On-demand Multi-Rate, Carrier Sense and Hidden Node Interference-Aware Channel Assignment Scheme in Wireless Mesh Network

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***Abstract*— The proposed interference avoidance channel assignment schemes can provide a significant advantage in term of aggregated throughput by assigning channels only to the active nodes and minimizing the intra-flow and inter-flow interference caused by hidden nodes. However, the negative aspect of the channel assignment schemes for the multi-rate multi-hop wireless mesh networks is the capacity reduction caused by channel reuse over low and high data rate links at the carrier sense and hidden node ranges. This paper proposed an On-demand Multi-Rate, Carrier Sense and Hidden node Interference-Aware channel assignment scheme (AODV-MRCSHDIA) to minimize the interference caused by low rate links at the carrier sense and hidden node ranges on the network throughput. The simulation experiment has been conducted to evaluate the AODV-MRCSHDIA over the existing schemes in term of packet delivery ratio and end-to-end delay.**

***Index Terms*— Wireless mesh network; On-demand routing; Multi-radio; Multi-channel; Multi-rate; Channel assignment.**

I. INTRODUCTION

A typical Wireless Mesh network (WMN) comprises of the number of permanent or semi-permanent wireless mesh routers that typically do not depend on power consuming constraints [11]. The mesh routers are practically Access Points (APs) which are provided with multi-radio interfaces. Each radio interface operates on a unique channel in the IEEE 802.11a/b/g bands. A pair of neighbor mesh routers can establish a logical link if they have a radio interface working on the same channel. This implies that with the increase in the number of the routers, some logical links may be assigned with the same channel. Hence, the capacity of WMN is influenced by the number of channel reuse among its nodes.

Nowadays, the family of IEEE 802.11 standards supports a multi-rate capability. For example, 802.11b standard provides four transmission rate (i.e., from 1- 11 Mbps) and 802.11a provides eight transmission rate (i.e., from 6-54 Mbps) according to the link quality. In a static wireless mesh network, the transmission rate of a wireless link depends on the distance between the link's endpoints [6]. Consequently, the greater distance between the link's endpoints, the lower transmission rate is chosen. In addition, the node coverage area is divided by the family of IEEE 802.11 standards into carrier sense and hidden node interference ranges. Hence, in this paper, we study the influence of channel reuse over low and high data rate links at the carrier sense and hidden nodes ranges on the network throughput. The contributions of the proposed scheme can be outlined as follows:

- Aplain channel interference index is developed to minimize the interference caused by multi-rate link sharing and hidden nodes.
- The channel assignment is integrated with the reactive routing discovery and proactive gateway discovery process with an aim to assign channels only to the active nodes and support both local and gateway traffic.

The organization of this paper is given as follows: Section two discusses the related work. The details of the proposed scheme are explored in section three. Section four discusses the simulation results and their analysis. Finally, the concluding remarks of this paper are given in section five.

II. RELATED WORK

The protocol model has been widely used by the channel assignment approaches in the multi-radio WMN due to its simplicity. However, this simplicity motivated the researchers to develop more accurate channel interference index for channel selection based on the protocol model and characteristics of WMN.

A channel interference index of interference-aware aims to minimize the number of the nodes sharing same channels has been proposed in [7]. However, more accurate interference indexes were proposed in [3, 14, 16, 15, 18]. In LA-CA [14], the links are ordered descending based on the link traffic load, whereas, the MesTic [16] ordered the links based on the traffic load, the distance of the link from the gateway and the number of interfaces per nodes. The CRB-CA [15] proposed to enhance the MesTic ranking formula by including the link quality and the link load in addition to the link distance and the number of interfaces. The JCAR [2] proposed a channel interference index based on the traffic load and path loss. In CA-LQSR [18], the scheme proposed the calculated transmission time as channel interference metric for channel selection. In [3], the authors proposed heuristic channel reassignment algorithm to adapt to traffic changes in the

WMN. The proposed solution takes into account the current traffic information and flow rate. In [8, 9, 17], greedy algorithms were proposed to assign channels for the links with maximum flow.

To overcome the hidden node problem, authors of [10] proposed a simple carrier sense and hidden node channel interference index which gives a channel with minimum hidden nodes higher priority to be selected. Moreover, the M-AODV-M [19] proposed a joint routing and channel assignment scheme to address the channel reuse problem along the established path.

However, all the interference and traffic aware channel interference indexes may not work well in multi-rate, multi-channel and multi-radio WMN due to their assumption that each link has fixed rate. Hence, channel interference index which takes into account the interference caused by the low rate links on the high data rate links was proposed by [4, 5, 6, 13].In [4], the channel assignment is formulated and solved as a joint CA, routing, multi-rate allocation and scheduling problems in multi-rate multi-channel WMN. In [6], the proposed scheme constructs the spanning tree WMN, where the gateway node is the root, based on a high-quality metric such as link quality. Similar to the [6], the CoCA[5] constructs the spanning tree topology based on the high-quality metric, then it proposed rate balance algorithm to distribute the links with low data rates over multiple children interfaces. In [13], the authors proposed centralized DR-CA for a single hop multi-interface wireless network where the number of interfaces per node equal to the number of available non-overlapping channels. However, none of the above addresses the effect of channel reuse over the low and high data rate links at the carrier sense and hidden node ranges in the network throughput that typically exists under realistic mesh nodes distributions.

III. PROPOSED SCHEME

In this paper, we propose two enhancements of our previous centralized reactive channel assignment algorithm (AODV-MRCR) [10, 12]. First, a multi-rate carrier sense and hidden node channel interference index is proposed. Second, a hybrid channel assignment that integrated channel assignment with proactive and reactive routing discovery process is proposed with the aim of assigning channels only to the active nodes. In this section, the unique aspects of AODV-MRCSHDIA scheme in the details are described and the aspects that are common with AODV-MRCR are neglected.

A. Multi-Rate, Carrier Sense and Hidden Node Channel Interference Index (MRCSHDI)

Let $G = (N, L)$ be a connectivity graph of WMN, where N is the set of WMN nodes and L is the set of direct wireless links. Hence, the carrier sense and hidden node conflict matrices of each link $i \in L$, where the link i connected the node n with the node m which can be expressed as follows.

$$\forall i, j \in L, \quad CS_{i,j} = \begin{cases} 1, & if\ j\ within\ i's\ hidden\ node\ range \\ & 0, Otherwise \end{cases} \tag{1}$$

$$\forall i, j \in L, \quad HD_{i,j} = \begin{cases} 1, & if\ j\ within\ i's\ hidden\ node\ range \\ & 0, Otherwise \end{cases} \tag{2}$$

Furthermore, the data rate of each link i (r_i) can be computed based on the distance between the link's endpoints. By given the CS, HD conflict matrices and k-hop channel usage information ($Link-CHL\ matrix$) of link i, the number of interfering links operates on channel c at carrier sense (n_{CS}) and hidden node (n_{HD}) ranges of link i can be computed as follows:

$$n_{CS} = \sum_{j=1}^{L} (CS_{i,j} * Link - CHL_{j,c}) \tag{3}$$

$$n_{HD} = \sum_{j=1}^{L} (HD_{i,j} * Link - CHL_{j,c}) \tag{4}$$

Since the proposed scheme aims to minimize the channel reuse over low and high rate links at hidden node range as well as to minimize the channel reuse over low rate links at carrier sense, we classified the carrier sense links into high compatible and low compatible data rate links. The procedure 1 is used to compute the number of links in each group. Consequently, the *MRCSHDI* is computed as in Equation 5.

$$MRCSHDI[c] = \alpha n_{CSHR} + \beta n_{CSLR} + (1-\beta) n_{HD} \tag{5}$$

B. Routing Discovery Process with Channel Selection

To improve the performance of AODV-MRCSHDIA for both types of the traffic, the AODV-MRCSHDIA carries the channel assignment into two stages as channel selection and interface switching as following.

i. Channel selection

The channel selection of router-to-router path established process is integrated with the gateway advertised message and the reactive routing discovery process to set up high throughput paths for the gateway and local traffic. Hence, the channel selection procedure is carried out when a node receives RouteREQuest message (*RREQ*) or Gateway Route REQuest message (*GRREQ*) messages. However, one of the most challenging issues of on-demand flow-based channel assignment is the frequent channel switching of the active links caused by receiving route discovery or repair messages. Thus, the AODV-MRCSHDIA used the link congestion level as an indicator to the channel switching in order to avoid the frequent channel switching. To achieve this goal, the AODV-MRCSHDIA prevents the active nodes from proposing a channel unless the currently used channel is congested. Hence, if the channel allocated to the received reserved route is not congested, the node proposes this channel as a route's Recommended Channel (RC). Otherwise, a new channel is chosen from the non-overlapping channels. The operation of the channel selection stage is illustrated by the example shown in Figure 1.

Grouping_Procedure()

Initialize $high_{curr}$, $high_{new}$, low_{curr} and low_{new} to zero
CLS ← Sort all carrier sense links in decreasing order based on data rate.
Assign the first element in the *CLS* list to the high rate group (G_{high}).
if (*last element in the CLS is not compatible with first element in CLS*) **then**
Assign the last element in the *CLS* list to the low rate group (G_{low}).
else
Initialize the low rate group(G_{low})to zero.
forall the $l \in CSL$ **do**
if(($l \notin G_{high}$) *and*($l \notin G_{low}$)) **then**
forallthe $i \in G_{high}$ **do**
$$high_{curr} = \frac{1}{1/r_i}$$
end
$$high_{new} = high_{curr} + \frac{1}{1/r_l}$$
Compute the impact of current link on the throughput of the high group.
end
if (($l \notin G_{high}$) *and*($l \notin G_{low}$)) **then**
forallthe $i \in G_{low}$ **do**
$low_{curr} = 1/(1/r_i)$
end
$$low_{new} = low_{curr} + \frac{1}{1/r_l}$$
Compute the impact of current link on the throughput of the low group.
end
Assign the current link to a group with minimum impact.
end
$n_{CSHR} = \text{numberoflinksingroup}\, G_{high}$
$n_{CSLR} = \text{numberoflinksingroup}\, G_{low}$

Algorithm 1: Grouping procedure to compute the number of the carrier sense links in each data rate group.

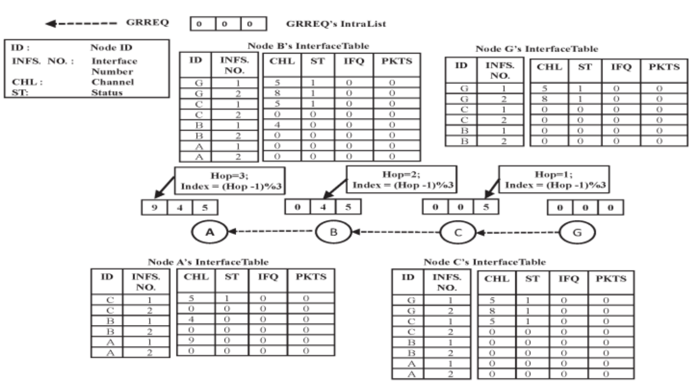

Figure 1: An example of integrated the channel selection with RREQ/GRREQ route discovery messages.

In Figure 1, the node *G* initiates the *GRREQ/RREQ* message for path discovery. Once the intermediate node *C* receives the *GRREQ/RREQ* message, it updates the corresponding entry of *InterfaceTable* with the *GRREQ/RREQ*'s *InterfaceTable* information and checks whether the node *G* has a free interface or not. Since the status of all interfaces of node *G* has the value of one which indicates that all interfaces are reserved, the node *C* proposes its recommended channel from the set of channels associated with node *G*. When the *GRREQ/RREQ* arrives at nodes *B* and *A*, both nodes found that the next hop nodes toward the destination have a free interface. Thus, each of them proposes its recommended channel from the available non-overlapping channels. At the end of this stage, each node along the established path has proposed a recommended channel.

ii. Interface Switching

The interface switching is carried out during the RouteREPly message (*RREP*) for local path discovery process and during the store-forward routing mechanism for the gateway traffic. Once a node receives a *RREP* message or it receives gateway traffic through unreserved route, it performs interface switching.

To perform interface switching, the node checks its interface table for channel approval. For example, assuming the node *A* performs the interface switching for link *A- B*. The node *A* checks the interface table to see if the channel is accepted or not. Recalling the channel is accepted if one of the following relations is satisfied:

1. $A(I_{free}) \neq \varnothing \,\&\, B(I_{free}) \neq \varnothing$
2. $RC \in A(c) \cap B(c)$

where $A(I_{free})$ and $B(I_{free})$ are the number of free interfaces at nodes *A* and *B*, respectively, while $A(c)$ and $B(c)$ refer to the set of channels assigned to the nodes *A* and *B*, respectively. If the channel is not accepted, the node switches the interface with the minimum number of nodes to the route's recommended channel. Finally, the node updates the route entry, interface table and broadcasts the *jointmessage* including with the all affected nodes.

Table 1
Simulation parameters

Simulation time	250 seconds
Comparison protocols	JCAR-TA[2], MCR [7]
Traffic type	CBR (UDP)
Packet size	512 bytes
Packet rates	300Kb
Simulation area	1000 × 1000 meter2
Transmission range	250 meters
Number of nodes	100
Number of connections	50
Number of Radio interfaces	*3*
Data rate	6, 9, 12, 18, 24, 36, 48, 54*Mbps*
β	0.4
Switching latency	80µs[2]

IV. Performance Evaluation

To evaluate our scheme, different scenarios were carried out based on ns-2[1] simulation. The common parameters for all the scenarios are given in Table 1. We considered the following performance metrics:

- Packet Delivery Ratio (PDR): The ratio of successfully received packet by destinations to the total number of packet sent by source nodes.
- End-to-end delay (E2ed): The time taken for the packet to be sent from the source node to the destination.

A. Routing Discovery Process with Channel Selection

In this scenario, the number of UDP flows is varied from 10 to 50; while other simulation parameters are given in Table 1. Figure 2 shows that as the number of flows increases, the PDR decreases whereas the end-to-end delay increases. For instance, the results obtained by AODV- MRCSHDIA, when the number of flows is 50, were higher than the MCR and JCAR-TA and were 61.4%, 30.6% for PDR and 57% 42.1% for E2ed, respectively.

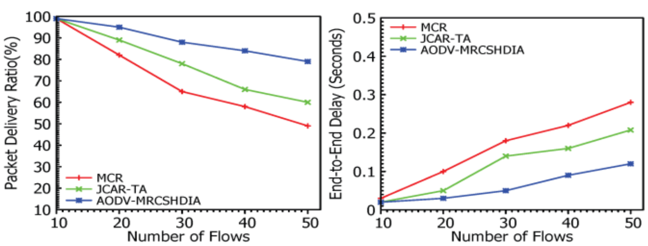

Figure 2: Results of varying the number of flows

The MCR and JCAR-TA can utilize all non-overlapping channels to minimize the interference caused by the multi-flow ongoing transmission. However, their channel interference index lead to increase the probability of low rate links sharing the same channel with the high data rate link which leads to multi-rate link sharing problem. This is because the MCR and JCAR-TA assume that each link has a fixed data rate. In contrast, the channel interference index of AODV-MRCSHDIA can balance the low-rate links among the available channels which, in turn, minimize the effect of the multi-rate link sharing problem in the network throughput.

B. Varying the Number of Channels

Figure 3 shows that the AODV-MRCSHDIA scheme achieves higher PDR improvement and lower E2ed over the MCR and JCAR-TA regardless of the number of channels used. For example, when the number of channels is small such as 5 channels, Fig. 3(a) shows that the PDR improvement of AODV-MRCSHDIA over MCR and JCAR-TA is about 105% and 57.5%. We can also observe from Figure 3(b) that the E2ed is about 50.7% and 30% better than MCR and JCAR-TA, respectively.

The improvement of the AODV-MRCSHDIA over MCR and JCAR-TA depends on its channel interference index and frequent interface switching.

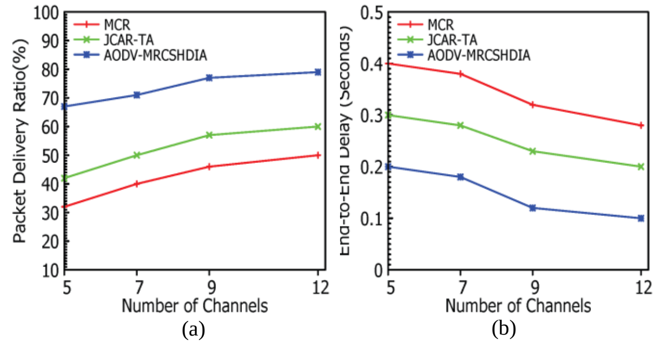

Figure 3: Results of varying the number of channels

The AODV-MRCSHDIA scheme has shown to be an efficient approach to migrate the hidden node and the multi-rate link sharing problems during the channel selection stage. Moreover, it minimizes the interface switching caused by broadcast property and channel reselection during the routing repair message. Thus, the AODV-MRCSHDIA has better channel utilization than MCR and JCAR-TA by assigning a channel to an active link based on the consideration of the impact of low rate and hidden links interference on the system throughput.

C. Impact of the Number of Interfaces

Figure 4 shows the PDR, and end-to-end delay with varying number of interfaces. As we see from Figure 4, the AODV-MRCSHDIA gains higher performance than JCAR-TA as more interfaces are being used

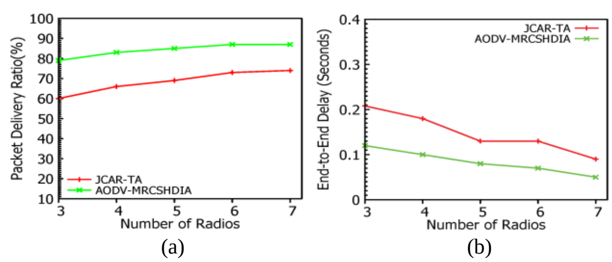

Figure 4: Results of varying the number of radios

For instance, when there are 50 flows with three, four, and five interfaces, the PDR of AODV-MRCSHDIA improved by 30%, 25%, and 22% over the JCAR-TA, respectively. Also, our scheme reduced the E2ed by 42%, 44% and 38% over the JCAR-TA with the three, four, and five interfaces, respectively.

The improvements of our scheme over the compared schemes can be explained by the fact that the interference index in AODV-MRCSHDIA can model the interference caused by the channel reuses over the low rate links at the carrier sense and hidden nodes. Thereby, increasing the number of network interfaces reduces the effectiveness of low-rate links upon the high rate links by redistributing the low-rate links among the node interfaces during the channel-to-interface binding stage.

V. CONCLUSION

In this paper, distributed on-demand multi-rate carrier sense and hidden node interference-aware channel assignment scheme called as AODV-MRCSHDIA is presented. The AODV-MRCSHDIA utilizes the static characteristics of mesh routers to develop a simple channel interference index for channel selection. The proposed interference index aims to reduce the influence of channel reuse over low and high data rate links at the carrier sense and hidden node ranges on the performance of WMN. In addition, the AODV-MRCSHDIA assigns channels only to the active nodes by integrating the channel assignment with the proactive and the reactive routing discovery process. The simulation results showed that the AODV-MRCSHDIA achieved higher PDR and lower end-to-end packet delay over the other contemporary channel assignment schemes.

REFERENCES

[1] NS. The Network Simulator, http://www.isi.edu/nsnam/ns/ (1989)

[2] Chiu, H.S., Yeung, K., Lui, K.S. "J-car: An efficient joint channel assignment and routing protocol for IEEE 802.11-based multi-channel multi-interface mobile ad hoc networks," *IEEE Transactions on Wireless Communications*, vol. 8, no. 4, pp.1706–1715, 2009.

[3] GAlvez, J.J., Ruiz, P.M., "Efficient rate allocation, routing and channel assignment in wireless mesh networks supporting dynamic traffic flows, " *Ad Hoc Networks,* vol. 11, no. 6, pp. 1765 – 1781, 2013.

[4] Glvez, J.J., Ruiz, P.M., "Joint link rate allocation, routing and channel assignment in multi-rate multi-channel wireless networks, " *Ad Hoc Networks,* vol. 29, pp. 78 – 98, 2015.

[5] Kim, S.H., Kim, D.W., Suh, Y.J., "A cooperative channel assignment protocol for multi-channel multi-rate wireless mesh network," *Ad Hoc Networks*, vol. 9, no. 5, pp. 893–910, 2011.

[6] Kim, S.H., Suh, Y.J., "A distributed channel assignment protocol for rate separation in wireless mesh networks," *Computer Communications* vol. 33, no. 11, pp. 1281–1295, 2010.

[7] Kyasanur, P., Vaidya, N.H., "Routing and link-layer protocols for multichannel multi-interface ad hoc wireless networks," *SIGMOBILE Mobile Computer Communications Review*, vol. 10, pp. 31–43, 2006.

[8] Li, S., Zheng, Z., Ekici, E., Shroff, N., "Maximizing system throughput by cooperative sensing in cognitive radio networks," *IEEE/ACM Transactions on Networking*, vol. 22, no. 4, pp. 1245–1256, 2014.

[9] Martignon, F., Paris, S., Filippini, I., Chen, L., Capone, A., "Efficient and truthful bandwidth allocation in wireless mesh community networks," *IEEE/ACM Transactions on Networking*, vol. 23, no. 1, pp. 161–174, 2015.

[10] Mogaibel, H., Othman, M., Subramaniam, S., Hamid, N. "On-demand carrier sense and hidden node interference-aware channel reservation scheme for common traffic in wireless mesh network," *In: Zeng, Q.A. (ed.) Wireless Communications, Networking and Applications, Lecture Notes in Electrical Engineering*, vol. 348, pp. 251–265. Springer India 2016.

[11] Mogaibel, H.A., Othman, M., "Review of routing protocols and it's metrics forwireless mesh networks. In: Proceedings of the 2009 International Conference of Association of Computer Science and Information Technology," *IEEE Computer Society, Washington, DC, USA*, pp. 62–70, 2009.

[12] Mogaibel, H.A., Othman, M., Subramaniam, S., Hamid, N.A.W.A., "On-demandchannel reservation scheme for common traffic in wireless mesh networks, Journal of Network and Computer Applications 35(4), 132–151, 2012.

[13] Niranjan, N., Pandey, S., Ganz, A., "Design and evaluation of multichannel multi-rate wireless networks," *Mobile Networks and Applications,* vol. 11, no. 5, pp. 697–709, 2006.

[14] Raniwala, A., Gopalan, K., Chiueh, T., "Centralized channel assignment and routing algorithms for multi-channel wireless mesh networks," *ACM Mobile Computing and Communications Review*, vol. 8, pp.50–65, 2004.

[15] Sarasvathi, V., Iyengar, N., "Centralized rank based channel assignment for multi-radio multi-channel wireless mesh networks," *Procedia Technology 2nd International Conference on Computer, Communication, Control and Information,*2012.

[16] Skalli, H., Ghosh, S., Das, S.K., Lenzini, L., Conti, M., "Channel assignment strategies for multi-radio wireless mesh networks: Issues and solutions," *IEEE Communications Magazine*, vol. 45, no. 11, 86–95, 2007.

[17] Wei, Y., Li, T., Ge, Z., "A channel assignment algorithm for wireless mesh networks using the maximum flow approach," *Journal of Networks* vol. 6, pp. 879–882, 2011.

[18] YUAN, F., LI, X., ming LIU, K., an LIU, Y., DU, X., rong SHI, X., "Distributed channel assignment combined with routing over multi-radio multi-channel wireless mesh networks," *The Journal of China Universities of Posts and Telecommunications*, vol. 19, no. 4, pp. 6–13, 2012.

[19] Zhou, J., Peng, L., Deng, Y., Lu, J., "An on-demand routing protocol for improving channel use efficiency in multichannel ad hoc networks." *Journal of Network and Computer Applications*, vol. 35, no. 5, pp. 1606 – 1614, 2012.