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Topology Preservation Low Interference Channel Assignment in Multi-Radio Multi-Channel Wireless Mesh Networks

Ashraf Alzubir and Adil A A Saed

Abstract The wireless network technologies have been popping up everywhere and becoming more popular day by day. Wireless Mesh Network (WMN) is one of the promising wireless technologies that provide effective, innovative and multi-hop solutions to provide the Internet connectivity to large number of mesh routers with a low cost of construction. The interference problem between wireless links is critical and challenging problem faced in networks that affects overall throughput. Hence, interference problem can be mitigated through efficient utilization of non-overlapping channels. Moreover, the multiple radios that are installed in each mesh router which operates in distinct channels enables the mesh routers to transmit packets simultaneously, resulting in increased throughput of the network. In this paper, the researchers propose a novel algorithm Topology-preservation Low-interference Channel Assignment (TLCA) that aims to reduce the interference problem between the wireless links and maintaining on network connectivity. TLCA ensures the capacity of the network is increase by efficient utilization of the limited available resources among the wireless links while satisfying the connectivity constraint of the network. TLCA distributes the channels between wireless links based on the radio status of the two nodes constitutes the target link and the behavior of CSMA/CA MAC protocol. Simulation results reveal improved performance of proposed scheme in terms of mitigating interference problem and enhance overall throughput of network as compared to existing work.

Keywords: Wireless Mesh Network, Channel Assignment, Interference, Multi-Channel, Multi-Radio, Throughput.

I. Introduction

Recently, the wireless mesh networks (WMN) have gained considerable attention due to their flexibility in building the multi-hop wireless access networks, solution for high capacity internet access and low-cost deployment [1-3]. In addition, WMNs has ability to integrate with various existing network technologies such as Wireless Sensor Networks (WSNs), cellular, Wireless-Fidelity (Wi-Fi) and Worldwide Interoperability for Microwave Access (WiMax) [2, 4, 5]. This feature of combined networks helps to enhance the communication reliability and increasing the coverage range of the given areas. The WMNs usually consist of Mesh Clients Set (MCS), Mesh Routers Set (MRS) and Mesh Gateways Set (MGS) [6, 7]. The mesh clients set (MCS) represent the end user devices such as laptops, cell phones and other wireless devices. In IEEE 802.11s standard, each MCS has only one interface for connecting through the frequency spectrum [8]. The mesh routers set (MRS) act as the backbone of the network topology. MRS has ability to connect the mesh clients set with the mesh gateways set through multi-hop environment. Furthermore, the mesh router supports the simultaneous transmission to increase the capacity of the network[9, 10] because each mesh router is equipped with multi-interface to connect with multi-channels in the network topology [11].The radio interfaces of the two routers can communicate with each other if they have common channel between them and are located within the transmission range of each other. The mobility of the mesh routers is extremely limited as compared to mesh clients set. Some of these mesh routers act as a mesh gateways set (MGS) to connect the local network with internet via wired connection.

In WMNs, the IEEE 802.11b/g and IEEE 802.11a standards have capability to support the environment of the wireless networks having three and twelve non-overlapping channels in the 2.4GHz and 5.0GHz band respectively [12-14]. Therefore, the aforementioned limitation of the non-overlapping channels increases the probability of interference problem between the adjacent links in the multi-hop networks. The interference problem is the critical factor in reducing the throughput of the wireless mesh network [15]. In

Dr. Ashraf Alzubier Mohmmmad is assistant professor in the International University of Africa (IUA) – Faculty of Computer Studies, Khartoum –Sudan.
He is now a head of information technology department in IUA, (ashrafali@iua.edu.sd).
Dr. Adil Ali A Saed is assistant professor in the International University of Africa (IUA) – Faculty of Computer Studies, Khartoum – Sudan.
He is now a head of information system department in IUA, (adil.sudan@gmail.com).

the literature, the interference aware channel assignment schemes in multi-radio multi channels are developed to enhance the throughput of the network through mitigating the interference problem while maintaining on the network connectivity [16, 17]. Equitable distribution of non-overlapping channels between the wireless links helps to reduce the impact of interference problem in a given network topology. Usually, the channel assignment algorithms depend on the interference models to capture the impact of interference between the wireless links. In literature, many interference models used to capture the effect of interference problem between the wireless links [18].

In this paper, a novel algorithm called Topology-preservation Low-interference Channel Assignment (TLCA) is proposed for interference channel assignment. TLCA aims to reduce the interference problem between the wireless links and maintaining on network connectivity. Further, the design of the static and centralized multi-radios multi-channels assignment scheme in TLCA is based on the concept of topology preservation [19]. Topology preservation means that all the links in the original topology will exist in the final topology after channel assignment process in multi-radio multi-channel. Furthermore, topology preservation can not only enhance the throughput of the network, but also provides compatibility between WMNs and other wireless networks[20].Moreover, TLCA ensures the capacity of the network is increase by efficient utilization of the limited available resources among the wireless links while satisfying the connectivity constraint of the network. TLCA distributes the channels between wireless links based on the radio status of the two nodes constitutes the target link and the behavior of CSMA/CA MAC protocol.

The rest of this paper is organized as follows: Section 2 describes the related work in pursuit of interference aware channel assignment schemes. Section 3 illustrates the system model and problem formulation. The design of proposed centralized channel assignment algorithm is presented in Section 4. Section 5 presents the performance evaluation of TLCA and experimental results. Finally, Section 6 concludes the paper.

II. Related Work

The interference aware channel assignment algorithms are developed to enhance the throughput of the WMNs through mitigating the interference problem[21] . In designing of the interference aware channel assignment schemes, channel distribution and link quality are used as metric to measure the level of interference[22]. The limitation on the number of the non-overlapping channels and number of the radio interfaces that are installed on each node makes the channel assignment design is extraordinarily complicated and proved to be NP-hard [15, 23]. In the literature, the existing channel assignment schemes are classified into different categories. Firstly, the channel assignment based on available knowledge of network topology, are classified into Centralized and Distributed channel assignment schemes [24].

Secondly, channel assignment based on channels frequency, are classified into Fixed/Static, Dynamic and Hybrid Channel Assignment schemes [25].

The interference aware channel assignment scheme proposed in [26], based on the dynamic and centralized channel assignment approaches called as Breadth First Search Channel Assignment (BFS-CA).

In this scheme, the authors utilize Expected Transmission Time (ETT) proposed by [27] as metric for the link quality. Moreover, the Conflict Graph (CG) that was proposed by [28] is extended to Multi Conflict Graph (MCG) to cover all the radio interfaces within each node. The MCG is used to represent and capture the impact of the interference present between the wireless links in a network topology. BFS-CA uses the output of the MCG as input in the proposed channel assignment process. In Common Channel Assignment (CCA) scheme [27], the fixed number of radio interfaces on each node are assigned with the same number of channels. The first radio interface on each node is assigned to first channel; second radio interface assigned to second channel and so on. The network connectivity in the CCA is guaranteed. However, the channel assignment process in CCA in terms of reducing the effect of interference between the wireless links is incompetent. The throughput would be optimal in the CCA, when the number of radio interfaces in each nodes increase to assign many channels. The proposed interference aware channel assignment scheme in [29] is based on the centralized channel assignment approaches called as Tabu-based Algorithm (CTA). In this scheme, the concept of the conflict graph is used to assigning the channels between the links in the network. The major objective of this algorithm is to mitigate the network interference problem while maintains on the constraints of the network connectivity. In the network topology, the constraint of the network connectivity ensures the multiple paths still exist between all the nodes after channel assignment. In [30]the proposed algorithm is based on the centralized channel assignment approaches called as Connected Low Interference Channel Assignment (CLICA). CLICA used the concept of topology preservation and topology control based on traffic independent in designing the channel assignment process. The main target of the CLICA is constructed network topology with low interference while preserving the network connectivity. In this scheme, the network topology is represented by the graph. CLICA gives all the nodes in the network topology a weight based on constructing the shortest path and the number of free radios interface. In this scheme the channel assignment priority gives to a node has only a single radio interface is unassigned. In the work presented by [22] proposed a new channel assignment algorithm to mitigating the interference problem in the network topology through high performance links. The proposed algorithm in this work is centralized channel assignment known as Utility Based Channel Assignment (UBCA). The topology graph is used to formulate the network topology and the conflict graph also is used to formulate the interference between the wireless links. UBCA gives each link in the network topology a weight equal the probability of packet delivery without considering the specific traffic pattern. In the work presented by [31] the authors proposed three algorithms for interference-aware channel-assignment named TICA, e-TICA, and e- TICA2. These algorithms aim to reduce the interference problem between the wireless links, increase the throughput of the network and guarantee the network is connected. In this work, topology control with the concept of power control is used in designing the proposed channel assignment algorithm. In the work presented by [32], the proposed algorithm improved the genetic algorithm NSGA-II to enhance the throughput of the network and reducing the interference while maintaining a maximum number of links between the nodes. In this work, the proposed interference aware channel assignment algorithm is formulated as topology control using the formulation of genetic algorithm. This algorithm aims to choose the number of links among all the links in the network topology to assign the channels without affecting on the efficiency of the network. In another attempt, the authors in [20] proposed non-overlapping channel assignment algorithm named as DPSO-CA based on topology preservation as explained by [19]. The DPSO-CA aims to balance between the maintaining the network connectivity and mitigated the co-channel interference based on organizing the mesh nodes with available channels. Moreover, the conflict graph model has been used to capture the interference problem between the wireless links in the network topology. In DPSO-CA supposes all nodes in the network topology have the same number of radios which are assigned the conformable set of channels to maximize the network connectivity.

III. MODEL AND PROBLEM FORMULATION

In this section, the system model and the formulation of the channel assignment problem in multi-radio multi-channel WMNs, are discussed in detail.

A. Network model

Generally, the physical topology of WMN is designed as an undirected graph $\mathrm{G_t} = (\mathrm{V_t}, \mathrm{E_t})$ as shown in **Fig.1.** Where $\mathrm{V_t}$ is the set of nodes in the $\mathrm{G_t}$ and is represented as $\mathrm{V_t} = \{\mathrm{v_1}, \mathrm{v_2}, \dots, \mathrm{v_N}\}$. All the nodes in $\mathrm{G_t}$ has a specific number of interfaces (multi-radios) such as $f_i(v) \geq 1$ (where i is interface number of the node$v, \forall v \in V_t$). $\mathrm{E_t}$ is the set of undirected links (edges) between the nodes in $\mathrm{G_t}$ which is represented as $\mathrm{E_t} = \{l_{(v_1,v_2)}, l_{(v_2,v_3)}, \dots, l_{(v_i,v_j)}\}$. The link $l_{(u,v)}$ between each of the two nodes u and v, in $\mathrm{G_t}$, only exist, when the physical location of both nodes is located within the transmission ranges T_R of each other. Suppose the interference range IN_R for each node is two times greater than the transmission range T_R (IN_R=2×T_R). The radio interfaces in each two adjacent nodes in $\mathrm{G_t}$ are operating on a common channel. The number of non-overlapping wireless channels available in the network are denoted as $CH = \{ch_1, ch_2, \dots, ch_n\}$.

TLCA assume that each wireless link should be assigned exactly one channel due to a limited number of non-overlapping wireless channels in IEEE 802.11 Standard. Furthermore, the number of the channels that should be assigned to each node $v_i(CA(v_i))$ must not exceed the number of radio interfaces that is equipped with that node ($CA(v_i) \leq f_i$). In TLCA, the assignment of channels $CA(v_i)$ to each link $l_{(u,v)}$ in $\mathrm{G_t}$ is performed, when following two conditions are satisfied:

1. The Euclidean distances d between any two nodes less than or equal to transmission ranges of each other ($d(u,v) \leq T_R$).
2. There is a common non-overlapping channel between any two nodes in the network topology ($CA(u) \cap CA(v) \neq \emptyset$).

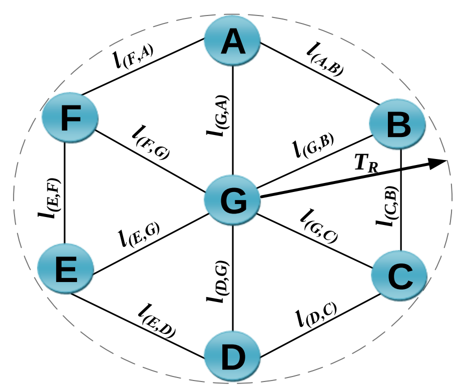

Fig.1. Undirected topology graph of wireless mesh network

Interference is one of the main problems faced by the communication channels in the wireless networks. In WMNs, the quantifying of the interference and the behavior of the medium access control (MAC) are essential components in the design and deployment of MCS-MRS in the WMNs. They have a direct effect on the throughput of the wireless network. Thus, the impact of interference between the wireless links and the behavior of the MAC protocols has been modeled extensively in existing literature. The most of existing design and deployment of wireless mesh networks are based on the Physical model, Protocol model and Extended Protocol model of interference [16, 23].

In Physical Model, the transmission between any two nodes ($\mathrm{N_i}$ and $\mathrm{N_j}$) to be succeed without collision when, the Signal Strength ($\mathrm{SS_{ij}}$) of sender node is strong enough to send the packets to the receiver and the Noise Ratio (NR_j) at the receiver node is above from a certain threshold, such as $SS_{ij}/NR_j >= SNR_{thresh}$. Where SS_{ij} is represents the signal strength at the sender node (N_i), NR_j is the total noise at the receiver node (N_j), and SNR_{thresh} is the threshold of signal to noise ratio[16].

In the Protocol Model, the data transmission between two nodes (A and B) to be succeed without collision between the data packet when, no other sender (node C) located within the carrier sensing range of the receiver (node B) is transmitting the data simultaneously during the time of data transmission [16]. On the other hand, if a sender (A) needs to send the data to receiver (B), the transmission is successful without interference if the following conditions are satisfied:

1. Euclidean distance between the sender and receiver (A and B) less than or equal to transmission ranged$d(A, B) \leq T_R$.
2. No other sender node C located within the carrier sensing range of B send packets to recever node B during the time of data transmission using the same channel between A and B.

The Extended protocol model of interference is defined by the authors in [23] to capture the impact of interference between the wireless links. This model is based on the Euclidean distance d between two adjacent nodes (sender-receiver pair) in the network topology. The two links $l_{(u1,v1)}$ and $l_{(u2,v2)}$ are interfering they use a common channel and the distances between them (sender-receiver pair) less than or equal to interference range of each other, such as $d(u_1, u_2),\ d(u_1, v_2),\ d(u_2, v_1),\ d(v_1, v_2) \leq IN_R$.

Most of the existing works in literature uses the concept of the conflict graph as defined in [28] to model the interference problem between wireless links.

In the conflict graph, $G_f = (V_f, E_f)$ all the links in network topology G_t represented as corresponding vertex. There is an edge between two vertices on the conflict graph $G_f$if the corresponding links in the network topology G_t interfere with each other [33]. In the conflict graph, we use the terms “vertex” and “edge” instead of “node” and “link” as in the network topology graph[34].

Definition.1. (Conflict Graph). A conflict graph $G_f = (V_f, E_f)$ is conduced by $G_t = (V_t, E_t)$ with $V_f = E_t$ and $(l_{(u1,v1)}, l_{(u2,v2)}) \in E_f$ if $l_{(u2,v2)}$ interfere with link of $l_{(u1,v1)}$ in G_t.

In this paper, the topology graph has been used to model the network topology while extended protocol model and conflict graph has been used to capture the effect of interference problem between the wireless links.

IV. THE PROPOSED TLCA ALGORITHM

This section introduces a novel multi-radio multi-channel algorithm called Topology-preservation Low-interference Channel Assignment algorithm (TLCA) which is static and centralize in nature. The aim of proposed algorithm is to reduce the interference problem between the wireless links and maintaining on network connectivity using the concept of topology preservation. TLCA selects all the links in the network topology and assign them efficient non-overlapping channels to avoid the problem of MAC collision based on the behavior of CSMA/CA protocol. Furthermore, TLCA ensures that network topology become more connected, when all the links in the network topology are assigned optimal channels. In order to improve overall network performance, there are some factors that need to be considered. Firstly, the delivery probability between the nodes in the networks depends on the length of the wireless link. This because; the sensing range between the senders and receivers is increasing dramatically by decreasing the distance between the nodes. Secondly, the direction for most of the data traffic in the wireless mesh network is to/from the mesh gateway. Thus, the probability to select the links close to the gateway by the routing protocol should be higher than the other links far from the gateway. Based on the aforementioned assumptions, the proposed TLCA algorithm has two phases. The first phase of TLCA is responsible for nodes and links scheduling. In this phase, TLCA divides all the nodes in the network topology into groups based on the number of hops. The nodes in each group are given a priority based on both, number of incident links and the distance from the gateway. The incident links for each node gives a weight equal the total of all neighboring nodes of the two nodes (u, v) constitute the target link $l_{(u,v)}$ as explained in Section 4.1. Therefore, all the incident links for each node v_i are arranged in descending order based on the link weight. The priority of channel assignment given to a link has highest weight. On the other hand, the second phase of the TLCA aims to select the least interference channel between all available non-overlapping channels. In this phase, TLCA starts to assign a channel for a link $l_{(u,v)} \in E_t$ from 1-hop (all the nodes within the 1-hop are connected directly to the mesh gateway) to N-hop in the network topology. TLCA visits all the nodes in each group (from 1-hop to N-hop) based on their priority order. Hence, the algorithm determines Available-Channel Set (ACS) for all incident links of the target node based on the proposed function of Least_Interference_Channel as explained in Section IV.*A*. The ACS contains all the channels that can be assigned to the target link. The channels in ACS are specified for each incident link based on the radio status of the two nodes constitutes the target link. Thus, TLCA selects the least interference channel for the candidate link from the list of ACS based on radio status of the two nodes constitutes a link.

In case, the two nodes constitute the target link $l_{(u,v)}$ have free radio interfaces, the ACS contains all the non-overlapping channels available in the IEEE 802.11s standard. TLCA selecting the least interference channel to the target link from the list of ACS based on the proposed function Least_Interference_Channel, which explained in Section IV.*B*. On the other hand, in case only one node of the two nodes constitute the target link $l_{(u,v)}$ have a free interface. The list of ACS contains just the channel assigned to incident links of a node which has no free radio. In this case, TLCA checks the list of the Neighboring Nodes (NNs) of the two nodes constitutes the target link. The list of NNs contains all the neighbor nodes for each of the two nodes constitutes the target link. In case the two ends of the target link have common nodes within the NNs of each other. This means there are wireless links located within the carrier sensing range of the target link according to the extended protocol model of interference. TLCA check there are channels assigned to links between the common node and the two nodes constitutes the target link. In case there are channels assigned to links between the common node and the two ends of the target link. TLCA defines a new list of channels called Candidate Channels List (CCL) to optimize the distribution of the channels between the links. The list of CCL contains all the channels which are assigned by links located within the carrier sensing range of the two nodes constitute the target link $\boldsymbol{l_{(u,v)}}$. Accordingly, TLCA selects the least interference channel to candidate link $l_{(u,v)}$ from both Candidate Channels List (CCL) and Available-Channel Set (ACS).

Finally, in case the two nodes constitute the target link does not have common nodes within the NNs of each other. Then, TLCA selects the least interference channel to the target link from the list of ACS based on the proposed function of the Least_Interference_Channel.

A. The Priority of the wireless Links

Usually, the direction of the most data traffic in the WMN is from/to the mesh gateway. Then, unfair distribution of the channels between the links close to the gateway may cause the problems of bottleneck links and data collisions in the network which degrade the overall performance of the network. The designing of the channel assignment process in TLCA aims to avoid the probability of the MAC collisions and bottleneck links between the wireless links. However, TLCA assumes that the data traffic between the wireless links is uniform throughout the network. Therefore, is very difficult assigning the non-overlapping channels between the wireless links without considering traffic flows in the network topology. Hence, TLCA uses the geometric location of each node in the network topology to estimate the links quality. In this work, all the nodes in the network topology are divided into groups based on the number of hops far from the gateway. In the TLCA, the priority is given to nodes close to the mesh gateway. Further, to distinguish between the nodes in the same group, TLCA uses Euclidean metric to compute the distance between the nodes as defined in the Equation.1.

$$D = \sqrt{(u_1 - u_0)^2 + (v_1 - v_0)^2} \qquad (1)$$

TLCA gives the priority to a node which constructs the shortest path between the nodes in the same group. This is because, the success of sending packets depends on the length of the wireless link between nodes. Hence, the rate of the process of sending and receiving packets be high whenever the distance between nodes is decreased.

In the TLCA, all the links close or emerges from the gateway are classified as high performance links. This is because most of data traffic in the network topology from/to the gateway. Therefore, TLCA gives the incident links of each node a weight $W\big(l_{(u,v)}\big)$ equals the total number of the neighbors of the two nodes which constitute the link as defined in the Equation.2.

$$W\big(l_{(u,v)}\big) = \sum_{u,v\in N}^{N} \big(N(u) + N(v)\big) - 2 \qquad (2)$$

Where $\mathrm{W}(l_{(u,v)})$ is the weight for the incident link$l_{(u,v)}$ of a node u in each group. $N(u)$ and $N(v)$ are the number of neighboring nodes for node u and v respectively that constitutes the link $l_{(u,v)}$. (-2) used to exclude the two endpoint nodes of the target link from the result of the summation.

As a result, TLCA gives the priority to a link which connects between several nodes to construct a high quality path between the gateway and other nodes within the network topology.

B. The least interference channel function

To assign the least interference channel to a specific link, TLCA seeking as much as possible to find a channel not used by the links located within the interference range of the two nodes constitute the target link. According to the conflict graph G_f, TLCA defines all the channels assigned to wireless links that potentially interfere with a link $l_{(u,v)}$ as $PICh(l_{(u,v)})$ by Equation.3.

$$PICh(l_{(u,v)}) = \sum_{u,v\in V_f}^{c\in C} l_{(u,v)}^{\sim}(ch) \qquad (3)$$

Where $\mathrm{l}_{(u,v)}^{\sim}$ represent the links that potentially interfering with the target link$\mathrm{l}_{(u,v)}$ and ch represent the channels that are assigned to links potentially interfering with the target link$l_{(u,v)}$.

In a given network topology, any channel in $PICh\big(l_{(u,v)}\big)$ is given a weight based on the number of times that have been assigned by the links that potentially interfere with the target link$l_{(u,v)}$. The set of potential interfering links includes all the links that are located within the interference range of the target link $l_{(u,v)}$. The aim of $PICh$ is to mitigate the collision between the co-located interfering links. On the other hand, TLCA defines all the candidate channels (ACS) for each link in the network topology to assist the equitable distribution of channels in the network.

To assign the least interference channel to a specific link $l_{(u,v)}$ in the network topology, TLCA checks the radios status of the two nodes formed the target link$l_{(u,v)}$. In case, the two nodes formed a link$l_{(u,v)}$ have free radios. Thus, the ACS contains all the available channels in the IEEE 802.11 package. Furthermore, to select the least interference channel for the target link$l_{(u,v)}$ there are two possibilities. Firstly, in case there are some channels in the ACS does not exist in$PICh$. This means there are some available channels that are not used by the links may interfere with candidate link$l_{(u,v)}$. Hence, the candidate least interference channel is selected from ACS based on least weight from the list of ACS. For example, suppose the potential interference links for a link l_1 are $l_{5,}l_6, l_7, l_8, l_9, l_{10}, l_{11}, l_{12}$ and l_{13}, and all of them assigned the non-overlapping channels such as $ch_1, ch_3, ch_2, ch_1, ch_1, ch_2, ch_3, ch_3$ and ch_1 respectivly. Then, $PICh$ contain all the channels assigned to wireless links that potentially interfere with a link l_1, and arranged these channels based on the number of times that have been assigned by these links as showing in the TABLE.1.

TABLE I

THE LIST OF CHANNELS IN $PICh$

Channel	ch_1	ch_2	ch_3
Weight	4	2	3

On the other hand, suppose ACS contain the channels ch_1, ch_2, ch_3, ch_4 and ch_5 and these channels are arranged based on the number of times that have been used in the network topology as showing in the TABLE.2.

TABLE 2

THE LIST OF CHANNELS IN ACS

Channel	ch_1	ch_2	ch_3	ch_4	ch_5
Weight	14	11	7	10	5

According to the proposed function of the Least_Interference_Channel, the least interference channel for the link l_1 is channel ch_5. This because there are some channels in the ACS does not exist in$PICh$. In this case the least interference channel is selected from ACS based on least weight from the ACS. As observed, TLCA helped in reducing the interference problem through selecting a channel from outside the list of $PICh$ (channels that are assigned to links potentially interfere with the target link l_1).

Furthermore, TLCA helps also in the fair distribution of channels by selecting the channel that has not been used much in the network topology (ch_5used 5 times only in the example).

Secondly, in case all the channels in the list of the ACS exist in the $PICh$. This means all the candidate channels which are used by the links in the network topology may interfere with the target link $l_{(u,v)}$. Thus, the candidate least interference channel is selected from the list of ACS based on least weight from the $PICh$. From the previous example, suppose ACS contain the channels ch_1, ch_2 and ch_3 with weight 10, 24 and 30 respectively. In this case the least interference channel for the link l_1 is channel ch_2. As observed, TLCA mitigates the interference problem through selecting the least interference channel from the list of $PICh$ (contains the channels that are assigned to links potentially interfere with the target link l_1).

In case, only one node from the two nodes formed the target link$l_{(u,v)}$ have free radio interfaces. As the mentioned earlier, the list of ACS contains just the channel assigned to a node which has no free radio. Each channel in the ACS is given a weight according to the number of times that have been used in the network topology. Thus, to select the least interference channel to the target link$l_{(u,v)}$ there are two possibilities. Firstly, in case the two ends of any link in the network topology are located within the carrier sensing range of both two nodes that constitute the target link $l_{(u,v)}$.

TLCA defines a list of channels termed Candidate Channels List (CCL) contains all the channels that are assigned to these links. The channels in CCL are given weights according to the number of times that have been assigned by the links that potentially interfere with target link$l_{(u,v)}$. Accordingly, TLCA selects the least interference channel to candidate link $l_{(u,v)}$ from both Candidate Channels List (CCL) and Available-Channel Set (ACS). In case there are common channels between CCL and ACS, the least interference channel is selected from these common channels based on least weight in the CCL. In case there are no common channels between CCL and ACS, the least interference channel is selected based on two possibilities. Firstly, there are channels in the ACS does not exist in $PICh$. Then, the least interference channel is selected from ACS based on least weight from the ACS. Second, all the channels in $ACS$are existing the $PICh$. Thus, the least interference channel is selected from ACSbased on least weight from the $PICh$. In case there are no common channels between CCL and ACS, the least interference channel is selected based on two possibilities like the previous stage.

Second, in case there are no links that their ends within the carrier sensing range of the both two nodes that constitute the candidate link$l_{(u,v)}$. The least interference channel is selected based on two possibilities. Firstly, in case there are channels in the ACSdoes not exist in$PICh$, the least interference channel is selected from ACS based on least weight from the ACS. Secondly, in case all the channels in

ACSexist in the $PI.ch$, the least interference channel selected from ACS based on least weight from the $PICh$.

V. Evaluation and Experimental Results

The simulation and numerical models are used to evaluate the performance of the proposed TLCA algorithm. The simulation model make use of NS-2.32 [35] simulator based on the work presented in [36]to evaluate the performance of the network while the numerical model [37] make use of MATLAB (2010) to verify the assumptions and analyzing the properties of the given network topology. The performance of proposed algorithm is compared with the relevant channel assignment schemes available in literature such as Common Channel Assignment (CCA) [27] and the Connected Low interference Channel Assignment algorithm (CLICA) [30].

A. The Numerical Results

In this section two numerical metrics *Network Capacity Gain* (NCG) and *Network Interference Weight* (NIW),which are earlier proposed in [23], are evaluated to verify the performance of the proposed TLCA algorithm. Furthermore, NCG and NIW are used to measure and evaluate the effect of interference between the wireless links and the network capacity of the network topology, respectively. During experimental study, variable number of nodes are considered within the area of 1000m ×1000m field. The number of radio interfaces are static (3 interfaces on each node) that are installed in each node. Furthermore, all the non-overlapping channels in IEEE 802.11a are used. In these experiments, suppose the interference range and the transmission range of all nodes in the network topology are static. For each node in the network topology, suppose the interference range (IN_R) is 500m and the transmission range (T_R) is 250m (IN_R = 2 × T_R).

The network capacity is defined as the maximum number of concurrent transmissions in the network topology as defined in [38], which involves two steps for calculating given metric. First, calculate all the independent sets of the conflict graphG_f, regardless of the channels that are assigned to wireless links within the independent sets. In the independent sets, all the wireless links within each set does not interfere with the adjacent sets. Equation.4 is formulated to calculate the independent sets within the given network topology.

$$InSet_i = \sum_{i=1}^{n} l_{(u,v)}^{\sim} \qquad (4)$$
$$\forall u, v \in V_f ; \forall l_{(u,v)}^{\grave{}} \in E_f$$

Where $InSet_i$ is independent set from $i = 1$ to n. n is the number of independent sets in the generating network topology. $l_{(u,v)}^{\sim}$ is the wireless link within each independent set.

Second, calculate the number of times for each channel that was used by the links located within all the independent sets. The Equation.5 is defined to calculate the total of all the channels that are assigned by the links within each independent set.

$$InCh = \sum_{i=1}^{n} InSet_i(ch) \qquad (5)$$
$$\forall ch \in CH$$

Where $InCh$ is the total number of times of a channel $ch \in CH$ which was assigned to links within the independent sets from $i = 1$ to n. n is the number of independent sets within the generating network topology.

Finally, the Network Capacity Gain (NCG) for the given network topology is defined in the following Equation.6.

$$NCG = \frac{All\_Links}{InCh} \qquad (6)$$

Where All_Links represents all links in the network topology, and InCh is the total number of times of a channel ch ∈ CH which was assigned to links within the independent sets.

The Network Interference Weight (NIW) is used to measure the effect of the interference between the wireless links after the channel assignment process. The NIW for a link is the total number of links that assign a common channel which are located within the interference range of the two end nodes that constitute thetarget link. The following Equation.7 used to calculate the network interference weight of the network topology.

$$NIW = \sum_{i=1}^{n} NIW_i \qquad (7)$$

Where NIW is network interference weight of all the links from $i = 1$ to n. n is the total number of links within the given network topology.

Fig.2 illustrates the network capacity gain of the three algorithms TLCA and CLICA and CCA. TCLA and CLICA outperforms the CCA due to efficient utilization of all no-overlapping channels available in IEEE 802.11a, while CCA just use three channels based on the number of radios in each node. It is also evident from the figure 4 that proposed TLCA algorithm outperforms CLICA in distributing non-overlapping channels between the wireless links in the network topology. Thus, the number of concurrent transmissions in the proposed TLCA algorithm is better than other relevant algorithms (CLICA and CCA).

Fig.3 illustrates the comparative analysis of network interference weight of the CCA, CLICA and TLCA. The results show that TLCA outperforms CLICA and CCA due to smaller size of collision domain and lower interference weight.

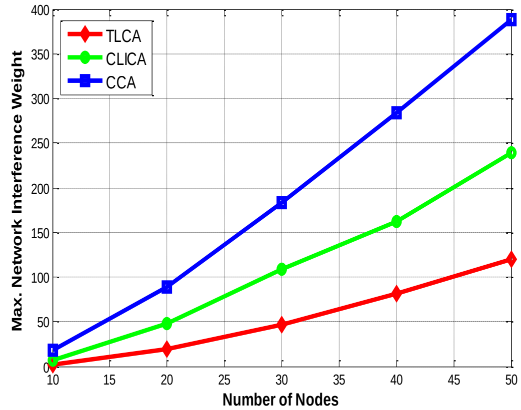

Fig.2. The network capacity gain of the network topology

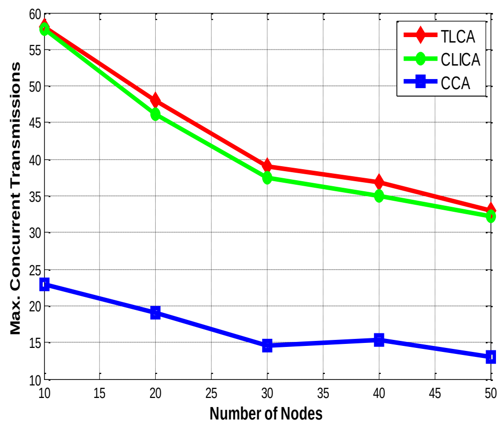

Fig.3. The interference weight of the network topology

VI. CONCLUSIONS

In this paper, we have proposed a new algorithm called TLCA for interference aware non-overlapping channel assignment in a multi-radio multi-channel wireless mesh network. The proposed algorithm TLCA is static and centralized channel assignment scheme. TLCA is formulated as a topology control based on the concept of topology preservation to mitigate the interference problem between the wireless links in the network. Further, TLCA ensures that aggregate network throughput is fairly distributed between the interfering links by efficient utilization of the limited available channels among the wireless links while preserving the network connectivity. Moreover, TLCA distributes the channels between links based on the radios status of the two nodes constitutes the wireless link and the behavior of CSMA/CA MAC protocol. The performance of TLCA is evaluated based on numerical model using MATLAB. The numerical results verify that the proposed algorithm accomplishes better performance in terms of interference.

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