MMS: Multi-rate Multicast Scheduling in Multi-radio Single-cell CR-WMNs

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ABSTRACT:
Recently, cognitive radio technology is mentioned as a new model for wireless communication. In this paper, by extending the previous works, we adopt both multi-radio and multi-rate technologies in single-cell multi-channel cognitive radio wireless mesh networks. In this regard, an efficient scheduling algorithm is introduced named Multi-Rate Multicast Scheduling (MMS). Multi-radio technology allows the nodes to simultaneously send/receive packets on the distinct channels. Consequently, the network throughput will be increased. Furthermore, since different transmission rates lead to different spectrum utilizations, efficient use of the multi-rate capability could improve the performance of the network. Numerical results of presented comprehensive simulations confirm the efficiency of the MMS algorithm.

KEYWORDS: Cognitive Radio, Multi-radio, Multi-rate, Scheduling, Single-cell.

1. INTRODUCTION

In recent years, by increasing the demand for wireless communication services, Cognitive Radio Networks (CRNs) have received much attention [1]. The measurements performed by several research centers, including Berkeley Wireless Research Center (BWRC), suggest idle parts among the spectrums assigned to the Primary Users (PUs) [2]. These idle parts are known as "spectrum holes" [3]. One fundamental challenge in CRNs is sharing the licensed spectrum for Secondary Users (SUs) without causing any interference for PUs. Actually, access to the spectrum holes depends on the location of SUs named heterogeneity property.

Cognitive Radio Wireless Mesh Networks (CR-WMNs) are a new class of CRNs which could provide robust and scalable solutions for spectrum utilization [4, 5]. Unlike traditional mesh or ad-hoc networks, CR-WMNs have the ability to sense the environment to detect the spectrum holes [5]. However, due to the limited radio resources and co-channel interference among the wireless links, some transmissions cannot be active at the same time. If the interfering transmissions are not managed correctly, collision increases the packet loss in the network.

The availability of high bandwidth in CR-WMNs increases the possibility of using the multimedia applications. In this regard, multicast routing provides underlying facilities for better utilization of the network resources [6]. Multicast traffic is raised to send the data packets from a source node to multiple destinations. Multicasting in CR-WMNs is affected by the challenges related to the dynamic spectrum opportunities, nature of the wireless medium, and cognitive environment [7], [8].

Two technical challenges, including Wireless Broadcast Advantage (WBA) and multi-radio technology, are raised in the field of wireless networks. According to WBA, a transmission can simultaneously cover all neighboring nodes located in its communication range [9]. On the other hand, equipping nodes with multiple radios tuned to the non-overlapping channels, named Multi-Channel Multi-Radio (MCMR) wireless networks, could significantly improve the performance of the network. MCMR technology can successfully manage the heterogeneity property and reduce the interference in CRNs.

In recent years, some works have shown that exploiting multiple radios provides more efficient routing and scheduling performance [10-15]. In line with this concept, [10], [11] consider multiple radios at each node to sense the channels contemporary. [12], [13] use two radios, one radio is served to a common control channel for sending the control packets such as

RTS/CTS and the second one for switching across all the other channels for data transmissions. Ref. [14] tries to get the advantages of multiple radios to tackle the hidden terminal problems in multi-channel CRNs.

In order to control the access time of transmitters to the available channels, TDMA is raised to appropriately schedule the transmissions at different time slots. This allows the nodes to use the minimal resources without interference. To this end, Ref. [16] proposes a joint scheme including multicast scheduling, power control, and channel assignment. [17] discusses minimizing the occupied time slots for multicast traffics in one cell of CR-WMNs. It uses the scheduling in both time and frequency domains along with the network coding technology.

Authors in [18] propose an assistance multicast scheduling for reducing the end to end multicast delay in CR-WMNs. The proposed scheme provides a multicast scheduling based on three assisting operations, namely intra-group assistance, inter-group assistance, and codeword exchange operation. Following the classic solutions for sensing and scheduling the spectrum holes in CRNs, recently, assistant strategies between SUs have been extensively used. This not only proposes an effective solution in spectrum sensing, but also helps to transmit packets via relay nodes. Generally, assistant strategies for delivering the multicast traffic are classed into two types: IntrA-Group Assistance (IAGA) and IntEr-Group Assistance (IEGA) [17]. These terms are frequently utilized in the literature to introduce assisting some nodes in one or more multicast sessions to each other.

Current wireless radios, e.g., IEEE 802.11, provide multiple transmission rates with different coding and modulation schemes. Since different transmission rates lead to different spectrum utilizations and different communication ranges [19], rate selection will affect the performance of the network. This issue becomes more complex when the channel diversity is also considered. In [15], an Interference Aware Joint Channel and Rate Selection (IA-JCRS) algorithm is presented to choose the best transmission rates and the best transmission channels for a given multicast routing tree. In [19], two cross-layer algorithms named “Interference and Rate-aware Multicast Tree (IRMT)” and “Interference and Rate-aware Broadcast Tree (IRBT)” are proposed in Multi-Rate MRMC-WMNs. They jointly consider rate and channel diversity, call admission control, and WBA. IRMT and IRBT decrease both number of transmissions and interference in the routing trees. Ref. [20] proposes two distributed strategies, named ‘‘Multicast Auto Rate Selection (MARS)’’ and ‘‘MARS Retransmit (MARS-R)’’. The MARS scheme uses the packet delivery ratio of the wireless links at various transmission rates. MARS-R facilitates the joint use of rate control and link-layer mechanisms to improve the reliability of high-throughput multicast flows.

This paper, by extending the previous works [17], addresses the multicast scheduling problem in single-cell CR-WMNs. To achieve this goal, we present an efficient algorithm named Multi-Rate Multicast Scheduling (MMS) which jointly exploits the assistant strategies, WBA and both multi-rate and multi-radio technologies. The result is to provide the ability of transmitting and receiving data at the same time over the maximum number of users. We first consider the problem for non-assistance strategy and then, it will be extended to the assistance strategy [17]. The proposed algorithm selects the transmission rate in such a way that improves the resources utilization.

The rest of this paper is organized as follows. In section 2, the network model and the assumptions are described. Section 3 is dedicated to proposing the MMS algorithm in detail. The simulation results are displayed in section 4. Finally, in section 5, some concluding remarks are outlined.

2. NETWOR MODEL

As shown in Fig.1, we consider a Single-Cell Multi-Channel Multi-Radio Multi-Rate (CR-WMN). A Mesh Router (MR) manages n-1 stationary Mesh Clients (MCs) randomly distributed in the network. MR has access to all available channels. Thus, MCs have at least one common channel with MR. Based on the local measurements, MR allocates the available channels to MCs with the available probability of P_a. Each node is equipped with NR half-duplex radios tuned to one of the C available non-overlapping channels, where channel switching is allowed at each time slot. It is assumed that the radios of each node could send packets at one of the M available transmission rates denoted by $\{r_1, r_2, \dots, r_M\}$. In addition, we suppose that the radios of the nodes are equipped with omni-directional antennas characterized by the same transmission power.

By considering the basic rate, we model the single-cell CRWMN as a directed graph $\boldsymbol{G}=(\boldsymbol{V},\boldsymbol{E})$, where, each $v \in \boldsymbol{V}$ corresponds to a cognitive mesh node and $\boldsymbol{E}$ denotes the set of communication links. Node x is directly connected to node y and establishes a wireless link $(x,y)_c$, if node y is within the communication range (R) of node x and both nodes have access to channel c.

Considering a dynamic traffic model, the multicast session requests arrive at the network without any prior knowledge about the future requests. Each session is stated with a specific bandwidth requirement. We apply a schedule-based MAC protocol in which the interfering transmissions must either be sent on different non-overlapping channels or different time slots.

Following the work in [17], all users of the cell are assumed to be in the interference range of each other. To model the interference in the network, we use the protocol interference model. According to this model, two co-channel transmissions are said to interfere with each other if at least one receiver of a transmission is located in the interference range of the transmitter of the other transmission.

3. MULTI-RATE MULTICAST SCHEDULING (MMS) ALGORITHM

As mentioned before, an effective approach to mitigate the co-channel interference is to equip the nodes with multiple radios tuned to non-overlapping channels. This allows the nodes to simultaneously send and receive on distinct channels at the same time slot. Thus, the network throughput will be increased.

In this section, by extending the works in [17], [21], we propose an efficient algorithm to schedule the multicast traffics in multi-radio multi-rate single-cell CR-WMNs.

In this work, the effect of both rate and radio/channel diversities on the total length of multicast period are studied. The proposed algorithm jointly considers the spectrum availability, both rate and radio diversities, and interference problem. In particular, different transmission rates lead to different spectrum utilizations and different communication ranges. Thus, rate selection will affect the performance of the network. Fig. 2 shows the flowchart of MMS algorithm in two states: Non-assistance strategy (Fig. 2a) and Assistance strategy (Fig. 2b). By definition [17], the forwarding process of a packet from an MC to other MCs is named as assistance strategy. Otherwise, if MR directly covers an MC of the cell, it is named as non-assistance strategy.

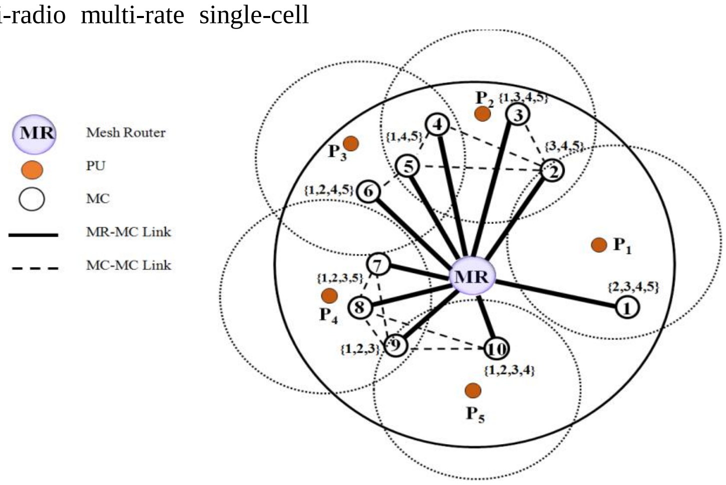


Fig. 1. A typical single-cell multi-channel multi-radio CR-WMN.

Consider Fig. 2a which shows the flowchart of the MMS algorithm in non-assistance strategy. For each session request, MMS develops the scheduling frame step by step. At each step of the algorithm, the uncovered receivers should be identified to directly be covered by MR. Initially, the available channels are sensed for each node in the network (Label 1). As previously mentioned, it is assumed that MR has access to all available channels. Thus, each MC has at least one common channel with MR. Based on the access of MCs to different channels and the minimum transmission rate, the network topology is formed. In fact, MMS first schedules different transmissions based on the base rate, i.e., 6 Mbps, and subsequently, the rate of each transmission will be improved/increased. Given the spectrum availability of nodes at each time slot, MR selects the best channel to cover a part of the uncovered nodes. In this regard, MMS jointly considers both multi-radio technology and WBA to maximize the coverage area. It aims to cover more number of receivers by a single transmission. This reduces the total number of transmissions, and accordingly, the multicast period will be decreased.

On the other hand, according to the half-duplex radios, each radio can only send or receive on a fixed channel at any time slot. Thus, at each time slot, the number of free radios for a node, including MR and SUs, should be checked. In the case which there is no free radios for MR or investigated receivers, the MMS algorithm postpones the scheduling process to the next time slots (Label 2) and goes back to label 1 for investigating the spectrum availability. Otherwise, the interference problem is examined for the selected channel. If the selected channel interferes with other transmissions at the current time slot, that channel is removed from the list of available channels for that time slot. This means that at least one receiver of the transmission is located in the interference range of the other transmitters of the considered time slate. Thus, they cannot simultaneously be scheduled. The first solution for avoiding the interference problem is switching to the other best channel and re-examining the process. Indeed, the transmission will be postponed to the next time slots if there is no idle channel without interference problem and all the mentioned steps are reconsidered.

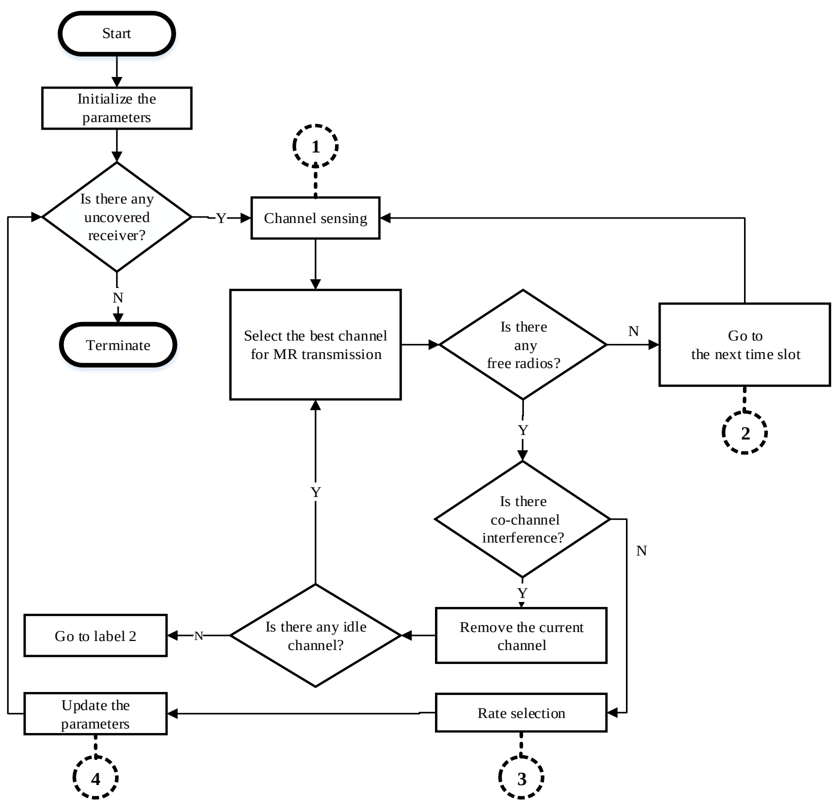
Recently, the current wireless radios provide multiple transmission rates with different coding and modulation schemes. Since different transmission rates result in different spectrum utilizations and communication ranges [19], "*transmission rate selection*" will affect the performance of the network. Let consider $x(r, k)$ and $L(x)$ as the transmission of node x on channel k at rate r and its traffic load, respectively. Transmission Time Fraction (TTF) of $x(r, k)$ is calculated as follows [19]:

$$TTF\,(x,r,k) = \frac{L(x,r,k)}{r}. \tag{1}$$

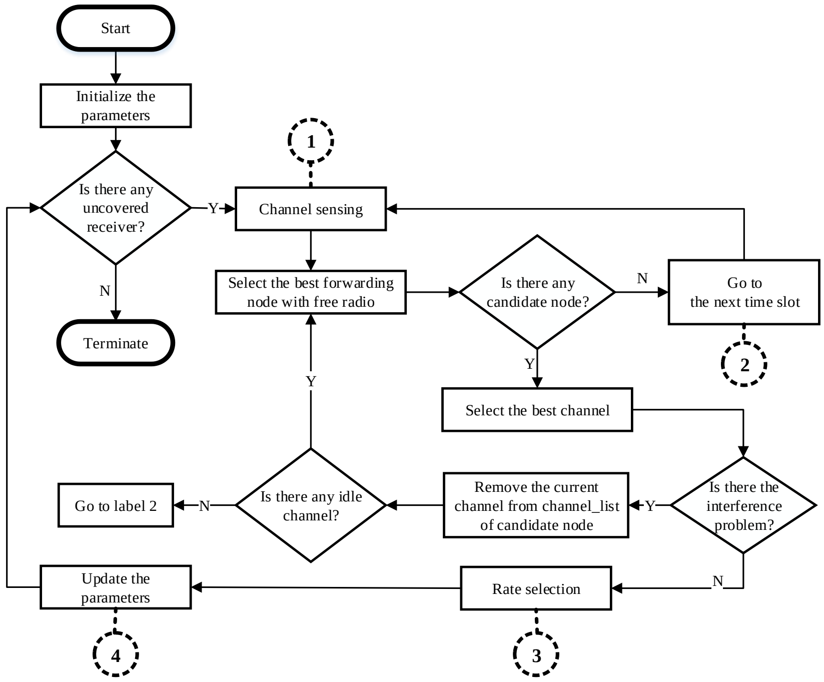
In fact, $TTF(x, k, r)$ shows the fraction of scheduling frame occupied by $x(r, k)$. According to (1), by increasing the transmission rate, transmission time fraction will be decreased. This means that the higher transmission rates take shorter time on the scheduling frame. In contrast, by increasing the transmission rate, the receiver sensitivity threshold will also be increased. Given the fixed transmission power assumption, this decreases the transmission range [19]. Thus, the higher transmission rates lead to a larger number of transmissions.

At the next step, MMS selects the best rate for the transmission (Label 3). To this end, it selects the maximum available rate which MR can still cover the corresponding receivers. This not only covers all receivers of that transmission, but also efficiently reduces its occupied time slots.

To clarify this problem, Fig.3a shows a multi-rate multicast scheme, in which MR aims to deliver packet a to the white nodes, i.e., nodes {2, 4, 8, 10, 11, 12}, and packet b to the gray nodes, i.e., nodes {1, 3, 5, 6, 7, 9}. Assume both traffic loads are 120 Kbps and the scheduling frame has 1000 time slots. The text written near each link shows the channel and rate of that link as C/R, respectively. Also, the concentric circles display the communication ranges of different transmission rates. Assume that each node is equipped with two radios. Thus, MR is able to send two transmissions at each time slot. Fig. 3b shows the scheduling frame for all transmissions. In the first transmission, MR sends packet a to nodes 2, 8, 10, 11, and 12 on channel 1 and rate 12Mbps. The transmission range of this rate covers all receivers while occupies only 10 time slots (Time slots 1 to 10).

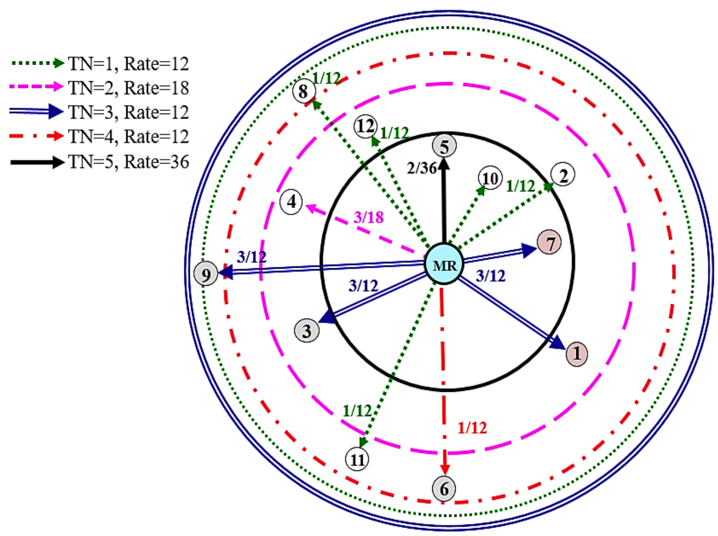


(a)



(b)

Fig. 2. Flowchart of the MMS algorithm (a) Non-assistant strategy and (b) Assistant strategy.



(a)

Time slots	[1-10]	[1-7]	[8-17]	[11-20]	[18-21]
Transmissions	TN=1 MR→{2,8,11,12}	TN=2 MR→{4}	TN=3 MR→{1,3,7,9}	TN=4 MR→{6}	TN=5 MR→{5}

(b)

Fig. 3. (a) A typical multi-rate multicast scheduling scenario in single-cell MCMR-CRWMN with two radios, (b) scheduling frame.

However, the use of the base rate results in occupying 20 slots. The next transmission for delivering this packet to node 4 is established on channel 3 from time slots 1 to 7 at rate 18Mbps. Nodes 1, 3, 7, and 9 receive their intended packet, i.e., packet *b*, on channel 3 and rate 12 from time slots 8 to 17 because of having no idle radios in MR. As the same way, nodes 5 and 6 gets packet *b* on channels 2 and 1, rates 36 and 12 from time slots 11 to 21, respectively. It is worth noting that all transmissions under multi-rate ability are shown in Fig. 3 according to the Transmissions Number (TN).

It is worth noting that after delivering the intended packets to the corresponding receivers of each session, the set of uncovered receivers, the available channels, and the radio status of the nodes should be updated (Label 4). The algorithm terminates when all receivers take their packet through the algorithm.

Unlike the non-assistance strategy, the assistance strategy not only uses the single-hop transmissions to cover the receivers, but also adopts some MCs to forward the packets to the other MCs. Fig. 2b shows the flowchart of the MMS algorithm in assistance strategy. In this figure, we point the same blocks with the previous flowchart with their labels.

Generally, the assistance strategy is classed into two types: IntrA-Group Assistance (IAGA) and IntEr-Group Assistance (IEGA) [17]. In assistance process, if two MCs belong to the same groups, it is referred to intra-group assistance. Otherwise, if the algorithm allows an MC from a group forwards data to MC from another group, it is named as inter-group assistance. The flowchart starts with initializing the parameters. Subsequently, spectrum availability for different nodes is determined. At each time slot, the covered nodes which have free radios along with MR are nominated as ‘‘candidate forwarding node’’ to compete with each other with the best available channel. A node/channel is preferred as the next forwarding node which covers more number of neighboring nodes by a single transmission. Certainly, both transmitter and receiver of a transmission should have an idle radio. If there is no free radio in a node, that node cannot be added to the candidate set. In this case, the other nodes are examined to eventually select a node with idle radio as the candidate node.

Similar to the non-assistant strategy, the interference problem should be studied to avoid the packet loss. If there is no interference, the candidate node chooses the appropriate rate to cover its receivers with respect to the communication range (Label 3 in Fig. 2b). Otherwise, that channel will be removed from the available channels list of the candidate node. In the absence of an idle channel, the algorithm selects another candidate node.

It is worth noting that the rate selection is similar to the previous strategy. Thus, it selects the maximum available rate which transmitter can still cover the corresponding receivers.

To better understand the subject under discussion, consider Fig. 4 which shows a typical multicast scenario in multi-radio single-rate single-cell CR-WMN. It is assumed that all nodes in the networks are equipped with two radios tuned to the non-overlapping channels. The white and gray nodes are interested in receiving packets *a* and *b*, respectively. The set written next to each SU presents its available channels. MR has direct link to SUs due to its access to all channels. At first, MR uses WBA to simultaneously deliver packet *a* to nodes $\{n_4, n_6, n_8\}$ on channel 5. Nodes $\{n_4, n_6, n_8\}$ along with MR can be nominated as ‘‘forwarding node’’ to compete with each other with the best available channel. In this case, n_6 is selected as the best candidate node to send packet *a* to $\{n_2, n_{10}, n_{11}, n_{12}\}$ on channel 1 by enjoying WBA. At the same time with the first transmission, n_8 is able to transmit packet *a* to n_9 on the other channel. It is worth noting that if n_9 has no access to channel 2 at time slot 1, it can receive the intended packet from MR or n_8 at the next time slots. In fact, the MMS algorithm solves the multicast co-channel interference by postponing the interfered transmission to different channels or different time slots. Moreover, n_8 can cover two neighboring nodes in another group on channel 4 under IEGA. To this end, it first should receive the intended packet related to another group from MR. All steps in the case of IEGA are similar to IAGA strategy except delivering the intended packet to the candidate nodes which have not received their intended packet yet. After sending packet *a* to nodes $\{n_1, n_3\}$ on channel 4, this node gets packet *b* from MR at next time slots.

Finally, we use a comprehensive example in Fig. 5 to compare the scheduling frame in a typical single-cell CR-WMN with 5 available channels for both single-radio (Fig. 5a) and multi-radio (Fig. 5b) states in assistance strategy. It is assumed that 10 SUs, i.e., nodes 1 to 10, are divided into two groups. The first group (white nodes) receive packet *a* and the second group (the gray nodes), i.e., $\{n_2, n_5, n_6, n_8, n_{10}\}$, receive packet *b*. The text written near each link shows the intended packet and channel of that link as Packet/C, respectively.

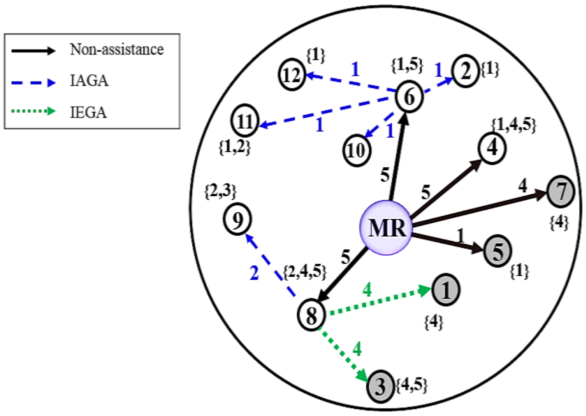


Fig. 4. A typical multicast scheduling scenario in multi-radio single-rate single-cell CR-WMN.

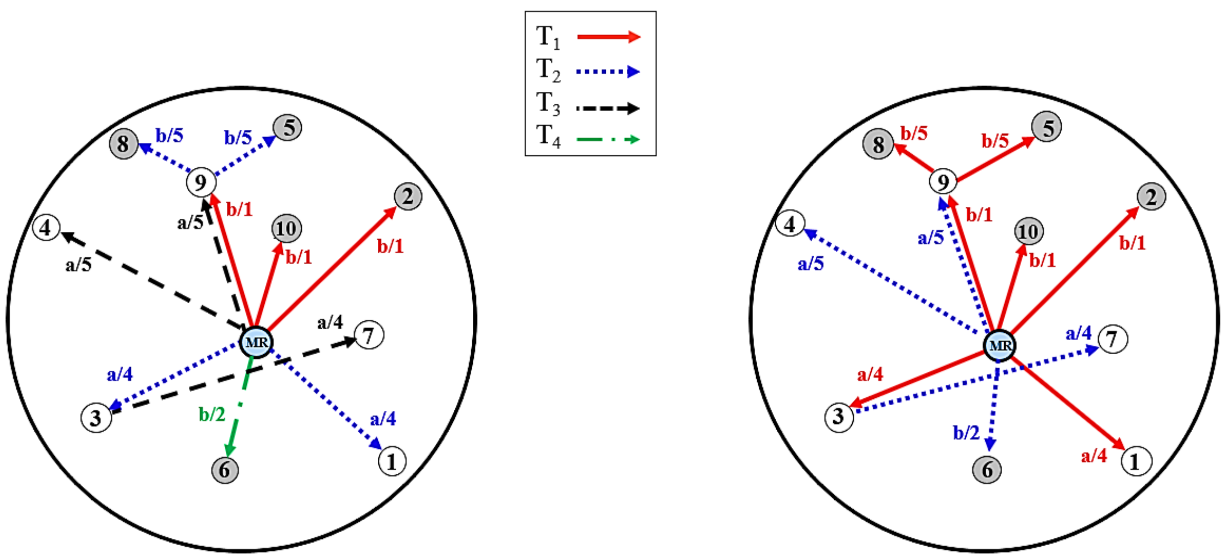
Table 1 presents the scheduling frame for non-assistance strategy and assistance strategy for both states of single-radio and two-radio assumption. In the assistance strategy, we consider both IAGA and IEGA.

In the single-radio state, when no form of assistant strategies is used, MR transmits the intended packets to all users in 6 time slots. However, exploiting IAGA and IEGA reduces the multicast period to 4 time slots. The results show that multi-radio technology leads to a dramatic reduction in the number of occupied time slots. As it is evident, by equipping each node with two radios, the multicast period is approximately half of the single-radio mode. This remarkable improvement in the number of time slots is due to the ability of simultaneously sending and receiving the intended packet in each node by applying multi-radio technology.

4. NUMERICAL RESULTS

In this section, we evaluate the performance of the proposed algorithm in different scenarios. To this end, we consider *n* nodes randomly distributed in a single-cell WMNs-CR over a 500×500 m^2 square area. The mesh router is located in the central point of the cell. The communication range is assumed 354 m, 315 m, 250 m, 199 m, 141 m, 89 m, 56 m, and 50 m for transmission rate of 6 Mbps, 9 Mbps, 12 Mbps, 18 Mbps, 24 Mbps, 36 Mbps, 48 Mbps, and 54 Mbps, respectively. Also, it is assumed that all nodes are located in the interference of each other. For single-rate scenarios, i.e., scenarios 1 to 4, each session requires one time slot. However, in multi-rate scenario, i.e., scenario 5, each transmission occupies 20, 14, 10, 7, 5, 4, 3, and 2 time slots in different rates, respectively. The receivers of each session are randomly selected among the nodes. Each point on the curves is the average performance of 60 individual runs for various topologies.

All scenarios are described by following parameters: *C* (Number of channels), P_a (Channel access probability), *NR* (Number of radios), *n* (Number of nodes), and *g* (Number of sessions).



(a) (b)

Fig. 5. A typical multicast scheduling scenario in single-cell MCMR-CRWMN for assistance strategy: (a) Single-radio state and (b) Multi-radio state.

Table 1. Multicast scheduling for described example.

	T	*T₁*	*T₂*	*T₃*	*T₄*	*T₅*	*T₆*
Single-Radio	**Non-assist.**	$MR \xrightarrow{a/1} (n_3,n_9)$	$MR \xrightarrow{a/4} (n_1,n_7)$	$MR \xrightarrow{a/4} (n_4)$	$MR \xrightarrow{b/1} (n_2,n_{10})$	$MR \xrightarrow{b/3} (n_5,n_8)$	$MR \xrightarrow{b/4} (n_6)$
	Assist.	$MR \xrightarrow{b/1} (n_2,n_9,n_{10})$	$MR \xrightarrow{a/4} (n_1,n_3)$ $n_9 \xrightarrow{b/5} (n_5,n_8)$	$MR \xrightarrow{a/5} (n_4,n_9)$ $n_3 \xrightarrow{a/4} (n_7)$	$MR \xrightarrow{b/2} (n_6)$		
Multi-Radio	**Non-assist.**	$MR \xrightarrow{a/1} (n_3,n_9)$ $MR \xrightarrow{a/2} (n_1)$	$MR \xrightarrow{a/4} (n_4, n_7)$ $MR \xrightarrow{b/2} (n_6)$	$MR \xrightarrow{b/1} (n_2, n_{10})$ $MR \xrightarrow{b/3} (n_5, n_8)$			
	Assist.	$MR \xrightarrow{b/1} (n_2,n_9, n_{10})$ $MR \xrightarrow{a/4} (n_1, n_3)$ $n_9 \xrightarrow{b/5} (n_5,n_8)$	$MR \xrightarrow{a/1} (n_4,n_9)$ $MR \xrightarrow{b/2} (n_6)$ $n_3 \xrightarrow{a/4} (n_7)$				

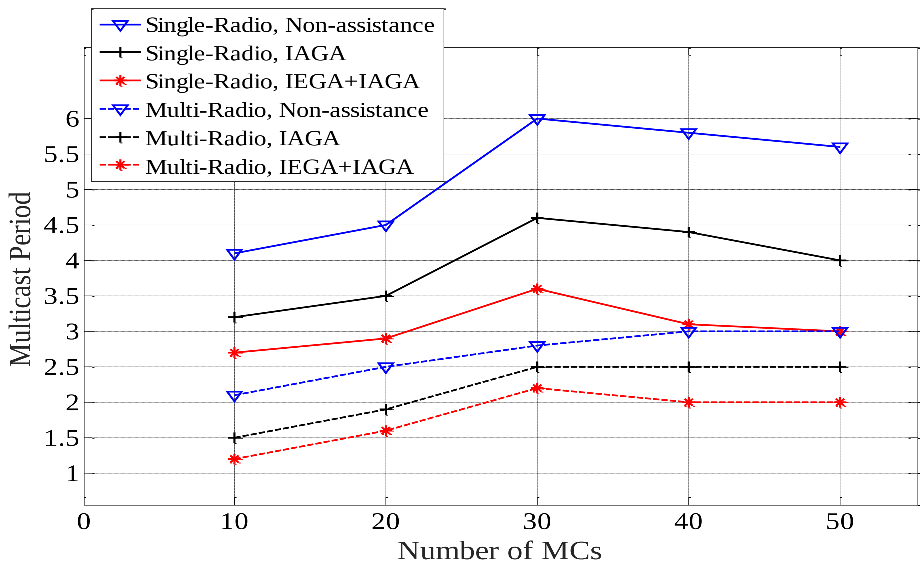


Fig. 6. Multicast period as a function of the number of MCs.

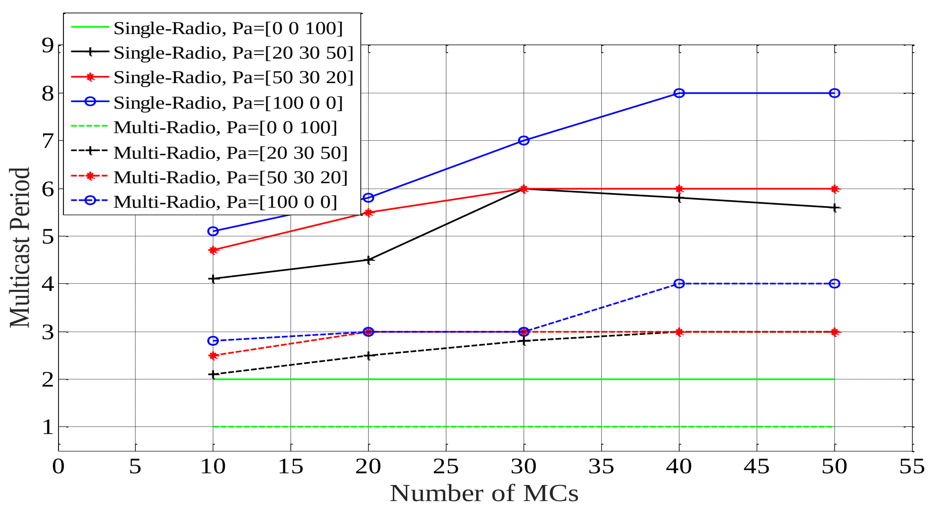


Fig. 7. Effect of P_a on the multicast period.

Scenario #1: In the first scenario, assuming r=6 Mbps, P_a= [20, 30, 50], C=3, and g=2, we study the performance of MMS algorithm for different number of MCs. The results are shown in Fig.6. Both assistant strategies lead to a considerable reduction in the multicast period. This is because the nodes can assist each other by switching to more accessible channels. However, IEGA shows better multicast period. On the other hand, multi-radio states have better performance than single-radio mode. The reason for this is the capability of all nodes (including MR and MCS) to simultaneously send and receive data. Furthermore, there is a slight increment in the number of time slots by increasing the number of receivers.

Scenario #2: In this scenario, assuming $r = 6\,\text{Mbps}$, C=3, and g=2, we evaluate the effect of P_a on the multicast period for IEGA strategy. The results are shown in Fig. 7. It is clear that the number of time slots considerably diminishes to one time slot along with exploiting WBA, multi-radio technology and having access to all channels. The graphs also show that the multicast period sharply drops from the single-radio to multi-radio state even with low access probability. As justified before, multi-radio technology allows the nodes to simultaneously send/receive packets on the distinct channels. Consequently, the network throughput will be increased.

Scenario #3: This scenario, assuming $r = 6\,\text{Mbps}$ and g=2, investigates the effect of channel diversity on the performance of the network. Toward this goal, we randomly distribute 5 to 25 nodes in the network and increase C from 3 to 7. The results of the non-assistant strategy are shown in Figs. 8 and 9 for P_a= [80, 20, 0] and P_a= [0, 20, 80], respectively. In P_a= [80, 20, 0], since the competition for using the sensed frequency channels decreases, every user mostly accesses to one available channel. Therefore, by increasing the number of users, the number of time slots in both single-radio and multi-radio states increases. In contrast, for P_a= [0, 20, 80], the users mostly access to all channels. Hence, by increasing the number of channels, the multicast period will be decreased.

Scenario #4: In this scenario, assuming r=6 Mbps, C=3, g=2, and P_a= [35, 30, 35], we compare the multicast period for different number of radios (Fig. 10). By increasing the number of radios, the multicast period decreases due to the possibility of simultaneous reception and transmission on different channels. An important point in this figure is the marked reduction from about five time slots to only one time slot by using assistance strategy and multiple radios in each node.

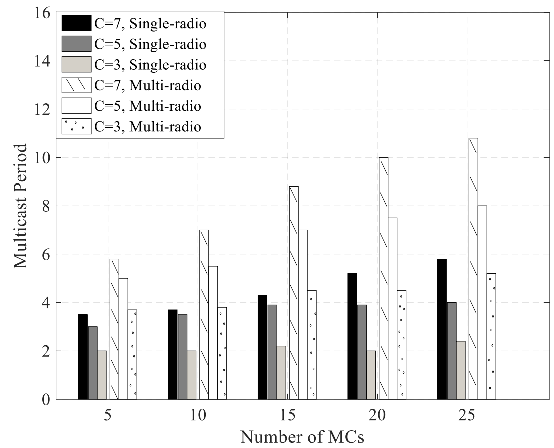


Fig. 8. Effect of number of channel on the multicast period for P_a= [80, 20, 0].

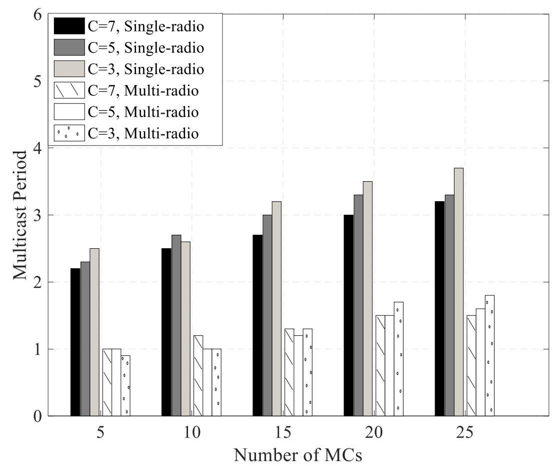


Fig. 9. Effect of number of channel on the multicast period for P_a= [0, 20, 80].

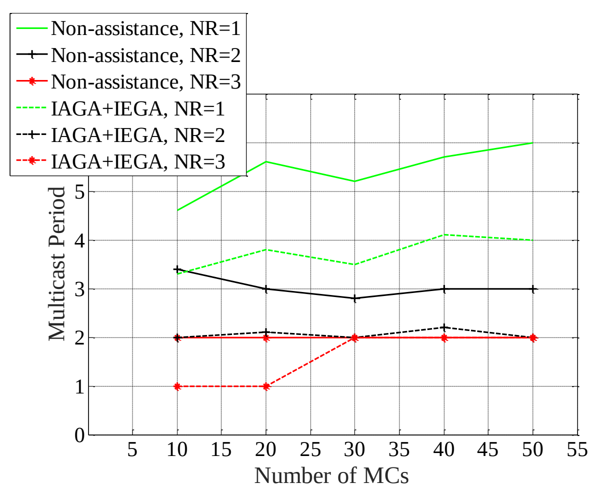


Fig. 10. Effect of number of radio on the multicast period.

Scenario #5: In the last scenario, we jointly investigate the effect of number of radios and multi-rate ability on the multicast period. To this aim, assuming C=3, g=2, P_a = [20 50 30], and non-assistance strategy, the number of nodes is varied from 10 to 50. The results are shown in Fig. 11. Taking the advantages of both rate and radio diversities significantly decrease the multicast period. In this regard, the state of "multi-rate, NR=3" shows much better performance than the other states. In this state, MMS selects the maximum available rate which MR can still cover the corresponding receivers. This not only covers all receivers of that transmission, but also efficiently reduces its occupied time slots.

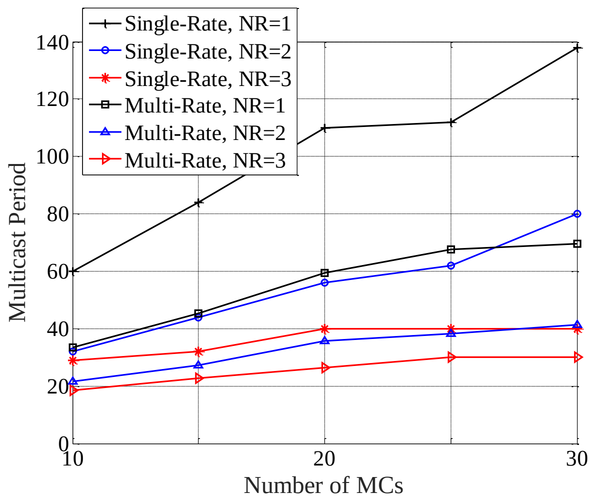


Fig. 11. Multicast period as a function of the number of MCs and number of radios for both single-rate and multi-rate stats

5. CONCLUSION

In this study, we jointly investigated the effect of using multi-radio and multi-rate technologies in CR-WMNs. In this regard, we proposed an efficient scheduling algorithm named MMS. It was found that using multi-radio nodes would lead to a reduction in the multicast period and increase the network throughput. The proposed scheme not only minimizes the number of number of transmissions, but also enjoys the advantages of high rates. In particular, we presented multiple scenarios to evaluate the effects of different parameters, including the number of MCs, channel diversity, number of radios, and rate diversity, on the network performance. Numerical results show the efficiency of the MMS algorithm.

REFERENCES

[1] S. Parvin, F. Khadeer, O. K. Hussain, S. Han, B. Tian, and E. Chang**, "Cognitive Radio Networks Security: A Survey, "***Journal of Net. and Commun. Application*, Vol. 35, No. 6, pp. 1691-1708, Nov. 2012.

[2] F. C. Commission, **"Spectrum Policy Task Force",** *Technical report,* Nov. 2002.

[3] X. Chen, Z. Zhao, T. Jiang, D. Grace and H. Zhang, **"Inter-Cluster Connection in Cognitive Wireless Mesh Networks based on Intelligent Network Coding,"** *EURASIP Journal. Adv. Signal Process,* Oct. 2009.

[4] A. A. El-Sherif and A. Mohamed, **"Joint Routing and Resource Allocation for Delay Minimization in Cognitive Radio Based Mesh Networks,"** *IEEE Trans. Wirel. Commun.*, Vol. 13, No. 1, pp. 186-197, Jan. 2014.

[5] T. Chen, H. Zhang, M. Matinmiko and M. D. Katz, **"CogMesh: Cognitive Wireless Mesh Networks,"** in *Proc. IEEE GLOBECOM Workshops*, Nov.2008, pp. 1-6.

[6] A. Avokh, G. Mirjalily, J. Abouei, and S. Valaee, **"On the Relationship between Multicast/Broadcast throughput and Resource Utilizations in Wireless Mesh Networks,"** *Hindawi, TSWJ*, Vol. 2013, Nov. 2013.

[7] J. Qadir, A. Baig, A. Ali, and Q. Shaf, **"Multicasting in Cognitive Radio Networks: Algorithms, Techniques and Protocols,"** *Journal of Net. and Commun. Application*, Vol. 45, pp. 44-61, Oct. 2014.

[8] W. Jihong, Sh. Wenxiao and J. Feng, **"On Channel Assignment for Multicast in Multi-Radio Multi-Channel Wireless Mesh Networks: A survey,"** *IEEE Journals and Mag.*, Vol. 12, No. 1, pp. 122-135, Jan. 2015.

[9] Z. Askari, A. Avokh, and M. D. Farzanegan, **"Low-Interference Multicast Routing in Multi-Radio Multi-Channel Wireless Mesh Networks Using Adaptive Directional Antennas,"** *Computer Communications*, Vol. 104, No. C, pp. 175-190, May 2017.

[10] A. Nasipuri and S. R. Das**, "Multichannel CSMA With Signal Power-Based Channel Selection For Multihop Wireless Networks,"** in *Vehicular Technology Conf. Fall 2000. IEEE VTS Fall VTC2000. 52nd Vehicular Technology Conference (Cat. No.00CH37152)*, Vol. 1, pp. 211–218.

[11] Nasipuri, J. Zhuang, and S. R. Das, **"A Multichannel CSMA MAC Protocol for Multihop Wireless Networks,"** in *WCNC. 1999 IEEE Wireless Commun. and Net. Conf. (Cat. No.99TH8466)*, pp. 1402–1406.

[12] O. Simeone, Y. Bar-Ness and U. Spagnolini, **"Stable Throughput of Cognitive Radios with and without Relaying Capability,** "*IEEE Trans. Commun*, Vol. 55, No. 12, pp. 2351-2360, Dec. 2007.

[13] B.J. Ko, V. Misra, J. Padhye, and D. Rubenstein, **"Distributed Channel Assignment in Multi-Radio 802.11 Mesh Networks,"** in *2007 IEEE Wireless Commun. and Net. Conf.*, 2007, pp. 3978–3983.

[14] Y. R. Kondareddy and P. Agrawal, **"Synchronized MAC Protocol for Multi-hop Cognitive Radio Networks,"** in *2008 IEEE International Conf. Commun.*, 2008, pp. 3198–3202.

[15] A. Avokh, G. Mirjalily, and J. Abouei, **"Joint**

Channel and Rate Selection for Multicast Routing Trees in Wireless Mesh Networks," *in Proc. of International Symposium on Telecommunications*, Nov. 2012. pp. 548-553.

[16] H. M. Almasaeid, T. H. Jawadwala and A. E. Kamal, **"On Demand Multicast Routing in Cognitive Radio Mesh Networks,"** in *Proc. IEEE GLOBECOM,* pp. 1-5, Dec. 2010.

[17] H. M. Almasarid and A. E.Kamal, **"Exploiting Multichannel Diversity for Cooperative Multicast in Cognitive Radio Mesh Networks,"** *IEEE/ACM Trans.*, Vol. 22, No. 3, pp. 770-783, Jun. 2014.

[18] H. M. Almasarid and A. E.Kamal, **"Assistance Multicast Scheduling in Wireless Cognitive Mesh Networks,"** in *2010 IEEE. ICC*, 2010, pp. 1-5.

[19] A. Avokh and G. Mirjalily, **"Interference-Aware Multicast and Broadcast Routing in Wireless Mesh Networks using both Rate and Channel Diversity,"** *Computer and Electronic Engineer*, Vol. 40, No. 2, pp. 624–640, Feb. 2014.

[20] P. Aravinda, K. Acharya, and E. M. Belding, **"MARS: Link-layer Rate Selection for Multicast Transmissions in Wireless Mesh Networks,"** *Ad-hoc Netw*, Vol. 9, No. 1, pp. 48–60, 2011.

[21] F. Aghaei, and A. Avokh**, "Throughput Improvement in Cooperative Multi-Radio Multi-Channel Cognitive Wireless Mesh Networks,"** *Journal of Intelligent Procedures in Electrical Technology*, Vol. 7, No. 27, pp. 27-40, 2016.