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Interference Aware, Topology, Power and Flow Control Channel Assignment Algorithm for Multi-Radio Multi-Channel Wireless Mesh Networks

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***Abstract*--** Multi-Radio Multi-Channel Wireless Mesh Network (MRMC-WMN) is a multi-hop wireless network that consists of a large number of mesh nodes. The availability of cost-effective multi-radio wireless network interface cards makes it possible to achieve higher throughput based on simultaneous transmission and reception. Each network interface card is equipped with different radio channels. But due to limited non-overlapping channels, MRMC-WMN suffers from the co-channel interference. Co-channel interference limits the capacity of each link and degrades the performance of the whole network. Efficient performance can be achieved from MRMC-WMN only by intelligent channel assignment algorithm. In this paper, we propose the Interference aware, Topology, Power and Flow Control Channel Assignment (ITPFC) algorithm based on the joint contribution of important factors such as topology control, co-channel interference, power control and flow control. The aim of this channel assignment algorithm is to minimize the co-channel interference and provide the appropriate link capacity to each node so that the network performance can be maximized. We have used NS-3 based WiMesh tool for simulation and evaluated the network performance in terms of throughput, delay, packet loss and number of channels used. Results have been compared with existing channel assignment algorithms and it is found that ITPFC Channel Assignment algorithm achieves better results.

***Keywords*--** Multi-Radio Multi-Channel Wireless Mesh Network, Channel Assignment, Network Interface Card, Power Control, Topology Control, Flow Control, WiMesh.

I. INTRODUCTION

Multi-Radio Multi-Channel Wireless Mesh Network (MRMC-WMN) has been introduced as a solution to provide wireless connectivity in large areas without the use of wired infrastructure. MRMC WMN supports a variety of emerging and commercial application areas e.g. neighborhood networks, broadband home networking and disaster management [1, 2]. WMNs are characterized by reliable, auto-configurable, self-organizing features and consist of a large number of mesh nodes. Mesh nodes act as mesh gateways, mesh routers, mesh aggregate devices and mesh clients as shown in Figure 1 [3]. All the nodes communicate with each other via multi-hop wireless configuration.

Due to the availability of cost-effective multi-radio network interface cards (NICs), nodes can transfer and receive data simultaneously which increase the parallelism of data transmission. Each node operates on different frequency channels to minimize the co-channel interference among nodes [4]. Each mesh router forward data to other nodes towards the destination node for data transmission because all the nodes work in ad-hoc mode. Gateway nodes are connected to the wired backbone for providing the backbone services to WMN [5]. As limited numbers of non-overlapping channels are available, this leads to the existence of co-channel interference in networks.

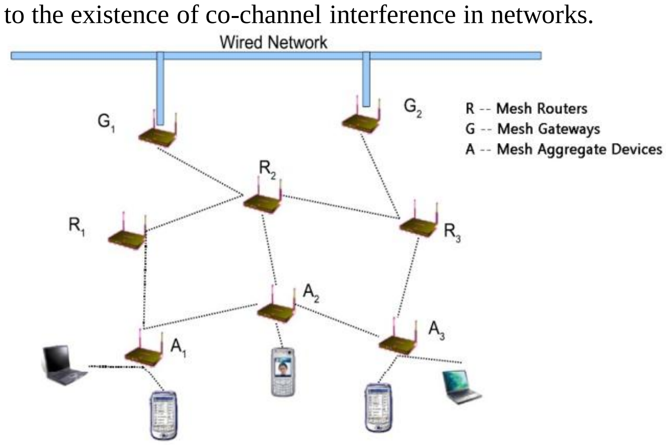

Figure 1. MRMC WMN Architecture

Co-channel interference limits the capacity of each link and reduces the network performance. To mitigate such co-channel interference in MRMC WMN, an efficient channel assignment algorithm is required. The process of making sure that all the interfering nodes are assigned different channels is known as the Channel Assignment [6]. It ensures that each node in the network has been assigned to the appropriate channel so that it can lead to significant enhancement in link capacity and media access performance of the network [7]. A channel assignment algorithm should have desirable qualities such as minimum connection setup time, load distribution among nodes, fault tolerance and scalability. Topology control, co-channel interference, power control and flow control are the important factors, which should be considered during the channel assignment. Topology control is a way to exploit links controllability to obtain the desired topology. Topology control creates the communication backbone of WMN by turning on/off node's NICs and by establishing the new links with nodes [8]. Topology control can logically change the network topology to improve the network operations such as link connectivity, energy efficiency, mobility resilience, network capacity increase and interference reduction etc [9]. In MRMC WMN topology control is mutually interlinked with power control, channel assignment and routing, which poses new challenges to its design.

Power control plays a very important role in WMN to control the transmission range and interference range of each node. Power control controls the transmission power of each node to the required level so that the network connectivity can be maintained and co-channel interference can be minimized [10]. In MRMC WMN efficient power control not only reduces co-channel interference but also increases channel reuse [11]. Power control can be made on per link, per destination or per packet basis. Flow Control is the process which makes sure that each node is getting the required link capacity. Due to the availability of co-channel interference capacity of each link has been reduced. If any node in the network is not getting sufficient link capacity it will slow down the transmission speed and reduce the network performance [12]. By controlling the flow of each link WMN achieves the maximum network throughput, traffic demand of each link and maximize the end-to-end data rate.

In this paper Interference aware, Topology, Power, Flow Control Channel Assignment (ITPFC) algorithm has been proposed for MRMC WMN based on the collective features of topology control, interference, power control and flow control. Simulation test-bed has been designed to implement and validate the proposed channel assignment algorithm. NS-3 based WiMesh simulation tool has been used for simulation. Proposed channel assignment algorithm dynamically controls the transmission power of each node and tends to reduce the co-channel interference as well as increase the link capacity. This algorithm ensures that if any link due to co-channel interference is not getting sufficient link capacity then shifts the channel with lower interference channel and fulfills the link requirement. Proposed ITPFC Channel Assignment algorithm has been compared with existing channel assignment algorithms in terms of throughput, delay, packet loss and channel use. It has been found that proposed algorithm performs better as compared to Flow based Channel, Power and Rate Assignment Algorithm (FCPRA), Load Aware Channel Assignment Algorithm (LACA) and Interference Aware Topology Control Channel Assignment Algorithm (IATC).

The paper is organized as follows. In Section II, Related work to channel assignment is described. Simulation experiment and proposed algorithms are discussed in Section III. Section IV presents the results and discussions. Finally, Section V concludes the paper and provides future scope.

II. RELATED WORK

In [13], the authors proposed a new Channel, Power and Rate assignment algorithm for Multi-Radio Wireless Mesh Networks. Authors analyzed the effect of controlling the transmission power and rate of each link. This algorithm computes the total utilization of link and assigns a new channel to fulfill the flow requirement of the link. The proposed algorithm has been compared with the FCRA algorithm, LACA and BSCA algorithm and found that the proposed algorithm performs better in terms of flow rates. The authors of [14] argued that topology control, Power control, channel assignment and routing functions are interlinked with each other. It is better to view topology control as a management functional block in connection with protocol layers in MRMC WMN. The Joint optimization approach for topology control has the advantages to enhance network performance in term of throughput, interference, link connectivity, and fairness. In [15], the authors proposed a joint routing, channel assignment and rate allocation algorithm. The main aim of this algorithm is to balance the incoming and outgoing traffic among all network nodes. Authors evaluate the proposed algorithm in terms of throughput and fairness ratio based on numerical experiments. Authors in [16] studied the working of interference models on channel assignment such as SIR model, protocol model and SIR model with shadowing. They proposed the effective method to create a conflict-free graph based on SIR with shadowing model. The main purpose of this method is to find interference-free radio channels. In [17], the authors proposed a Link-Layer protocol with learning automata channel assignment algorithm to solve the problem of interference among the channels. The aim of this intelligent algorithm is to find the best states that satisfy each node for the assigned channel. Results show that LLLA perform better as compare to Ad-hoc on demand distance vector algorithm in terms of packets dropped, end-to-end delay and average goodput.

Authors in [18] calculated maximum transmission power of base station as well as the transmission power of primary transmitters, so that primary receivers can meet the SINR constraints on receiving channel. Distributed power update among network nodes employed by the base station and primary transmitters, maximizes the coverage area of the cognitive network. In [19], the authors proposed Distributed Flow-Radio Channel Assignment algorithm for accompanying distributed protocol in the context of MRMC-WMNs. Authors say that flow-radio and channel assignment procedures must obey the physical constraints imposed by the radios as well as the topological constraints imposed by routing. The proposed algorithm has been evaluated on large random topologies and found that it performs better as compared to the existing algorithms. In [20], the authors proposed a Load Aware Channel Assignment algorithm that determines the traffic load on each link and then assigns the appropriate channel. The proposed algorithm tries to minimize the co-channel interference and to uplift the link capacity. The proposed algorithm has been compared with Identical Channel Assignment algorithm and Neighbor Portioning Channel Assignment algorithm and it is found that the proposed algorithm has better performance.

The authors of [21] proposed Interference Aware Topology Control Channel Assignment algorithm and QoS Routing for MRMC WMNs. This algorithm assigns the channels for each node in such a manner that the network should have minimum interference among each node. Simulation results show that the proposed algorithm improves the network performance by 57% as compared to the Common Channel Assignment algorithm. Authors of [22] proposed Channel and Rate Assignment algorithm for MRMC WMNs. Authors demonstrated that not only the channels but also the transmission rate of the links have to be properly selected to make a given set of pre-computed flow rates schedulable. The proposed algorithm has been analyzed through numerical simulation based on the Markov Chain Model. In [23], the authors developed WiMesh, a simulation tool to evaluate and compare various algorithms (channel assignment, rate allocation and power control) for MRMC WMNs. WiMesh contains a core library, three distinct function libraries and three utilities, which helps to conduct simulation experiments. In [24], the authors proposed a Gravitational Search Channel Assignment algorithm to solve the problem of co-channel interference. A local discrete search operator is used with Gravitational Search algorithm to find the best channel for each node. The proposed algorithm performs better as compared to Interference Aware Topology Control Channel Assignment algorithm in respect of minimum interference and higher throughput.

The authors of [25] introduce joint channel assignment and routing algorithm based on graph edge coloring problem and partially overlapped channels for MRMC WMNs. Partially overlapped channels provide more flexibility and increase the frequency reuse. Simulation comparison shows that the proposed algorithm performs better as compared to ETX and ETT in terms of average delay and throughput. In [26], authors proposed Weight Aware Channel Assignment algorithm to support mobile multicast for WMNs. The proposed algorithm assigns channels based on path forwarding weight, channel separation and the distance between nodes. Simulation results show that the proposed algorithm performs better as compared to level channel assignment algorithm in terms of throughput, transmission time and delay. Authors of [27] proposed joint routing, scheduling and channel assignment algorithm based on Latin Squares. This algorithm organizes cliques for inter-cluster and intra-cluster in the network based on nodal interference information. Then this algorithm applies Latin squares to map the clique-based clustering structure to radios and channels for communication purposes. Then algorithm schedules the channel access among nodes within each cluster in a collision-free manner.

In [28], the authors proposed Topology Controlled Interference Aware Channel Assignment algorithm for MRMC WMNs. This algorithm assigns channels based on power control and topology control algorithms to minimize the co-channel interference and to maximize network throughput. NS2 based simulation shows that the proposed algorithm performs better as compared to common channel assignment algorithms in terms of network throughput and fairness among traffic flows. Authors of [29] proposed GA-based Channel Assignment algorithm. This algorithm evaluates the traffic load on each link and provides the optimal solution to reduce the interference among links and improve the network performance. Simulation results show that the proposed algorithm performs better as compared to C-Hyacinth and GACA-Identical Load in terms of packet loss and network throughput.

III. SIMULATION SETUP

To evaluate the proposed ITPFC Channel Assignment algorithm, NS-3 based WiMesh simulation tool has been used. For this, a topology of 30 nodes has been deployed in 300m X 350m area as shown in Figure 2.

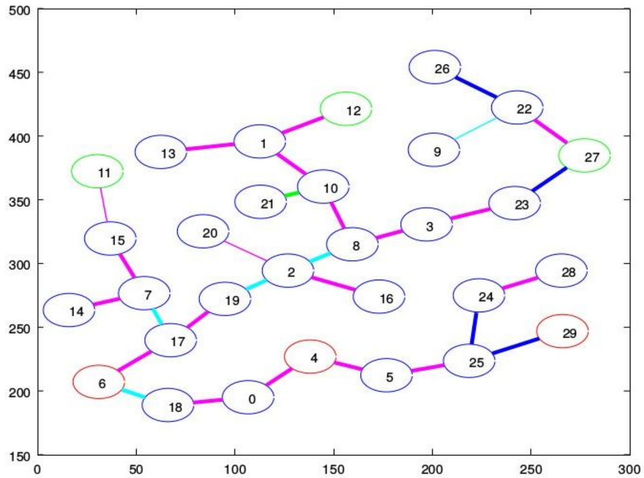

Figure 2. Network Topology

All nodes are equipped with three network interface cards. Out of these 30 nodes, 3 nodes act as aggregate nodes and 3 nodes act as gateway nodes. All nodes are located on the random location in the network. Each node in the network has been configured according to Table 1.

Table 1. Node configuration values

Description	Value
Area	300m X 350m
Transmission Power	Optimal Power Control Algorithm
Number of Nodes	30
Aggregate Nodes	3
Gateway Nodes	3
Transmission Gain	1 dBi
Receiver Gain	1 dBi
Routing Protocol	MPLS
Transmission Speed	6Mbps
Simulation Time	600 secs
No. of Channels	11
Traffic Type	On-Off
Interference Model	SINR
Receiving Threshold	-46dBm
Flow Monitor Interval	1 sec

To evaluate the performance of the network, simulation has run for 600 seconds. For better performance evaluation all 11 channels are used in network and capacity of each link is set to 6 Mbps. On-Off traffic is used for data transmission among nodes. Interference Model is set to Signal to Interference plus Noise Ratio (SINR). MPLS routing protocol is used as a routing protocol.

Proposed ITPFC Channel Assignment algorithm has been developed in three stages. In the first stage, the network has been deployed based on the above configuration by using Interference Aware Topology Control channel assignment algorithm [21]. This channel assignment algorithm assigns the channel with minimum co-channel interference among nodes, keeping in view the network topology. Algorithm establishes only that link which is required for data transfer among nodes and that leads towards minimum co-channel interference.

To minimize co-channel interference and for better network performance transmission power of each node must be controlled up-to required transmission range. In the second stage, the Optimal Power Control algorithm has been designed to dynamically control the transmission power of each node up to the required transmission range using the Friis transmission equation [30]. This algorithm minimizes the co-channel interference and increases the link capacity.

In third and final stage, performance has been further boosted by designing channel assignment algorithm based on Flow Control algorithm. This algorithm checks that whether the link has required link capacity to transfer the data or need to reassign different channel. If required, algorithm reassigns different channel which has less co-channel interference among neighbor nodes and allocates required link capacity. Each link has been provided with the suitable amount of bandwidth/capacity so that data can be transferred faster and without loss.

The pseudo code of the proposed algorithm is given below.

Algorithm 1 ITPFC Channel Assignment

Input: G(V, E), $\forall$ u $\in$ V, $\forall$ e $\in$ E

1. Construct a graph G(V, E) with 30 nodes topology.
2. Apply the Interference Aware Topology Control Channel Assignment Algorithm.
3. Measure the network parameters.
4. Apply the Optimal Power Control Algorithm (Algorithm 1.1) for each node u $\in$ V.
5. Apply the Flow Control Algorithm (Algorithm 1.2) for each node u $\in$ V.

Construct a graph *G* having *V* nodes and *E* links from the given topology of 30 nodes. Apply the Interference Aware Topology Control Channel Assignment algorithm for each node in the network. This algorithm uses all available 11 channels and assigns them to nodes as low co-channel interference among other nodes. It also finds the potential interference links in the network and sorts them in descending order. The best possible channel with least interference among nodes is assigned to the smallest value of potential interference link. This algorithm establishes only required link with minimum interference among each other.

Algorithm 1.1 Optimal Power Control (OPC)

Input: G(V, E), $\forall$ u $\in$ V
1. Q $\leftarrow$ {u}
2. While Q is not empty
3. u $\leftarrow$ Extract one node from Q
4. find d(u - v) where v is an adjacent node of (u)
5. Set $P_{rx}thresh$ value = P_{rx}
6. $P_{tx} = P_{rx} - G_{tx} - G_{rx} - 20\log_{10}\left(\frac{\lambda}{4\pi d}\right)$
7. Set P_{min} = P_{tx}
8. if $P_{min}(u) < P(u)$, then $P(u) = P_{min}(u)$
9. if $P_{min}(u) > P(u)$, then $P(u) = P_{min}(u)$
10. if $P_{min}(u) == P(u)$, then do nothing.
11. End while
12. Stop

Let us assume a graph *G* having *V* nodes with *E* edges. The algorithm 1.1 considers all network nodes *u* one after another. A queue *Q* is generated and all nodes *u* are inserted in that queue. To calculate minimum power for each node, nodes are extracted one by one from the queue (lines 1-3). In this algorithm, P_{rx} and P_{tx} are represented as receiving power and transmitter power respectively. G_{tx} is represented as transmission gain and G_{rx} is denoted as and receiver gain. *d* is represented as the distance in between the nodes. Transmission power already assigned to node *u* is represented as *P(u)*.

In line 4, distance is calculated from node *u* to neighbor node *v*. The receiver threshold power $P_{rx}thresh$ is set as P_{rx}. In this work $P_{rx}thresh$ is set to -46 dBm. In lines (6-7), transmission power P_{tx} is calculated and assigned as minimum transmission power P_{min}. If the minimum transmission power P_{min} is less than assigned transmission power *P(u)*, ($P_{min} < P(u)$), then set P_{min} as transmission power of node *u*. If calculated power P_{min} is more than assigned power *P(u)*, ($P_{min} > P(u)$), then set P_{min} as transmission power of node *u*. In this case, Optimal Power Control algorithm finds that assigned transmission power is less than required minimum transmission power and increases transmission power up to required level. If calculated power P_{min} is equal to the assigned power *P(u)*, ($P_{min} == P(u)$) then there is no need to change the transmission power of node *u*.

Algorithm 1.2 Flow Control

Input G(V, E) $\forall$ u $\in$ V
1. Calculate flow f (u $\rightarrow$ v), where v is an adjacent node of (u)
2. Calculate capacity $C = W\log_2\left(1 + \frac{P}{N_0 W + I}\right)$
3. if f (u $\rightarrow$ v) $\leq$ C, then do nothing
4. else
   if $\mathcal{A}$ (u) < n && $\mathcal{A}$ (v) < n, then, where n is the no. NICs
5. $\mathcal{A}$ (u) $\leftarrow$ $\mathcal{A}$ (u) $\cup$ {c}, $\mathcal{A}$ (v) $\leftarrow$ $\mathcal{A}$ (v) $\cup$ {c}, assign channel c to link (u $\rightarrow$ v), where c is least interference common channel.
6. endif
7. if $\mathcal{A}$ (u) = n && $\mathcal{A}$ (v) < n, then
8. Select $\mathcal{A}$ c from node u, c $\in$ $\mathcal{A}$ (u), c $\notin$ $\mathcal{A}$ (v)
9. $\mathcal{A}$ (v) $\leftarrow$ $\mathcal{A}$ (v) $\cup$ {c}, assign channel c to link (u $\rightarrow$ v)).
10. endif
11. if $\mathcal{A}$ (u) = $\mathcal{A}$ (v) = n && $\mathcal{A}$ (u) $\cap$ $\mathcal{A}$ (v) = {c}, then
12. Assign channel c to link (u $\rightarrow$ v).
13. else
14. Assume $\mathcal{A}$ (u) = c1 && $\mathcal{A}$ (v) = c2
15. Merge c1,c2 in to c'
16. $\mathcal{A}$ (u) $\leftarrow$ $\mathcal{A}$ (u) $\cup$ {c'}, $\mathcal{A}$ (v) $\leftarrow$ $\mathcal{A}$ (v) $\cup$ {c'}, assign channel c' to link (u $\rightarrow$ v), where c' is least interference common channel.
17. endif
18. endif

Assume a graph *G* having *V* nodes and *E* edges. Line 1 calculates the flow *f (u → v)* between node *u* and *v*. This algorithm calculates the capacity C of link *c (u → v)* by using the (1) at line 2.

$$C = W\log_2\left(1 + \frac{P}{N_0 W + I}\right) \quad (1)$$

In this equation *W* is represented as bandwidth, *P* and *No* are represented as average power received and noise factor respectively. *I* is represented as interference [31].

In line 3, if the flow of link *f (u → v)* is less than and equal to the capacity *C* then no need to do anything. If the flow of link *f(u → v)* is more than capacity *C* of the link and both nodes *u* & *v* have channels less than the number of NICs *n* then assign the common channel *c* to both nodes and link *(u → v)* (lines 4-6). Where *c* is the least interference channel. In lines 7-10, if the numbers of channels of node *u* are equal to the number of NICs *n* and node *v* has channels less than numbers of NICs *n* then select the channel *c* from node *u* and assign to node *v* and link *(u → v)* as a common channel for both the nodes. In lines 11-17, if both nodes *u* and *v* have an equal number of channels as the number of NICs *n* and *c* is the common channel among them, then assign the channel *c* to link *(u → v)*. Otherwise select channel *c1* from node *u* and channel *c2* from node *v*. Merge both of the channels into channel *c'* and assign merged channel *c'* to both nodes *(u and v)* and link *(u → v)* as a common channel between node *u* and *v*. *c'* will be the least interference channel that will provide expected amount of link capacity.

Finally, the proposed ITPFC Channel Assignment algorithm assigns the channels to nodes that have less interference and provides more channel capacity. Proposed algorithm improves the network performance in terms of throughput, delay, packet loss and channel use. Comparison of the proposed algorithm with other algorithms from literature has been discussed in next section.

IV. RESULTS AND DISCUSSION

To evaluate the effectiveness of the proposed algorithm, a number of simulation experiments have been performed and results are compared with Flow based Channel, Power and Rate Assignment Algorithm (FCPRA), Load Aware Channel Assignment Algorithm (LACA) and Interference Aware Topology Control Channel Assignment Algorithm (IATC). Comparisons of these algorithms are given below.

A. Throughput

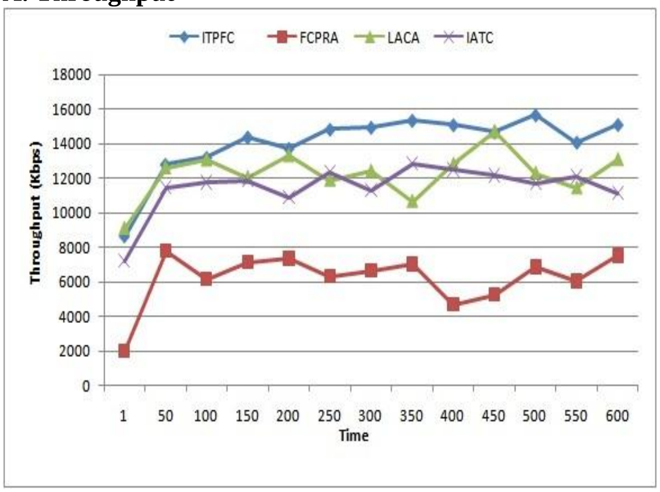

Figure 3. Throughput comparison of ITPFC with FCPRA, LACA, IATC

Table 2. Throughput Comparison

Time	ITPFC	FCPRA	LACA	IATC
1	8602.27	1987.78	9093.5	7208.54
50	12783.5	7768.32	12634.9	11446.8
100	13194.7	6146.11	13091.9	11721
150	14371.4	7117.15	12063.7	11858.1
200	13720.2	7334.21	13331.8	10864.2
250	14828.4	6328.9	11915.2	12337.9
300	14942.6	6637.34	12429.3	11298.3
350	15353.9	7014.34	10681.4	12817.7
400	15091.1	4683.84	12829.2	12475
450	14657	5232.19	14737	12143.7
500	15662.3	6854.4	12303.6	11686.8
550	14074.4	6031.87	11458.3	12063.7
600	15102.5	7494.14	13103.3	11115.6

Throughput specifies the maximum and minimum data rate supported by the network. Figure 3 and Table 2 shows the comparison of throughput obtained from proposed ITPFC Channel Assignment algorithm with FCPRA, LACA and IATC Channel Assignment algorithms. It has been observed that ITPFC Channel Assignment algorithm performs better as compared to other algorithms. Co-channel interference limits the maximum achievable throughput of the network. ITPFC Channel Assignment algorithm controls the co-channel interference of each node by using the Optimal Power Control algorithm moreover the Flow Control algorithm provides better link capacity for each link. Low interference and higher link capacity allow more and faster data transfer between nodes. These factors result in higher throughput in the network. Table 2 depicts that the highest throughput achieved by ITPFC Channel Assignment algorithm is 15662.3 Kbps and lowest throughput is 8602.27 Kbps.

B. Delay

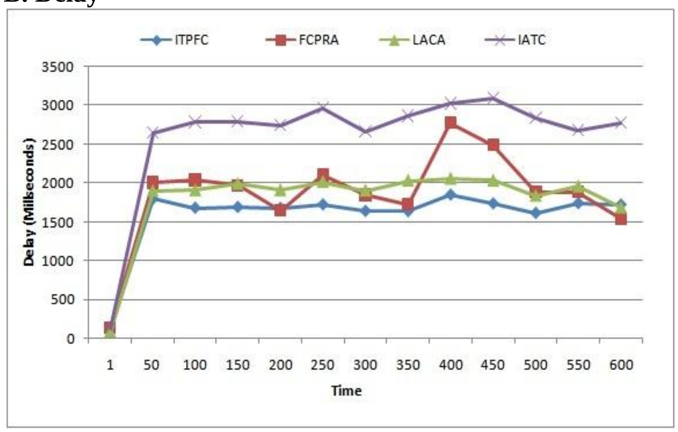

Figure 4. Delay comparison of ITPFC with FCPRA, LACA, IATC

Table 3. Delay Comparison

Time	ITPFC	FCPRA	LACA	IATC
1	133.803	142.033	91.1877	137.501
50	1793.9	2005.71	1898.69	2651.09
100	1680.05	2034.51	1909.13	2785.11
150	1690.43	1967.52	1991	2789.58
200	1677.14	1644.94	1910.11	2740.23
250	1722.39	2097.1	2015.91	2961.77
300	1639.96	1847.12	1903.29	2667.02
350	1636.61	1726.17	2031.85	2865.22
400	1848.4	2771.68	2055.91	3024.82
450	1735.52	2485.28	2032.65	3091.22
500	1614.62	1884.74	1835.5	2835.95
550	1739.62	1882.74	1957.03	2683.63
600	1721.99	1541.91	1684.93	2776.81

Due to low capacity links and existence of co-channel interference causes delay in the network. Figure 4 and Table 3 illustrates the comparison of delay occurred in the proposed ITPFC Channel Assignment algorithm with FCPRA, LACA and IATC channel assignment algorithms. It can be seen that the ITPFC Channel Assignment algorithm has lesser delay as compared to other algorithms. The reduction in network delay is due to less co-channel interference in the network and higher throughput obtained from the proposed algorithm. This algorithm controls the flow among network nodes and increases the link capacity up to the required level. It allows faster data to be transmitted in the network and results in reduced network delay. As per Table 3 the lowest delay occurred in the network using ITPFC channel assignment algorithm is 133.803 ms and highest delay is 1848.4 ms.

C. Packet Loss

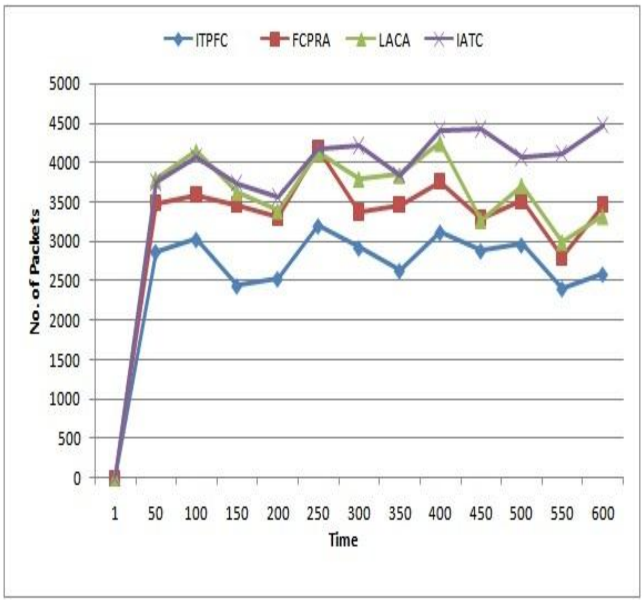

Figure 5. Packet loss comparison of ITPFC with FCPRA, LACA, IATC

Table 4. Packet Loss Comparison

Time	ITPFC	FCPRA	LACA	IATC
1	0	0	0	0
50	2867	3488	3786	3746
100	3024	3594	4141	4069
150	2434	3470	3625	3736
200	2524	3312	3386	3556
250	3196	4181	4121	4180
300	2915	3375	3793	4203
350	2628	3466	3839	3838
400	3115	3768	4248	4402
450	2881	3302	3266	4418
500	2955	3516	3709	4058
550	2399	2799	2990	4111
600	2583	3464	3319	4465

Packet loss generates extra overhead on the network by retransmitting the lost packets. Figure 5 and Table 4 demonstrates the packet loss comparison of ITPFC Channel assignment algorithm with FCPRA, LACA and IATC Channel Assignment Algorithms. The number of packets lost by using the ITPFC Channel Assignment algorithm is lesser as compared to other algorithms. This is due to the higher capacity links provided by the proposed algorithm. Higher capacity links help to transfer more data and reduce the chances of packet loss. This leads to less packet loss in the network. Higher throughput and lesser delay achieved in the network also proves that the network losses less number of packets. As shown in the Table 4 minimum number of packets lost in the network are 0 (zero) and maximum number of packets lost in the network are 3196.

D. Channel Used

Table 5 shows the comparison of number of channels used by the proposed ITPFC Channel Assignment algorithm and IATC channel assignment algorithm. In IATC, 34 numbers of radio interfaces are off while in ITPFC Channel Assignment algorithm 40 numbers of radio interfaces are off. Table 2 also shows the different and less number of channels used in ITPFC Channel Assignment algorithm as compared to IATC such as node 0 used two radio interfaces, node 1 used all the three radio interfaces and node 3 used only one radio interface. Less number of channels used in network validates that the network has less co-channel interference among nodes and consumes less electric power. Therefore, it provides the better network performance.

Table 5. Channel Used in Network

Node id	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
IATC	1	3	6	9	1	11	2	4	7	9	3	11	4	5	5	7	8	3	2	6	6	10	9	10	3	1	7	2	4	5
	2	4	7	10	11	1	3	5	9	0	8	0	0	0	0	11	0	4	0	1	0	0	6	2	4	3	0	6	0	0
	0	5	8	0	0	0	0	7	8	0	10	0	0	0	0	0	0	1	0	0	0	0	7	0	0	5	0	0	0	0
ITPFC	1	2	4	6	1	7	9	11	5	2	2	11	3	4	11	11	6	10	9	4	6	2	2	6	7	8	6	3	7	2
	6	3	5	0	7	8	10	0	6	0	8	0	0	0	0	0	0	11	6	9	0	0	6	3	0	7	0	6	0	0
	0	4	6	0	0	0	0	0	8	0	0	0	0	0	0	0	0	9	0	0	0	0	0	0	0	2	0	0	0	0

V. CONCLUSION AND FUTURE SCOPE

In this paper, Interference aware, Topology, Power and Flow Control Channel Assignment algorithm has been proposed for Multi-Radio Multi-Channel Wireless Mesh Networks. This algorithm assigns channels based on several important factors such as topology control, co-channel interference, power control and flow control. Channel assignment plays a vital role in the performance enhancement of network. NS-3 based WiMesh tool has been used to simulate the network scenarios. A random topology has been deployed to validate the effectiveness of the proposed ITPFC Channel Assignment algorithm. This algorithm has been developed in three stages. In the first stage, using Interference Aware Topology Control Channel Assignment algorithm, the network of 30 nodes has been deployed. In the second stage, performance has been improved by applying Optimal Power Control algorithm. This algorithm dynamically controls the transmission range and interference range of each node. In the third stage, performance has been further boosted using channel assignment algorithm based on Flow Control algorithm. In Flow Control algorithm channel with appropriate link capacity has been allocated to each node to enhance the performance of the network.

Results have been evaluated from the simulation experiments in terms of throughput, delay, packet loss and channel use. These results have been compared with existing Flow based Channel, power and Rate Assignment Algorithm, Load Aware Channel Assignment Algorithm and Interference Aware Topology Control Channel Assignment Algorithm. It has been found that the proposed ITPFC Channel Assignment algorithm performs better and significantly enhances the network performance as compared to above-said algorithms. Further, this work can be extended by adding routing functionalities along with the proposed channel assignment algorithm. Time taken by channel assignment/reassignment is also an important issue. This can also be considered as an extension of the proposed channel assignment algorithm for further research work.

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