

Distributed Efficient Channel Allocation Technique for Multi-Radio Multi-channel Interference-aware Multi-path Routing Protocol in Wireless Mesh Networks.

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Abstract: The major change in the wireless network standards has attracted researchers to utilize benefits of several data services in various applications. Wireless Mesh Networks which follows 802.11 standards are very best alternative to Local Area Networks and Metropolitan Area Networks. There is a need for better utilization of the 802.11 spectrum in Mesh Networks environment when transmitting data through mesh networks. Recent work shows the increase in utilization of 802.11 spectrum for wireless mesh networks. An effort has been made to design and develop a distributed, self healing, self stabilizing protocol that's assigns channels to mesh nodes in large wireless mesh networks. The efficiency of the protocol is demonstrated with extensive measurements using Qualnet simulator. The distributed channel assignment algorithm improves the capacity of the networks by an average of 25% in comparison to a homogenous channel assignment.

1. Introduction

Wireless Mesh Networks (WMNs) [1] has become very popular and important in wireless technology and industry fields. WMNs are believed to be a promising technology to offer high bandwidth for wireless access to the Internet. The fixed wireless mesh routers and gateways are highly connected each other in a ad hoc manner in WMN. The normal wireless devices are connected for communication services where mesh routers are equipped with functionalities of IEEE standard series [2]. Mesh router performs the role of data aggregator and also role of relay data gateways. WMN gateways are devices with high bandwidth that can provide internet connections to routers. Data flows can be formed in multi-hop manner from wireless devices through each mesh routers to the gateways, or to other mesh routers and devices in other areas. There are many efforts seen to maximize the network throughput in a multi channel multi radio wireless mesh networks. The approaches of the currently available solutions are based on the static or dynamic channel allocation schemes. Multi-radio wireless mesh networks (MR-WMNs) are being increasingly deployed to provide affordable Internet access on large residential areas. MR-WMNs allow the supported mesh clients (MCs) to access the Internet gateway by multi-hop packet forwarding over the mesh routers (MRs), which can be equipped with multiple radio interfaces [3]. There is a need of hybrid multichannel multi-radio wireless mesh networking architecture where each mesh node has both static and dynamic interfaces.

Multi-channel technique can significantly avoid transmission competition and collision in the same channel. There is no

interference among orthogonal channels because they use non overlapping frequency bands. Routing protocols assigning diverse channels to each hop of data flow can reduce intra-flow channel interference and competition therefore can improve end-to-end throughput times. Wireless devices are able to equip more radios which are working in a specified channel. The data is switched and transmitted in specified when radio with antenna is used. This makes transmission full duplex and also provides more efficient routing. Multi-path routing strategies are also designed to split and transmit data through two or more different paths to destination simultaneously. However, multi-path routing cannot achieve times of throughput as we expect since inter-/intra-flow channel competition and interference. Therefore it is required to develop multi-channel and multi-path routing protocol in WMNs.

In wireless mesh networks, due to the broadcast nature of shared medium and wireless links prone to major interfere during multiple transmissions in close spatial proximity. The wireless transmission happening at sender and receiver side is heavily affected by the interference and simultaneous activity of network interfaces utilizing the same channel in close spatial proximity at receiver side may result in collisions. This may result once again in retransmission of message. The resending of messages is not guaranteed by the sending node due to carrier sense threshold is exceeded by ongoing transmissions of nearby nodes in IEEE 802.11 based networks which leads to increase in delay. . It has been clearly mentioned that interference is one of the major causes for performance degradation in wireless networks [4]. Channel assignment mechanism has been developed on the MAC layer to synchronize the medium access and thus reduce interference effect. The idea of channel assignment is to minimize the network-wide interference by utilizing non-overlapping (also called non-interfering or orthogonal) channels for otherwise interfering wireless transmissions. The key challenge of the problem is how to assign the available channels in a way that interference is minimized and the network performance in regard of the network capacity is maximized while ensuring network connectivity. A resulting channel assignment using different non-overlapping channels can decrease interference but also alter the network topology. When the network interfaces of two neighboring network nodes operate on non-overlapping channels they do not interfere with each other but also the nodes cannot communicate directly. Thus, there is a trade-off between channel diversity and network connectivity. With the realization of the Internet of Things (IoT), the number of wireless devices operating in the unlicensed frequency bands is rapidly growing. Therefore, it is an important issue for efficient channel assignment to also address external

interference. This task is not trivial, since the external networks and devices are not under the control of the network operator and their radio activity is therefore hard to capture. Since their behavior may vary over time, especially considering mobile devices such as smart phones and laptops, it is also hard to predict and model their future behavior. For this reason, many channel assignment algorithms have neglected the impact of external interference.

2. Related work

Adya et al [5] suggested simplest channel assignment approach called as Common channel assignment (CCA). All the radio interfaces of were tuned to the same set of channels. The main advantage of this approach is have to enhanced network connectivity with single and multiple radio interfaces which improve the network throughput. Here the drawback of CCA was in gain when the number of non overlapping channel is much higher than the number of radio interfaces. This was not efficient solution and also degrades in utilization of network resources [6].

Raniwala et al., [7] presented dynamic centralized channel assignment and routing algorithm, where traffic is mainly directed towards gateway nodes, assuming that the offered the traffic load on each virtual link is known. The account of bandwidth limitation of each link is taken into consideration to ensure the network connectivity when channels are assigned. This channel assignment scheme on links may cause a “ripple effect”, whereby already assigned links have to be revisited, thus increases the complexity of the scheme.

Pollak and Wieser et al., [8] developed *First Random Channel Assignment algorithm* (FRCA) which is a a dynamic and centralized load aware channel assignment and routing algorithm for multi-interface multi-channel WMN. This approach takes into account the network traffic profile. FRCA algorithm assigns radio channels to links considering their expected loads and interference effect of other links, which are in interference range and which are tuned to the same radio channel. In FRCA, if the any of the link load is higher than link capacity, the algorithm goes back and tries to find better solution. The limitation of this algorithm ends when no further improvement is possible.

Ramachandran et al. [9] propose a centralized channel assignment algorithm which is performed by a central server that periodically collects dynamically changing channel interference information. This work of particular interest is in channel selection method which takes into account dynamically changing network status and more static information. The performance gain of dynamically changing networks requires localized interaction between nodes and needs to be stabilized incurring much less overhead in assigning channel.

In [10],Mishra et al. explore the possibility of utilizing partially-overlapping wireless channels in 802.11 access points, and show that intelligent assignment of non orthogonal channels increases overall channel utilization and the system performance. Bong-Jun Ko et. Al. [11], presented a fully a fully-distributed mechanism that assigns 802.11 channels to multi-radio nodes in wireless mesh networks. The assignment algorithm shows stable and desirable channel configuration so that the routing protocols can exploit the maximum to provide better end-to-end

performance. The constraints in 802.11 devices and distributed nature ensure it works well with large-scale networks. The experiments were conducted on small wireless mesh networks test bed and shows only improvement between 20% and 50%.

3. Mesh Network Model

A. Network Model

The graph coloring theory [12] is used as a base for the theoretical modeling of channel assignment problem. There are two related terms in mesh networks such as communication range and interference range. Communication range is the range in which a reliable communication between two nodes is possible. The interference range is the range in which transmission from one node can affect the transmission from other nodes on the same or partially overlapping channels. The interference range is always larger than the communication range. The simple network is shown in figure 1.1.

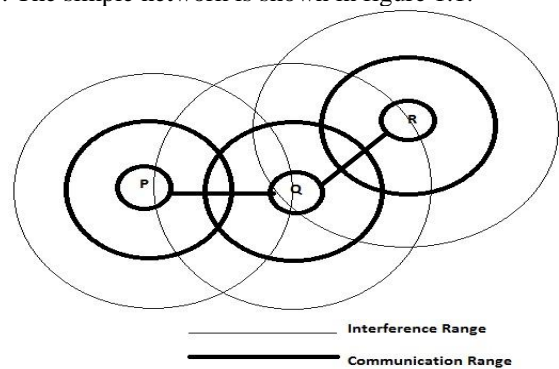


Figure 1. Mesh Nodes showing interference and communication range

The edges (links) set E includes all the communication links and set of vertices V consists of the network nodes in the network. A link e between a pair of nodes (v_i, v_j) ; where $v_i, v_j \in V$ exists if they are within the communication range of each other and are using the same channel. The graph G is said *connectivity graph*. The links in the graph in the network topology is referred as logical links. The interference in network model may be depicted as the concept of Interfering edges and denoted for an edge e as $IFE(e)$. The concepts of connectivity graph, interfering edges and conflict graph are illustrated in Figure 2.

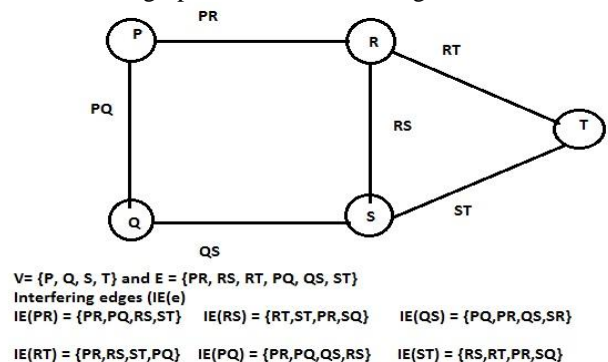


Figure 2. Connectivity Graph and Interference edges

The interference edges $IFE(e)$ are defined as the set of all edges which are using the same channel as edge e but cannot use it simultaneously in active state together with edge e . All edges are competing for the same channel hence the goal of channel assignment algorithm is to minimize the number of all edges e thereby increasing capacity.

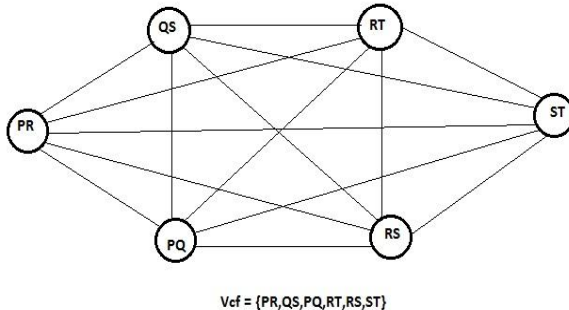


Figure 3. Conflict Graph

The interference edge helps in deriving at the concept of conflict graph. The conflict graph is shown in Figure 3. The conflict graph G is represented as $G_{cf}(V_{cf}, E_{cf})$ which consists of set of edges E_{cf} and the set of vertices V_{cf} . The vertices V_{cf} have a one relation with the set of edges E_{cf} of the connectivity graph (i.e. for each edge $e \in E_{cf}$, there exists a $vcf \in V_{cf}$). As for the set E_{cf} of the conflict graph, there exists an edge between two conflict graph vertices vcf_i and vcf_j if and only if the corresponding edges e_i and e_j of the connectivity graph, are in $IE(e)$ set of each other. Hence, if two edges interfere in the connectivity graph, then there is an edge between them in the conflict graph. The conflict graph can now be used to represent any interference model.

B. Mesh Network Architecture

Mesh network consists of mesh clients, mesh routers and mesh gateways. Mesh clients are end-user devices, equipped with at least one 802.11 wireless card. They are the users of the mesh network, and each client connects to at least one (typically only one) mesh router to have their packets forwarded from/to mesh gateways or other mesh clients. Mesh routers are 802.11 wireless nodes (typically stationary) that act as the wireless access points of the mesh clients. These routers form a multi-hop wireless network infrastructure, and forward packets between mesh clients and mesh gateways or between mesh clients using some ad-hoc routing protocol. Mesh gateways are connected both to the wired network (e.g., Internet) and to 802.11 wireless network, being the relaying points of the traffic between wireless mesh network and external wired network. Mesh gateway serve or perform dual roles and act as a mesh router when it is required. This dual role may be useful when flow traffic within the mesh network is not only between mesh clients and mesh gateways, but also between pairs of mesh clients. The main focus is to increase the utilization of available spectrum in the wireless multi-hop network. The dynamic allocation of channels with in wireless allows us to utilize the bandwidth of the mesh networks at maximum.

4. Distributed Channel Assignment

A. Distributed versus Central Channel Assignment

The wireless spectrum has to be utilized maximum as much as possible. There are several central channel allocation schemes available and which are used in the mesh network to maximize the utilization. When the positions and hardware configuration of all nodes in the mesh networks are not known, central channel allocation becomes difficult. The traffic and flow demands keeps changing dramatically over short period of time in a large mesh networks, central channel allocation schemes suffer from lack of bandwidth and non availability of resources.

Nodes or links between nodes may fail or move slowly, and the assignment of channels to nodes and routes within the mesh network should adapt accordingly, but that such changes occur on a timescale much larger than the changes in flow demands. A well-designed distributed solution can handle these small changes gracefully that only affect small portions of the network at a time, with decisions to be made based on local information. Thus, it is very much required to propose a well designed distributed efficient channel allocation technique for Multi-Radio Multi-channel Interference-aware Multi-path Routing Protocol in Wireless Mesh Networks. A distributed mechanism to the channel allocation and routing problems that *stabilizes* to a configuration that maximizes the throughput of an “average” flow within the mesh network. An optimal solution would clearly need to simultaneously consider the channel allocation and routing problems. However, achieving the stability of a good joint solution is extremely difficult, as the selection of channels greatly impacts the desirable set of routes, and the choice of routes affects how one would assign channels within the network to specifically support these routes.

B. Distributed Dynamic Channel Allocation Algorithm

The distributed channel assignment mechanism is applied to the networks with ideal wireless transceivers that can receive data on all the channels regardless of the channel choice for transmission. Assume that the nodes in the network have limited numbers of radio cards, each of which can transmit and receive on a single channel at a time.

Algorithm DistributedChannelAllocation;

Initialization

Node is able to transmit on a single channel that is freely selected from any K available channels simultaneously.

Node is allowed to choose its sending channel without interference with other sender (on interfering channels)

Assign each node to a channel through which it transmit data.

Assume node i can transmit on a single channel and select any N available channels and listen to all of them simultaneously. Each node should get fair chance of sending the data with least interference.

Let set of N nodes, $S = \{1, 2, \dots, N\}$ and there are K wireless channels $1, \dots, K$, when frequency spectrum can possibly overlap. We need to calculate channel interference cost function $f_c(x, y)$. it provides the relative interference expressed between channels x and y . $f(x, y) \geq 0$ and $f(x, y) = f(y, x)$. The value of 0 indicates that channels x and y do not interference with one another. As the gap between x any y increases the $f(x, y)$ decreases.

Let S_i be the set of nodes in i 's interference range. Here node i selects a channel that minimizes the sum of interference cost.

C_k : Channel of each node where k belongs to S_i

C_i : i 's existing channel

The node is permitted to select any one channel, when there are multiple channels that minimize the interference cost is available. If the sum of the interference cost is minimized before the choice of channels that minimize the interference cost is available. If the sum of interference cost is minimized before the choice of channel, then the node does not make any changes.

For all the links $k = 1, \dots, K$

Find the interference cost $f(k, c_j)$.

Node i selects a channel that minimizes the sum of interference cost from the set of nodes S_i

$F(K) = \sum F(k, c_j) \forall j \in S_i$

When there are multiple channels that minimize the interference cost, the node can select one of them randomly.

If $F(C_i) > F(k)$ for any $k = 1, \dots, K$ then $C_i = K_{min}$ where $k_{min} = k: F(k) \leq F(k')$

If the prior choice minimizes the sum of interference costs, then the node makes no change. The mesh node i 's select channel only on the information available in its local proximity. This makes algorithm fully distributed which uses the information available within its local region.

i. Load Criticality Estimation

The load criticality is calculated by assuming that the perfect load balancing across all acceptable paths between each communicating pair of nodes. Let $U(s,d)$ denote the number of acceptable paths between pair of nodes (s,d) , $U_k(s,d)$ is the number of acceptable paths between (s,d) which pass a link k . Another $V(s,d)$ be the estimated load between node pair (s,d) . The expected traffic load ϕ on link k is calculated as given by Raniwala et. Al., [7] :

$$\phi = \sum U_k(s,d)/U(s,d) \cdot V(s,d)$$

This equation implies that the initial expected traffic on a link is the sum of the loads from all acceptable paths, across all possible node pairs, which pass through the link. Because of the assumption of uniform multi-path routing, the load that an acceptable path between a pair of nodes is expected to carry is equal to the expected load of the pair of nodes divided by the total number of acceptable paths between them.

ii. Link capacity estimation

The link capacity (channel bandwidth available to a virtual link) is determined by the number of all virtual links in its interference range that are also assigned to the same radio channel. So when estimating the usable capacity of the virtual link, we should consider all traffic loads in its interference range. According to the channel assignment rules, the higher load a link is expected to carry, the more bandwidth it should get. On the other side, the higher loads its interfering links are expected to carry, the less bandwidth it could obtain. Thus, the link capacity should be proportional to its traffic load, and be inversely proportional to all other interfering loads. Thus, the capacity $bw(i)$ assigned to link i can be obtained as per Badia et al.,[13] Conti et al.,[14], Raniwala et al.,[7] using the following equation :

$$bw(i) = \phi_i / \sum \phi_j * C_{ch} \quad j \in Intf(i)$$

where ϕ_i is the expected load on link i , $Intf(i)$ is the set of all virtual links in the interference link i . C_{ch} is the sustained radio channel capacity as mentioned in badia et. Al., [13].

5. Simulation Environment

The performance of distributed channel assignment protocols in WMN environment is simulated using Qualnet 5.2 [17]. The simulation software Qualnet 5.2 is software that provides scalable simulations of wireless networks. The network topology of 50 static nodes are created and placed randomly within area of 1000 m x 1000 m. The distance between nodes was set to 250 m. The capacity of all the data links was fixed at 10 Mbps. Each scenario simulation is ran over for 900 seconds and data collected over those runs are averaged. The 802.11 a/g is used as radio type and 802.11a standard as MAC protocol without using RTS/CTS. The broadcast data rate in this simulation is 10 Mbps with Constant Bit Rate (CBR) traffic source, sending at a rate of 1 packet per seconds. The packets with 512 bytes size is scheduled on a first in first out (FIFO) basis [15]. A constant shadowing model with two-ray propagation path loss model is used in this simulation. The default simulation parameters used are shown in Table I.

TABLE 1: Simulation Parameters

Parameter	Value
Simulation area	1000 x 1000 meter
No of Nodes	50
Radio Type	802.11 a/g
Routing Protocol	Multipath
Transmission range	250 meters
Slot size K	25 ms
Number of Slots in a quarter of linkframe	4
Data packet size	512 bytes
Weight between perfect and avg traffic δ	0.3
High Threshold T_h adjusting S/R ratio	3
Low Threshold T_l adjusting S/R ratio	0.6
Path Loss model	Two-ray propagation
Channel Frequency	2.4 GHz

We chose three performance metrics for simulation evaluation:
Average End-to-end Delay: The average time taken for a packet to reach the destination. It includes all possible delays in the source node and in each intermediate host, caused by queuing at the interface queue, transmission at the MAC layer, routing discovery, etc. Only successfully delivered packets are counted.
Average Throughput: The sum of data packets delivered to all nodes in the network in a given time unit (second).
Packet Loss: Occurs when one or more packets being transmitted across the network fail to arrive at the destination.

6. Results and Discussions

The comparison of Distributed Channel Allocation Multipath Routing Protocol carried out with varying traffic load and number of available channels.

A. Performance evaluation against varying traffic loads

The figure 4 shows the throughput of distributed channel allocation carried out with varying traffic load. The comparison is made between two set of mesh nodes. During first round with 25 nodes, high throughput is delivered against the 50 nodes. This is because distributed channel allocation allows nodes to share the channel efficiently with less interference. All nodes in the network will be able to get the fair chance of channel acquisition and perfect utilization. As the traffic load increase, the sharing of channels as increases in turn has clear effect on the throughput.

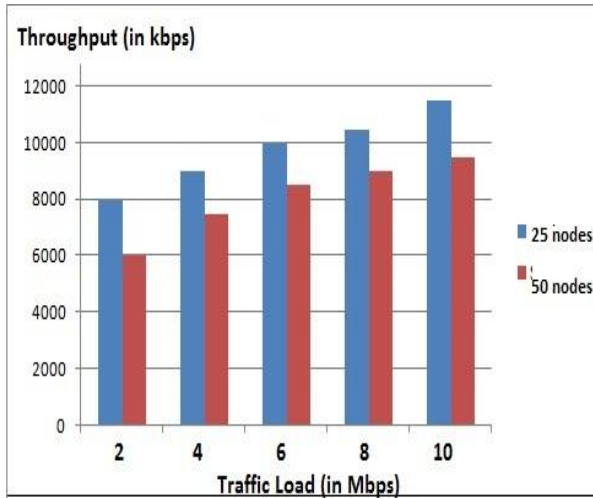


Figure 4. Throughput against Traffic Load offered

The figure 5 shows the end-to-end delay of distributed channel allocation carried out with varying traffic load. The comparison is made between two set of mesh nodes. During first round with 25 nodes, low delay is recorded against the 50 nodes. This is because distributed channel allocation allows nodes to share the channel efficiently with less interference. All nodes in the network will be able to get the fair chance of channel acquisition and perfect utilization. As the traffic load increase, the sharing of channels as increases in turn has clear effect on decrease in end-to-end delay.

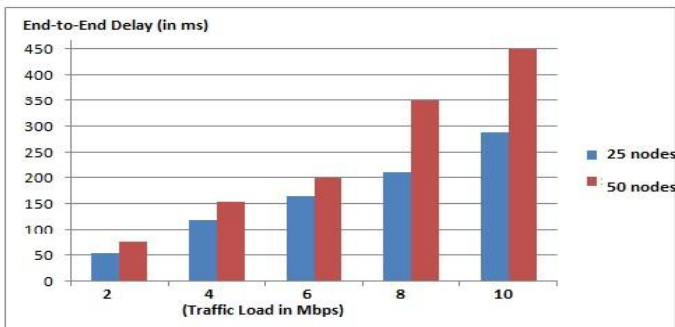


Figure 5. End-to-end Delay against Traffic Load offered

The figure 6 shows the packet loss due to distributed channel allocation was carried out with varying traffic load. The comparison is made between two set of mesh nodes. During first round with 25 nodes, low packet loss is recorded against the 50 nodes. This is because distributed channel allocation allows

nodes to share the channel efficiently with less interference. Due to less interference, has an effect on less number of packet losses. All nodes in the network will be able to get the fair chance of channel acquisition and perfect utilization. As the traffic load increase, the sharing of channels as increases in turn has clear effect on increase in packet loss.

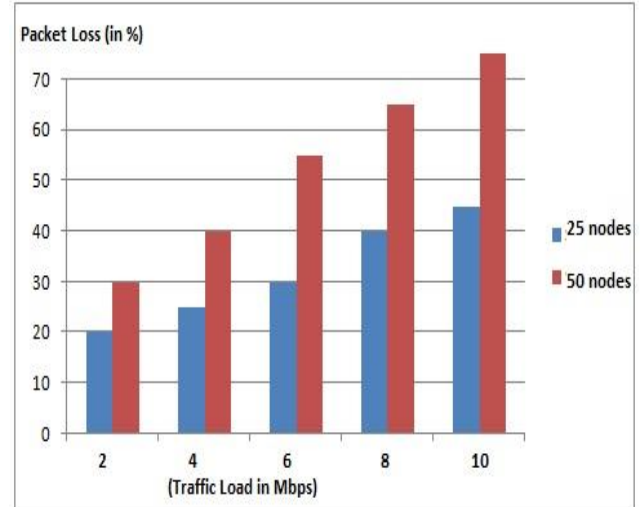


Figure 6. Packet Loss against Traffic Load offered

B. Performance evaluation against number of radio interfaces

The figure 7 shows the throughput of distributed channel allocation carried out with varying radio interfaces. The comparison is made between two set of mesh nodes. During first round with 25 nodes, high throughput is delivered against the 50 nodes. This is because distributed channel allocation allows nodes to share the channel efficiently with less interference. All nodes in the network will be able to get the fair chance of channel acquisition and perfect utilization. As the traffic load increase, the sharing of channels as increases in turn has clear effect on the throughput. There is clear increase in 25 to 35% throughput when numbers of channels are available due to multiple radio interfaces using distributed channel allocation.

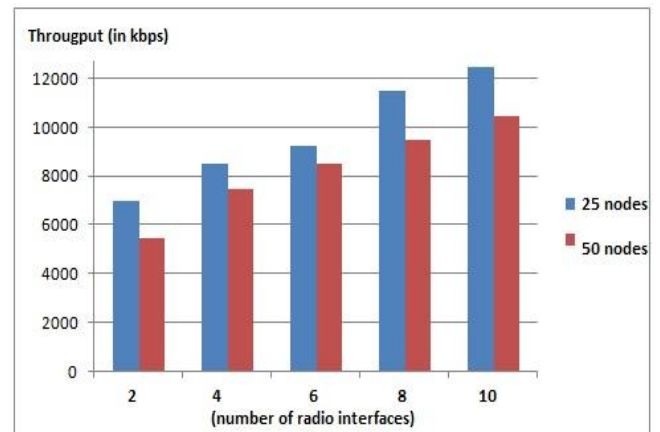


Figure 7. Throughput against number of radio interfaces available

The figure 8 shows the end-to-end delay of distributed channel allocation carried out with varying radio interfaces. The comparison is made between two set of mesh nodes. During first round with 25 nodes, low delay is recorded against the 50 nodes.

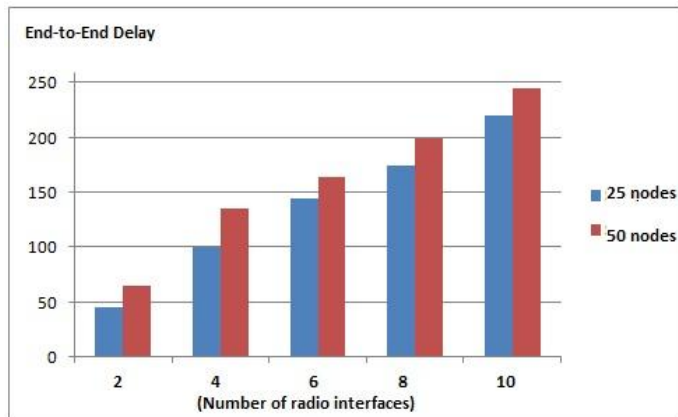


Figure 8. End-to-end Delay against number of radio interfaces available

This is because distributed channel allocation allows nodes to share the channel efficiently with less interference. All nodes in the network will be able to get the fair chance of channel acquisition and perfect utilization. As the traffic load increase, the sharing of channels as increases in turn has clear effect on decrease in end-to-end delay. There is clear decrease in 20 to 25% end-to-end delay when numbers of channels are available due to multiple radio interfaces using distributed channel allocation.

The figure 9 shows the packet loss due to distributed channel allocation was carried out with varying radio interfaces. The comparison is made between two set of mesh nodes. During first round with 25 nodes, low packet loss is recorded against the 50 nodes.

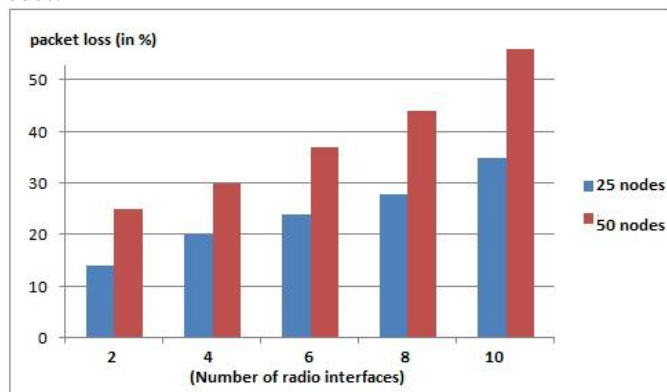


Figure 9. Packet Loss against number of radio interfaces available

This is because distributed channel allocation allows nodes to share the channel efficiently with less interference. Due to less interference, has an effect on less number of packet losses. All nodes in the network will be able to get the fair chance of channel acquisition and perfect utilization. As the traffic load increase, the sharing of channels as increases in turn has clear

effect on increase in packet loss. There is clear decrease in 10 to 15% packet loss when numbers of channels are available due to multiple radio interfaces using distributed channel allocation.

7. Conclusion

The performance evaluation of fully distributed channel allocation algorithm which assigns available channels to multi-radios nodes in wireless mesh networks is carried out using scalable simulator QualNet. This distributed algorithm which optimizes the channel allocation of links in a multi-radio wireless mesh network to increase throughput of the network by reducing interference between links in the network. The simulation results shows the increase in the capacity of wireless mesh networks between 10% to 35% over the traditional channel allocation mechanism. The assignment algorithm stabilizes to a required configuration which multipath routing can exploit to provide better end-to-end system performance. The existing devices are to be equipped with distributed nature to make ensure that it is sufficiently executed on a large scale mesh networks. The experiments are ran over moderate mesh wireless mesh networks and as future work it can be extended to a large size mesh networks.

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