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Optimal Power Control Algorithm for Multi-Radio Multi-Channel Wireless Mesh Networks

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Abstract

Multi-Radio Multi-Channel Wireless mesh networks (MRMC WMNs) is the self-configuring backhaul providing internet access for last mile users through multi-hop forwarding. The increasing demand for low cost wireless networks coverage has motivated a high interest in multi-hop communications based recent and significant IEEE 802.11s WMN standard. One of the main challenges being faced by WMN is co-channel interference. Co-channel interference badly affects the WMN and degrades the network performance. Power control is an effective means for reducing the co-channel interference. Power control plays a very important role in order to restrict the transmission range as well as interference range and prevent unwanted interference between various nodes. By controlling the transmission power of each node up to desired transmission range, the co-channel interference can be reduced and improves the network performance. Transmitter gain, receiver gain, receiving threshold value, distance between nodes are the important factors that must be considered to find required minimum transmission power. Most of the existing work simply assume that each transmitter should use the fixed minimum transmit power needed to reach its receiver, and this would maximize the network capacity by reducing the co-channel interference. This paper proposes an Optimal Power Control algorithm to find the minimum transmission power required for each node based on the above important factors and its effect has been analyzed in terms of throughput, packet delay and packet loss. It has been observed that the proposed algorithm performs better and obtained better results as compare to the fixed power allocation approach.

Keywords: Multi-Channel Multi-Radio Wireless Mesh Networks, Power Control, Co-channel interference, NS-3, WiMesh.

INTRODUCTION

Multi-Radio Multi-Channel Wireless Mesh Network is a collection of wireless mesh nodes forming a self healing network. Connections among mesh nodes occur via multi-hop wireless configuration without the support from a fixed infrastructure such as a base station. Mesh routers collect and relay the traffic generated by mesh clients [3]. Mesh routers have additional gateway and bridging functionalities. Due to this functionality, mesh routers ensure the compatibility of wireless mesh networks with older and new networks such as the cellular, IEEE 802.15, IEEE 802.16, sensor networks, etc. Mesh clients, which are normally mobile devices, are dependent on mesh routers for data delivery towards the destination nodes [15]. MRMC-WMNs are used in various real-time applications including battlefield communications, disaster recovery, and search & rescue operations [16].

Mesh devices contains more than one radio interfaces which operates on multiple channels to increase network throughput. With the advancement in technology the cost of multi radio network interface cards has dropped considerably and has enabled the users to simultaneously transmit and receive data over different frequency channels [19]. Network performance can be enhanced by using the non overlapping channels for uplink and downlink radio links. Data can be transmitted from a source node to multiple destinations nodes based on multicast communication. Due to availability of multiple radios and simultaneous transmissions, WMN is affected by co-channel interference [14]. Co-channel interference is a common deployment issue that occurs because the same frequency channel is used by two or more nodes that are located in relative proximity to each other. Power control is an effective mean for controlling the co-channel interference and extends the network performance. Power control is a mechanism used in wireless networks to reduce the transmission power of a node to the minimum necessary level to maintain the link connectivity with a certain quality [5]. Figure 1 shows a network with six nodes and three wireless links. For each node, interference range is represented by outer circle and transmission range is represented by inner circle [17].

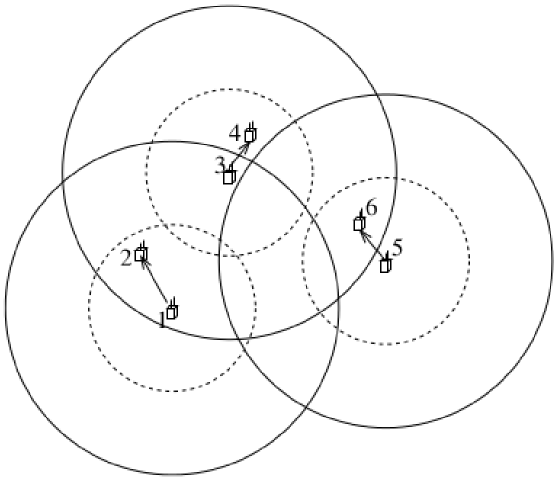

Figure 1: Transmission and interference range [17]

If two nodes are within transmission range they can transfer data to each other. If transmission range is more than required level and nodes are using same channel, Interference will take place. As shown in Figure 1 if nodes 1 & 2 and nodes 3 & 4 are operating on same channels then they are in interference range and also interfering to each other. This co-channel interference reduces the link capacity as well as the network performance. By controlling the transmission power to the desired level, interference can be reduced, resulting in better network performance.

Effects of power control

The transmit power decides the medium access control performance because the spatial channel frequency reuse depends on the number of interfering nodes.

- The selection of power levels maintains the connectivity among the network nodes and consequently power control ensures packet delivery to its destination [19].
- The selection of power level affects the capacity of each link and also affects the network throughput [10].
- Power control also affects the network structure, which further has cascading affect on number of hops, and the end-to-end delay.

This paper is an attempt to dynamically control the transmission power of each node in the network by considering the important factors of power control. WiMesh tool has been used to evaluate the performance of MRMC-WMN. NS-3 based WiMesh tool has been developed by Stefano Avallone and is being used for conducting research in the field of MRMC-WMNs from last few years [2]. It is used by various researchers to evaluate and compare the performances of a number of channel assignment algorithms, transmission rate and power control algorithms.

The paper is structured as follows. In Section II, work related to power control is described. Materials and methods are discussed in Section III. Section IV presents the results and discussions. Finally section V concludes the paper.

RELATED WORK

Hoang et al. [7] 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 updation among network nodes employed by base station and primary transmitters which result in maximize the coverage area of cognitive network. Tang et al. [19] aimed to limit interference among nodes while maintaining connectivity link among nodes. The paper demonstrated a K-connected potential communication graph to discover a suitable channel which reduces the maximum among the size of the collision domain for all the nodes subject to the constraint that the induced graph must still be K-connected. Authors proposed Interference Aware Topology Control (IATC) channel assignment algorithm to minimize interference among nodes and used the fixed transmission power for each node. This algorithm improves the network performance by 57% in term of connection blocking ratio. Chaudhry et al. [5] tried to calculate the least amount of transmission power necessary to establish communication among each of the nodes in the network, using appropriate propagation models. Based on cross-over distance between nodes, authors used Free Space propagation model and two-ray propagation model. Using these models minimum power is calculated and applied on each node and found that it improves the network throughput.

Liu et al. [11] explained that if links are assigned with partial overlapped channels with more available power levels, then network can perform better in terms of throughput and fairness ratio. This is due to the liberty of the nodes to select suitable power level rather than using higher power level. This results in minimum interference among channels, more parallel transmissions and better data rate. Luo et al. [13] investigated how optimal throughput impacted with regard to power control. It was observed that availability of two power levels yielded better performance as compare to only one power level. Power step size has important significance on performance gain. If power levels carefully chosen for converging and diverging traffic patterns then network will be satisfied with small number of power level. It shows 20% improvement in throughput as compared to a single power level throughput.

Ouni et al. [14] proposed a joint scheduling, power control and routing algorithm and discussed the benefit of enabling continuous power control. By using the regular power control for each node in network is much more favourable for better network capacity and for lower spatial reuse and better network throughput. Authors compared the fixed power algorithm with variable power control and found that in fixed power algorithm, high transmission power coupled with high energy consumption and leads to higher capacity. But same can be achieved using multi-hop communication with lower transmission power using variable power control algorithm. Gokbayrak et al. [6] summarised that the nodes of WMNs do not have any concern regarding the energy conservation as they have constant power supplies. But to prevent interference some kind of power control is still required. As the power level of transmitting node is increased, a better signal strength is observed at the destination node. But the similar improvement in signal strength is also observed at the unintended nodes, resulting in additional interference. Therefore, in the SINR model, power levels must be selected very carefully in order to obtain parallelism in data communication on several links and to increase the spatial reuse.

Tandjaoui et al. [18] focussed on the interplay between the channel assignment, multi-path routing and power control, while considering the physical interference model. The obtained results show that a substantial saving of used spectrum can be achieved by enabling parallel transmissions that carry heavy data traffic. However, time-sharing remains also a desirable access scheme due to its ability to group the transmissions made by nearby or non-disjoint links in a limited number of channels. Furthermore, authors carried out an extensive number of experiments to investigate the impact of several network parameters such as offered loads, radio patterns and network density. Ke-hao et al. [10] deduced the quantitative result of the per-node average throughput capacity of Cognitive Wireless Mesh Network with power control. Power control mechanism aimed to maximize the channel capacity while ensuring that the interference tolerated by the primary users does not exceed a threshold value. Authors derived the per-node average throughput capacity of network based on two topologies i.e. square topology and triangle topology. It has been shown from the simulation results that the link capacity with power control is better than the without power control. Shi et al. [17] investigated the power control technique to control the transmission power of each node in network so that network performance can be optimized. Due to large design space and the coupling relationship between power control and upper layers, it is very difficult to control the transmission power on per node basis. Authors proposed a formal mathematical model for joint scheduling, routing and power control. The numerical results show the efficacy of the proposed solution and offer insights on the behaviour of per-node based power control. Avallone et al. [3] analyzed the effect of controlling the transmission power of each node and the data rate of each wireless links on the efficiency of the channel assignment. Authors assumed that a minimum power level must be decided for each node so that connectivity should be maintained among nodes. Authors proposed a new channel, power and rate assignment algorithm and showed that it outperformed as compare to the previous proposals.

SIMULATION MODEL

In order to evaluate the optimal transmission power in MRMC-WMN, NS-3 based WiMesh simulation tool has been used. In proposed work random topology as shown in Figure 2 has been generated in 300m X 350m area.

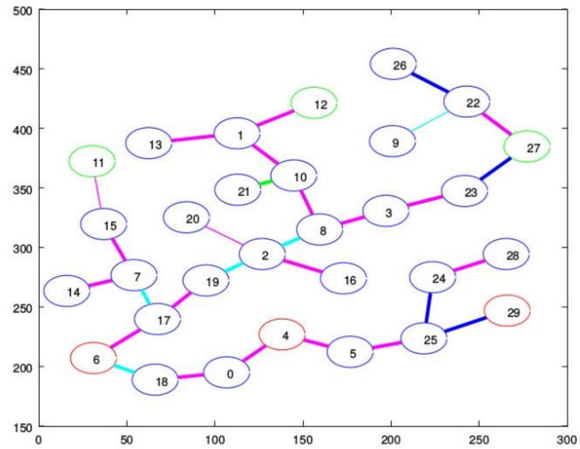

Figure: 2 Network Topology

Thirty nodes have been deployed on random locations and each node is configured as per Table 1. Three nodes act as aggregate nodes, three nodes act as gateway nodes and each node in network have been equipped with three radios.

Table 1: Parameter values used in work

Description	Value
Area	300m X 350m
Transmission power	14 dBm
Aggregate Nodes	3
Gateway Nodes	3
No. of radios per Node	3
Transmission Gain	1 dBi
Receiver Gain	1 dBi
Routing Protocol	MPLS
Transmission Speed	6 Mbps
Channel Assignment Algorithm	IATC
Simulation Time	600 secs
No. of channels	11
Traffic Type	On Off
Interference Model	SINR

Channels are assigned based on Interference Aware Topology Control channel assignment algorithm [19] having least interference among the links. The capacity of each link is set as 6 Mbps. For better performance in network all 11 channels are used and On Off traffic is used for data transmission. In first phase of simulation transmission power is fixed as 14 dBm. Simulation was run on this configuration for 600 minutes and performance based on throughput, packets loss and delay has been evaluated. As shown in Figure 1 due to uncontrolled transmission power, there is interference among the nodes, so it is necessary, that transmission power of each node must be controlled to improve the network performance. Since MRMC-WMN is a multi-hop topology, data travels from source to destination through intermediate nodes. The transmission range should be restricted to its neighbour nodes for better communication between nodes. Minimum transmission power required for each node has been calculated by using the algorithm 1. In algorithm 1 Friis transmission equation has been used to calculate the minimum transmission power [20]. The Friis transmission equation (1) describes how well the energy is exchanged between transmitter and receiver.

$$P_{rx}(db) = P_{tx} + G_{tx} + G_{rx} + 20\log_{10}\left(\frac{\lambda}{4\pi d}\right) \quad (1)$$

The equation was first presented by Danish-American radio engineer Harald T. Friis. This equation is essential in the analysis and design of wireless communication systems. It relates the power fed to the transmitting antenna and the power received by the receiving antenna when the two antennas are separated by a sufficiently large distance.

Algorithm 1: Optimal Power Control (OPC)

Input: G(V,E), ∀ u ∈ V

1. Q ← {u}
2. While Q is not empty
3. u ← 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 works for each network node *u* one by one. All nodes *u* are inserted in a queue *Q* and extracted one by one to find the minimum power for each node (lines 1-3). In this algorithm P_{rx} is denoted as receiving power and P_{tx} is denoted transmitter power. We denote G_{tx} and G_{rx} as transmission gain and receiver gain respectively. *d* is the distance in between the nodes. *P(u)* is the transmission power already assigned to node *u*. In algorithm 1 line 4 calculates the distance of node *u* from other neighbour nodes. The threshold receiving power P_{rx}thresh is set as P_{rx}. In this work P_{rx}thresh is set to -46 dBm. Lines (6-7) calculate the transmission power P_{tx} and assign it as minimum transmission power P_{min}. If calculated power P_{min} is less than assigned power *P(u)* ($P_{min} < P(u)$) then assign P_{min} as transmission power of node *u*. If calculated power P_{min} is greater than assigned power *P(u)* ($P_{min} > P(u)$) then assign P_{min} as transmission power of node *u*. Because, If the assigned power is less than the required minimum transmission power then the proposed algorithm will increase the transmission power to the 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*.

We applied the proposed Optimal Power Control algorithm that dynamically calculates the minimum transmission power for each node. Lesser the *tx* power of nodes in the network, lesser the co-channel interference and more is the network capacity. The proposed approach has been evaluated in terms of throughput, delay and packet loss. Results have been compared with fixed power allocation IATC algorithm [19] and have been discussed in next section.

RESULTS AND DISCUSSION

A number of simulation studies have been performed to evaluate the performance of the proposed Optimal Power Control (OPC) algorithm and the results thus obtained are compared with fixed power allocation IATC (FP-IATC) algorithm.

Throughput

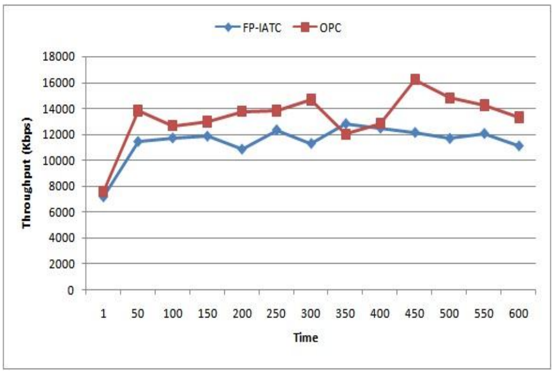

Figure 3: Throughput comparison of OPC with FP-IATC

Figure 3 shows the comparison of throughput obtained from proposed Optimal Power Control algorithm with fixed power allocation IATC algorithm. In this comparison Optimal Power Control algorithm improves the network throughput by 21% approximately and performs better as compare to fixed power allocation approach. Even throughput is marginally comparable at some points. The maximum achievable throughput of network is limited by the co-channel interference. When transmission power of each node is controlled and restricted by the proposed algorithm, co-channel interference has reduced. It increased the capacity of each link inside the network and allows more data to transfer between nodes, resulting in higher throughput.

Delay

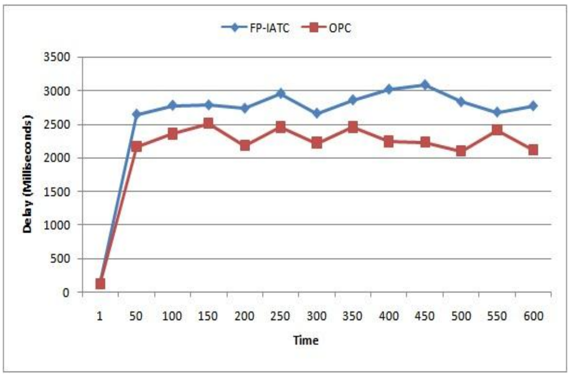

Figure 4: Delay comparison of OPC with FP-IATC

Figure 4 demonstrates the delay in the network with respect to time. It can be seen that the network with Optimal Power Control algorithm performs better than the network with fixed power allocation IATC algorithm in terms of delay. Result shows that proposed algorithm exhibited approximately 17% less delay as compared to existing fixed power allocation. The reduction in network delay is due to the higher throughput obtained from network. When transmission power is controlled by proposed Optimal Power Control algorithm, then it reduces the co-channel interference among the nodes and increases the network capacity, which tends to transfer data faster. Hence the reduction in network delay has been observed.

Packet Loss

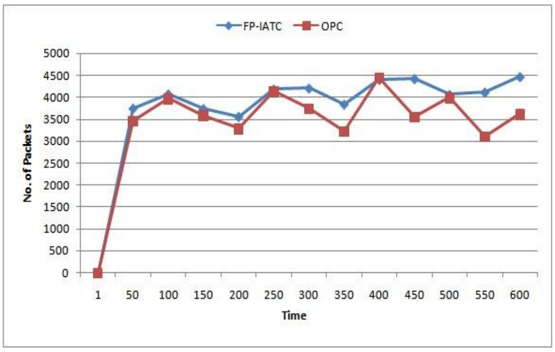

Figure 5: Packet loss comparison of OPC with FP-IATC

Figure 5 shows the comparison of number of packet lost in Optimal Power Control algorithm with fixed power allocation IATC algorithm. The number of packet lost in the Optimal Power Control algorithm is 12% lesser than the fixed power allocation approach. This is due to the higher throughput and lesser delay in network. When network obtains higher throughput, it allows more data to transfer from node to node. This leads to less packet loss in network.

CONCLUSION

In this paper an Optimal Power Control algorithm for MRMC-WMNs has been proposed. Power control plays a vital role to control the transmission range and interference among nodes. The interfering nodes degrade network capacity as well as network performance. NS-3 based WiMesh tool has been used to simulate the network scenarios. A random topology has been deployed and channels have assigned based on Interference Aware Topology Control Channel Assignment algorithm. Transmission power of each node is dynamically controlled to the required minimum level by using Optimal Power Control algorithm. Results have been evaluated in terms of throughput, delay and packet loss. A comparison of results with fixed power allocation IATC algorithm has been made. It has been found that network with proposed Optimal Power Control algorithm performs better as compared to the fixed power allocation approach.

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