radio Multi-Channel (MR-MC) wireless networking arises in the context of wireless mesh networks, dynamic spectrum access via cognitive radio, and next-generation cellular networks. Therefore, adjacent transmissions should be carried over non-overlapping channels to avoid mutual interference by the use of multiple channels [9]. Each node i.e. equipped with multiple radios is capable of working in a full-duplex mode by tuning the transmitting and receiving radios to two non-overlapping channels. The increasing demand for high data rate and reduction in radio costs has greatly demandable research on MR-MC networks. Most research work has been done on capacity analysis, channel and radio assignment, and routing protocols.

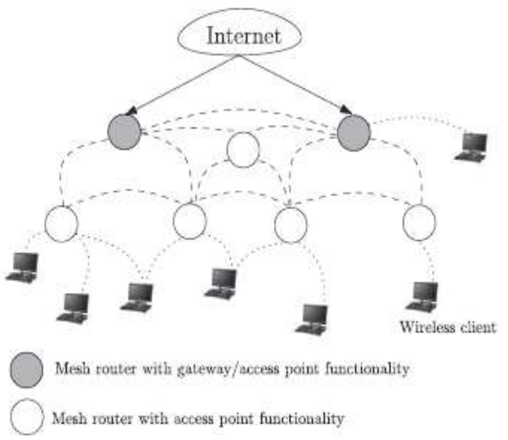

Figure 1. The system architecture of the multi radio WMNS.

Figure1 [6] shows that Multi radio WMNS consists of a wired infrastructure (internet) and static wireless mesh routers. Each wireless mesh router have access point that serves as an ingress or egress for the aggregate traffic associated with the mobile/wireless clients in its coverage area. This type of traffic is routed to the end from the wired infrastructure via multiple wireless hops formed by the wireless mesh routers. Each wireless router may be equipped with multiple wireless radios each of which operates on an orthogonal channel. Each node in our system can algebraically combine incoming packets according to the random linear networks coding schemes before forwarding the resulting combine packets to other nodes by its broadcast link. We assume that all wireless nodes and all wireless transmissions are in broadcast mode. Those wireless nodes that hear such transmissions may engage
in packet forwarding. It is also assumed that our system operates synchronously in a time-slotted mode.

Routing in MR-MC WMNs

Multicast is an important aspect of network service. Which is the delivery of information source to destination using simultaneously? QOS requirement proposed by many different multicast application are versatile. Among them end-to-end delay is a very important QOS metric. The multicast tree cost which is used to evaluate the utilization of network resource which is also an important QOS metric in wireless networks where limited radios and channels are available. In WMNs, if two mesh routers are in radio transmission range want to create the communication link between them, they must tune their radios to the same channel. However, the wireless interference occurs when two links whose distance is less than 2 hops away are assigned to the same channel to support the concurrent communications, which is known as channel conflict. The interference caused by channel conflict degrades the performance of the wireless communication. Hence in multicast routing, each link on the multicast tree requires to be assigned to one channel and the assignment should lead to minimum interference. Therefore, the QOS multicast routing in WMNs involves not only to search a routing tree but also to assign proper channels to its links [10].

Characteristics of MR-MC WMNs:-These are the main characteristics of MR-MC WMNs are as follows:-

Interference- Interference is the main factor that degrades the performance of wireless network. The primary goal of channel assignment is to minimize interference within the MR-MC WMNs by utilizing multiple radios and multiple channels. To address the interference issue, two models were proposed i.e Protocol Model and Physical Model. A very simple one, the Protocol Model can be described as follows: (1) each radio has a transmission range and an interference range, with the former less than the latter; and (2) a transmission from radio X to radio Y is successful if Y is in the transmission range of X and not in the interference range of radios. Compared with the Protocol Model, the Physical Model is close to reality but quite complex than protocol model. It can be described as follows: (1) a transmission is successful if the Signal to Interference and Noise Ratio (SINR) of the transmitter's signal at the receiver is larger than a threshold value; and (2) the interference and noise power at the receiver consists of the noises generated by other ongoing transmissions and the ambient noise in the network.

Load- A basic factor for making the routing decisions in MR-MC can be exchanged by the Channel Assignment (CA) decisions. Thus, routing is dependent on CA. On the other hand, routing can change the traffic load distribution in the network, which is a primary factor considered by CA to reduce the interference dynamically. So in this case, CA is also dependent on routing. To handle such a relationship between CA and routing, two ways are proposed in the surveyed CA approaches. In one way, CA is viewed as a lower-layer mechanism and does not consider the traffic load, while routing is viewed as an upper-layer mechanism and is fully responsible for distributing the traffic load. Thus, being independent of CA, any routing protocol should be supported by the CA mechanism. In the other way, CA and routing are viewed to be mutually dependent, so they are combined in order to obtain optimal network performance.

Cost effective- Wireless mesh networks (WMNs) are believed to be the cost-effective solution to build self-organized network for covering the places where wired network's deployment is not available or costly and serve as broadband wireless access to the internet.

Throughput- Throughput is the most important factor for network performance. Having a deterministic relationship, they are generally addressed together. To obtain optimal throughput in MR-MC WMNs, the channel assignment (CA) approaches need to consider the following two basic strategies. First, reducing interference is almost the most effective method in achieving the optimality, and it is better to make this method adaptive to the dynamic network traffic. Second, links should be treated differently when assigning channels, since different links in MR-MC WMNs impact through- put to different extents. For example, the backbone links carry much more network traffic than the stub links, so they should be given more bandwidth either by assigning more number of con- current channels or by assigning less interfered channels. In this sense, an MR-MC WMN is analogous to a wired enterprise/campus network consisting of a hierarchy of Ethernet switches, where the ports on an upper-level switch usually have much more bandwidth than the ports on a lower-level switch.

Voice over Internet Protocol (**VoIP**) is a methodology or concept that is consisting of group of technologies for the delivery of voice communications and multimedia sessions over Internet Protocol (IP) networks. The term Internet telephony refers to the provisioning of communications services such as (fax, SMS, voice-messaging, voice) over the public Internet. The principles that are involved in originating VoIP telephone calls are similar to traditional digital telephony, and it involves signaling, encoding, channel setup and digitization of the analog voice signals. Instead of being transmitted over a circuit-switched network, the digital information is packetized and transmission occurs as Internet Protocol. Early providers of voice over IP services offered business models and technical solutions for the architecture of the telephone network. Second generation providers such as Skype have built for private user bases, providing benefit of free calls and easy convenience. Third generation providers such as Google Talk have adopted the concept of VoIP systems that employ signaling protocols to control the signaling, set-up, and releasing of calls and session control. VOIP over mesh network is challenging, although cheap and convenient. Wireless mesh network over WLAN faces a number of technical problems (a) providing quality of service (QOS) sensitive VOIP traffic in presence of best efforts TCP data traffic (b) packet loss due to channel interference [6].

Once VoIP over WLAN becomes popular, many cell phone/Wi-Fi handset owners will migrate to using VoIP over WLAN inside the administrative boundaries of the public places, campuses, enterprise buildings, airports or in WLAN equipped homes. The benefits of mesh network compared to wired LAN connecting Wi-Fi access points are: i) better coverage; ii) ease of deployment and expansion; iii) reduced cost of maintenance iv) resilience to node failure. Such type of mesh network has potential of creating an enterprise-scale or supporting multiple users while driving these users from using fixed phones to wireless VoIP phones. In such a mesh network with 2Mbps link speed, the number of supported calls reduces from 8 calls in single hop to one call after 5 hops. This significant reduction in the number of supported calls can be attributed to following factors: a) packet loss over multiple hops b) decrease in the UDP throughput because of self interference and c) high protocol overhead for small VoIP packets [18].

2. Related work

In this work we focus on designing a 802.11 based wireless mesh network that can efficiently support the VoIP performance. Specifically, our main objective is to use multi radio multichannel networks in which we can increase the performance of VOIP by considering some parameters like delay, jitter, and throughput and packet loss. We address several performance optimization issues that lead to significant benefits in capacity and in the quality of VoIP. In particular, for increasing capacity (performance).We investigate on the following three directions: use of multiple radios, efficient routing and use of multihop packet aggregation to reduce overhead.

Recently, with growing importance of VoIP, several research works have addressed the performance issues of supporting VoIP over Internet. The use of switching among multiple paths to reduce delay was proposed in S.Tao and A.Estepa. There are currently many solutions that solve hand off issues in real time communications in wireless mesh network were presented by Danilova and N. Rivera. Some initial studies on the performance of real-time applications over 802.11 were presented by Sobrinho and Yeh. A significant research has been conducted in the area of 802.11 based wireless multihop mesh network. Study has been conducted to understand the capacity of multihop network. When transporting VoIP over the Internet, the major factor affecting the performance is path delay as for good quality, VoIP requires 200ms or less one way delay.

S.Garg and M.Kappes represents analytical studies on the number of calls that can be supported in a single hop WLAN. The study reports that increasing the payload per frame increases the number of supported calls. Another research work on minimum interference channel assignment in multi radio wireless mesh networks. Our work uses this network to increase the performance of VOIP. Several performance optimization schemes were proposed for VoIP over WLAN: Samrat Ganguly and Vishnu navda proposed various performance optimization for deploying VOIP services in mesh network.

Kyasanur and vaidya [24] propose a hybrid channel assignment strategy, some interfaces on a node have a fixed assignment, and the rest can switch channel as needed. To put thing in perspective our work present algorithm for making these fixed assignment. In remaining related work it drives upper bound the capacity of wireless multihop network with multiple channel s and it investigate granularity of channel assignment decision by assigning channel at the level of components in single radio networks. Yu et al. propose the use of dual queue of 802.11 MAC to provide priority to VoIP, while Wang et al. propose packet aggregation to increase capacity.

The static channel assignment problem in multi-radio WMNs has been investigated in the literature recently. We can roughly distinguish between interference-aware channel assignment algorithms, which aim to minimize some network-wide measure of interference, and traffic aware channel assignment algorithms, which aim to make a given set of flow rates schedulable. In A. Raniwala, K. Gopalan, T. Chiueh [2] [3], Centralized channel assignment and routing algorithms for multi-channel wireless mesh networks are introduced. In a hybrid channel assignment scheme is proposed where some radios are statically assigned a channel while the remaining radios can dynamically change their frequency channel. The algorithms proposed and mainly differ in the order in which links are visited and in the criteria used to select the channel to be assigned to a radio. It is assumed that the traffic profile is known which is used to determine an estimate for the expected link load. The channel assignment algorithm visits all the links in decreasing order of the expected link load and selects the channel which minimizes the sum of the expected load from all the links in the interference region that are assigned the same radio channel. The algorithm proposed by visits the links in decreasing order of the number of links falling in the interference range and selects the least used channel in that range.

Many researchers dedicated their ideas for multi-path routing protocol as well as multi-channel link protocols, but most of them approach those two problems separately. For the multi-channel MAC and link layer, authors in used single transceiver while authors in used multi-transceivers to design their protocols. The target is to improve network capacity, reduce collision, and contention among nodes. Wireless mesh networks (WMNs) have been a popular research topic as wireless devices have become more affordable, which was followed by the mass adoption of wireless technology. Because of its robust, reliable and cost-efficient features, many companies have developed different WMNs protocols and products for different application purposes. However, no industrial standard existed for WMNs, and thus, these devices were incompatible with each other. Therefore, the Institute of Electrical and Electronics Engineering (IEEE) started the 802.11s Task Group (TG) in July 2004 to unify the research and establish a draft standard for WMNs.

W. Ryan, there are also several studies on Wireless Mesh Communications related to different applications and topics. Discusses the deployment of different handoff approaches for public safety disaster recovery networks presents an experimental study of Multimedia traffic performance in mesh networks investigates several methods to improve voice quality, as well as to study the performance of VoIP in Wireless Mesh Networks.

Awoniyi & Tobagi analyzed effect of fading on VoIP performance and VoIP capacity in presence of real data traffic is studied by Anjum. A measurement based capacity estimation model is explained. The authors have used an interference map based on which VoIP traffic is routed through the least interfered zones. All of these works have analysed results from simulation or test beds and none provided any analytical model to give a precise estimate of VOIP.

Kyasanur and Vaidya [24] propose a hybrid channel assignment strategy: some interfaces on a node have a fixed assignment, and the rest can switch channels as needed. To put things in perspective, our work presents algorithms for making these fixed assignments. The authors and address joint channel assignment, routing, and scheduling problems. These papers make an assumption of synchronized time-slotted channel model as scheduling is integrated in their methods. This makes modelling network throughput straightforward and consideration of a joint channel assignment and routing problem practical. However, the synchronized time-slotted model is hard to implement in commodity radios that use 802.11, as in 802.11 scheduling is done following a CSMA-based random access paradigm. In addition, these works often make impractical assumptions. For example, Jain et al.'s approach requires an enumeration of all maximal sets of no interfering links and Kumar et al. considers networks with bounded “interference degrees.” Each of these works has different goals, for instance, Gupta *et al*. are interested in the asymptotic capacity of the network while Karnik *et al* are interested in explicitly finding the maximum sustainable throughput. While Florens *et al.* and Gargano *et al* are interested in minimizing the number of time-slots required to collect a single packet of data from every node in the network at the gateway, Ramamurthi *et al* and Birmiwal *et al* are interested in minimizing the overall average delay when the arrival traffic follows a Poisson process.

X. Wu et al have performed analysis of Delay and throughput using M/D/1 queuing theory by model the gateway nodes as independent M/D/1 queue stations, and derived closed-form solutions for the bottleneck delay and throughput with linear and grid topologies of wireless mesh network have analysed the throughput, packet loss, and delay and also consider the impacts of interference on modelling the mesh hop nodes as M\M\1. Sunny et al have solved the problem of modelling the average delay in an IEEE 802.11 DCF wireless mesh network with a single root node under light aggregate traffic in Wireless Mesh Networks using M\M\1 Queue. Literature review reveals that WMNS has emerged as a useful technology for various real time applications. This provides motivation for conducting investigation into VoIP performance of WMNs [1].

3. Problem formulation

Wireless mesh networks (WMNs) are consists of multiple hops and mesh topology that has been evolved as a key technology for a variety of applications including metropolitan area networking, broadband home networking, enterprise networking, community and neighbourhood networking [1]. WMNs are composed of three distinct wireless network elements: mesh routers (access points), mesh clients (mobile or others) and mesh gateway (mesh routers with gateway functionalities). Mesh clients connect to mesh routers using a wireless or a wired link. Every mesh router performs forwarding/relaying of data for other mesh routers, and also certain mesh routers have additional capability of being as Internet gateways. Such gateway routers have a wired link which carries the traffic between the mesh routers and the Internet. The WMNs have lot of attractive advantages such as self configuration, self-organization, self-healing, enabling quick deployment, cost effectiveness and easy maintenance. The WMNs inherit almost all characteristics of general wireless ad hoc networks (e.g. distributed communications, decentralized design,). Unlike the mobility of ad hoc nodes, mesh routers are usually fixed. Therefore, ad hoc network is an important design target for energy constrained and energy efficient. On the other hand, mesh routers have no limitations regarding energy consumption and energy constraint. Traditional WMNs operate in single-radio single channel (SR-SC) architecture where each mesh router are consisting of only one network interface card (NIC) and all the mesh routers share only one common radio channel. In such a networking scenario, the network suffers from low throughput and capacity due to frequent back offs and packet collisions, especially for real-time applications such as VoIP transmission. There exists significant interference between these standard non-overlapping channels in the current commodity IEEE 802.11 hardware, this type of problem can be resolved by using better frequency filters in hardware for multi-channel use. Hence, the use of single-radio multiple-channels (SR-MC) has been proposed to elevate the performance of WMNs [4] [5]. Compared with the SR-SC architecture, the SR-MC architecture can help to increase network throughput and to elevate the interference. An effective solution to improve throughput and to overcome high latency of WMN, would be using Multi-Radio Multi-Channel (MR-MC) architecture. In such a networking scenario, each mesh router is equipped with multiple NICs and each NIC can operate on multiple frequency channels. With MR-MC architecture, multiple receptions/transmissions can happen concurrently, and neighbouring links assigned to different channels can carry traffic free of interference. In this work, we use MR-MC WMNs to elevate the network performance by considering various parameters like delay, jitter, throughput, Mean Opinion Score (MOS). And compare the result of these parameters with SR-MC WMNs by using Qual net simulator.

4. Performance evaluation/Results

This section presents the results from the performance tests made with the intention to compare the usual single channel, single radio set up to MRMC under fair condition. We performed a set of simulations to compare SR-MC with MR-MC. We start with discussing various parameters used for comparison of MRMC with SRMC.

Evaluation of Average jitter

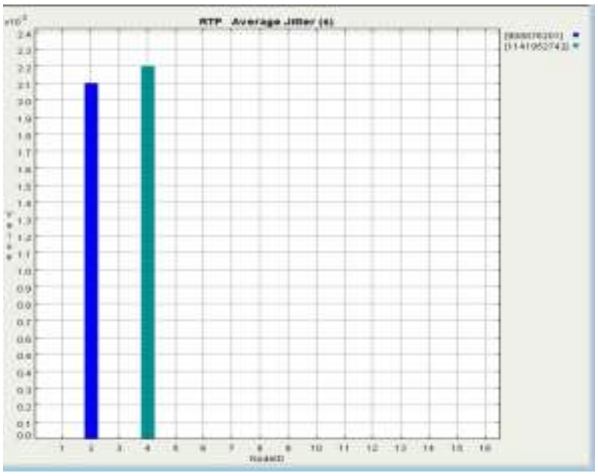

Figure 4. Average jitter SR-MC

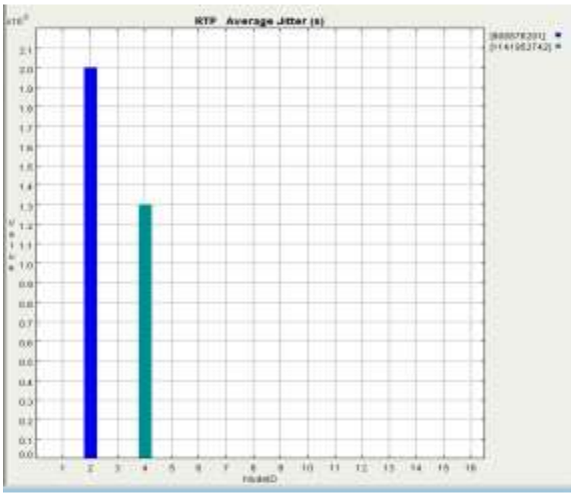

Figure 5. Average jitter MR-MC

In figure 4 and 5, we compare the results of average jitter in SR-MC and MR-MC. We investigate that average jitter in SR-MC at node id (4) is 22ms and in case of MR-MC, average jitter at node id (4) is decreased by 13ms.

Evaluation of Packet sent/received

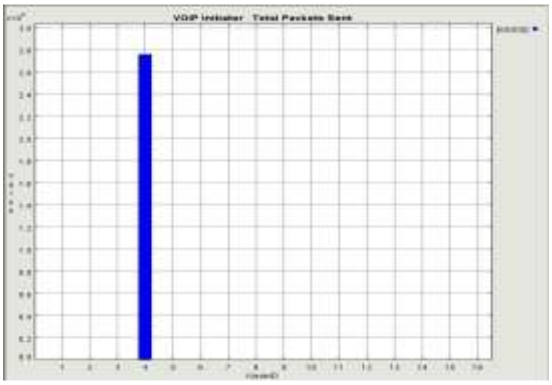

Figure 6. Total packet sent SR-MC

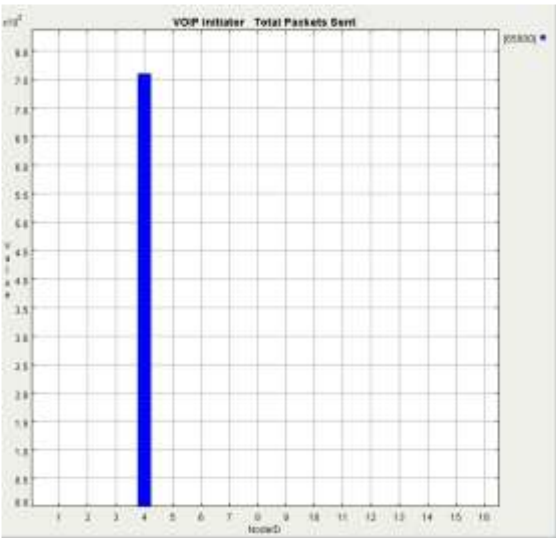

Figure 7. Total packet sent MR-MC

In figure 6 and 7, we compare the results of SR-MC and MR-MC. We measured that the number of packets sent in SR-MC at node id (4) is 27ms. Again we can observe that MR-MC achieves best performance, as the resulting number of packet sent is increased by 76ms.

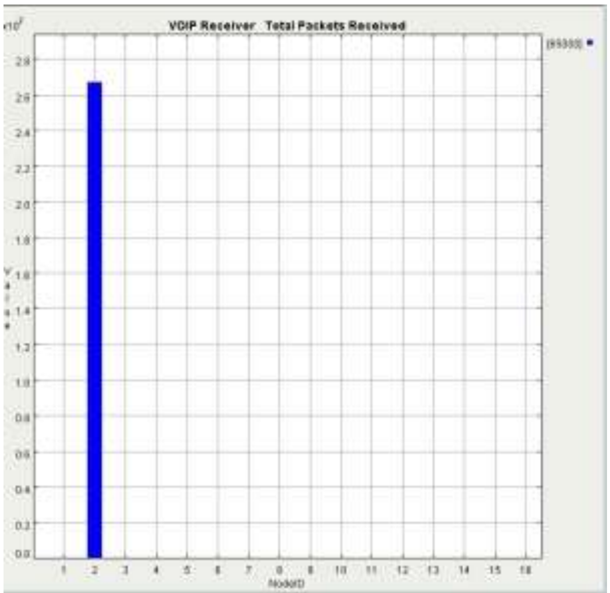

Figure 8. Total packet received SR-MC

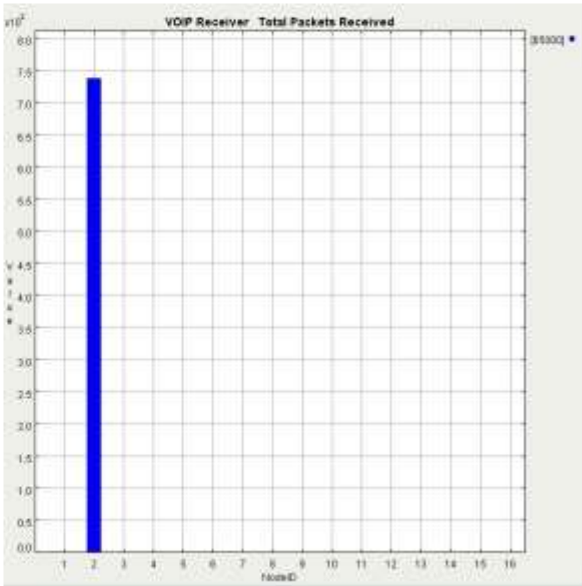

Figure 9. Total packet received MR-MC

In figure 8 and 9, we observed that the number of packet received in SR-MC at node id (2) is 27ms. But in case of MR-MC, the number of packet received ratio is increased by 74ms.

Evaluation of Mean Opinion Score

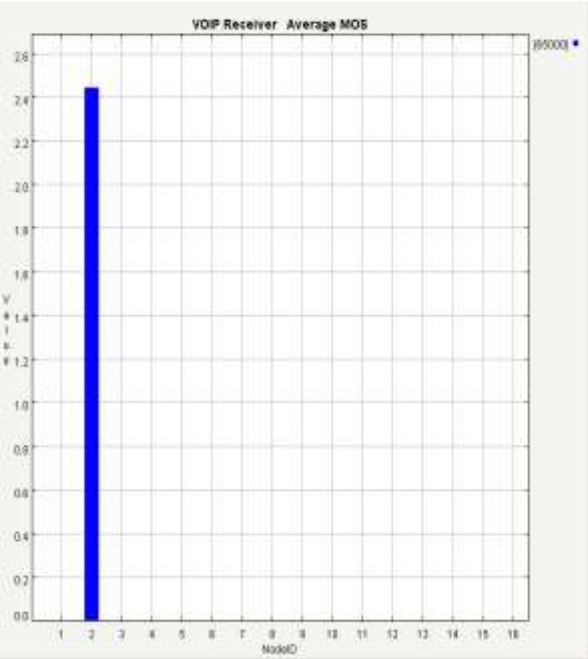

Figure 10. VoIP receiver MOS SR-MC

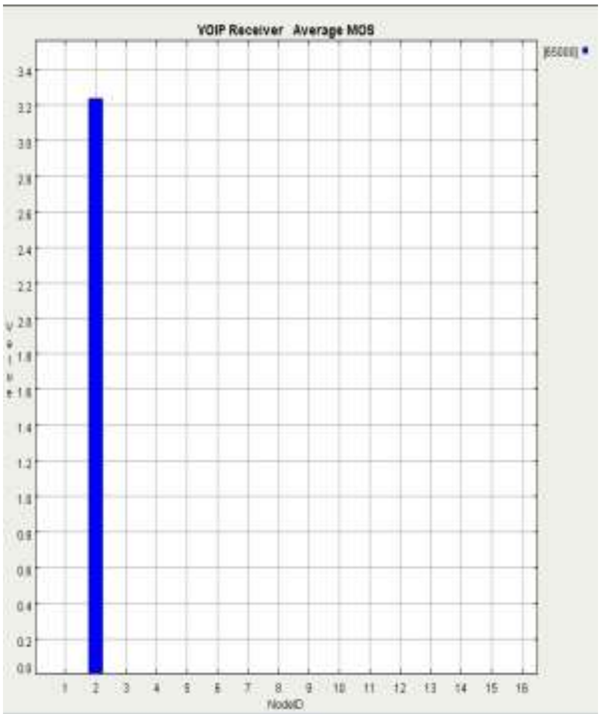

Figure 11. VOIP Receiver MOS MR-MC

In figure 10 and 11, we observed that the value of MOS at node id (2) in SR-MC is 2.5. And again we calculate the value at same node in MR-MC, it will be 3.3.

Evaluation of One Way Delay

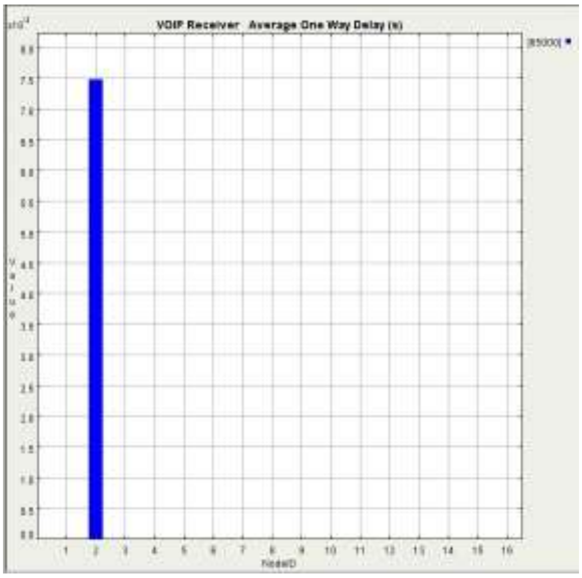

Figure 12. One way delay SR-MC

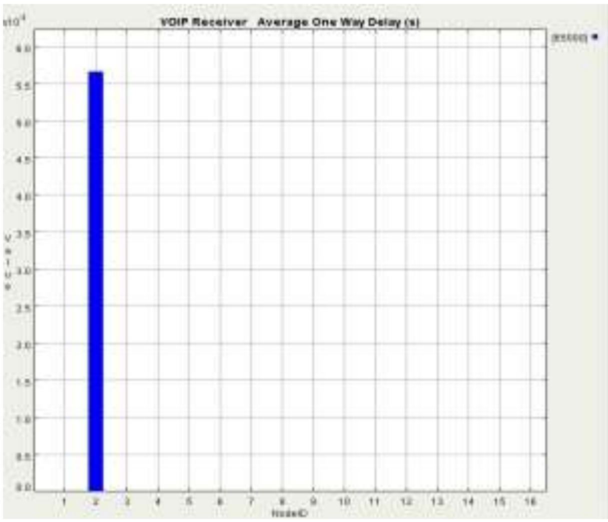

Figure 13. One way delay MR-MC

In figure12 and 13, we showed that the packet delay measured for node id (2) in SR-MC is increased by 75ms. Again we observed that the packet delay measured for the same in MR-MC is decreased by 56ms.

5. Conclusion

With the increasing demand of wireless technologies, the MR-MC architecture has been adopted as a better solution. To fully exploit its advantages on improved network performance, new design and operation challenges need to be dealt with. In this article, we presents a study of real time voice communication QOS in terms of throughput, packet loss, MOS (mean opinion score) and end to end delay. Instead of using single radio schemes, we use multiple radios (interfaces) to increase bandwidth, capacity and decrease interference. We have also implement and compare the results of single-radio and multi-radio WMNs by using QUALNET simulator. We investigated that the result of these parameters are better in MR-MC as compare to SR-MC. The proposed framework can be extended with more research.

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