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Qos Based Joint Channel Assignment and Routing in Wireless Mesh Networks

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Abstract: In this paper, channel assignment and routing problems have been investigated for Wireless Mesh Networks (WMNs). A dynamic and distributed channel assignment protocol has been proposed which generates the network topologies ensuring less interference and better connectivity. The proposed channel assignment protocol is capable of detecting the node failures and mobility in an efficient manner where the channel monitoring module precisely records quality of bi-directional links in terms of link delays. In addition, a Quality of Service based Multi-Radio Ad-hoc On Demand Distance Vector (QMR-AODV) routing protocol has been devised. QMR-AODV is multi-radio compatible and provides delay guarantees on end-to-end paths. The inherited problem of AODV's network wide flooding has been solved by selectively forwarding the routing queries on specified interfaces. Simulation results show that the QoS based delay routing metric, combined with the selective route request forwarding, reduces the routing overhead from 24% up to 36% and produces 40.4% to 55.89% less network delays for traffic profiles of 10 to 60 flows, respectively.

Key words: Wireless Mesh Networks · Multi-Radio Multi-Channel · Quality of Service · Routing

INTRODUCTION

Wireless Mesh Networks (WMNs) [1-4], a key technology in the wireless access, have emerged recently to provide on the go connectivity to the end users. WMNs are dynamic multi-hope networks having the self-organization and self-configuration capabilities. Conceptually, WMNs have been evolved from Mobile Ad-hoc Networks (MANETs) [2] and thus inherit the forwarding and self-configuration capabilities from there. WMNs consist of two main components,*i.e.*, Mesh Points (MPs) and Mesh Clients (MCs). While MPs are the wireless routers interconnected to one another in a multi-hop fashion to form what is called the mesh backbone, end users MCs typically consist of the client machines accessing the Internet through the mesh backbone with wired or wireless medium. Depending on the location and functionalities of MPs in WMNs, they are further divided into three categories [2]. Those mesh routers which give connectivity to the end users are called Mesh Access Points (MAPs) and are usually located at the user premises while the mesh routers inside WMNs backbone, which are responsible for forwarding the MCs data to/from the Internet, are called Mesh Points (MPs). There are some backbone routers, called Gateways, which provide connectivity between WMNs backhaul and the Internet through wired medium. WMNs are a promising technology to provide broadband wireless connectivity in the user premises [5] due to their rich resources and fixed wireless routers, having stable power supplies. The multi-hop capability results in a scalable solution for otherwise limited ranged networks. These networks are highly resilient as failure of some nodes has no effect on the connectivity of end users and overall network at large. The always connected and robustnature of WMNs qualifies it to be deployed as future broadband wireless solution in the user premises. Due to the advantages of WMNs, IEEE has established subgroups to include mesh capability in their existing standards like IEEE 802.11s for Wireless Local Area Networks (WLANs), IEEE 802.15.5 for Wireless Personnel Area Networks (WPANs) and IEEE 802.16e for Wireless Metropolitan

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Area Networks (WMANs) [6, 7]. Many commercial products are also available in market for the deployment [8, 9] and vendors like Motorola, Nokia and Mesh Dynamics have implemented practical WMNs topologies [10-12]. The work presented in this paper is related to the IEEE 802.11 based WMNs.The Multiple-Radio capability and their assignment to multiple non-overlapping channels, makes WMNs as one of the prime candidate to be deployed as the future wireless broadband access technology. However, WMNs are facing the same inherited problems of capacity limitations and interference being in the category of multi-hop wireless networks. First, the multi-hop nature of its routers put an upper bound on the end-to-end data rate achievements. Secondly, the interference phenomenon needs to be earnestlyaddressed while developing any protocol for such types of networks. Support for providing the Quality of Service (QoS) to the recent broadband applications like Voice over IP (VoIP), Video Conferencing and Online Gamming is one of the essential requirements from the access technologies. These QoS in the form of delays and bandwidth must not be compromised and should be guaranteed for the smooth functioning of the network. If channel assignment is one of the deterministic parameter in improving the capacity of the network by minimizing the interference and providing communication parallelism among the multiple radios of the neighbouring nodes, routing, on the other hand, plays an equally important role by providing the guaranteed end-to-end path selection based on some required metric. Both these issues are interdependent and hence affect each other. This paper addresses the joint routing and channel assignment problem for the WMNs, where the channel assignment scheme tries to minimize the interference of the network while ensuring the connectivity. Routing, on the other hand, provides an end-to -end guaranteed path based on the end users' delay requirements. A MANET routing protocol, called Ad-hoc On Demand Distance Vector (AODV) [13], has been extended to make it Multi-Radio Multi-Channel (MRMC) compatible and to provide an end-to-end path to the end users ensuring the maximum tolerable delays guarantees. The decision of end-to-end route selection between a pair of source-destination nodes is taken based on the end users requirements and the match of each individual link capabilities. Experimental results show that the proposed scheme achieves low network latency, high throughput and low routing overheads in the network. The rest of our paper is organized as follows. Section 2 provides the literature review relevant to our work. Section 3 presents the system model. Section 4 presents the proposed channel assignment and routing protocols. In section 5, we present the evaluation of the proposed scheme while section 6 concludes the paper.

Related Work: Channel assignment has been studied widely for cellular communication systems [14], where various schemes have been proposed. With the emergence of WMNs and its capability of supporting multiple radios at its routers, MRMC has been a hot research topic since 2004. Since a MRMC scheme affects the network interference level, connectivity, scalability, throughput, routing, latency and fairness, therefore, considerable research has been conducted in this area for the last few years. Similarly, routing and MRMC assignment are studied as a combined problem in various studies. The centralized channel assignment problem based on graph theory has been studied by [15-18], where network topology has been considered as a graph G (V, E) [19] where V and E, the set of vertices and edges in graph, show the set of nodes and links of the wireless network interconnecting these nodes respectively. Marina *et al*. [15] proposed an algorithm which assigns channels to nodes according to priority by applying the depth-first searching technique over the network graph. Their proposed algorithm has the disadvantage of being greedy in some aspects and fairness in channel assignment is compromised. Tang *et al*. [16] further extended the work of [15] by including weights in the link matrix of the network topology, thus capturing the interference in some way. The main requirement of this scheme is an equal number of radios on each node and it provides strong connectivity than [15]. In [17], the authors have formulated channel assignment as coloring the conflict graph with the aim of minimizing the total interference in the whole network. In [18], the authors modeled MRMC problem as Multi-Radio Conflict Graph (MR-CG) for the first time, to truly capture the multi-radio concept in graph theoretical analysis. Their formulation has two main objectives*, i.e.*, calculation of interference inside the backbone (internal interference) and external interference from the sources outside the network. A set of other centralized schemes formulate the channel assignment problem based on the network flows [20-22]. In all these approaches, the network flow, in the form of end-to-end or on each link, is assumed to be known to the channel assignment algorithm in advance. This global link load information is further fed to the centralized scheme for channel assignment. Raniwala *et al*. [20] considered a centralized load aware channel assignment with routing in MRMC WMNs. They have solved the channel assignment problem first followed by routing with a greedy heuristic. Their centralized algorithm first measures the flow on each link by using heuristics and then assign channels accordingly, taking gateways of the WMNs as the starting reference point. Kodialam *et al*. [21] have solved channel assignment in WMNs by considering it as a joint problem with routing and scheduling. The authors in [22] solved flow based channel assignment along with routing as a joint problem by using the concept from linear programming. All the flow based centralized channel assignment schemes assume a constant traffic flow which is not always the case in bursty or un-predictable networks. Further, the basic flaw associated with the centralized schemes is the failure of the central operation point responsible for channel assignment, which could lead to the whole system's standstill. In distributed algorithms, the pioneering work of Raniwala *et al*. [23] solves channel assignment and routing as a combined problem. They have proposed a WMNs architecture called "Hyacinth", which assumes the presence of gateway/gateways in the WMNs backbone. The solution provided is gateway centric and the merit of this scheme is it's adaptation to the varying load inside the network. This scheme performs routing in the first stage followed by the channel assignment. The channel assignment is guided by the routing, where load on each link is measured and channels are assigned accordingly. The architecture presents a parent-child relationship among the nodes of WMNs. Gateways are considered as the initial root/parent of all the other nodes in the network and this relationship goes down till the MAPs. Only the parents can assign channels to the downward children nodes. The disadvantage of this scheme is the long time it takes to assign channels to the new nodes which join the network. The second drawback in this work is the parent-child relationship in the nodes of the network. If a parent node in the network fails, all the children are isolated from the mesh topology. Das *et al*. [24] proposed DMesh, where the authors have suggested the use of directional antennas. Their solution is identical to that of [23], inheriting the same parent-child relationship during the channel assignment. The limitation of this scheme is the manual setup of directional antennas in a specific focus during deployment and this setup is unchangeable. The work of Xing *et al*. [25] is based on the superimposed codes theory, where the channels are assigned to nodes in distributed manner. Each node computes the superimposed code and assigns channels to the interfaces according to its own interference constraint. The limitation of this scheme is its scalability, which is constrained by the number of nodes in the network. To further improve their mechanism, the authors have proposed partition of the whole network into different cells. In [26], the authors have proposed a joint channel allocation and congestion control mechanisms. In [27], the authors have addressed topology control and channel assignment. At the network start up, the network nodes are grouped together in clusters and the channel assignment is run in the next phase. The intra-cluster connectivity is provided by a default common channel. Kyasanur and Vaidya [28] have proposed channel assignment based on the probabilistic usage of each channel by each radio. They divide the whole set of radios into two groups *i.e.,* static/non-switchable and dynamic/switchable. Their channel assignment algorithm switches the static radios only at periodic manner while the dynamic radios are switched from one channel to another with the variation of traffic demand. Joint routing and channel assignment algorithms have been studied in [20-23, 29-31], where both problems have been solved together. Although, QoS has not been considered explicitly as a source- destination performance measure in their design, all these studies try to provide a solution having minimum interference in the network or high throughput and high connectivity. In [20, 23], the authors have addressed the problem by considering routing first and in second phase assign channels iteratively to the links based on the network load information. The authors in [30] have solved the routing and channel assignment problem by splitting the large optimization problem into small manageable sub-problems. The feasible solution is obtained after independently solving the sub-problems and splitting the flows at different paths while minimizing the interference. Their solution obtains the load balancing across the mesh backhaul routes. Rad *et al*. [31] have solved the joint routing and channel assignment problem by considering it as a linear mixed integer problem and cross layer information is used to compute the routes and assign channels to the paths accordingly. All the above cited research has tackled the QoS indirectly by considering the flow information. However, no bounds for the QoS parameter have been considered in their work as for as the end-to-end applications demands are concerned.

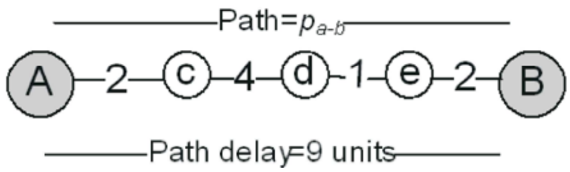

Fig. 1: End-to-end path delay example

The problem of QoS based routing for MANETs has been considered by [32-34], where routing is performed without channel assignment. Each approach has devised specific route metric for the selection of best end-to-end path. For designing the routing metrics for WMNs, Campista *et al*. [35] have discussed the key performance parameters.

A QoS based routing and channel assignment scheme is proposed by Bakhshi *et al*. [36], where the authors perform routing in the network according to their pre-defined routing metric and then assign channels according to the end users demands. Their provided solution is dynamic but centralized.

In this paper, we propose a dynamic and distributed QoS based routing and channel assignment scheme in MRMC WMNs keeping in view the end users demands. To the best of our knowledge, all the studies till now have ignored the mobility of the backbone WMNs routers by considering them as always static. Further, the channel assignment scheme presented in this chapter captures the mobility of the WMNs backbone routers and efficiently re-assigns channels to them at their new locations.

System Model: An infrastructure based hierarchicalWMN is considered where Mesh Clients, consisting of end users, access the Internet via Mesh Backbone. There is always some data at the Mesh Clients or at the server connected to the gateways, which have some QoS demands in terms of end-to-end network delays. The application scenarios of WMNs are always in the form of data travelling to or from the Mesh Clients towards the gateways. This means that the QoS provided on an end-to-end path must be bi-directional. For instance, consider the example given in Figure 1, where node A wants to send some data to node Bon path P_{a-b}. Let α_{a-b} be the maximum delay node A's data can tolerate, on-end-to end path P_{a-b}, where the total path delay is the cumulative delays of individual links. If α_{a-b}>=9 units, the path is feasible for the said application. However, delays on bi-directional links are not the same from both sides. For example, it is possible that node A`s data experiences one type of delay while sending it to node c; on the opposite, c might experience different delay when sending some data to node A on the same link.

Generally, for a path P_{a-b} in the multi-hop network, the end-to-end delay is given by:

$$Path_{Delay} = \sum_{i=1}^{|l|} l^i delay \quad (1)$$

where l^i_{delay} in the Equation (1) is the delay associated with the i^{th} link across the path.

Let S={S_1,S_2,S_3,....., $S_{|S|}$} be the set of source nodes requesting for some delay sensitive data like a request from the network to find a route to a video conferencing application or a VoIP server. Let D= {D_1, D_2, D_3, ..., $D_{|D|}$} be the set of destination nodes in the network. In the case of WMNs, the (S_i, D_i) is always the (end user nodes, gateways) or (gateways, end user nodes). Let each (S_i, D_i) have some data to send across the WMNs backbone through a path $P_{S-D}$with the some delay constraint. Since WMNs consist of multi-hop routers spreading across multiple collision domains and each router is equipped with multiple radios deployed to multiple channels, therefore, there are multiple possible routes for this data to transport from the source to the destination. The routing function is to select such a route across these multiple collision domains so that the delay constraint imposed by the (source, destination) is satisfied.

A channel assignment scheme based on minimum interference is proposed to achieve the above objective. Secondly, a reactive routing protocol is extended for MRMC WMNs which achieves the minimum requirements set by the end users applications. Both routing and channel assignment are inter-dependent because a certain channel assignment strategy affects the routing decisions on each node whereas the load due to the already established connections by the routing decisions can trigger the channel re-assignment.

QoS based Channel Assignment and Routing: We consider an 802.11 based WMNs, where each mesh router is equipped with *K* multiple radios/IEEE 802.11 compatible network interfaces. The topology of the network is considered relatively static and only a few routers are able to move in the whole network. Multiple orthogonal channels, *C*, (12 or 3) are available to each node as according to the IEEE 8021.11 a/b/g standards. All the routers, afterwards called nodes, have equal transmission capabilities. This means that all the radios of the nodes belong to the same technology *i.e.,* either IEEE 802.11a or

IEEE 802.11 b/g. Similarly all the radios have the same transmission and interference ranges as defined in these standards. A node can assign only one radio to a specific channel. This is necessary because assigning the same channel to two different radios of a specific node causes co-channel interference [37]. The aim of the channel assignment scheme is to assign channels from the channel set *C* to each link connecting two radios of a pair of nodes in the mesh backbone such that the interference is minimized.

Channel Assignment: We follow the protocol model [38] for developing the proposed channel assignment and routing scheme. The channel assignment model consists of the following sub-modules, where the interference is minimized using a similar concept as in [25].

- Initialization and channel assignment
- Channel/link Assessment and Neighbors Monitoring
- Channel Re-Assignment

Initialization and Channel Assignment: This module assigns multiple non-overlapping channels from the set C to the multiple radios set K of the nodes. The aim of channel assignment is to produce a network topology inside the WMNs backbone so that each link gets a channel causing minimum interference and the backbone is highly connected. In this work, it is assumed for simulation purposes that the channel assignment process is initiated at the gateways. Our assumption is based on one of the basic characteristic of WMNs data traffic which travels from MAPs all the way towards the gateways. This assumption is made in all gateways oriented channel assignment protocols [20, 23, 24]. However, the algorithm is flexible enough that the starting point can be any mesh router in the mesh backbone. It is assumed that there is no prior channel assignment inside the backbone and all the radios of all nodes listen to arbitrary channels for broadcast messages. Broadcast messages are special type of messages as defined in IEEE 802.11 standard, where the destination address is set to all 1's. Any node *N* in the WMNs backbone can initiate the channel assignment process by sending a special channel assignment request in the form of CH_{Req} frame. The first field of this frame is set to broadcast address so that all the neighboring nodes listen to it. The second field is the MAC address of source node which initiated the CH_{Req} frame. The third field is the Request Type which shows the type of the frame used in the proposed channel assignment protocol. Six types of frames are used in the proposed model. CH_{Req}, CH_{Reply}, CH_{Usage}, $CH_{UsageReply}$, CH_{Ack} and *Hello*, each having its own code in the Channel Type field, as shown in Figure 2. The fourth field of CH_{Req} is 4 bits long showing the number of channels available to the system. Four bits are sufficient to cover all the non-overlapping channels in the IEEE 802.11 standards. However, the fourth field of the $CH_{UsageReply}$ packet consists of 26 bits, where each two bits are used to show the usage of a channel by the replying node. Upon listening the CH_{Req} broadcast, all the neighboring nodes reply with a CH_{Reply} frame in a unicast manner, setting those channel fields where this node has assigned its radios before, with the value of 1, if no prior channel is assigned by the replying node, this field is set to zero accordingly. CH_{Reply} frame has exactly the same fields as that of CH_{Req} but with the last field having 26 bits as shown in the Figure 2. Each 2 consecutive bits in the last filed of CH_{Req} represents the number of channels the replying node maintains in its Neighboring Channel Usage (NCU) table. Upon receiving the CH_{Reply} frame, the initiating node *N* assigns channels to its radios according to the following rules:

- Assign among those channels which are not already been assigned to one of the initiating node own radios. This is necessary to avoid the co-channel interference on the initiating node.
- Assign a channel to each interface while applying rule 1 in neighbors prospective. This will ensure to avoid the co-channel interference on the neighboring nodes. For this, initiating node looks at the channels already been assigned by the sending nodes to their interfaces.
- Initiating node *N* assigns those channels to the interfaces which cause least interference to it by looking at the Neighbor's Channel Usage (NCU) list.
- If all channels under consideration cause same level of interference to initiating node *N*, send a unicast message to each neighboring node requesting for their NCU lists. Assign channels to each specific interface, causing least interference to the specific neighboring node.
- If neighboring nodes NCUs have a tie, assign channels to each interface arbitrarily keeping rules 1 and 2 in view.

An example channel assignment is shown in the Figure 3. Five non-overlapping channels are available to the system and node 'a' initiates the channel assignment process by broadcasting the CH_{Req} frame to all of it

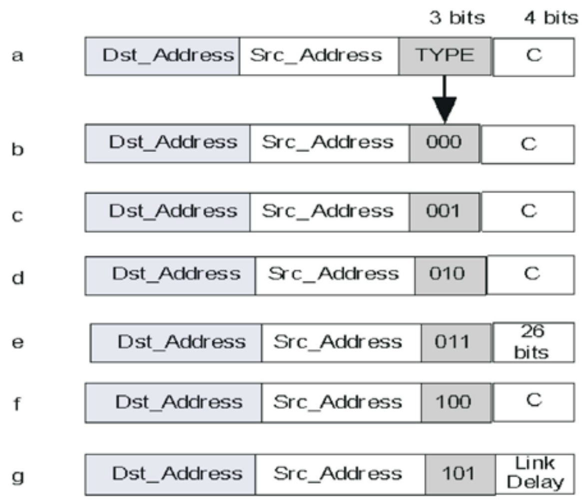

Fig. 2: (a) Generic MRMC frame type (b) CH_{Req} (c) CH_{Reply} (d) CH_{Usage} (e) $CH_{UsageReply}$ (f) CH_{Ack} (g) Hello Message

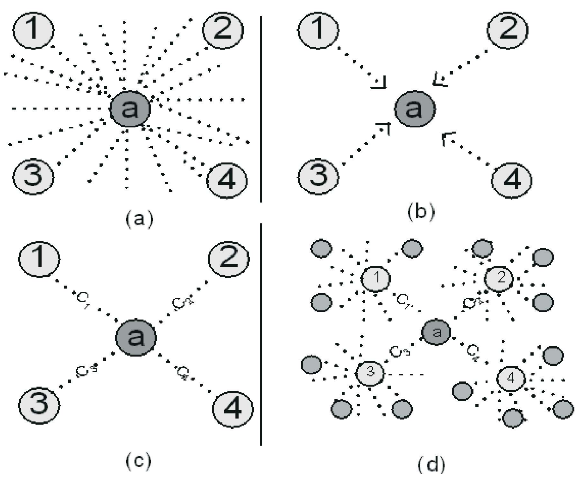

Fig. 3: An example channel assignment

neighbors nodes 1, 2, 3 and 4, as shown in the Figure 3(a). When these nodes receive the CH_{Req} frame (Figure 3(b)), each unicasts the CH_{Reply} frame to the initiating node, on the channel on which it has received the CH_{Req} broadcast. In the Figure 3(c), node ‘a’ assigns channels to its neighbors according to rules 1-5 mentioned earlier. Those nodes upon channel assignment to at least one of their interfaces, repeat the process for their neighbors, as shown in the Figure 3(d).

Each node keeps the record of channel usage in two separate tables. The first one is of its own interfaces and the channels assigned to each. This table, called the Channel Usage Table, contains the information of each interface of the current node *N*, channels assigned to each interface and the MAC addresses of other neighboring nodes to which this current node *N* is connected through these specific interfaces. Table 1 shows the Channel Usage Table for a node *N* where the first column in the table shows the interfaces/radios $\{inf_1, inf_2, \ldots, inf_n\}$ of the node N. The second column shows the MAC addresses of the neighboring nodes to which it is connected through its interface (inf_i) in the corresponding previous column. The next column shows which channel is used by the node N for its connection to the corresponding neighboring node. The second table is called Neighboring Channel Usage (NCU) table. As shown in the Table 2, the table shows node *N*’s NCU for all its neighbors and their channels they have assigned to their interfaces. First column shows the node number/MAC address and the corresponding columns show the channel usage of each neighboring node on each channel. The rank of a channel is calculated by the node *N* as the number of interfaces assigned to *C* by all its neighbors, accordingly. Information required for rule 1 is available to node *N* from its own Channel Usage Table. For rule 2, the initiating node gets the information from the NCU to avoid the co-channel interference on the neighboring nodes. The information in NCU is also used to calculate the rank of each channel usage by node *N* in its neighborhood and it selects a channel according to rule 3 causing least interference to node *N*.

If all the channels are of the same rank, it means that all cause the same level of interference to the initiating node *N* and therefore it sends a CH_{Usage} frame to each neighbor and requests their NCUs. All neighboring nodes reply with a $CH_{UsageReply}$ frame containing theirs NCUs ranks for each channel. The channels are assigned to each interface according to the ranks of each channel in the neighboring node’s NCUs. This last step reduces the chances of interference for the neighbor nodes.

Once the initiating node *N* assigns channels to all of its interfaces, it sends the last frame called CH_{Ack} to all its neighbors which contain the channel usage of the current node *N*. All the neighboring nodes update their NCUs for the initiating node *N*, accordingly. All the neighbors of the initiating node *N*further repeat the above procedure to assign channels to their remaining interfaces in stages. This process continues till all the nodes in the network have assigned channels to all of their interfaces. The proposed algorithm can be initiated by any node of the WMNs network and multiple nodes can start the same process simultaneously. Once a node *N* has assigned channels to all its interfaces, it does not listen to further broadcast CH_{Req} frames. The channel re-assignment is

Table 1: An example Channel Usage Table

Node MAC	Neighbors /MAC	Ch_1	Ch_2	Ch_3	……	Ch_n
Inf_1	1	1	0	0	…..	0
Inf_2	2	0	1	0	…..	0
…	…	…	….	….	…	…
inf_n	x	0	0	0	….	1

Table 2: An example Neighbouring Channel Usage (NCU) table at node N for all its neighbours {1, 2, 3…, x}

Node/MAC	Ch_1	Ch_2	Ch_3	……	Ch_n
1	1	1	0	…..	0
2	0	1	1	…..	0
…	…	….	….	…	…
x	1	0	0	….	1
Channel Rank	2	2	1	…	1

Table 4.1.2: Links Quality State Table on each node

MAC address	$Qav_{length}(bits)$	$\delta_{av}(seconds)$	Tx_{rate}	$\alpha_{av}(Seconds)$
Inf_0	X	Y	Z	a
Inf_1	X	Y	Z	b
--	--	--	--	c
Inf_n	X	Y	Z	e

triggered in two cases. First, if a neighboring node fails and second, if the set routing threshold is not met by all the interfaces of a specific node. This will be explained further in the Section 3.5.4.

Channel Assessment and Neighbours Monitoring: When each node assigns channels to all of its radios/interfaces, they switch to the monitoring state. Monitoring state is the state in which each node frequently monitors the channel usage status of all its interfaces. Each node also monitors the status of all its neighbors, whether they are alive or not, through the exchange of *Hello* messages. The *Hello* messages, as shown in the Figure 2(g), are also used to update the link delay by the nodes they are connected through. This is necessary because the link delay on a bi-directional link is different from both nodes prospective. A greater delay in the *Hello* message replaces the smaller one on both nodes. Monitoring the link status is needed to calculate the metric for the QoS based routing later on, as discussed in the Section 3.5.3, where the decision of selecting an end-to-end path is made based on the individual links quality in the path.

Each node, in the monitoring state, maintains and frequently updates a table called the Channel State Table. This table, as shown in the Table 3, contains information about the quality of the individual bi-directional links between each pair of nodes sharing a common channel and has four parameters *i.e.,* Average Queue Length, Average MAC layer *backoffs*, Transmission rate and Average Lost packets retransmission time. Average Queue Length is the average taken over specific period of time of the MAC layer's queue associated with the interface of a node. This parameter indicates how much a single application layer packet has to wait in the queue of the interface. Average MAC layer *backoff*is the average value taken over specific times for the number of successful transmitted packet. Transmission time/rate is the number of bits a node's interface can transmit over a medium in per unit time. This value depends on the physical layer modulation techniques and the width of frequency called bandwidth. The Lost packet retransmission is the time it takes for retransmission of lost packets in a given number of packets transmitted over a link.

The QoS parameter for the proposed routing protocol is defined in terms of links delays expected to be experienced by a single application packet, when it is routed over the end-to-end path consisting of individual bi-directional links. The delay sensitive applications like video or audio should have an end-to-end delay guarantees from the network. The information provided by the channel monitoring module is available to the network layer as shown in the Figure 4. Delay of an end-to-end path in an 802.11 based WMNs depends on many parameters. Since IEEE 802.11 is a shared wireless medium and even in MRMC there is always a chance that a given channel *C*, assigned to a link connecting two radios, is also assigned to another link in the same transmission or interference ranges. This makes each radio to follow the access mechanism for the wireless medium called Distributed Coordination Function (DCF) in IEEE 802.11

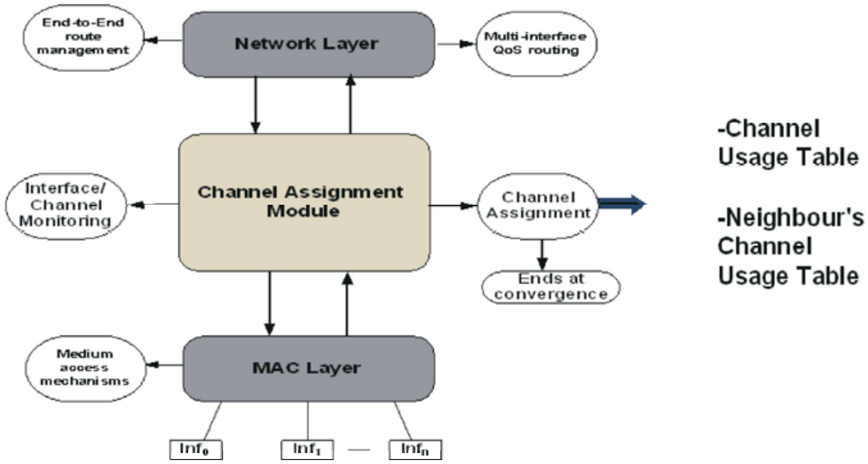

Fig. 4: Cross layer information for link monitoring and routing decisions

literature [39, 40, 41]. The *backoff time* in DCF system, in which a transmitting system goes into the idle state, increases exponentially with each lost frames. Even with DCF arbitration for the shared medium, there is always a chance of losing packets on the wireless medium.

This parameter is captured in terms of packet loss ratio and is accurately calculated. The lost packet ratio is the number of lost packets *x* in a given number of transmitted packets *y*. In IEEE 802.11, those packets are considered lost for which the transmitting MAC does not receive an acknowledgement. Let a node sends *y* number of packets on one of its interface, say inf_0, in which x packets are lost, the expected retransmission time for one lost packet is calculated as:

$$\alpha_{av} = \left(\frac{x/y}{Tx_{rate}} \right) \quad (2)$$

This delay information is captured in the parameter α_{av} and is averaged over time. Similarly, there is a limit on the medium and radio capability to transmit at some bounded rates. Each node calculates this average transmission rate (Txr_{ate}) for each of its link associated with each of its radio and shows the number of bits transmitted over a link per unit time. Transmission rate value is calculated from the link queue. This whole information is fed to the total delay which is supposed to be experienced by a single packet to be considered for forwarding through a specific interface's link.

$$T_{delay} = (\delta_{av} + \partial_{app} * T_{per\_bit} + \alpha_{av}) \quad (3)$$

where T_{per_bit} is calculated as follows:

$$T_{per\_bit} \frac{Q_{av\_length}}{Tx_{rate}} \quad (4)$$

where ∂_{app} in the Equation (3) is the MAC layer frame size in bits and the variable δ_{av} in the Equation (3.3)represents the average *backoff* on the specified interface, where the expected δ_{av} for a single packet is calculated as follows. Let the backoff incurred over a link during m successful transmitted frames be n, then the expected backoff for one packet (δ_{av}) is calculated as:

$$\delta_{av} = \frac{m}{n} seconds \quad (5)$$

The total delay calculation for a single packet is maintained in a separate table associated with each interface of a node. As shown in the Figure 5, node B is connected to node A through interface0 (inf_0) where channel $C_2$is assigned to their shared link. Similarly, it is connected to node C through interface1 (inf_1) with C_1assigned to their common link. The figure shows the delays calculations for each individual links. This delay information is updated in a bi-directional manner through the periodic *Hello* message exchange. If delay *x* milliseconds maintained by node B for B-C link is less than the delay it received from node C for the same link in the periodic *Hello* message, *x* will be replaced with the new delay for the same link. All nodes update this delay information for the bi-directional links in a similar way.

QoS Based Routing: Quality of Service (QoS) is the provisioning of some guarantees by the network to the end users in terms of a set of performance parameters like delay, jitter, band width and packet loss [35].

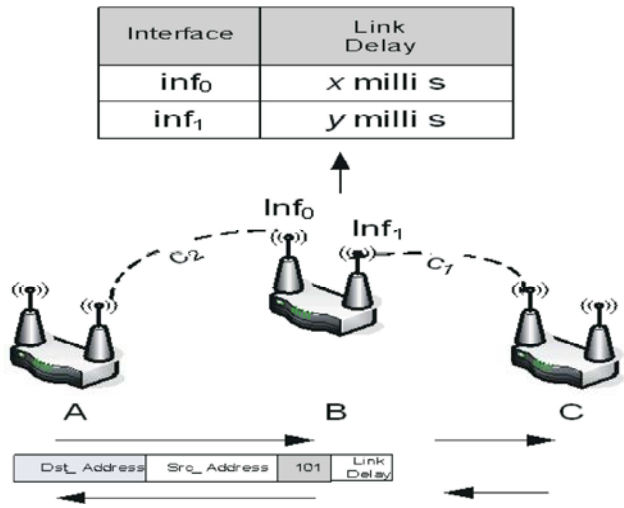

Fig. 5: "Hello" Message exchange for delay updates and neighbour's monitoring

Since routing determines the end-to-end path for each source-destination pair in a network, therefore, it is one of the important design factors to be considered in providing these QoS guarantees to the end users. In MANETs, all the standard routing protocols have explicitly ignored this important issue. Since MANETs are emergency networks and extremely mobile, QoS provision is very difficult task to be achieved on an end-to- end basis. The main factor in deciding the QoS is the routing metric, *i.e.,* the parameter or set of parameters based on which the routing decisions take place. Almost all MANETs routing protocols use minimum hop count as the only metric and the shortest path is considered as the best path. While minimum hop count is a best metric in networks where reach-ability is the only concern, the end users of WMNs put some constraints other than mere reaching to the destination.

QoS of the end users is considered as a prime parameter in the proposed joint routing and channel assignment scheme. The MANETs AODV protocol has been used as a base for developing the routing protocol in the proposed solution. However, AODV has the some shortcomings when used in its original form in the WMNs. First, it is based on network level flooding to forward a route request, thus creating a lot of extra overhead packets. For example, for a network of *N* nodes and for finding a single path between any source and destination, a total of (*N*-1) route request packets are flooded in the entire network as reported in one of our previous work [42]. Second, there is no defined metric for routes selection in the AODV and thus QoS can't be supported explicitly. Although, AODV prefers the shortest paths, but shortest paths can be worst in providing the QoS as compared to the longest ones in the wireless networks. Third, AODV only supports Single-Radio Single-Channel MAC architecture, while WMNs routers are equipped with Multiple-Radios operating on multiple non-overlapping channels.

AODV works as follows. For a pair of Source-Destination (*S, D*), S broadcasts the requests to its neighbours for a route to *D* with RREQ packet. It is on demand in the sense that requests are only sent by the source node, whenever it needs to have connection with the destination for sending some data. All the neighbours of *S* rebroadcast this route request to their neighbours and the process continues until it reaches either the intended destination or an intermediate node, which have updated route to the destination *D*, Destination Sequence Number field along with Destination IP address in the RREQ packet is used in the later case. Intermediate nodes avoid duplicate RREQ reception by dropping them if the Originator IP and RREQ ID of the current message is matched with the one maintained by it for the previous RREQ packet. Upon reaching the destination, a unicast RREP packet is sent back to the neighbouring node through which it received the first RREQ packet. All next RREQs for the same requests are dropped by the destination. Routes in AODV are maintained through route error (RERR) messages. If a source node moves, it reinitiates the route to the destination. If an intermediate node along the path moves, the neighbour nodes notice this and inform sender node of this failure by sending back the RERR message.

A WMNs backbone can be exposed to two types of data as for as its end users are concerned, one which has a bound on some QoS parameters; for example, video and audio applications are extremely delay sensitive and if these requirements are not met, it can severely affect users perception and the quality. The other category of applications which do not need any specific requirements can be considered as best effort as for as the network bandwidth and delay requirements are concerned. Providing of QoS in WMNs is essential as its deployment forecast in the future wireless broadband access technology.

Similarly, we divide the applications for the proposed MRMC routing scheme into two categories. One, which has some bounds on the QoS of end-to-end path and others which is best effort and do not need any services from the underlying network in terms of delays and bandwidth *e.g.,* FTP, HTTP and other delay insensitive applications.

The AODV extension in the proposed solution is called Quality of Service based Multi-Radio Multi-Channel capable AODV (QMR-AODV) [43]. In the simple AODV and Multi-Radio AODV (AODV-MR) [44, 45], the selected end-to-end path does not ensures the QoS requirements and simply establish routes for the requesting users. In the case of AODV-MR, multiple radios are deployed on each node and these radios are tuned to the multiple non-overlapping channels as present in the IEEE 802.11a/b/g standards. When a source,S, needs a route to a destination, D, a RREQ is broadcasted by the source node on all of its interfaces simultaneously. If the RREQ is not a duplicate, each neighbouring node of the source 'S', upon hearing this broadcast, re-broadcasts the RREQ all of its interfaces. This process of broadcasting continues and disseminates in the whole network until the destination is found. It is important to mention that in the case of AODV-MR, those neighbouring nodes which share a common channel hears the broadcast on that channel. Before broadcasting the RREQ, each node maintains the reverse route, which points towards the source node from which this current node has received the RREQ packet. The flooding mechanism, as discussed before, even worsen in AODV-MR as each mesh router now rebroadcasts the RREQ packet on multiple interfaces creating a total of (N-1)x i overhead packets, with an N routers WMNs backbone each having *i* interfaces. Further, there is no QoS provisioning in both these protocols. Generally, the proposed QMR-AODV works as follows: As shown in the Figure 6, when an end user wants to establish a connection with the destination (Gateway), it sends the modified RREQ packet. The modified route request packet has four important fields to be considered by the end users as well as the rely routers. As shown in the Figure 7, first the D flag, it is set by the route requesting node which needs this RREQ to be replied by the destination only. Thus, a RREQ with D flag set will never return a path to destination from an intermediate node. This ensures that a path returned by QAODV-MR will always satisfy the end-to-end requirements of user's applications. The first bit in the reserved field is either set or zero. If this bit is set by the requesting end user, it is an indication for the intermediate nodes that some specific QoS is required by the source node. The last field of modified RREQ packet is divided into two halves, the first half shows the maximum delay an application can tolerate (User's QoS Bounds) for each of its individual packet on end-to-end basis. The RREQ packet initiator node, based on the application requirements, sets this field by putting the appropriate value of maximum delay, which can be tolerated by the end users application on the end-to-end path requested. The second half of this field, Total Path Delay, shows the cumulated delay of the path from the initiating node to this current node so far. Upon receiving the RREQ packet, the intermediate node (and the destination node if that is the case) first checks the Destination IP address in the REEQ packet as shown in the algorithm of Figure 8. If a match is found between the Destination IP and the IP address of the current node, the RREQ is for a path request to this node and a RREP is unicasted to the initiating node.

If the current receiving node is not the destination, then the intermediate node first checks the D flag and the first reserved bit. If both are zero, the request is considered as a normal AODV RREQ and is forwarded over multiple radios/interfaces of the node, as shown in the flowchart of Figure 6. If current node is not the destination, then all the interfaces of this current node are evaluated for providing the required QoS (delay) as requested by the source node as follows.

The intermediate node adds up the delay of bi-directional link associated with the current interface as maintained by the channel monitoring module, discussed in the Section 4.2.1. This updated delay associated with the link/channel assigned to the interface of the node under consideration is added up with last 16 bits field, Total Path Delay and is compared with the User's QoS demanded delay. First, the flooding associated with the AODV-MR [44, 45] is reduced from (N-1)xi to (N-1) in the case if only one interface of all the routers in the path is satisfying the QoS requirements. Another advantage is that by setting the D flag in RREQ packet, only the destination is bound to reply the RREP packet.

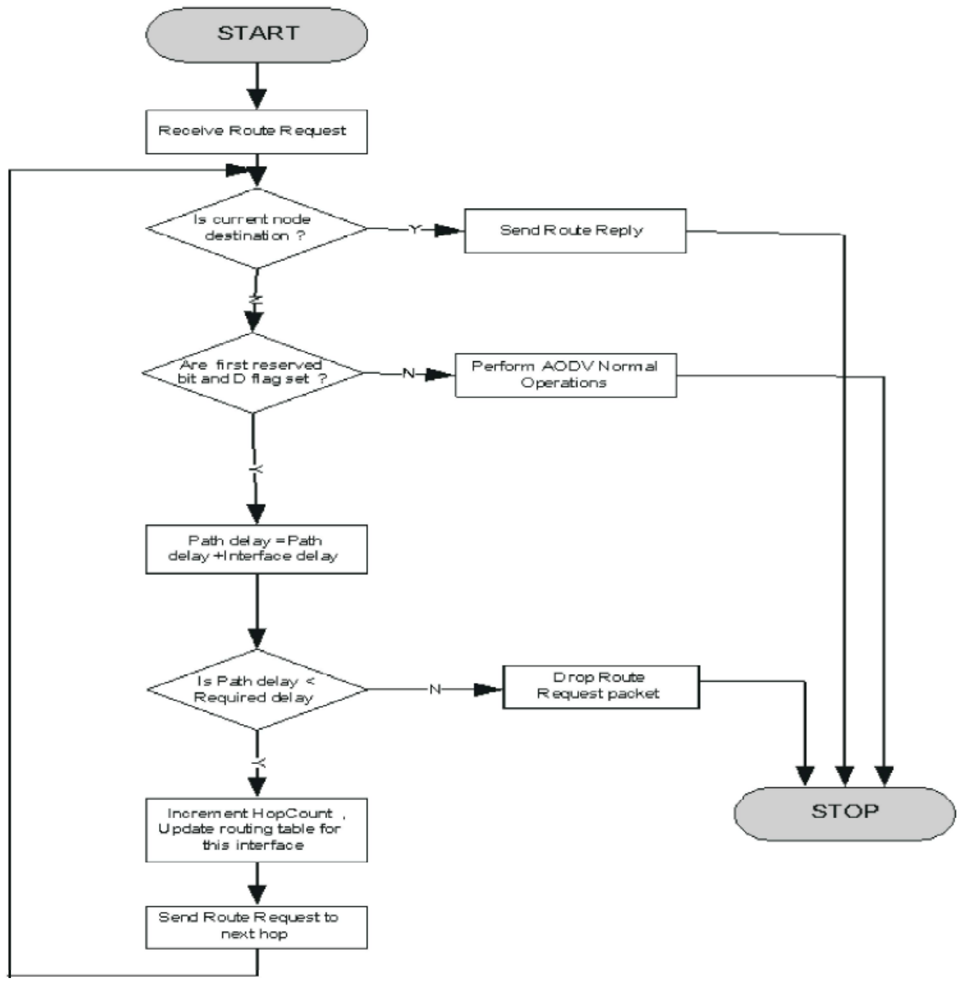

Fig. 6: The modified RREQ flow of function

```
                        Set=1 in RRQ

 -+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|     Type      |J|R|G|D|U|                     |   Hop Count   |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                            RREQ ID                            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                    Destination IP Address                     |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                  Destination Sequence Number                  |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                    Originator IP Address                      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                  Originator Sequence Number                   |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| User's QoS Bounds             | Total Path  Delay             |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Fig. 7: Modified RREQ packet format

This, combined with the QoS value comparison on each node's interface ensures the requested quality of the end-to-end path.

Channel Re-Assignment: Nodes can fail inside the network backbone and this failure can affect the performance of network in terms of connectivity and

```
        foreach node(n) on receiving RREQ packet
                 If RREQ_DEST_IP== NODE_IP      //then this node is the destination
Send RREP
else if (D=0 and Reserved=0)
                 Forward packet through normal AODV-MR/AODV operations
                 else                  // QMR-AODV operations
                        fori=inf_0 to inv_ent
                        Total_Path_Delay=Total_Path_Delay+ inf_i_delay
                              If {Total_Path_Delay≤ User's required delay
                        Hop_Count=Hop_Count+1
                              Send RREQ to next hop
else
                              Drop RREQ for inf_i
end if
nexti
        end if
```

Fig. 8: Algorithm for QoS (delay) based on demand routing

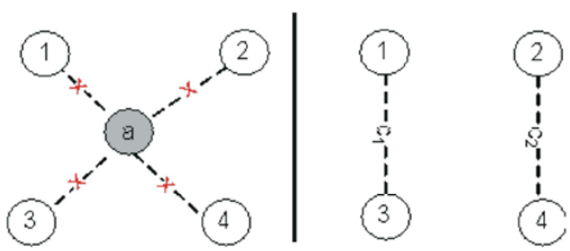

Fig. 9: Nodes failure and channel reassignment

throughput. If a channel assignment scheme is not capable to detect the node's failures, the network nodes can go into isolation. For self-configurable networks like WMNs, node failure should be tackled effectively. In the proposed channel assignment and routing scheme, the channel re-assignment is triggered with three events. First, if a node fails with some or all of its interfaces then this node failure is detected by the Channel Assignment module and channel re-assignment is performed in that locality. Although, WMNs have relatively very static topology and the routers are almost fixed, however, in some cases the routers can be mobile *e.g.,* if the routers are integrated from the Vehicular Network infrastructure inside the WMNs backbone, then mobility can be expected. In this case, a node can move from one location to another one due to mobility. This can impact the topology of the network in terms of connectivity. This information should be captured in an efficient way. Third, there might be some cases that all the interfaces of a certain node are not complying with any of the QoS based RREQ from the end users. This latter case can happen, for example, when the channel assigned to a specific node's link is interfering too much with other links in its range.

If a node fails or moves from one location in the backbone to another location, this failure or movement is detected by the neighbouring nodes through the periodic *Hello* messages. Let suppose a node 'a' fails in the example network shown in the Figure 9, it means that all of its neighbours will not receive the periodic unicast *Hello* messages from node 'a'. This will mean two possible events. Either the node in the vicinity has failed or it has moved to a location which is no longer in the transmission range of its previous neighbouring nodes. This event triggers the channel re-assignment module.

Each neighbouring node, which had a connection with node 'a', will remove the channel assignment information as mentioned in the Tables 1 and 2 of Section 4.1.1. In the next phase, the interface on which the neighbouring nodes were connected to node 'a' are available for channel re-assignment. Each neighbouring node of failed node 'a' broadcasts the CH_{Req} frame on all the channels. Any neighbouring node with an interface unassigned to any channel can reply with the CH_{Reply}unicast message. The channel re-assignment is performed in a similar way as mentioned in the Section 4.1.2.

Similarly, if a node 'a'moves from its current location to some other location inside the network backbone, this event is considered the same as node failure by all its neighbours and channel re-assignment is performed as mentioned for node failure. However, the re-located node, when no longer receiving the periodic *Hello* messages from its neighbouring nodes, realizes of its movement and starts broadcasting CH_{Req} messages on all of its interfaces. If there is any node in its neighbourhood (inside the transmission range) having no channel yet assigned to one of its interface, will reply with the CH_{Reply} unicast message. However, it is possible that at the new location there is no node whose interface is available for this new channel re-assignment.

The channel re-assignment can also be triggered by the routing request service threshold configured on each node. If a node rejects all the QoS based RREQ's on all of its interfaces for a certain threshold number of times, the channel re-assignment module triggers. This, however, is performed by the affected node by sending the CH_{Req} unicast messages to all of its neighbours. The requesting node, upon receiving the CH_{Reply} messages from its neighbours re-assigns channels as according to the channel assignment rules mentioned earlier in the Section 4.1.2.

Simulation Setup and Performance Evaluation: This section presents the performance evaluation of the proposed channel assignment and QMR-AODV routing protocols. Network Simulator-NS2 version 2.34 [46] was used for development and simulation of the proposed model. Four performance metrics, Routing Overhead, Packet Delivery Ratio, Average Network Latency and Response Time, were observed for a set of two different scenarios. Simulation in each scenario was run 20 times each and the average was plotted in each case to build confidence in the observed results.

Routing Overhead: Routing Overhead refers to the number of routing control packets generated inside the network.

Packet Delivery Ratio (PDR): PDR refers to the ratio of the number of packets which succeeded to reach at the destination to those packets which were generated by the end user's applications. *i.e.,*:

$$PDR = \text{Total Received packets}/\text{Total generated packets} \quad (6)$$

Average Network Delay: This parameter refers to the total delay occurred inside the network for the data packets. The latency or delay is measured by calculating the time elapsed between the packet generation at the end user's nodes and when they reach at the destinations.

Average Response Time: Average Response Time is the average of time elapsed between each RREQ and when the source node gets the RREP packet.

Simulation Setup for Delay Sensitive Data: In this scenario, a network of 30 mesh routers was deployed in an area of 1000m x1000m in a grid topology. End users Mesh Clients generate Constant Bit Rate (CBR) UDP traffic with some specific delay constraint for each packet.The performance of the proposed scheme is compared with a Multi-Radio AODV (AODV-MR) [43, 44] scheme and comparative analysis is done. All the simulation parameters are given in the Table 4.

Routing Overhead: As shown in the Figure 10, both the AODV-MR and QMR-AODV produce almost the same number of routing overhead packets at the beginning. The reason is that for less number of flows, QMR-AODV functions the same as the AODV-MR due to less load and hence less congestion in the networks. Effectively, all the interfaces of intermediate nodes are conforming to the QoS delays bounds of RREQs of the end users applications. Furthermore, when the number of flows increases from the end users, the network gets congested and QMR-AODV outperforms AODV-MR by producing less amount of routing overhead. This is because QMR-AODV now forwards the RREQ only on those interfaces of the intermediate nodes which are capable to handle the requested delay. On contrary, with increase in the network load, AODV-MR functions the same by broadcasting each RREQ on all of its interfaces except the one on which it was received. This linear increase in the routing overhead is evident from the Figure 10 for number of flows 30 and onwards. The AODV-MR produces 24% more routing overhead for 30 flows going up to 36.1% for 60 flows, as compared to QMR-AODV.

Average Network Delay: The Average Network Delay of QMR-AODV is compared with AODV-MR for different number of end users generated flows. As shown in the Figure 11, QMR-AODV performs better by producing less latency in the network for all its data packets. The prime reason is the QMR-AODV's route selection mechanism based on the delay condition. While AODV-MR selects any route without QoS guarantees and thus the data is stacked on the congested links inside the network. Secondly, AODV-MR broadcasts RREQ messages on all of its interfaces which creates more congestion inside the network and hence more latency. As depicted by the Figure 11, the Average Network Delay increases for AODV-MR abruptly with the increase in the end user generated flows while QMR-AODV's latency increases very steadily. Overall, the average network delay for AODV-MR increases from 40.4% to 55.89% for traffic profiles 10 flows to 60 flows, comparatively.

Table 4: Simulation Setup

Simulation Parameters	Assigned Values
Topology	Grid
Number of Mesh Routers	30
Number of Interfaces(inf) on each Mesh Router	3
Number of Mesh Clients	45
Medium Access Control (MAC)	IEEE 802.11a
Number of Channels	8
Propagation	TwoRay Ground reflection
Transmission Range	250 meters
Max Interface Queue length	50
Routing Protocols	AODV-MR, QMR-AODV
Mobility Model	None(Static)
Number of flows	Varies (10 to 60)
Packet Size	1000 bytes
Packet generation rate	128 kbps per flow
Simulation time	600 Seconds
Topology covered area	1000x1000 meters

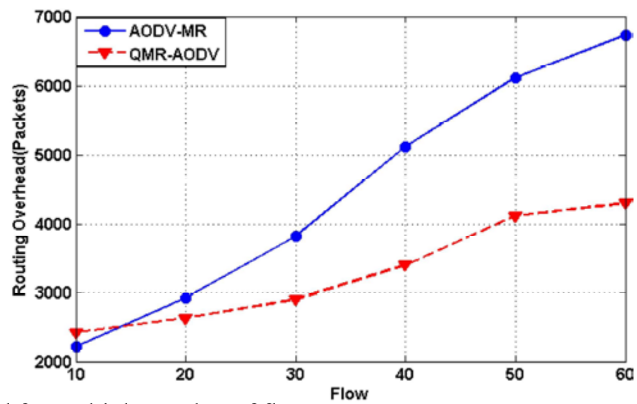

Fig. 10: Routing Overhead for multiple number of flows

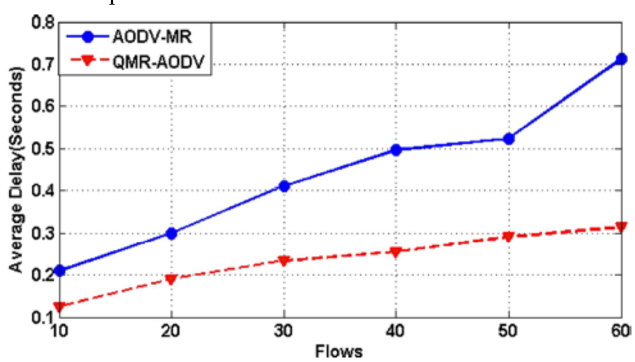

Fig. 11: Average Network Delay for multiple number of flows

Packet Delivery Ratio (PDR): PDR is an important performance measure of any routing protocol and indicates its significance in terms of achieved throughput on end-to-end paths. As shown in the Figure 12, both protocols perform equally at lower generated flows, where their PDR is almost equal to 100 percent. However, when the number of users flows increases, the PDR starts dropping for AODV-MR. AODV-MR produces more routing overhead causing more network congestions and collisions. Secondly, it selects whatever path is available and thus the end node's data is either lost due to queue overflows or due to collisions on the links. On the other hand, QMR-AODV selects paths with the delay guarantees and unicasts the RREQ packets on specific interfaces. This reduces the overhead inside the network leading to less collisions and congestions. Each end node data gets a confirmed service in terms of delays on end-to-end path and thus less data is lost during the

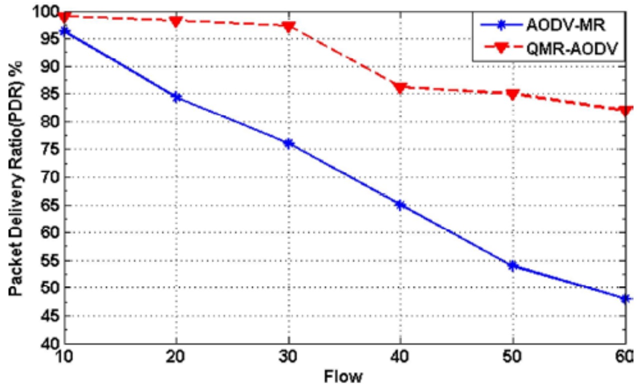

Fig. 12: Packet Delivery Ratio (%) for multiple number of flows

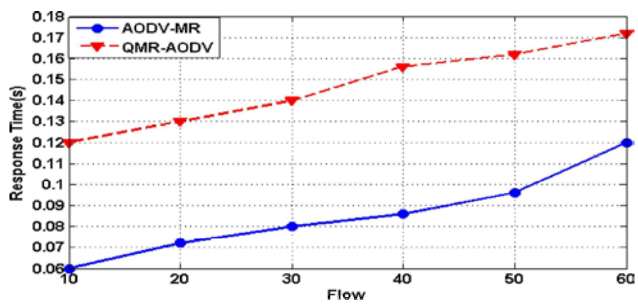

Fig. 13: Average Response Time of the routing protocols

communication. Overall, QMR-AODV performs better to carry upto 70% more data on extremely congested network as compared to AODV-MR.

Average Response Time: The Average Response Times of both protocols is measured by taking the average of the time elapsed between all RREQs and their returned RREPs at the source nodes, for different number of flows. The Average Response Time is given by:

$$R_t = P_t + N_d \quad (7)$$

where R_t is the total average response time, P_t is the average processing time each RREQ and RREP packets takes for it's operation for determining the end-to-end route from source to destination and N_d is the delay associated with the network.

As shown in the Figure 13, AODV-MR's has a better response time for low as well as high traffic profiles. The reason is that each QMR-AODV's RREQ packet is assessed for delay requirements and the interface compatibility. This takes extra processing time for RREQ to reach at the destination. On the contrary, AODV-MR's RREQ packets are only processed at the intermediate nodes for the routing information and then broadcasted on all the interfaces. This reduces the end to end latency for the RREQ-RREP cycle between the source and destination nodes. Second, AODV-MR's RREQ might return a path for the source node's RREQ from the intermediate nodes and thus extremely decreasing the response time.

Simulation Setup for Varying Number of Radios: In this scenario, the number of radios/interfaces per node was incremented from 2 to 8 in step 1. Each time, the average delay and routing overhead was measured based on an average of 20 simulation runs. Number of flows generated by the end nodes was kept 30. All the remaining parameters were kept as according to the Table 4. IEEE 802.11a was used as the underlying MAC as in the Section 5.1.

Figure 14 shows the effect of varying the number of nodes interfaces on the routing overhead. When the number of radios/interfaces on each node is 2, the Routing overhead is almost equal for both AODV-MR and QMR-AODV. This is because both are using one interface for reception and the other one for transmitting the data. In this case, QMR-AODV only unicasts the RREQ packet to its next hop neighbour when the interface is capable of meeting the delay requirements. AODV-MR broadcasts the RREQ packet as it arrives only on the second interface. Since in a two interfaced nodes, the possibly of collision is minor keeping in view the number of channels available in IEEE 802.11a and hence both performs equal.

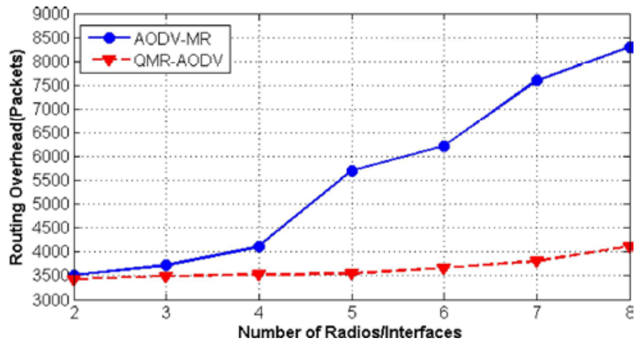

Fig. 14: Routing Overhead with varying number of network interfaces/radios

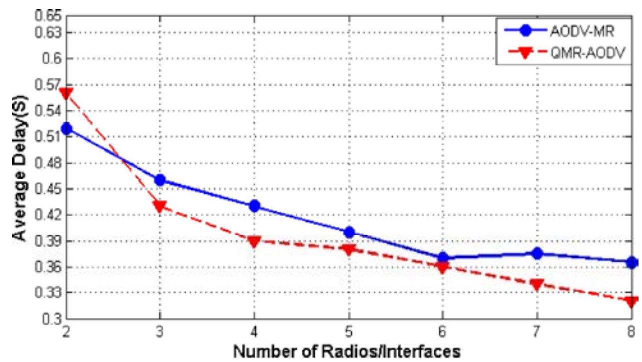

Fig. 15: Average Delay with varying number of network interfaces/radios

However, when the number of radios on each node is increased to 4, an abrupt change in the routing overhead is observed for AODV-MR. This is because the RREQ is now broadcasted on all the interfaces causing more routing overhead. On the opposite, a very small increase in the QMR-AODV's routing overhead is observed with varying the number of radios per node. The reason is that QMR-AODV's selective forwarding of the RREQ messages to its next hop neighbours which effectively reduces the number of RREQ diffusion in the network. The Figure 14 also shows a linear increase in the routing overhead for AODV-MR from 6 to 8 radios case. This means that AODV-MR fails to work efficiently with large number of interfaces per node.

Figure 15, shows the Average Delay experienced by all the packets inside the network comparatively with varying the number of radios per node. The average delay is high for both protocols when the number of interfaces is 2, where AODV-MR does better with less average delay as compared to QMR-AODV. The reason for high delay with less number of radios for both the protocols is that the network is less connected with fewer radios per node. More interfaces per node means more connectivity and more routes to the destination. It also means that with more radios per node, more parallel communication links and load distribution is achieved. With fewer interfaces per node, each link is congested with the high amount of data from the end users, which leads to congestion and network latency. For 2 interfaces per node, AODV-MR performs better than QMR-AODV because of the possibility of the latter to drop a RREQ from transmitting to the next node based on the non-compliance with the QoS requirements. Thus, those RREQs packets, which never get RREPs, are re-sent by the end source nodes and thus increase the total delay.

However, QMR-AODV outperforms AODV-MR when the number of radios per node increases as can be seen in the Figure 15. This is because, increasing the interfaces per node for the same number of users' flows, connectivity increases and hence there are more chances for the RREQ to be sent on those interfaces which can meet the end users required QoS delay requirements. This ensures the data is always routed through best possible paths leading to fewer delays. Second, QMR-AODV comparatively produces less RREQ as mentioned earlier and thus decreasing the chances of congestion in the network.

CONCLUSION

This paper presents joint channel assignment and routing scheme for Multi-Radio Multi-Channel WMNs.

The proposed channel assignment scheme ensures low interference by assigning the non-overlapping channels to the multiple radios with a dynamic and distributed scheme based on channel usage exchange messages. The channel assignment scheme is capable of detecting nodes failures and mobility within the WMNs backbone. The delays associated with the bi-directional links are accurately captured by the channel monitoring module in terms of average queuing delays, backoffs, transmission rate and retransmission for the lost packets. This delay information is further used by the QoS based routing scheme as a metric for determining the end-to-end path. The proposed QMR-AODV routing protocol controls the network wide flooding of conventional AODV by selective forwarding the RREQ packets. This helps to decrease the network routing overhead. QMR-AODV returns a guaranteed end-to-end path according to the applications requirements as each node assesses each of its interface during the RREQ packet forwarding, for complying with the applications required minimum delay bounds. Further, the proposed scheme improves the packet delivery ratio, network latency and effectively reduces the routing overhead.

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