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Distributed optimal congestion control and channel assignment in wireless mesh networks

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ABSTRACT

Wireless mesh networks have numerous advantages in terms of connectivity as well as reliability. Traditionally the nodes in wireless mesh networks are equipped with single radio, but the limitations are lower throughput and limited use of the available wireless channel. In order to overcome this, the recent advances in wireless mesh networks are based on multi-channel multi-radio approach. Channel assignment is a technique that selects the best channel for a node or to the entire network just to increase the network capacity. To maximize the throughput and the capacity of the network, multiple channels with multiple radios were introduced in these networks. In the proposed system, algorithms are developed to improve throughput, minimise delay, reduce average energy consumption and increase the residual energy for multi radio multi-channel wireless mesh networks. In literature, the existing channel assignment algorithms fail to consider both interflow and intra flow interferences. The limitations are inaccurate bandwidth estimation, throughput degradation under heavy traffic and unwanted energy consumption during low traffic and increase in delay. In order to improve the performance of the network distributed optimal congestion control and channel assignment algorithm (DOCCA) is proposed. In this algorithm, if congestion is identified, the information is given to previous node. According to the congestion level, the node adjusts itself to minimise congestion.

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1. INTRODUCTION

Multiple radio multiple channel WMN uses IEEE 802.11 radios. It has a cross-layer design. Scheduling is done in the physical layer, channel allocation in the data link layer, routing in the network layer, and congestion control at the transport layer. To admit a flow, the parameters like the number of packets that travel in a path, the channel used for each link, and the capacity of each link have to be determined. Finding optimum solutions to increase the utilization of the network is not feasibly. Most of the existing works are in design perspective to derive feasible solutions. Giannoulis *et al*. [1] proposed a congestion control and channel assignment algorithm based on clique for multiple-radio wireless mesh networks.

All the available multiple paths for flow and all the existing cliques are considered in this algorithm. The implementation is not feasible due to the complexity. Ning *et al*. [2] focused on scheduling in link layers and routing in the network layer. Between the links, fairness is ensured and high priority is given to the links with low congestion and large queue to improve throughput. The solution given is the centralized one and fairness is considered in terms of link but not for flows. In multi-radio multi-channel wireless mesh network (MRMC WMN), the congestion control process will regulate the permitted rate of flows based on the available data rate of the links. The aggregate flow rate should not exceed the available bandwidth of the links. Bandwidth availability is based on the SINR. SINR is based on channel assignment and power control schemes. The links that operate on the same channel may interfere with others if they are very near.

2. LITERATURE REVIEW

In a static channel allocation scheme, the connection between the nodes is maintained by making sure that every node shares a common channel to its neighbours in the channel allocation phase. But the performance of the network can be affected while deciding the priority of the node to communicate with the network. Due to this, network separation or partition and increase in path length may arise. Many algorithms are proposed to address this issue by assigning channels properly. A review of various channel allocation schemes regarding node connectivity is given in this section. Centralized tabu-based algorithm (CTA) is given by Subramanian *et al*. [3]. The method aims to reduce interference while maintaining the node connectivity. The authors articulated the channel assignment issue as a conflict graph method. The node connectivity is mentioned as *'k'* network connectivity. In k connectivity, every node is connected with only *'k'* nodes. The connectivity will be maintained in all the nodes in the network after assigning the channel too. The merit of CTA is given as it has only very low network interference and the demerit is, it fails to consider the existence of multiple links between the pair of nodes. Breadth first search channel assignment (BFS-CA) algorithm is proposed by Subramanian *et al*. [4] to minimize external and interflow interference in multiple radio multiple channel wireless mesh networks. In this method, every node will measure the external interference by the radio frequency monitoring mode periodically and the gathered information is sent to the central authentication system (CAS) [5]. Based on the received information, CAS generates the multi-radio conflict graph (MRCG). The central server assigns a channel to every mesh routers by maintaining the connectivity of the network and reducing the interference in the wireless networks.

Devare et al. [6] proposed an enhanced BFS-CA called Autonomous network reconfiguration system channel assignment (ANRSCA). This system reassigns the failed link. If there is any link failure, depends on the collected information, the channel assignment is re-computed by the gateway using BFS-CA. Subramanian et al. [6], proposed another version of BFS-CA as Reality Check BFS-CA (RC-BFS). This algorithm is developed by Revathi *et al*. [7]. The physical interference model is merged with the protocol model in reality check mechanism to overcome the demerits of the protocol interference model. The BFS-CA is the first method which considered external interference. The limitations of this method are it is suitable only for MR-MC WMN in which gateway is the centre point for network traffic. The channel switching will occur more frequently since this algorithm is adapted to the changes in the external interference. Marina *et al.* [8] proposed an algorithm called connected low interference channel assignment (CLICA) to identify low interference and connected topologies. Depends on the traffic load and distance to the gateway, each node will identify the default order to make the decisions about the channel assignment.

Tang *et al*. [9] proposed interference survivable topology control problem (INSTC) and it is *'k'* Connected. In this method, the overall interference of the link is nothing but the total number of links that are available within the interference of that particular link. Mohsenian Rad *et al*. [10] proposed TiMesh. It splits the channel assignment algorithm into two phases. The first phase is linear programming (LP) to solve the channel allocation and topology control jointly. TiMesh algorithm uses iterated local search (ILS) to search the sub-optimal solution [11]. The second phase finds the route from the source node to the receiver node depends on the constraint in the channel capacity. Joint topology control, power, and routing (JTCR) algorithm is proposed by Chen et al. [12], to exploit channel diversity and spatial reusability. The condition of channel utilization is periodically monitored. If this method finds that the channel is overloaded, it finds a feasible condition based on equivalent channel air time metric (ECATM). Based on power control a centralized Topology and Interference aware channel allocation (TICA) scheme is proposed by Choudhry *et al*. [13]. Here every node will send a HELLO packet to collect the neighbour's information. Information about the node is stored in power neighbour table (PNT). Depends on select x less than X algorithm, the gateway forms the direct neighbour table (DNT), then it finds the required minimum power to reach every node. After the power calculation, network connectivity is monitored. The goal of this algorithm is to reduce the interflow interference as well as to maintain the connectivity. Discrete particle swarm optimization channel allocation (DPSO-CA) scheme is proposed by Cheng *et al*. [14, 15]. For optimization, DPSO-CA uses a population-based search in which the individual population is called particles. This algorithm initializes the particle value that is genuine for channel assignment and also satisfies the radio constraints and topology preservation. This algorithm maintains a single link among any two pairs of nodes. Due to this, some interfaces are not utilized efficiently to improve the capacity. This method assumes that the traffic caused by each link as constant, hence it is not suitable for a dynamic network.

Combination of local search algorithm and gravitational search algorithm named improved gravitational search algorithm (IGSO) to find a solution for channel assignment is proposed by Doraghinejad *et al*. [16]. Here the total interference of the network is the sum of the entire interfering link. Minimum shortest and interference disjoint path (MSITD) is proposed by Bao *et al*. [17] to find a k-connected network topology. Cluster based topology control and channel assignment (ComTac) is proposed by Naveed *et al*. [18] and cluster based channel allocation (CBCA) by Athota *et al*. [19, 20-25], to reduce the aggregated interference and maintain the node connectivity. Clustering and channel assignments are the two phases of this algorithm. The first phase depends on the distance. Nodes in the network are grouped as a cluster in terms of hop count from cluster head. Then the links with high interference are removed using a spanner graph for assigning channel.

From the literature survey, most of the methods are proposed for single radio single-channel wireless mesh networks. If multiple radio multiple channels is used then the performance of the network can be improved significantly. Therefore, to improve the network performance, it is proposed to have distributed optimal congestion control and channel assignment algorithm (DOCCA) uses the physical interference model.

3. RESULTS AND ANALYSIS

MRMC WMN is considered where mesh routers are provided with four radios and all the interfaces are dedicated to a channel till the channel assignment. MRMC WMN is taken as graph G = (R, L), where R is the mesh router set, and L is link set. The nodes i, j ϵ R, two links will exist (i→j) and (j→i) if the nodes *'i'* and *'j'* are in its communication range. The interference is considered as model-based interference. In model-based interference, the link may interfere with each other in its communication range. Generally, for packet transmission, the packet should reach the receiver node and the acknowledgment for the packet should reach the sender node.

4. DOCCA ALGORITHM

The proposed distributed optimal congestion control and channel assignment (DOCCA) algorithm has six phases as follows,

a. Network formation and neighbour identification
b. Price based congestion control
c. Decoupling approach
d. Local channel assignment
e. Distributed channel allocation
f. Optimum congestion control

4.1. Neighbour identification

Node in the network periodically sends HELLO packets contain its node ID through its all existing radio interfaces. All nodes within its transmission range will receive this and note its neighbour ID, the link with which it received the HELLO packets and the channel which is assigned to that particular interface. With all information, all nodes in a network must build a neighbour table. Neighbours are connected to the node directly within its communication range. Using neighbour identification phase each node can identify its multiple link neighbours.

4.2. Price based congestion control

If the available bandwidth is greater than the required bandwidth flow is admitted. Once flow is admitted, link price needs to be checked. If the link price is equal to zero at equilibrium, the link is considered as congestion less link and the flow can be transmitted in the same channel. If the link price is not equal to zero the particular link can be identified as critical link and the flow need to be transmitted on a different link. Therefore, channel reassignment is necessary.

4.3. Decoupling approach

Decoupling approach has five interlinked steps:

a. Channel utility
b. Channel rate calculation
c. Formation of interference matrix
d. Link selection
e. Channel assignment

Consider X_s is the flow rate for the flow *'s'* where $s \in S$ and $U_s(X_s)$ is the utility function of the flows. The channel utility can be calculated as,

$$\text{Channel utility} = \sum_s U_s(X_s) \quad (1)$$

The interference matrix I is $L * L$ matrix where

$$I_{i,j} = \begin{cases} 1 & if\ the\ link\ j\ lies\ with\ in\ the\ communication\ range \\ 0 & otherwise \end{cases}$$

Interference is based on the node arrangement in the network and the interference model used. The link 'i' may suffer from self-interference if $I_{i,i} = 1$. The parameters link price, data rate, and channel assignment are proposed for all the nodes.

4.4. Local channel link assignment

In local channel link assignment, each node verifies the link price for every flow that passes through the node. If the link price is non-zero at equilibrium, the node assumes that the link is critical for the flow and it identifies another link to transmit the flow. To select the channel link, dynamic link quality measurement and link distortion detection schemes are used. To calculate link quality metric, channel idle time, packet delivery ratio and packet lost due to hidden terminal problems are considered. For deterioration detection, each node monitors its neighbour's expected throughput table. If the expected throughput table of the present link is smaller when compared with other links, it is considered as link deterioration. It is not necessary that this condition is always being the same. To conclude whether the link is deteriorated or not, the node compares the expected throughput with the threshold value α. If the difference between the expected throughputs exceedsα, then it can be considered as deteriorated link. The threshold value is considered as 80 Kbps in this algorithm. If the current link is identified as a critical link, replace it with new link and the change should be intimated locally to the nodes within its communication range and the source node. If the link price is zero at equilibrium, it is a non-critical link, and the same link can be utilised to transmit the flow. In this case, the nodes may or may not perform dynamic link quality measurement. But the node will not change the current link since the link is not a critical link.

4.5. Distributed channel allocation

In distributed channel allocation phase the channel allocation is considered as binary channel allocation. For any link $l \in L$ and any channel belongs to set of available channels, it can be considered as $'1'$ and channel can be allotted to the link l. Else it is $'0'$. The transmit power of the sender node at link $'l'$ is $'p_l'$. The path loss (Q_{il}) from sender node $'i'$ to the receiver node $'j'$ can be represented as,

$$Q_{il} = \frac{G_t G_r \lambda^2}{(4\pi)^2 d_{il}^2} \quad (2)$$

d_{il} → Distance among sender node and receiver node
G_t → Antenna gains of the sender.
G_r → Antenna gains of the receiver.
λ → Wave length of the signal.

5. PERFORMANCE EVALUATION

Initially the nodes broadcast HELLO packets. The nodes within its transmission range will reply to the hand shake signal. The node which receives the HELLO packets stores the neighbour's information in its routing table. Each node is enriched with four radios. Increasing the number of radios minimises the number links sharing a radio. This increases the performance of the network. Figure 1 shows the comparison of DOCCA performance based on throughput. The number of channels to the neighbouring links is increased. The mutual interference and congestion in the network is reduced and the throughput is improved. Figure 2 shows the comparison of DOCCA performance based on delay. Analysis of delay is made between price-based and DOCCA. Delay is low in DOCCA compared to price-based method because based on congestion, the channel is more efficiently allocated, and high priority is given for few interference nodes.

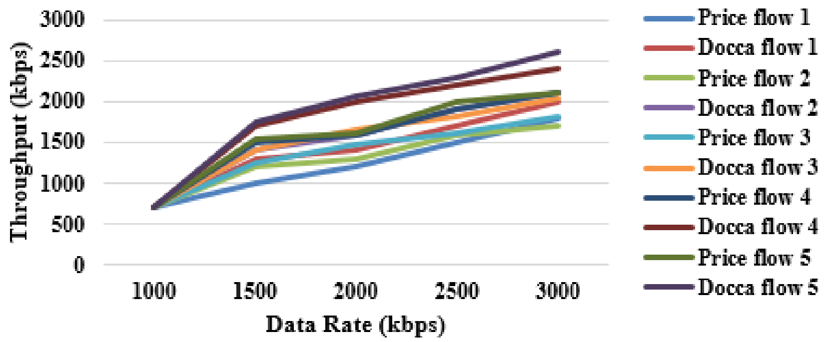

Figure 1. Comparison of DOCCA performance based on throughput

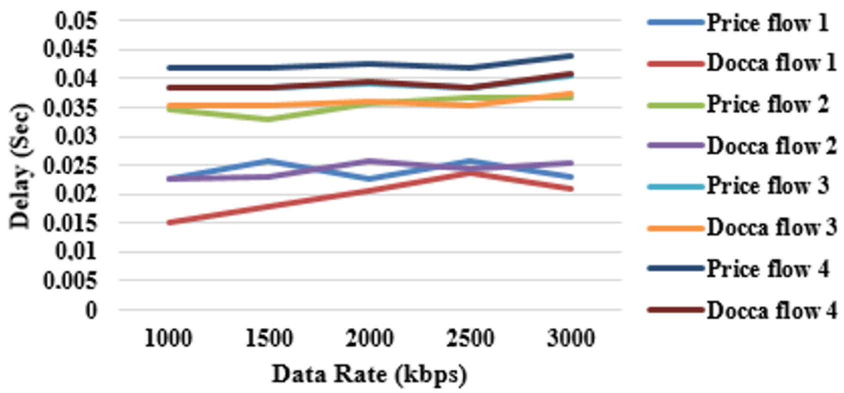

Figure 2. Comparison of DOCCA performance based on delay

Figure 3 shows the comparison of DOCCA performance based on average energy consumption. In DOCCA the average energy consumption is low when compared with price-based algorithm. Performance is analysed for five flows and in all the five flows the average energy consumption is less. Figure 4 shows the comparison of DOCCA performance based on residual energy. From the simulation, it is observed that the residual energy in the proposed algorithm is greater when compared with the price-based algorithm.

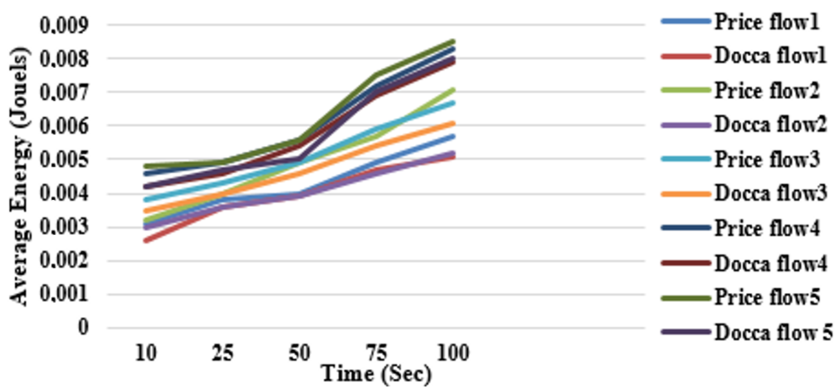

Figure 3. Comparison of DOCCA performance based on average energy

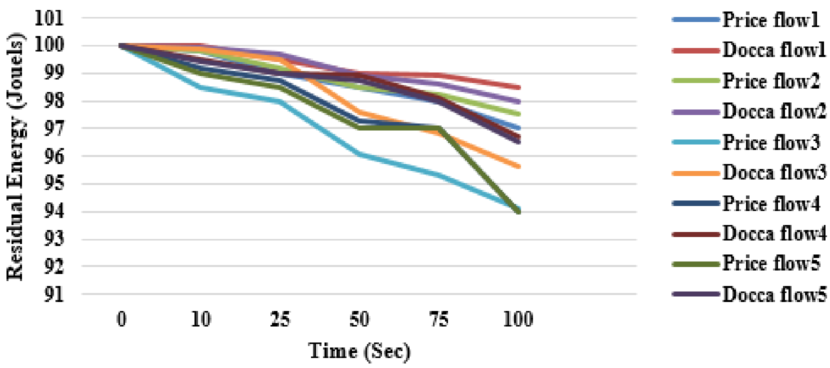

Figure 4. Comparison of DOCCA performance based on residual energy

6. CONCLUSION

In a wireless mesh network, interference affects the data rate and causes congestion in the network. To reduce the congestion and to improve the performance of the network in multiple channel multiple radio wireless mesh networks, DOCCA is proposed. The proposed algorithm has five stages namely network formation and neighbour identification, price-based congestion control, decoupling approach, local channel assignment, and optimum congestion control. In network formation and neighbour identification phase network is formed and nodes are placed randomly. Nodes broadcast HELLO packets in the network to identify its two-hop neighbours and the information about the neighbour is stored in its routing table. In the price-based congestion control phase, the node checks the available bandwidth with that of the required bandwidth for the incoming flow. If the available bandwidth is greater than the required bandwidth the flow can be admitted else the flow can be dropped.

The decoupling approach consists of five steps namely channel utility, channel rate, interference matrix formation, finding the connected channel, and routing the packets. In the local channel assignment, the price value of each link is monitored at equilibrium. If the link price is non-zero at equilibrium, the node assumes that the link is critical for the flow, and it identifies a new link to transmit the flow. In a distributed channel allocation phase, channel allocation is considered a binary channel allocation. For every transmission path loss, data rate, signal to interference noise ratio is calculated. Then the available bandwidth is compared with the required flow rate. If the required rate is less than when compared with the available data rate channel is allotted to the flow.

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