TOPOLOGY PRESERVATION AND CONTROL APPROACH FOR INTERFERENCE-AWARE NON-OVERLAPPING CHANNEL ASSIGNMENT IN WIRELESS MESH NETWORKS

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*To my late father **Alzubir Mohammad Ali**. May Allah SWT be pleased with him and grant him Al Jannah (Ameen)*

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ABSTRACT

The Wireless Mesh Networks (WMN) has attracted significant interests due to their fast and inexpensive deployment and the ability to provide flexible and ubiquitous internet access. A key challenge to deploy the WMN is the interference problem between the links. The interference results in three problems of limited throughput, capacity and fairness of the WMN. The topology preservation strategy is used in this research to improve the throughput and address the problems of link failure and partitioning of the WMN. However, the existing channel assignment algorithms, based on the topology preservation strategy, result in high interference. Thus, there is a need to improve the network throughput by using the topology preservation strategy while the network connectivity is maintained. The problems of fairness and network capacity in the dense networks are due to limited available resources in WMN. Hence, efficient exploitation of the available resources increases the concurrent transmission between the links and improves the network performance. Firstly, the thesis proposes a Topology Preservation for Low Interference Channel Assignment (TLCA) algorithm to mitigate the impact of interference based on the topology preservation strategy. Secondly, it proposes the Max-flow based on Topology Control Channel Assignment (MTCA) algorithm to improve the network capacity by removing useless links from the original topology. Thirdly, the proposed Fairness Distribution of the Non-Overlapping Channels (F-NOC) algorithm improves the fairness of the WMN through an equitable distribution of the non-overlapping channels between the wireless links. The F-NOC is based on the Differential Evolution optimization algorithm. The numerical and simulation results indicate that the proposed algorithms perform better compared to Connected Low Interference Channel Assignment algorithm (CLICA) in terms of network capacity (19%), fractional network interference (80%) and network throughput (28.6%). In conclusion, the proposed algorithms achieved higher throughput, better network capacity and lower interference compared to previous algorithms.

ABSTRAK

Rangkaian Mesh Tanpa Wayar (WMN) telah menarik minat yang ketara disebabkan oleh penggunaannya yang cepat dan murah serta keupayaannya untuk menyediakan akses ke internet yang fleksibel dan sentiasa ada. Cabaran utama untuk menggunakan WMN adalah masalah gangguan antara pautan. Hasilnya gangguan terbahagi kepada tiga masalah iaitu daya pemprosesan terhad, kapasiti dan keadilan bagi WMN. Strategi pemeliharaan topologi digunakan dalam kajian ini bagi meningkatkan daya pemprosesan dan menangani masalah kegagalan pautan dan pembahagian WMN. Walau bagaimanapun, algoritma penyerahan saluran sedia ada yang berasaskan strategi pemeliharaan topologi telah menyebabkan gangguan yang tinggi. Oleh itu, terdapat keperluan bagi meningkatkan daya pemprosesan rangkaian dengan menggunakan strategi pemeliharaan topologi sambil mengekalkan sambungan rangkaian. Masalah keadilan dan kapasiti rangkaian dalam rangkaian padat adalah disebabkan oleh sumber sedia ada yang terhad dalam WMN. Oleh itu, eksploitasi sumber sedia ada yang cekap dapat meningkatkan penghantaran serentak antara pautan dan meningkatkan prestasi rangkaian. Pertamanya, tesis ini mencadangkan algoritma Pemeliharaan Topologi Penyerahan Saluran Gangguan Rendah (TLCA) untuk mengurangkan kesan gangguan berasaskan strategi pemeliharaan topologi. Kedua, ia mencadangkan algoritma Aliran-maksima berasaskan Penyerahan Saluran Kawalan Topologi (MTCA) untuk meningkatkan kapasiti rangkaian dengan membuang pautan tidak berguna daripada topologi asal. Ketiga, algoritma Kesaksamaan Pengagihan Saluran Tidak Bertindih (F-NOC) yang dicadangkan dapat meningkatkan keadilan pada WMN melalui pembahagian sama rata bagi saluran tidak bertindih antara pautan tanpa wayar. F-NOC adalah berasaskan algoritma pengoptimuman Evolusi Berbeza. Keputusan berangka dan simulasi menunjukkan bahawa algoritma yang dicadangkan mempunyai prestasi yang lebih baik berbanding dengan algoritma Penyerahan Saluran Gangguan Rendah Bersambung (CLICA) dari segi kapasiti rangkaian (19%), gangguan pecahan rangkaian (80%) dan daya pemprosesan rangkaian (28.6%). Kesimpulannya, algoritma yang dicadangkan mencapai daya pemprosesan yang lebih tinggi, kapasiti rangkaian yang lebih baik dan gangguan yang lebih rendah berbanding dengan algoritma sebelumnya.

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LIST OF ABBREVIATIONS

ACK	-	Acknowledgment
ACS	-	Available Channel Set
BFS-CA	-	Breadth First Search Channel Assignment
CAEPO	-	Channel Assignment Exploiting Partially Overlapping Channels
CAEPO-G	-	Load-Aware Channel Assignment Exploiting Partially Overlapping Channels
CAS	-	Channel Assignment Server
CBCA	-	Cluster Based Channel Assignment
CCA	-	Common Channel Assignment
CCL	-	Candidate Channels List
CG	-	Conflict Graph
CIL	-	Coordinated Interference Links
CLICA	-	Connected Low Interference Channel Assignment
CSMA/CA	-	Carrier Sense Multiple Access with Collision Avoidance
CTS	-	Clear-To-Send
DCAS	-	Dynamic Channel Assignment Strategies
DCF	-	Distributed Coordination Function
DE	-	Differential Evolution
DPSO	-	Discrete Particle Swarm Optimization
DPSO-CA	-	Discrete Particle Swarm Optimization for Channel Assignment
DSSS	-	Direct Sequence Spread Spectrum
ESS	-	Extended Service Set
ETT	-	Expected Transmission Time
FLIC	-	Function of the Least Interference Channel
FNI	-	Fractional Network Interference
F-NOC	-	Fairness distribution of the Non-Overlapping Channels
FSC	-	Function Selection Channel

HCAS	-	Hybrid Channel Assignment Strategies
IBSS	-	Independent Basic Service Set
IEEE	-	Institute of Electrical and Electronics Engineers
I-Factor	-	Interference Factor
I-Matrix	-	Interference Matrix
KCA	-	Knowledge-based Channel Assignment
LANs	-	Local Area Networks
LIC	-	Least Interference Channel
MAC	-	Medium Access Control
MCG	-	Multi Conflict Graph
MCS	-	Mesh Clients Set
MGS	-	Mesh Gateways Set
MR-MC	-	Multi-Radios Multi-Channels assignments
MRS	-	Mesh Routers Set
MTCA	-	Max-flow based on Topology-control Channel Assignment
NC	-	Network Capacity
NCIL	-	Non-Coordinated Interference Links
NNs	-	Neighboring Nodes
NR	-	Noise Ratio
NS	-	Network Simulator
OFDM	-	Orthogonal Frequency Division Multiplexing
PCF	-	Point Coordination Function
PCU-CA	-	Probabilistic Channel Usage based Channel Assignment
PICh	-	Potentially Interfere Channel
PSO	-	Particle Swarm Optimization
RTS	-	Request-To-Send
RW	-	Roulette Wheel
SAIS	-	Scenario of Asymmetric Incomplete State
SCAS	-	Static Channel Assignment Strategies
SIR	-	Signal-to-Interference Ratio
SR-SC	-	Single-Radio Single-Channel
SS	-	Signal Strength
SSC	-	Scenario of Sender Connected
SSIS	-	Scenario of Symmetric Incomplete State

TCA	-	Topology Control Algorithm
TCP	-	Transmission Control Protocol
TICA	-	Topology-controlled Interference-aware Channel-assignment Algorithm
TLCA	-	Topology preservation for Low interference Channel Assignment
UBCA	-	Utility Based Channel Assignment
UDP	-	User Datagram Protocol
U-NII	-	Unlicensed National Information Infrastructure
VCA	-	Varying Channel Assignment
WMN	-	Wireless Mesh Network

CHAPTER 1

INTRODUCTION

1.1 Overview

Recently, wireless network technologies are emerging everywhere and become more popular. Wireless Mesh Network (WMN) is one of the innovative wireless technologies that provide effective multi hop solutions to provide internet connectivity to a large number of wireless nodes at low cost of construction (Vural *et al.*, 2013; Tsao *et al.*, 2014). As shown in Figure 1.1, the components of a WMN consist of Mesh Clients Set (MCS), Mesh Routers Set (MRS) and Mesh Gateways Set (MGS) (Kumar and Chilamkurti, 2012). MRS connects the mesh clients with the mesh gateways through multi-hop wireless mesh environment. MRS has the ability to support the simultaneous transmission between the wireless links to improve the network capacity. This is because the architecture of the MRS is equipped by multi-interface to connect with varying channels. The architecture of Multi-Radio Multi-Channel (MR-MC) of the mesh router is defined by the IEEE 802.11s standard (Wang and Lim, 2008). The protocol stack architecture of MR-MC mesh router is designed to support multiple radio interfaces to assign multiple channels which can be used for the transmission between the routers in WMN. In the architecture of MR-MC, the network capacity is improved based on the architecture design of the Medium Access Control (MAC) and Physical layer that are installed for each radio within the mesh routers (Benyamina *et al.*, 2012).

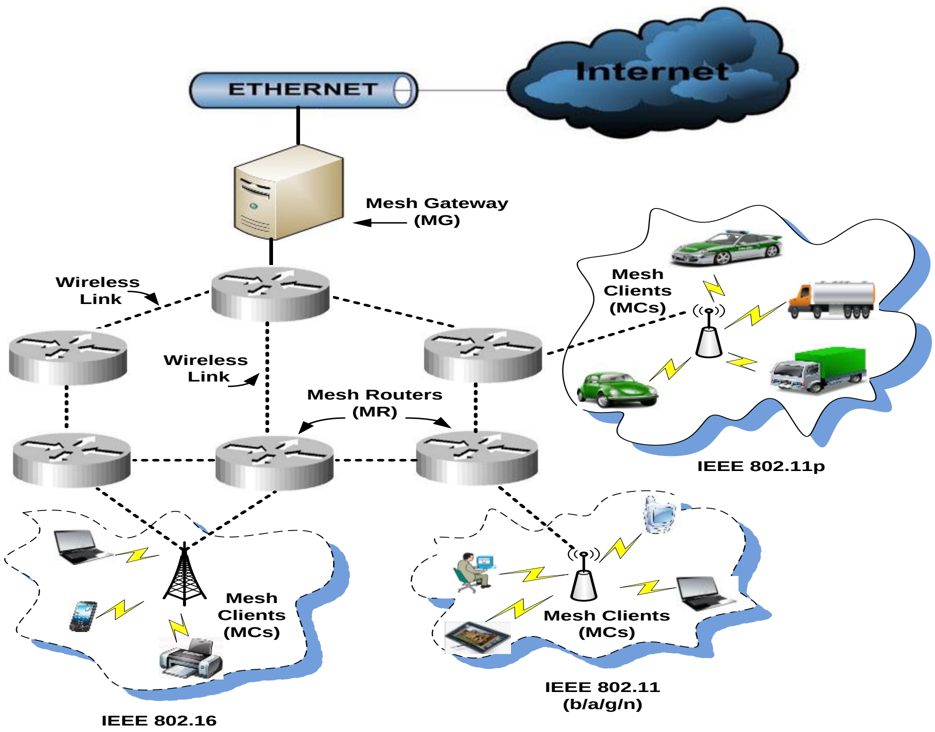


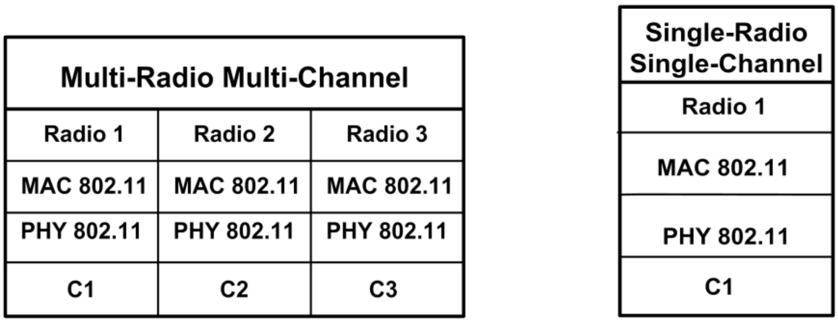
Figure 1.1: Components of wireless mesh network (Ali *et al.*, 2014)

In WMNs, the interference is a major factor that affects the throughput of the wireless links (Kumar *et al.*, 2011). Therefore, the throughput limitation between the wireless links is one of the basic challenges faced by the WMNs, compared to the links in wired networks. This is because the communication medium in the wireless networks is shared and affected by the signal strength of the frequency rather than the wired networks which take place through a dedicated medium (Ali *et al.*, 2014). The location of the overlapping wireless links and the distribution of non-overlapping channels between these links have a big impact on mitigating the interference problem (Skalli *et al.*, 2007a). However, the limitation on the non-overlapping channels in IEEE 802.11 standard and number of the interfaces within each node makes the interference problem extraordinarily complicated for WMNs. Moreover, the overall throughput of the wireless network can be affected by the signal strength of the channels assigned to the co-located interfering links (Ding and Xiao, 2011).

The Interference problem affects both the transmission source and destination sides. On source side, the rate of the data transfer is adversely affected by the interaction of Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) based MAC layer. On destination side, the interference problem causes data collisions that result in packet loss sent by source which may lead to reduction of overall throughput of the link (Saurav *et al.*, 2011). Moreover, the source nodes start sending packets simultaneously when the random access of the protocol CSMA/CA MAC is employed. Thus, the transmission opportunity of the active links stops by the CSMA/CA to avoid the collision of the packet between the interfering links. The impact of interference between the links and the behavior of the MAC protocols has been studied extensively in the literature. However, most of the proposed interference models have limitations when captured and analyzed the impact of the interference based on the behavior of the CSMA/CA MAC protocol (Ali *et al.*, 2014). Consequently, one of the challenges faced in the design of interference aware channel assignment algorithms is selection of the appropriate interference model which is compatible with the behavior of the CSMA/CA MAC protocol to improve the network performance. The motivation of this research is to address the impact of interference between the wireless links by developing the channel assignment algorithms using the appropriate interference model to improve the performance of the network.

1.2 Problem Background

WMNs are considered as promising solution for internet access in wide areas. In WMN, the problem of network capacity in the architecture of Single-Radio Single-Channel (SR-SC) is improved significantly by the architecture of the MR-MC. Figure 1.2(a) and Figure 1.2(b) illustrates the protocol stack of the MR-MC and SR-SC respectively. In MR-MC, the capacity of the network can be improved by a factor equal to the number of radio interfaces which are installed on the nodes (Riggio *et al.*, 2011). This is because, the concept of MR-MC supports the concurrent transmission between the wireless links and then the capacity of the overall network is increased (Chaudhry *et al.*, 2010a; Gálvez and Ruiz, 2013). The use of multiple channels can decrease the effect of interference present between the links. However, the channel assignment on the basis of interference present between the co-located channels becomes critical due to some constraints such as: the number of all the available non-overlapping wireless channels in IEEE 802.11 standard is limited (Duarte *et al.*, 2012; Ning *et al.*, 2014; Wu *et al.*, 2014). In the MR-MC architecture, the wireless nodes has limited number of radio interfaces to assign varying channels. Based on the test bed results defined by Bahl *et al.* (2004), the maximum number of interfaces that are equipped on each node must not exceed four radio interfaces per node. Additionally, the network is considered more connected when a common channel is used between all the links. However, using a common channel in a given network leads to increase the impact of interference between the links (Ahmed *et al.*, 2014; Athota and Negi, 2014). Therefore, to maintain the network connectivity is a challenging task faced by most of the algorithms that aims to mitigate the impact of interference between the links. Thus, the balance between mitigation of the impact of interference and to maintain the network connectivity, to increase the overall performance of the network, is a complex task.



(a) **(b)**

Figure 1.2: Protocol stack of MR-MC and SR-SC

The following sub-sections discuss in detail the issues related to the design of the channel assignment algorithms.

1.2.1. Topology Preservation for Low Interference Channel Assignment

Topology preservation is a strategy used to address the problems of link failure and partitioning of the wireless network (Doraghinejad *et al.*, 2014). In this strategy all the links in the original topology exist in the final topology after the channel assignment process in order to maintain the network connectivity. The main challenge faced by this strategy is the high impact of interference between the links in MR-MC of the WMNs. This is because the number of the available channels and the number of radio interfaces per node is limited. The channel assignment process in the topology preservation strategy is considered as a NP-hard due to the restrictions mentioned in the Section 1.2 (Marina *et al.*, 2010; Kumar *et al.*, 2011; Athota and Negi, 2014; Doraghinejad *et al.*, 2014).

In WMNs, the direction for most of the data traffic in the wireless mesh network is to/from the mesh gateway. Thus, the links close to the gateway are crowded and considered as high-performance links. Consequently, most of the work in the topology preservation field such as Marina *et al.* (2010), Kumar *et al*. (2011), Yong *et al*. (2013) and Athota and Negi (2014) gives the channel assignment priority to links close to the gateway to avoid the congestion problem. Hence, unfair distribution of the channels between the links close to the gateway may cause the problems of bottleneck links and data collisions in a given network topology (Yong *et al.*, 2013). To this end, most of the existing algorithms in the literature aims to assigning varying non-overlapping channels efficiently to mitigate the impact of interference between the links. Thus, some of the existing channel assignment algorithms have two phases of link scheduling and channel assignment to distribute the channels effectively and mitigate the impact of interference between the links.

The CBCA proposal by Athota and Negi (2014) presents a clustering algorithm named Cluster Based Channel Assignment. The CBCA consists of three stages such as nodes clustering, interfaces binding and channel assignment process. The main target of this algorithm is to mitigate the impact of co-channel interference and ripple effect between the links based on the availability of the channels and interfaces in

WMN. In this algorithm, all the radio interfaces of the nodes are used by channels to guarantee the network connectivity between the nodes in different clusters. Moreover, all the nodes are divided into clusters based on the number of hops to utilize the available channels effectively and mitigate the impact of interference between the nodes in the same cluster. However, the CBCA lacks of a mechanism to guarantee the channels are distributed equitably between the links in a given topology. Accordingly, the overall capacity of the network is affected.

Doraghinejad *et al.* (2014) proposed an interference aware channel assignment algorithm based on Gravitational Search Algorithm (GSA). The proposed algorithm named as Improved version of GSA (IGSA). The IGSA aims to utilization of available channels effectively while maintaining on the network connectivity. The proposed algorithm has the abilities of exploration and exploitation the available resources concurrently to find out the best solution. The IGSA algorithm guarantees the network connectivity. However, major challenge faced by the IGSA is associated with the lack of a mechanism to guarantee the effective distribution of the channels between the links close to the gateway.

Cheng *et al.* (2013) proposed an interference aware channel assignment algorithm based on Particle Swarm Optimization (PSO) technique. The proposed algorithm named as Discrete PSO (DPSO) algorithm. The DPSO aims to mitigate the impact of interference between the wireless links while maintaining on the network connectivity. DPSO uses the values of the best solution (pBest) and global best value (gBest) to select the least interference channel for each link. In the DPSO, the channels are assigned randomly to all the links in the network topology. Thus, the DPSO algorithm guarantees the communication between all the nodes in the network topology. However, major challenge faced by the DPSO is associated with the lack of a mechanism used to distinguish between the links in the given network topology, especially the wireless links close to the gateway in order to avoid the bottleneck problem.

Marina *et al*. (2010) proposed an interference aware channel assignment algorithm named Connected Low Interference Channel Assignment (CLICA) algorithm. The proposed algorithm is static channel assignment based on graph coloring problems. The main target of the CLICA is to construct a network topology with low interference while preserving the network connectivity. The CLICA assigns a rank, to all the nodes in the network topology, based on shortest path construction and the number of free radio interfaces. In this algorithm, the channel assignment priority is given to a node that has only a single unassigned radio interface. The drawback of this algorithm is to dynamically adjust the nodes priority which lead to high overhead in the network (Si *et al.*, 2010). Moreover, the connectivity constraint between the nodes in CLICA is achieved by using the topology preservation strategy. However, the main limitation faced by the CLICA is leaves some nodes with unassigned radio interfaces, which reduces the throughput of the network.

Finally, most of the existing interference aware channel assignment algorithms based on topology preservation strategy focused on mitigating the impact of interference between the links. However, most of these algorithms lack a mechanism to ensure distribution of the channels equitably between the links. Additionally, most of these algorithms also aim to distribution of the channels between the links regardless of the behavior of CSMA/CA protocol that developed to improve the overall throughput of the network.

1.2.2. Topology Control based on Non-overlapping Channels Assignment

The strategies of the topology control in the WMN are used to mitigate the impact of interference problem between the links, or improving the energy consumption while maintaining on the network connectivity (Chaudhry *et al.*, 2012; Liu and Bai, 2012). In the literature, most of the works apply the topology control interlinked with channel assignment in MR-MC to enhance the network performance (Naveed *et al.*, 2007). Moreover, the properties of the multi paths in the MR-MC are used in the network topology to maximize the network capacity by increasing the simultaneous transmissions between the wireless links (Nezhad and Cerda-Alabern, 2010).

One of the challenges faced by the topology control strategies, in the dense network topology, is the number of co-located interfering links between the mesh nodes is higher. Consequently, it is difficult to eliminate the impact of interference between the links completely in dense wireless networks while maintaining on the network connectivity, due to the restrictions that have been discussed in the Section 1.2 (Ali *et al.*, 2014). However, some of these algorithms focus to utilize all the available non-overlapping channels effectively to reduce the impact of interference between the links while maintaining on the network connectivity. In practice, routing protocols favor links which offer higher performance. Therefore most of the links with lower quality are likely useless. In the literature , some of the work applied the process of channel assignment based on removing the useless links from the original topology to improve the network capacity.

Chaudhry *et al.* (2012) proposed an interference aware channel assignment algorithm based on topology control strategy. The proposed algorithm names as Topology-controlled Interference-aware Channel-assignment Algorithm (TICA). The main target of this algorithm is mitigating the impact of interference problem while maintaining on the network connectivity. TICA proposed a new technique names as *select x for less than x* to intelligently assign the non-overlapping channels between the wireless links. The technique of the *select x for less than x* is used to build connected network topology based on the shortest path length (selecting the nearest neighbors for each node). In the TICA, the radio interfaces available on each node are static. One interface on each node is used for control message through a common channel, while the other interfaces are used for data traffic. The main challenge faced by the technique of the *select x for less than x* in the proposed TICA algorithm is used to build connected network topology based on shortest path length regardless to find alternative paths between the nodes.

Nezhad *et al.* (2010) proposed an algorithm named as Utility Based Channel Assignment (UBCA) in order to assign the non-overlapping channels between the links. The UBCA aims to select a set of links to be used out of all available links in the network topology. The main objective of this algorithm is to mitigate the impact of interference over high performance wireless links. The UBCA gives each link in the network topology a weight equal to the number of links that potentially interfere with target link. Thus, the process of channel assignment in UBCA starts from links with the higher weight. The UBCA removes some of the useless links from the original topology, when the alternative path between the nodes exists and the two nodes which established the link do not have any free radio interfaces to assign the channel. In the case if there is no free radio interface between the two nodes that constituted the link then, the channel merging process is applied to find a common channel between the two nodes. Therefore, the UBCA algorithm guarantees the multi-paths between two nodes in the network topology. Moreover, the UBCA assigns a channel for each link in the network topology in order to maintain the network connectivity. However, the main limitation faced by the UBCA algorithm is that there is no mechanism used to guarantee that the channels are distributed equitably between the links in a given topology. Moreover, the problem of channel merging in the UBCA algorithm may lead to hinder the channels distribution, between the links, optimally.

Chen *et al.* (2009) proposed a channel assignment algorithm based on the genetic NSGA-II algorithm to improve the throughput of the WMNs. The main target of proposed algorithm is to find the optimal topology with minimum interference and maximum number of links between the nodes. The proposed algorithm aims to choose a subset of links among all the links in the network topology to assign the channels without affecting much on the efficiency of the network topology. The main challenge faced by the GAs is a random channel distribution between the nodes based on the fitness function values. Accordingly, in the GAs algorithm no mechanism is used to ensure the fair distribution of the channels between the links to maximize the network capacity. Additionally, there is no mechanism used to distinguish the links between the nodes in the given network topology, especially the links close to the gateway to avoid the bottleneck problem.

Finally, the existing channel assignment algorithms based on the strategies of topology control focus on mitigating the impact of interference between the links by selecting a set of high performance links. However, some of the algorithms have limitations on the equitable channel distribution between the links. There are some algorithms which select a set of high performance links in order to assign the channels regardless to find out the alternative paths between the nodes.

1.2.3. Fairness Distribution of the Non-Overlapping Channels

Generally, the fairness in WMNs be classified into two strategies, fairness per-flow and fairness per-node. The fairness per-flow aims to equal share of the amount of packets flowing between the multiple paths. The challenge faced by this strategy is associated with unfair flows between the links close to the gateway when the multiple traffic flows share the same link which lead to the congestion problem (Chaudhry *et al.,* 2012). The fairness per-node aims to equal access, to the wireless medium, for each node in the network topology. The challenge faced by this strategy is that the impact of interference between the links leads to obstruct the nodes that operate on a conflicting channel to access the wireless medium. Consequently, the interference problem in WMNs severely affects the overall network throughput in the schemes of multi-hop flows (Jianjun *et al.,* 2014). Usually, the end-to-end throughput is affected by the link which has minimum throughput due to the impact of interference. One of the critical issues in the fair distribution of the non-overlapping channels is to provide high bandwidth between the nodes to ensure effective communication between them. Hence, a fair distribution of channel capacity between the links in the network topology is significantly important. This is because of the fact that the average of overall network throughput in multi-hop flows is limited by the wireless link which has the least throughput.

To improve the overall throughput of the network, most of the existing work focuses on to distribute the non-overlapping channels between the links effectively and mitigate the impact of interference between the links. Thus, the capability of the whole network topology depends on the total bandwidths of the channels that assigned between the links. In the literature many research works use the fairness distribution channels between the wireless links to improve the overall throughput of WMNs.

Chaudhry *et al.* (2015) proposed simple computational strategies to find the interference-free communication based on minimum number of channels. The proposed strategies are formulated based on the Signal-to-Interference Ratio (SIR) model. In this work, one radio interface in each node is used as control radio to exchange the control messages between the nodes in a given network topology. This work uses the conflict graph based on the SIR model to capture and analyze the impact of interference between the wireless links. The coloring of conflict graph strategy is used to mitigate the impact of interference between the wireless links. The technique of the *select x for less than x* in the TCA algorithm defined by Chaudhry *et al.* (2012) is used to find the minimum number of channels with interference free. The main objective of this work is to improve the throughput while maintaining the fairness among the traffic flows. However, the main challenge faced by this work is to use one radio interface from each node to exchange the control messages between the nodes while the number of interfaces is less as compared to the number of the channels. As a result, the available resources are not utilized optimally to improve the throughput of the WMNs.

In another research, Jianjun *et al.* (2014) proposed a dynamic channel assignment algorithm based on the bipartite-graph model. The proposed algorithm aims to achieve relative fairness between the nodes to maximize the end-to-end throughput flows in multi-hop flows. This work uses the bipartite-graph to model the channels and nodes in a given network topology. In this algorithm, each node uses only the channels that are located within the transmission range. The channel is available to only one node at a time. This work uses minimal of the total bandwidths of the channels assigned between the nodes to represent fairness. The proposed algorithm aims to distribute the channels between the links effectively to improve the fairness between the links. The main challenge of this algorithm is the overhead of channel switching.

Cheng *et al.* (2012) proposed a non-overlapping channel assignment algorithm named as a Discrete Particle Swarm Optimization for Channel Assignment (DPSO-CA). The proposed algorithm is based on topology preservation as explained by Subramanian *et al.* (2008). The authors designed channel assignment algorithm using the technique of the DPSO to find the optimal network topology. DPSO-CA is based on the multi-objective function which achieves two conflicting goals (mitigate the interference problem while maintaining on the network connectivity). Moreover, the proposed algorithm DPSO-CA aims to balance between the maintained network connectivity and mitigation of the co-channel interference based on organizing the mesh nodes with available channels. The DPSO-CA selects one radio interface within each node to assign a common channel in the initialization process of the network topology. The major challenge faced by the DPSO-CA is that there is no mechanism to ensure that the channels are distributed equitably between the links. The equitable distribution of the channels between the links helps to improve the network capacity by increasing the simultaneous transmissions between the links. Additionally, the usage of a common channel between the nodes makes the network topology more connected, but this leads to increase the impact of interference between the links.

Recently, many researchers have used the optimization techniques in the interference aware channel assignment algorithms to improve the overall throughput of the WMN (Alabady and Salleh, 2013; Cheng *et al.*, 2013; Doraghinejad *et al.*, 2014). Hence, the selection and adaptation of an appropriate optimization technique, for channel assignment with a mechanism to ensure equitable channel distribution between the links, have a significant impact in improving the throughput of the WMNs.

1.3 Problem Statement

This research addresses the problem of interference in the WMN which limits the throughput, capacity and fairness of the network. In the WMNs, the topology preservation strategy is used to improve the throughput and addresses the problem of the network connectivity. However, the impact of interference between the links is high in the topology preservation strategy due to all the links in the original topology which exist in the final topology after the channel assignment process.

In the dense network topology, the network capacity is adversely affected, due to the higher number of co-located interfering links and the limited available number of the non-overlapping channels which are operating between these links. Consequently, the number of the concurrent transmission between the wireless links deteriorates.

The fairness in the WMN is adversely affected by the impact of interference between the wireless links which obstructs the nodes, to access the wireless medium, that operate on a conflicting channel. Consequently, the interference problem severely affects the overall network throughput in the multi-hop flows schemes. The overall network throughput average in multi-hop flows is limited by the wireless link which has the least throughput.

1.4 Research Questions

This research raises several challenges and these challenges are addressed by providing the answers to the following questions:

i. How to select the least interference channel effectively to improve the throughput and mitigate the impact of interference between the wireless links while the network connectivity is maintained?

   a. What parameters should be considered to distinguish the wireless links to improve the overall network performance?
   b. What metrics should be considered to select the least interference channel among all the non-overlapping channels?

ii. How to remove the useless links from the original topology to increase the concurrent transmission between the wireless links and improve the network capacity?

  a. What criteria should be considered to maintain the network connectivity?
  b. How to derive multi-criteria functions to distinguish and rank the wireless links of the network topology and assign them the non-overlapping channels?

iii. How to distribute the non-overlapping channels equitably between the wireless links to improve the fairness of the WMN?

  a. How to develop and adapt the differential evolution algorithm with a roulette wheel method to find and reassign the optimal channel to each link to improve the fairness of the network?
  b. What criteria should be considered to select the least interference channel among all the non-overlapping channels?

1.5 The Aim

The aim of this research is to mitigate the impact of interference between the wireless links in order to improve the throughput, capacity and fairness of the WMN. However, the network connectivity is maintained by the efficient utilization of the non-overlapping channels between the links.

1.6 Research Objectives

The main objectives of this research are:

i. To develop an algorithm to select the least interference channel from the available non-overlapping channels using the topology preservation strategy to improve the throughput while the network connectivity is maintained.

ii. To develop an algorithm to improve the network capacity by increasing the concurrent transmission between the links while satisfying the connectivity constraints by applying the topology control strategy.

iii. To develop an improved algorithm for fairness by distributing the non-overlapping channels equitably between the links to enhance the overall throughput of the WMN.

1.7 Significance of the Study

The increased density of the WMNs deployments can provide the users an improved network performance. In the WMN, an equitable distribution of the non-overlapping channels between the links may result in the delivery of better quality of service such as video and voice streaming. However, an increased interference may lead to the challenges of significant degradation of throughput, capacity and fairness. The location of the overlapping links and the distribution of the non-overlapping channels between these links help to mitigate the impact of the interference.

In this research, the proposed algorithms guarantee that the non-overlapping channels are distributed equitably between the links to improve the throughput and to mitigate the impact of interference. The links close to the gateway are classified as high performance links and are assigned varying channels to avoid the bottleneck link problem. The channel assignment algorithms are formulated based on the CSMA/CA protocol to avoid the data collision between the nodes. The removal of the useless links from the original topology, while the connectivity constraints are satisfied, may result in an improved network capacity performance by increasing the concurrent transmissions between the links. Moreover, the use of optimization techniques significantly improves the WMNs fairness through an equitable distribution of the channels capacity between the links.

1.8 Research Scope

The scope of this research covers the following points:

i. All the mesh routers in the network are equipped with multiple radio interfaces in order to assign multiple channels.
ii. The external interference which generated by the wireless links of the adjacent networks is not under consideration.
iii. The partial channels in the IEEE 802.11a/b standards are out of the scope of this research.
iv. The number of distinct channels that can be assigned to a mesh router is bounded by the number of radio interfaces.
v. The proposed channel assignment algorithms are static in nature and are executed when the WMNs is initialized.

1.9 Thesis Organization

This research comprises seven chapters. The remaining chapters are organized as follows:

Chapter 2 provides an extensive review of the literature of the area of research, problem background and highlight the shortcomings of most of existing algorithms that have been employed in the interference aware channel assignment algorithms.

The chapter has highlighted the shortcomings and advantages of the most of the interference models which are used to capture and evaluate the impact of interference in the WMNs.

Chapter 3 describes the research methodology and experiments used to obtain the objectives of this research. It highlights the design, implementation and verification of the proposed interference-aware non-overlapping channel assignment algorithms that are applied in this research.

Chapter 4 presents the proposed Topology-preservation for Low-interference Channel Assignment (TLCA) algorithm that develops to improve the throughput while maintaining on the network connectivity using topology preservation strategy.

Chapter 5 presents a detailed description for the design and development of the proposed Max-flow based on Topology-control Channel Assignment (MTCA) algorithm. The MTCA is developed to increase the network capacity by removing the useless links from the original topology to increase the number of concurrent transmissions between the links.

Chapter 6 presents the details of the design and implementation of the proposed Fairness distribution of the Non-Overlapping Channels (F-NOC) algorithm. The algorithm is developed to improve the fairness of the WMNs through the equitable distribution of the non-overlapping channels between the links while satisfying the constraints of the network connectivity.

Chapter 7 concludes the research and presents the research achievements. Moreover, the possible future directions are also described in detail.

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