Priority-based Minimum Interference Channel Assignment Technique for Multi-Radio Multi-Channel Wireless Mesh Networks

Raja Hasyifah Raja Bongsu, Abdullah Muhammed, Shamala Subramaniam, and Mohamad Afendee Mohamed

***Abstract*—Wireless mesh networks (WMN) have been attracting the interest of many researchers in these recent years. Several researchers worked on the optimisation of network performances for multi-radio multi-channel WMN with constrained channel resources. Others demonstrated that partially overlapping channels could expand these limited resources. Where there are insufficient resources, interfered links may significantly impact the capabilities of the channel. The problems of channel assignment have been considered NP-hard problems. A PRIority-based Minimum Interference Channel Assignment (PRIMICA) algorithm has been developed to minimise the effect of interference on WMN efficiency by assigning the radio to the least-interfering available channel. Channels are assigned based on the priority weight of the interfering node with the lowest value. The proposed algorithm outperformed network throughput, packet loss ratio, and end-to-end delay, as demonstrated by performance simulation.**

***Index Terms*—Channel assignment, interference, multi-radio multi-channel, partially overlapped channels, Wireless Mesh Network**

I. INTRODUCTION

WIRELESS Mesh Networks (WMNs) provides multi-hop infrastructure which enables wireless services to various applications in metropolitan, university, local, and personal areas [1]. The number of users in WMNs is increasing due to the expansion of usage in e-commerce, audio streaming, file sharing, and printer sharing. The characteristics of spatial reuse, fault tolerance, and self-organisation are inherited from ad hoc networking and conventional wired networks [2]. WMNs provide low-cost [3, 4] and simple solutions for controlling and monitoring various applications.

A WMN is a type of wireless network that consists of multiple nodes connected to each other to form a mesh topology. This type of network is designed to improve the network capacity by allowing multiple routes for data transmission. In a multi-radio multi-channel (MRMC), mesh nodes are equipped with multiple radios and can use multiple channels to transmit data, further increasing network capacity. The WMN is depicted in Fig. 1 as a set of mesh clients (MC), mesh routers (MR), and mesh gateways (MG), with each node connected to the others through a wireless connection. The mesh gateway is linked to the Internet through wired links. MCs may be static or mobile, while MRs is usually immobile. MRs, which provides a multi-hop wireless mesh between the MCs and MGs for internet access, are the backbone of the WMNs [2]. MRs are responsible for distributing data traffic within the network. MGs act as gateways, providing mesh clients with internet connectivity through a wired connection. There are two types of channels in IEEE 802.11: orthogonal channels (OCs) and partially overlapped channels (POCs). OCs do not overlap with other channels in the frequency domain and are used channels 1, 6, and 11, while POCs overlap with other channels, as in Fig. 2.

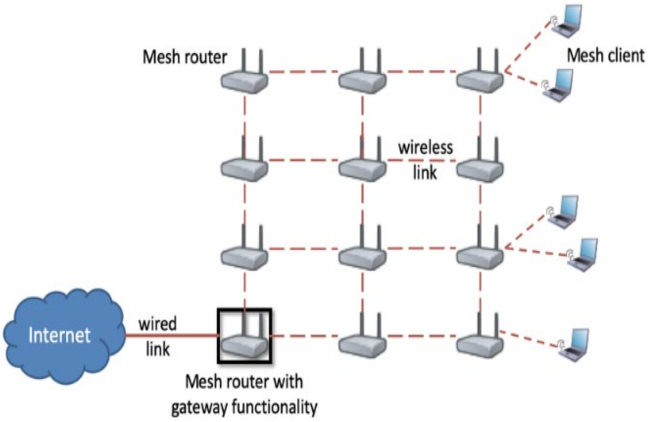


Fig. 1. The Wireless Mesh Network Infrastructure

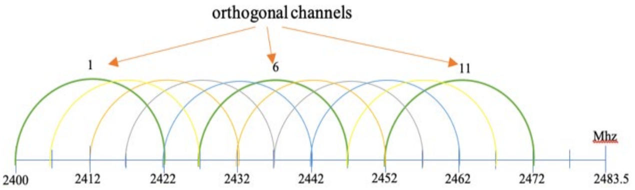


Fig. 2. Orthogonal channels and partially overlap channels

Manuscript received April 4, 2022; revised April 2, 2023.

Raja Hasyifah Raja Bongsu is a lecturer at the Faculty of Informatics and Computing, Universiti Sultan Zainal Abidin, Malaysia. (corresponding author, e-mail: rajahasyifah@unisza.edu.my).

Abdullah Muhammed is a professor at the Faculty of Computer Science And Information Technology, Universiti Putra Malaysia, Malaysia (e-mail: abdullah@upm.edu.my).

Shamala Subramaniam is a professor at the Faculty of Computer Science And Information Technology, Universiti Putra Malaysia, Malaysia. (e-mail: Shamala_ks@upm.edu.my).

Mohamad Affendee Mohamed is a professor at the Faculty of Informatics and Computing, Universiti Sultan Zainal Abidin, Malaysia. (e-mail: mafendee@unisza.edu.my).

Network capacity is one of the most critical criteria for evaluating network performance. Physical connections provide network or channel capacity, which indicates the maximum transmission rate. However, WMNs have restricted network capacity due to the interference caused by multiple links communicating simultaneously. Interference may occur inside communication links that connect pairs of wireless nodes if they use the same frequency channel due to their proximity and transmission power [5]. Estimating interference is a non-deterministic polynomial-time hard (NP-hard) problem [6].

Research has been done on channel assignment schemes focusing on preventing interferences to increase network throughput and improve of network capacity [7]. Several methods have been developed to determine the assignment for each radio and channel in WMNs. One effective way to mitigate the interference in WMNs is by using MRMC [8], equipping nodes with multi-radio interfaces and transmitting packets through multi-channel. The predicted correlation between the experimentally observed performance of a channel assignment deployed in WMNs and interference estimates may be significant.

Interferences can be avoided by assigning different links to the same channel. However, multiple sharing of the same channel can accumulate to an unacceptably high level of total interference at a single connection [8], [9]. This interference affects packet transmission, causing one or more re-transmissions, leading to substantial decreases in network performance [10]. It is Usually inevitable to assign the same channel for neighbouring nodes due to the unavailability of sufficient channels. Hence, the capabilities of parallel transmissions among nodes and network throughput will be limited.

Interference cannot be reduced due to the insufficient OCs in 802.11b/g. However, this issue can be alleviated by partly overlapping 802.11b/g channels in channel assignment. [10] demonstrated the utilisation of POCs with an enhancement of parallel transmission and network capacity. As a result, it effectively minimised network interference and increased network throughput. The findings also revealed that the interference range was related to channel separation. The minimum channel separation between channels should be 5. If it was less than 5, a significant amount of interference could occur. They suggested that properly utilising POCs for channel assignment could decrease the total interferences in WMNs. This is consistent with the finding of [11], which revealed that the throughput might be improved with POCs. The usage of multiple radios and the efficient use of POCs provided a notable improvement in parallel transmissions and network throughput. Quality of Service (QoS) is an important aspect in WMNs as it ensures that critical data is transmitted with a higher priority and reliability. A WMN with MRMC capability and proper QoS implementation can greatly improve network capacity and ensure reliable data transmission.

The paper is organised into four main sections. The first section introduces the fundamentals and structure of MRMC WMNs, followed by a detailed overview of the concept. In Section 2, several relative works in channel assignment approaches are described. Section 3 proposes a PRIority-based Minimum Interference Channel Assignment (PRIMICA) algorithm to assign channels for each link in the WMNs to overcome the limitations of the current approach. The performance of PRIMICA is presented in Section 4, which includes the examination of its effectiveness in network throughput, end-to-end delay, and packet loss ratio. Section 5 summarises the findings of this paper. The experimental steps are summarised as follows:

1. A traffic-irrelevant channel assignment model is used, and each link is assigned a channel before transmitting data to improve channel assignment.
2. Compared to peer-to-peer, traffic is more concentrated between the Internet and clients.
3. The interference range is theoretically calculated to increase network throughput compared to the interference range obtained by field measurement.

II. Related works

Network capacity is a vital aspect when developing a channel assignment. According to previous findings, Load-Aware Channel Assignment (LA-CA), as customised by [12], orders the links in descending order based on traffic loads. At the same time, Mesh-based Traffic and Interference aware Channel assignment (MesTic), developed by [13], ranked the links based on traffic load, connection distance from the gateway, and the number of interfaces per node. The MesTic rate formula was proposed and improved by the Centralised Rank Based Channel Assignment (CRB-CA) algorithm [14], which combined the connection efficiency and linked the loads with the link distance and several interfaces. The MR assumed a stationary position and was fitted with two radios but did not utilise POCs.

As mentioned earlier, a better interference model identifies the effects of POCs interference. Currently, several well-known interference models are available. For example, Connected Low Interference Channel Assignment (CLICA), established by [15], considers three other constraints regarding network capacity to control the proposed model's interference level. CLICA could ensure network connectivity and stability while assigning channels. However, CLICA does not qualify the queuing delays or switching delays. It is also not promising to minimise interference and maximise network throughput.

Adaptive Dynamic Channel Allocation (ADCA), developed by [16], focuses on throughputs and delays to lower packet latency while maintaining network performance in a hybrid architecture. ADCA is ineffective in congested traffic and ignores interference and environmental consequences. In comparison, Topology-controlled Interference-aware Channel Assignment (TICA), introduced by [17], use the edge-colouring principle in assigning channels to links by reducing interference from co-channels, leading to greater network throughput. TICA is centralised and quasi-static and completely ignores external interference, traffic load, queuing delay, and environmental effects. Another researcher [18] proposed a centralised channel assignment scheme for multi-radio multi-channel wireless mesh networks. The channels are assigned to the connection to reduce total network interference while increasing network capacity using POCs.

As discussed in [19], the frequency channel is a wireless network's most critical and limited resource. Many studies have been conducted to find ways to minimise these interferences and improve throughput. One way is to assign limited channels to network interfaces in a multi-radio multi-channel wireless mesh network. Network throughput can be optimised with full utilisation of OCs and POCs by formulating the optimal channel assignment problem. The network capacity is usually inversely proportional to the neighbour node degrees for many interfaces and nodes. Since network connectivity and network capacity are linked, it's critical to improve network capacity while accounting POCs to ensure good network cohesion.

Several studies have been developed based on the Two-ray Ground model as an interference model. A model and applied path loss of the signal have been developed by [20], [21]. According to the theoretical approximation, co-channel interference is calculated based on node power and antenna gain. On the other hand, the carrier sensing threshold may determine the adjacent channel interference. Compared to measurement results, theoretical results may accurately predict the relationship between channel spacing and the POC interference range. POCs have been used by [20], [21] to introduce a channel algorithm which assigns the channels to access and support networks with different frequency bands for end-to-end transmission.

The Partially Overlapped Channel Assignment (POCA) algorithm proposed by [20] considered network traffic to minimise total network interference but not considered distributed channel assignment. POCA reduced the number of frequency channels used in WMNs while improving network performance and allowed mesh routers to use partially overlapped channels to establish mesh links with their neighbours, leading to improved network capacity, coverage, and robustness. However, POCA less capable in interference management so that, it can optimize WMNs.

The End-to-end Load-Aware Partially Overlapped Channel Assignment (ELIA-POCA) modelled by [21] revealed that load-aware channel assignment can be applied to networks. ELIA-POCA improved the channel assignment process in WMNs and considered the end-to-end traffic load in the network, resulting in a more balanced network load and improved network performance. However, ELIA-POCA lack in handling dynamic network conditions and complex network environments.

In comparison to OCs, POCs have a much smaller interference spectrum. The range decreases as the frequency channel separation increases, with non-overlapping channels experiencing a complete reduction. [22] suggested a model to improve WMN throughput by minimising interference between co-located interfering links using the IEEE 802.11 standard's optimised spectral re-usability of joint channels. Although the model satisfies the network's connectivity constraint, it distributes network resources equally among the interfering links.

Min-interference and Connectivity based Partially Overlapped Channels Assignment (MC-POCA) algorithm [23] adjusted the connectivity factor to improve the network performance. The adjustment of the factor is overwhelmed by channel interference. Consequently, it increased the average response delay because the users must wait for the next listening window to receive a message. Moreover, frequent transitions may result in a high average delay.

Interference between neighbouring links is a drawback of multi-hop wireless networks. Each node in a multi-hop environment can transmit new packets and forward those received from other nodes [24]. Some previous researchers designed a channel assignment model by considering mathematical methods and other factors such as channel interference [7], [8], [25]. Various models have been proposed for the interference model and used an undirected graph to show the interference relation among links in the network. For example, [25] and [26] used the conflict graph, while [15] and [27] applied the connectivity graph for unicast communications in WMNs with the utilisation of OCs for data transmission.

According to TABLE I, the channel assignment algorithm with POC utilisation will dramatically increase network efficiency due to WMN's current network ability and interference issues. The PRIMICA with efficient interference avoidance is presented to improve network throughput and reduce packet loss rate.

The significant difference between the proposed PRIMICA with POCA and MC-POCA algorithms is how to effectively allocate the available radios and channels among the routes. The proposed PRIMICA consider channel conditions before assigning a channel. A PRIMICA is proposed to identify and avoid nodes or channels with high interference to overcome the weakness of POCA and MC-POCA. Different from POCA and MC-POCA, PRIMICA considers the channel conditions. The load conditions at the current node, neighbouring nodes and interfering nodes are also considered.

TABLE I
ANALYSIS OF CHANNEL ASSIGNMENT ALGORITHM

Algorithm	**Used POC**	**Interference**	**PLR**	**Network Throughput**	**Delay**
[14]	-	-	-	/	-
[17]	-	/	-	/	-
[16]	-	/	-	/	/
[25]	-	/	-	/	-
[18]	-	/	-	/	-
[20]	/	/	/	/	/
[21]	/	/	/	/	/
[27]	-	/	-	/	-
[22]	/	/	-	/	-
[8]	/	-	-	/	/
[23]	/	/	/	/	/
[26]	/	/	/	/	/
[7]	-	/	/	/	/

III. PRIORITY-BASED MINIMUM INTERFERENCE CHANNEL ASSIGNMENT

PRIMICA proposed a channel assignment algorithm for WMNs to reduce the interferences of the total network. The proposed algorithm considers both the Internet and clients and also peer-to-peer traffic. Peer-to-peer traffic occurs at layer 1 OSI, a physical layer to forward packets to neighbours. Mesh occurs at layer 3 OSI, which provides multi-hop facilities. This algorithm uses various channel selection parameters to use all of the WMNs' available channels. The best channel should be chosen for each connection based on these selection criteria to reduce total interference in all sessions. The main aim is interference minimisation to ensure that a high-priority link does not receive more interference than a low-priority link.

Nodes for the mesh backbone are fixed and equipped with two wireless network interfaces. Links between nodes are considered undirected, with one link for each direction. Based on IEEE 802.11, the symmetric interference protocol is ideal for obtaining real-time interference and ensures successful communication over an undirected connection. Since it requires receiving the link-layer reply packet from the receiving endpoint, the transmitting endpoint must be free of interference. Thus, there should be no transmission for two endpoints of the links within the interference range. Fig. 3 represents the nodes and links to discover the distance between neighbours.

PRIMICA establishes a topology by deciding which node's interface communicates with its neighbour. The topology discovery will determine the number of nodes that interfere and the distance to the mesh gateway. The distance between the node and the mesh gateway indicates the number of hops. Then, PRIMICA assigns a channel to each connection based on the interference constraint by minimising total network interference. In the case of links with the same interference constraint value, priority is given to links with a higher degree and the minimum hop count from the gateway. The primary purpose of the proposed PRIMICA is priority-aware interference mitigation for all nodes in WMNs.

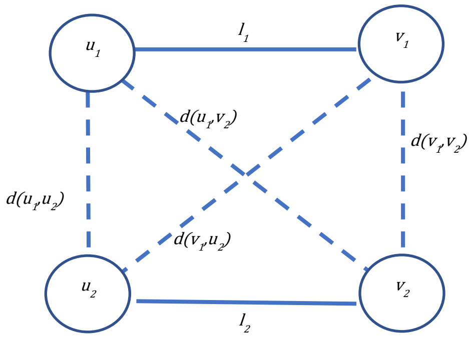


Fig. 3. Distances for each node

A. Interference Constraint Model

The study focuses on WMN, which is described as MR connected to the nearby MR in a one-hop distance and has multi-hop transmission capability. The assumption is all MR are stationary. The corresponding MR has a further intention compared to MC in analysing the network improvement because the backbone network mainly determines the performance of WMNs [28]. The broadcasting nature of wireless links in WMN impacts packet transmission between node nodes i and j, if node j is within the interference range of node i. As referred to [28], the interference model defines interference. The distance $d(l_1,l_2)$ between link $l_1=(u_1, v_1)$ and $l_2=(u_2, v_2)$ is defined as the shortest distance between any two links l_1 and l_2, that is:

$$d(l_1,l_2) = \min (d(u_1,u_2), d(u_1,v_2), d(v_1,u_2), d(v_1,v_2)) \qquad (1)$$

The two-hop interference model interprets the interference range in a WMN as twice its communication range [29]. This model calculates the interference relation based on the distance between two nodes. The interference relationship ($I(i,j)$) is considered the distance between links and channel separation when two nodes know the channels they use. $|c_i - c_j|$ is the channel separation between nodes i and j, with c_i and c_j denoting the two nodes' respective channels. There are 11 channels usable in an IEEE 802.11 b/g-based WMN. The interference range varies with channel separation, as shown in TABLE II [15].

TABLE II
IDEAL SPECTRUM FOR INTERFERENCE RANGE RATIOS

Channel Separation	**Interference Range**
0	2.0R
1	1.2R
2	0.7R
3	0.5R
≥5	0R

R denotes the interference range for two links $l_1 = (u_1, v_1)$ and $l_2 = (u_2, v_2)$. The channel separations involve six classes: 0, 1, 2, 3, 4, and ≥5. The channel separation is 5 or greater, indicating the channel's most massive interference. For any two nodes, the corresponding potential channel separations range from 0 to 10. If the channel separation is less than 5, then no interference occurs.

Eq. (2) shows how the separation and distance of the channel between nodes i and j are utilised to define the relationship as a binary variable.

$$I(i,j) = \begin{cases} 1, & d(i,j) \leq interfereR(|c_i - c_j|) \\ 0, & d(i,j) > interfereR(|c_i - c_j|) \end{cases} \qquad (2)$$

where $interfereR(|c_i - c_j|)$ is the interference range for channel separation, with $d(i, j)$ the distance from i and j nodes. Interference can only occur while nodes are within the interference range of each other. We use theoretical computation for $interfereR(|c_i - c_j|)$.

The form of interference distinguishes an undirected connection from a directed link. A directed link has asymmetric interference, while an undirected link has symmetric interference. Supposedly, the recipient of an addressed connection wishes a packet from the sender to be received successfully. As the sender requires the recipient's link-layer acknowledgement, there should be no transmissions of nodes in the interference range. In that case, it does not expect a node within the interference range of the recipient to transmit.

Channel assignment for all connections occurs before any data flow transmissions throughout the network. When the scheme is performed, no channel or link workload and no modifications to channel assignment are required regardless of the sources and destinations of the network's transmitted traffic. A traffic-irrelevant channel assignment scheme helps eliminate the need for traffic-relevant channel assignment schemes to adapt to workload changes. So, node-to-node connections are considered undirected. Therefore, we apply the symmetric interference model in Eq. (2) to satisfy the IEEE 802.11 MAC protocol and provide efficient communication across an undirected connection. Furthermore, we must first locate the actual interference links before determining the channel assignment.

The interfering nodes used Eq. (2) for validating a node-to-node interference with all potentially interfering nodes in the channel assignment. For node *i*, the corresponding weight, w_i, can be expressed as in Eq. (3) where n_i represents the number of nodes that interfere with node *i* and h_i represents the hop count distance from node *i* to the gateway.

$$w_i = \frac{n_i}{h_i} \tag{3}$$

The average number of interfering nodes ($INcons_i$) for node *i* determines its interference limitation. The maximum number of nodes on the topology that potentially interferes with node *i*, ($MaxIN_i$) is used to calculate $INcons_i$ as follows:

$$INcons_i = \sum_{k=1}^{Max\_IN_i} \binom{Max\_IN_i}{k} \times k \times \left(\frac{6}{11}\right)^k \times \left(\frac{5}{11}\right)^{Max\_IN_i - k} \tag{4}$$

where 6/11 and 5/11 represent the probabilities of interference between node *i* and one of its potentially interfering nodes. Based on Eq. (3) and Eq. (4), the interference constraint setting for each node is calculated by evaluating the weight and the average number of the interfering node. The interference cost ($interCost_i$) for each node is calculated using the following equation:

$$interCost_i = INcons_i + w_i \tag{5}$$

Detailed implementation of how to calculate interference constraint is shown in Algorithm 1.

Algorithm 1. Interference Constraint

```
Valid ← 1
Eq. (4)← 0
foreach node $j$ in the possibly interfering node set of $i$
    if node $j$ has been assigned channel
        determine value $I(i,j)$
        if $I(i,j) > 0$
            if $w_j > w_i$
                if the delay constraint of node $i$ violated to using this channel
                    valid ← 0
                    break
                end if
            end if
            Eq. (4)← Eq. (4) + 1
        end if
    end if
```

B. Channel Assignment

Since the number of radios on a node may be smaller than the number of channels available, the number of various channels assigned to the node's links must not exceed the number of radio interfaces [6]. Each node selects its best channel to minimise interference, as shown in Algorithm 2.

Algorithm 2. Channel Assignment

```
$Int_{C_{ch}}^{i} \leftarrow \sum_{n_j \in S_i} I(i,j) \times interCost_i$
if Eq. (7) < Eq. (8)
    bestChannel ← $ch$
    Eq. (8)← Eq. (7)
end if
```

Since each node has many interfering nodes, the best channel for each node cannot be determined independently. When two or more nodes are close, their channel preferences are affected by one another. As a result, the order of channel assignment for a node and its interfering nodes must be calculated. Eq. (6) refers to the maximum interfering costs, $Max_{Int_{ch}i}$ to determine the order of channel assignment among nodes in PRIMICA. S_i is the node that interfere with node *i*.

$$Max_{Int_{ch}i} = \sum_{n_j \in S_i} interCost_j \tag{6}$$

where n_j is a node that interferes with node i and $interCost_j$ is a node n_j's priority weight. A higher priority weight interfering node causes a higher interference cost, nodes with a larger are prioritised in channel selection to minimise interference based on the descending order arrangement.

Algorithm 3 depicted how PRIMICA solved the problems.

Algorithm 3. PRIMICA

```
foreach node $i$ in $V$
calculate $Max\_IN_i$
foreach node $j$ in the interfering node set of $i$
    calculate $Max\_IN_j$
    if $Max\_IN_i < Max\_IN_j$
        $AC$ ← Φ do
        foreach channel $ch$ in $CH$
            Interference Constraint Setting
        end for
        Eq. (8)← ∞
        foreach channel $ch$ in $AC$
            Channel Assignment
        end for
    end if
end for
end for
```

Some qualified channels (*ch*) may satisfy each of the requirements above after checking all available channels. As in algorithm 2, Eq. (7) determines the interference cost for each qualifying channel ($Int_{C_{ch}}^{i}$) for node *i*. For instance, if node *i* interferes with node *j* (*I(i,j)=1*) as in Eq. (2) and the interference cost is applied to $Int_{C_{ch}}^{i}$ Because communication between node *i* and node *j* using *ch* cause interference.

$$Int_{C_{ch}}^{i} = \sum_{n_j \in S_i} I(i,j) \times interCost_i \tag{7}$$

where S_i refers to all interfering nodes for node i. The interference cost of each node on the network is accumulated by computing $Int_{C_{ch}}^{i}$ on a node-by-node basis. Finally, Eq. (8) discover the optimal channel by comparing all eligible channel assignments to decide which one has the lowest value of $Int_{C_{ch}}^{i}$, where *AC* denotes the set of appropriate channels for node *i*.

$$\underset{c \in AC}{Minimum}\, Int_{C_{ch}}^{i} \tag{8}$$

IV. PERFORMANCE EVALUATION

Detailed numerical tests were used to determine the accuracy and efficiency of the proposed PRIMICA algorithm based on the results of several experiments. Our topology model used infrastructure mesh networks in a grid and random topology. All of the nodes in the mesh backbone were fixed and placed 250m from each other. A free-space path loss model was applied to attenuate the signal strength, and Rayleigh distribution was considered to impact a distribution environment. A random topology was created using 60 nodes and 5 to 14 flows. TABLE III shows the simulation parameters for PRIMICA.

TABLE III
IDEAL SPECTRUM FOR INTERFERENCE RANGE RATIOS

Simulation Parameters	Values
Simulation time	100s
Size of grid	5x5/6x6/7x7/8x8/9x9/10x10
System bandwidth	2Mbps for IEEE 802.11b standard 6Mbps for IEEE 802.11a standard
Traffic source	CBR (UDP)
Flow type	Peer-to-peer traffic and Internet-oriented traffic co-exist
Packet sending rate	2Mbps
Packet size	512bytes
Transmission range	250m
Co-channel interference range	550m
Antennas	Omni-directional
Number of flows	5~14
Channel used	1~11
Simulator	OmNET++4.6

Three performance metrics were used to evaluate PRIMICA: network throughput, end-to-end delay, and packet delivery ratio. The network throughput was determined by the amount of data received at the destination divided by the first and last received packet duration. When a packet leaves the source and arrives at its destination, the time is known as the end-to-end delay. The average end-to-end delay of all received packets was then calculated. The packet loss ratio was calculated by dividing the total number of packets sent by the total number of packets lost. The average packet loss ratio was taken from all the receivers.

Multiple experiments with PRIMICA were carried out to determine its quality. The first series of tests compared the throughput obtained by both schemes as a function of network size. In the second series of experiments, the impact of end-to-end delay was investigated in a multi-hop environment with varying network sizes. The packet distribution ratio was studied in a multi-hop mesh environment by adjusting the number of mesh routers in the final experiments. The tests were repeated ten times with various packet sources or destinations to reduce errors and unpredictable effects, and an average is shown in the graphs.

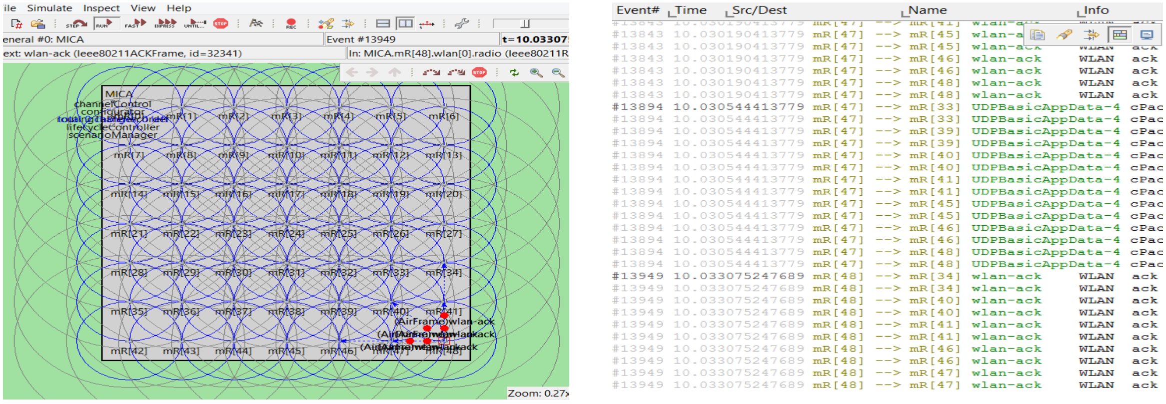
A. Simulation Results

Simulation experiments have been conducted to investigate how the network size influences the network performance with a specified amount of CBR flows. The grid dimensions vary from 5x5 to 10x10. After completing the channel assignment, packets are transmitted to the destinations according to the identified traffic flows in some consecutive timeslot. Fig. 4 represents the simulation environment. Fig. 4(a) shows the simulation of a WMNs with grid 7x7, while Fig. 4(b) displays the details of the simulation event. Fig. 4(c) shows the list of packets from which the source arrived at which destination.

The performance evaluation of PRIMICA in grid networks is presented in Fig. 5, revealing valuable insights into the impact of network size on its throughput, delay and packet loss ratio. As depicted in Fig. 5(a), the network throughput of PRIMICA surpasses that of MC-POCA and POCA for all network sizes, indicating its potential to facilitate more parallel transmissions, reduce end-to-end delays, and enhance network throughput.

Similarly, Fig. 5(b) shows that PRIMICA outperforms MC-POCA and POCA in terms of average end-to-end delay, especially for larger networks, achieving a significant reduction of up to 50% in packet transmission delay. It is worth noting that heavy interference in the 5x5 grid causes PRIMICA to experience more delay compared to other network sizes. Overall, the results suggest that larger network sizes provide more opportunities for PRIMICA to perform efficiently and effectively.

Furthermore, Fig. 5(c) highlights that PRIMICA delivers a lower packet loss ratio compared to MC-POCA and POCA, particularly for larger networks, except for small network sizes where the limited network resources constrain their ability to handle all transmissions. In an 8x8 network grid, PRIMICA and MC-POCA exhibit similar packet loss ratios, whereas assigning a 5x5 network grid to different channels may result in a higher average packet loss ratio and longer average end-to-end delay.



```
Event#  Time              Src/Dest                Name                  Info
#13843 10.030190413779 mR[47] --> mR[45] wlan-a
#13843 10.030190413779 mR[47] --> mR[45] wlan-ack
#13843 10.030190413779 mR[47] --> mR[46] wlan-ack          WLAN   ack
#13843 10.030190413779 mR[47] --> mR[46] wlan-ack          WLAN   ack
#13843 10.030190413779 mR[47] --> mR[48] wlan-ack          WLAN   ack
#13843 10.030190413779 mR[47] --> mR[48] wlan-ack          WLAN   ack
#13894 10.030544413779 mR[47] --> mR[33] UDPBasicAppData-4 cPac
#13894 10.030544413779 mR[47] --> mR[33] UDPBasicAppData-4 cPac
#13894 10.030544413779 mR[47] --> mR[39] UDPBasicAppData-4 cPac
#13894 10.030544413779 mR[47] --> mR[39] UDPBasicAppData-4 cPac
#13894 10.030544413779 mR[47] --> mR[40] UDPBasicAppData-4 cPac
#13894 10.030544413779 mR[47] --> mR[40] UDPBasicAppData-4 cPac
#13894 10.030544413779 mR[47] --> mR[41] UDPBasicAppData-4 cPac
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#13894 10.030544413779 mR[47] --> mR[48] UDPBasicAppData-4 cPac
#13894 10.030544413779 mR[47] --> mR[48] UDPBasicAppData-4 cPac
#13949 10.033075247689 mR[48] --> mR[34] wlan-ack          WLAN   ack
#13949 10.033075247689 mR[48] --> mR[34] wlan-ack          WLAN   ack
#13949 10.033075247689 mR[48] --> mR[40] wlan-ack          WLAN   ack
#13949 10.033075247689 mR[48] --> mR[40] wlan-ack          WLAN   ack
#13949 10.033075247689 mR[48] --> mR[41] wlan-ack          WLAN   ack
#13949 10.033075247689 mR[48] --> mR[41] wlan-ack          WLAN   ack
#13949 10.033075247689 mR[48] --> mR[46] wlan-ack          WLAN   ack
#13949 10.033075247689 mR[48] --> mR[46] wlan-ack          WLAN   ack
#13949 10.033075247689 mR[48] --> mR[47] wlan-ack          WLAN   ack
#13949 10.033075247689 mR[48] --> mR[47] wlan-ack          WLAN   ack
```
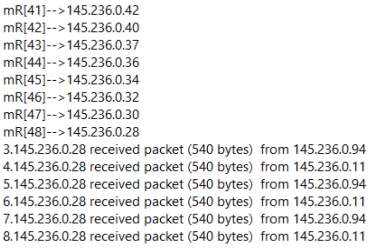

(a) The simulation for grid 7 x 7

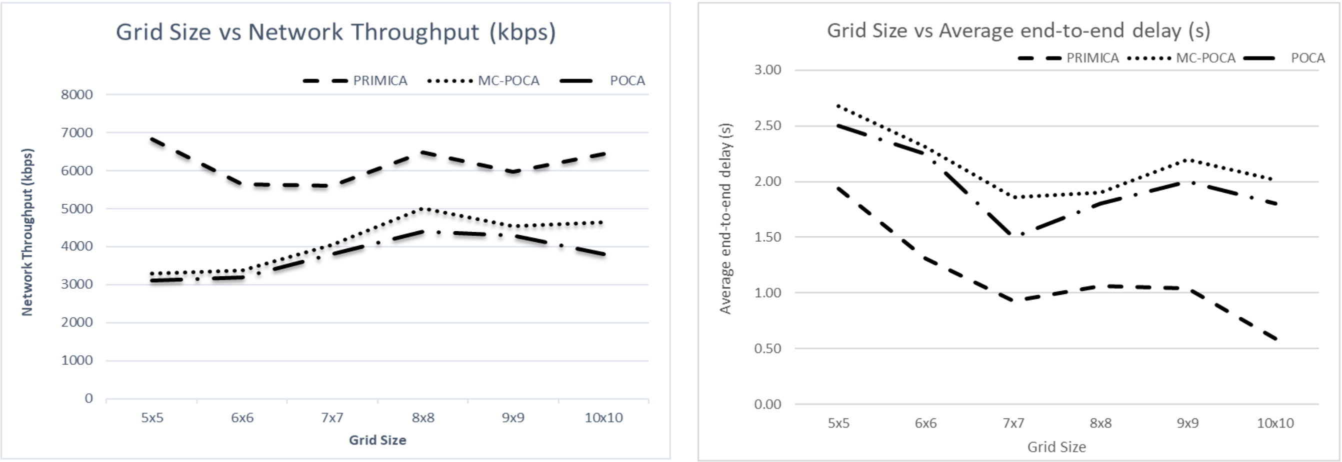
(b) The detail of the simulation event



```
mR[41]-->145.236.0.42
mR[42]-->145.236.0.40
mR[43]-->145.236.0.37
mR[44]-->145.236.0.36
mR[45]-->145.236.0.34
mR[46]-->145.236.0.32
mR[47]-->145.236.0.30
mR[48]-->145.236.0.28
3.145.236.0.28 received packet (540 bytes)  from 145.236.0.94
4.145.236.0.28 received packet (540 bytes)  from 145.236.0.11
5.145.236.0.28 received packet (540 bytes)  from 145.236.0.94
6.145.236.0.28 received packet (540 bytes)  from 145.236.0.11
7.145.236.0.28 received packet (540 bytes)  from 145.236.0.94
8.145.236.0.28 received packet (540 bytes)  from 145.236.0.11
```

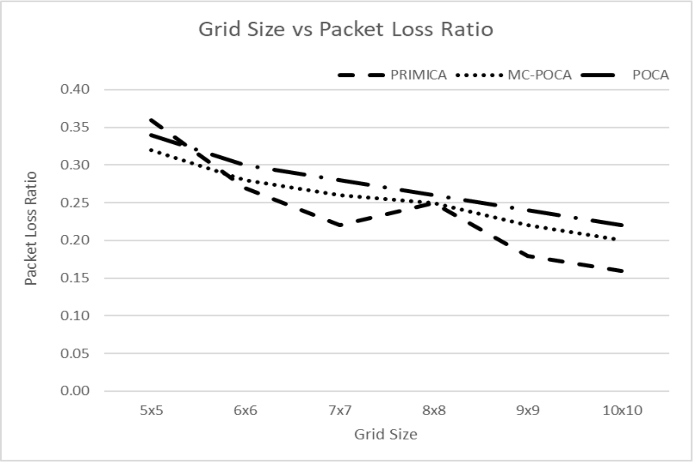
(c) The list of the packet received

Fig. 4. The simulation environment



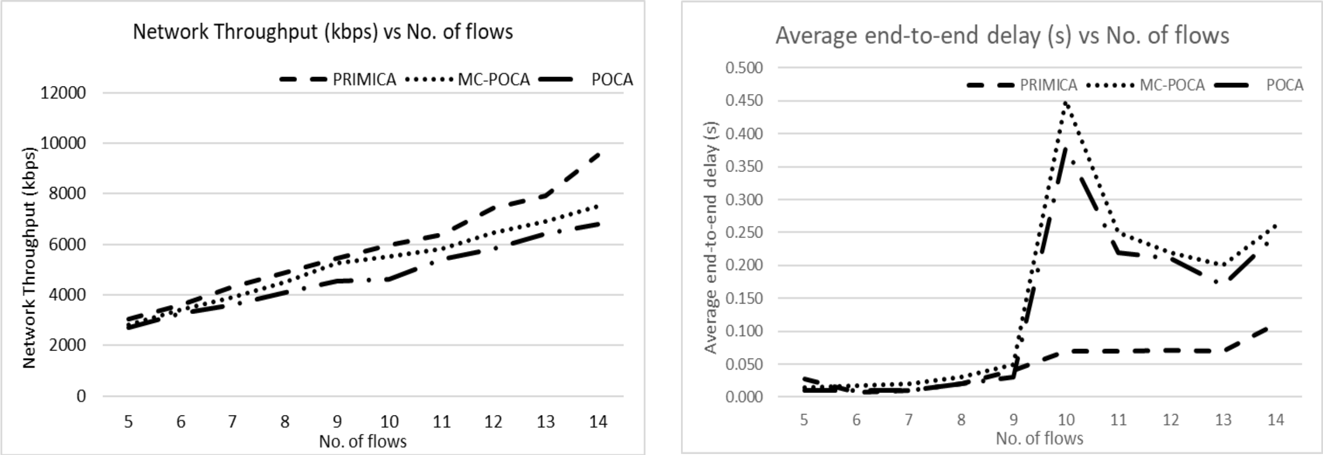
(a) Network throughput vs network size

(b) Average end-to-end delay vs network size



(c) Packet loss ratio vs network size

Fig. 5. Simulation Result for Grid Topology



(a) Network throughput vs number of flows

(b) Average end-to-end delay vs number of flows

Fig. 6. Simulation Result for Random Topology

Overall, the findings underscore the critical role of network size in influencing the performance of PRIMICA, with larger networks offering greater potential for enhancing its throughput, reducing delay, and minimizing packet loss.

Figure 6 represents the performance results of PRIMICA in a random network. We can observe that the performance of PRIMICA method is consistently better than that of the other two methods (MC-POCA and POCA) across all flow sizes as shown in Fig. 6 (a). Additionally, it is also evident that the network throughput of all methods generally improves with an increasing number of flows processed. The figure indicates that the PRIMICA method achieves the highest network throughput for all flow sizes, followed by MC-POCA and POCA.

Fig. 6 (b) shows that the performance of the PRIMICA method is generally better than that of the other two methods for all flow sizes. Additionally, we can observe that the performance of all methods tends to improve as the number of flows processed increases. For example, while the performance of PRIMICA and POCA methods remains relatively stable across flow sizes, the performance of the MC-POCA method appears to deteriorate significantly as the number of flows processed increases beyond 10 flows. The values indicate that the PRIMICA method generally achieves the lowest average end-to-end delay across all flow sizes, followed by POCA and MC-POCA. However, based on the data provided, it appears that the PRIMICA method is generally the most effective for processing flows, followed by the POCA method, and the MC-POCA method is the least effective for processing larger numbers of flows.

In general, achieving high network throughput and low average end-to-end delay are both important considerations in network performance. The PRIMICA appears to perform well in both metrics and may be a good choice for many network applications. The PRIMICA method generally achieves the highest network throughput and lowest average end-to-end delay, while the MC-POCA method appears to perform the worst in both metrics, especially for larger numbers of flows.

PRIMICA can eliminate interference and the parallel transmission of more flows, thus improving network performance. PRIMICA's network throughput increases with the increase in network size since a more extensive network allows for more parallel transmissions, giving them more opportunities to demonstrate their ability to reduce end-to-end delay and increase network throughput. When channel resources are fully utilised, the network throughput can be increased up to 55%. PRIMICA also has a significantly shorter average end-to-end delay than MC-POCA and POCA. With PRIMICA, packets may reach their destinations quickly, improving network throughput even if the packet loss ratio is higher. It is anticipated that, if POCs are exploited properly, the average end-to-end delay can be decreased by 54%, which is important, especially for time-sensitive traffic.

V. CONCLUSION

In scientific literature, the partially overlapped channels assignment algorithm is frequently used to increase the capacity of wireless mesh networks, especially when dealing with dense topology networks. This paper proposed a PRIMICA algorithm that can reduce network interference among nodes. Nodes with multiple interfaces transmitting packets on different channels will improve the performance of WMNs. While numerous advantages, this network has some drawbacks due to poor channel utilisation. Based on the results, PRIMICA is recommended for interference mitigation to optimise channel utilisation. PRIMICA may support higher throughput with reasonable delays and packet loss ratio. The results also prove that the proposed algorithm could improve network efficiency. Our initial goal has been to emphasise on channel assignment and current routing protocols for WMNs built for multiple radios. But this study has opened room towards the study to improve the efficiency of this method by combining it with a routing protocol. The channel assignment integrated with routing will be used in our future works to achieve this.

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