Game Theoretic Approach for Channel Allocation and Throughput Maximization in Wireless Mesh Network

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***Abstract*—Recently, demand of wireless communication is increasing rapidly. In this field of wireless communication, wireless mesh networks have been proven a significant technology to provide better performance for real time multimedia communications. There are various applications present in this field of wireless communication where some of the applications are data-intensive in nature which focuses on the quality of received data and end-to-end performance of network for providing better quality of service. These applications are known are deadline –driven requests in wireless communication system. There are various schemes have been developed in last decade to support wireless mesh network and providing better quality of service and experience for end user. Still throughput, delay and packet delivery rates are challenging tasks in this field. To address this issue, here we develop a novel approach for QoS provisioning in wireless mesh networks. Proposed approach is based on the Cooperative Game Theory approach. This work mainly considers on the avoiding the interference channels and selection of better channel with the help of coordination among mesh routers and provides better channel assignment (CA) strategy for real time communication in wireless mesh networks. According to this work, channel assignment problem is formulated by mesh routers as players in the game and an optimization problem is obtained which is resolved by developing a new approach. In new approach, finalization criteria are considered to meet for better end-to-end performance of the network. Simulation study is carried on MATLAB simulation tool. Experimental results are obtained and compared with state-of-art channel assignment technique. According to the comparative analysis, better results are reported in proposed approach compared to existing schemes.**

Keywords-Game theory, Mesh network, channel assignment, cooperative

I. INTRODUCTION

During recent years, demand of multimedia communication has grown tremendously due to drastic improvement in communication technologies. The multimedia services demands for better quality of service for end-user during communication. There are various challenges present in the field of next generation wireless communication such as implementation cost, more coverage area, higher-density coverage area etc. Implementation cost of these wireless networks depend upon number of base station requirement, frequency bands etc. Other issues present in the wireless communication technology are known as interoperability, network reliability, fault tolerant and end-to-end throughput of the network etc.

In order to meet the requirements of Quality of Service (QoS) of network, Wireless Mesh Network has attracted researchers due to its significant performance nature for wireless communication [1]. Wireless Mesh Network doesn't require any centralized infrastructure, WMN (wireless mesh networks) provide large coverage area and it is self-configurable in nature which makes it more feasible to implement for dense communication scenarios [2].

Wireless Mesh Networks are widely used in various application such as providing internet access, security, surveillance, industrial application, academic applications and emergency network deployments such as disasters. As discussed before that mesh networks are self-maintaining and comprises of low cost of wireless routers which reduces implementation cost of the network. Moreover, WMNs are self-forming in nature which provides more scalability to the network resulting in better quality of communication.

Wireless mesh network advantages and characteristics are given as follow:

- Reliability of network: During communication, wireless mesh networks follow arbitrary path between transmitter node and receiver node. This scheme of arbitrary path providing results in elimination of single point failure during communication and improvement in network reliability [3].

- Lower cost of implementation: In today's communication scenario, main aim of service providers is to avail the maximum connection possibility to end users with the help of 802.11 based networking standards. In order to meet this criteria, access points (APs) need to be deployed. In wired networks, infrastructure cost affects the deployment whereas in wireless mesh network no pre-predefined architecture is present which reduces the implementation cost of the network [4].

- Large coverage area: Wireless mesh networks provide large range of coverage for communication. For small distances

WLANs has been proven an efficient technique but the performance of WLANs degrades when it is implemented for longer distance. In this case, WMNs are significantly increasing the performance of communication [5].

These advantages of WMNs make it feasible to implement for real time applications. However, WMNs have broadcast nature of wireless multimedia data where simultaneous transmission of multimedia data occurs resulting in interference among communicating links. Since, WMNs are multi-hop networks where interference of previous nodes affects the performance of next communicating nodes. The overall performance network faces performance issues due to this interference [6]. On other hand, more number of devices which are sharing the same spectrum also degrades the network performance [7].

Still there are various challenges present in Wireless Mesh network based communication scenarios. These challenges are discussed below:

- Network Plan: This is a crucial task for researchers to be dealt with, before implementing the mesh networks i.e. analysis of hardware resources, communication interfaces which are responsible for implementation cost and network performance in terms of end-to-end throughput, delay etc.

- Network Provisioning: During implementation of mesh networks, a network provisioning scheme need to be developed which can be used for network provisioning to maintain the communication link between mesh routers and mesh clients.

- Network security: In today's communication era, various intrusions and attacks are present which can damage the deployed WMN network by breaking the network security. Various security protocols have been developed but due to lack of centralized architecture, security performance of these networks needs to be addressed.

- Scalability: Wireless mesh networks are used for large coverage area without increasing number of nodes and performance also should not degrade. This can be addressed in WMNs by developing a new scalable routing.

In real time communication scenarios of WMN, communication interfaces are more than the available frequency channels where each wireless node can consist of more number of interfaces which may result in interference among links which are assigned to the communicating channels resulting in performance degradation of network. Major issue in wireless mesh networking is known as channel assignment for real time communication. Existing methods for channel assignment suffer from the complexity issue in WMN and not able alleviate the problem of network performance.

To address this issue of channel assignment and network performance improvement, in this work we propose a new approach for optimal channel assignment using game theoretic approach. Game theoretic approach is introduced in this work to address the complex communication scenarios, node mobility, link quality prediction etc. Main contributions of this work are as discussed below:

- Development of interference modeling with the help of interference measurement.

- Implementation of game theoretic model

- Channel assignment modeling

- Development of optimal channel assignment approach for WMN

Rest of the paper is organized as follows: section 2 deals with related work in this field of channel assignment in wireless mesh networks, proposed solution for channel assignment is presented in section 3 section 4 gives detailed simulation study and section 5 gives concluding remarks of the proposed work.

II. RELATED WORK

This section describes the most recent studies for wireless mesh network communication, aiming on the performance improvement of mesh networks. Alim et al [8] presented survey for channel assignment techniques for wireless mesh network. This work studied the various issues present in mesh networks such as channel diversity, interference and channel switching issues. According to this survey, various techniques have been proposed for single-radio mesh networks but these techniques cannot be implemented for multi-radio mesh networks.

Zhou et al [9] discussed about the performance issue in wireless mesh networks. According to this study, authors have analyzed cross-layer based architectures and heuristic approaches, this analysis reported that these techniques are not capable to provide desired performance for wireless mesh networks. To overcome the issues, authors have presented a new approach aiming g on the maximum gateway utility. This work considers cross-layer based architecture as base design and assumes a problem as network utility maximization (NUM) considering multiple gateways. Later this optimization problem is resolved by developing traffic splitting, rate controlling,routing and scheduling approach. This method splits the traffic and distributes it to multiple gateways for communication by achieving optimal solution.

Setchi et al. [10] developed a scheme for heterogeneous wireless mesh network to obtain better connectivity, large coverage area and improved quality of service. This study is based on the heterogeneous network scenario where various devices are present. These devices uses different format for data transmission, standards and different technologies which makes heterogeneous mesh communication more complex. In this article authors developed a new approach for IEEE 802.11 mesh network for long-term evolution communication network. Moreover, an efficient routing protocol is also developed here which utilizes concept of reinforcementlearning to support the transmission scenario by selecting the proper channel based on the network parameters. This approach resolves the issue of packet transmission for long distance scenarios, network interference and improves the capacity by utilizing unlicensed spectrum bands. Simulation study of this approach reported better performance when compared with other existing schemes.

Chakraborty et al [11] developed a new approach to find the hiddennode in mesh networks. Hidden nodes affect the overall performance of the network in terms of throughput. This issue is addressed with the help of an opportunistic model. According to this model, characteristics of IEEE 802.11 standards are utilized for data frame aggregation and packet blocking acknowledgement. During communication, hidden nodes causes throughput degradation because of collision and in the high-throughput requirement scenarios it becomes very challenging to solve because of size of physical layer, channel response delay etc. Hence this work introduces a new approach for collision avoidance in mesh network utilizing carrier sense multiple access (CSMA) technique.

In [12], authors considered the scenario of wireless mesh network development based on the budget constraints and capacity improvement of the network. Main aim of this work is tp provide optimal solution for link positions to address the capacity issue of the network. In order to perform this, single-radio single –channel mesh networks are considered and mixed-integer linear programming based problem is formulated for capacity improvement.

Nargesi et al [13] introduced multicast routing schemes for wireless networks. Generally, multicasting routing schemes are developed for wire line communication and cannot be used efficiently for wireless networks due to their characteristics. Various routing schemes have been developed which are aimed on to improve the performance by reducing the number of re-transmission during communication. If the number of re-transmissions are reduced then the bandwidth consumption and interference is also reduced which improves the performance of wireless mesh networks. In this work, distributed multicasting based routing protocol is developed for wireless mesh network scenarios to improve the data delivery rate and throughput with the help of path construction scheme.

Wang et al [14] explored a new approach of wireless mesh network for partially overlapped channels. This work mainly aims on the channel assignment, to obtain better performance in terms of throughput and end-to-end efficient flow transmission. Proposed approach is capable to handle the variousloads on the network during real time communication but throughput, packet delivery rate and delay still remains a challenging task in this field of wireless mesh networking.

III. PROPOSED MODEL

In previous section we have discussed most recent studies aiming on performance analysis of wireless mesh network. Conclusion of literature review indicates that still there are various challenges present which need to be addressed in wireless mesh network. Channel assinment is a challenging task which is affecting parameter for performance of wireless mesh network. In thsi work, we develop a new approach for channel assignement. This approach is based on the Game Theoritic approach.

In order to develop this apprach,we follow below mention stages:

- Interference modeling
- Channel assignment based on Game thoeritic model
- Development of optimal solution for channel asignment.

A. *Interference modeling*

In section I, we have discussed that interference is a crucial parameter which affects the performance of wireless mesh networks. To address this issue, first of all we develop an interference model for mesh network.

Channel assignment problem can be considered as an optimization problem by considering the utilization of available channels to other interfaces of mesh network, resulting in performance improvement by minimizing the interference. Range of interference depends on the distance within the interference occurs. In this work, we have considered two different transmissions to analyze interference scenario. Since, we are concentrated on multi-channel environment which consist of four different interference scenarios, need to be addressed.

Let us consider two pairs of mesh nodes which are equipped with transmitter/sender and a receiver where sender of first pair is denoted by $\mathcal{S}_1$ and receiver is denoted by $\mathcal{R}_1$. Similarly, sender and receiver of second pair are denoted as $\mathcal{S}_2$ and $\mathcal{R}_2$. It is assumed that all nodes lie in the interference range. Here we discuss four types of interferences scenarios.

B. *Co-channel interference:* According to this interference, let us conisder that all the nodes of each pair are operating in the same channel. However, this type of interference is less effective due to the nature of CSMA techniques.

Let us consider that node $\mathcal{S}_1$ of first pair initiates the communication with $\mathcal{R}_1$ and transmits packet. During this process, node $\mathcal{S}_1$ validates the status of communication medium whether is available or busy. If status is available, then packets are transmitted otherwise packet transmission is discarded. At this stage, both sender nodes are forwarding packets to receiver nodes corresponding to each pair. Hence, medium status is flagged as busy which makes $\mathcal{S}_2$ to withdraw the communication until medium status is flagged as available.

C. *Othogonal channels:* Let us conisdet tha $\mathcal{S}_1 - \mathcal{R}_1$ and $\mathcal{S}_2 - \mathcal{R}_2$ are using orthogonal channels for communication. In this scenario also, we assume that node $\mathcal{S}_1$ sends packet to node $\mathcal{R}_1$,meanwhile node $\mathcal{S}_2$ is waiting for ideal medium. In this case, no interference occurs because of available frequency bands.

D. *Adjacent Channel Interference (ACI):* This interference is most effecting interfernce the performacne of WMN capacity. According to modeling of this interference, $\mathcal{S}_1 - \mathcal{R}_1$ assigned to channel 1 and $\mathcal{S}_2 - \mathcal{R}_2$ assigned to channel 3. Here also we conisder the same communication model as conisdered for co-channel interference. In this model channel1 and channe 3 are presnet in the same band which causes complexity to decode the transmitted packets resulting in packet error. This packet error decreases network performance in terms of throughput.

E. *Self-Interference:* This is the phenomena where communicating node itself causes interference during communication. This interference occurs when multiple omni-directional antennas are used by radios.

In this work we have considered above mentioned interferences and developed a new approach for channel assignment.

F. *Interference Measurement*

In this section we present the scheme of interference measurement with the help interference modeling. Let us assume that interference measurement is denoted by $M_{i,j}$. This measurement requires distance between nodes, channel separation as input. Spectral overlapping between channel i and j is obtained. Channel separation is denoted by δ where $\delta = |i - j|$ and maximum distance is denoted as $D(\delta)$.

In order to carry out the interference measurement, we consider following cases:

If $\delta \geq 5$ or $d > D(\delta)$ then $M_{i,j} = 0$

This case doesn't induce any interference in communication because of orthogonal channel assignment between i and j .

If $0 \leq \delta < 5$ and $d \leq D(\delta)$ then interference measurement is given as $1 < M_{i,j} < \infty$.

This is the measurement of two radios which are assigned to orthogonal channels and distance is also in the interference range. For this scenario, interference is given as

$$M_{i,j} = \frac{D(\delta)}{d}$$

If $0 \leq \delta < 5$ and $d = 0$ then $M_{i,j} = \infty$

This scenario shows self-interference scenario during communication in wireless mesh network.

G. *CHANNEL ASSIGNMENT MODELING USING GAME THEORY*

In this section we develop a game theoretic model for channel assignment in wireless mesh network. According to game theory perspective, Mesh routers are considered as players to model the Game. In this work, our main aim is to develop an efficient technique for channel assignment in mesh networks with the help of Game Theoretic approach. Furthermore, mesh routers are free to make decision according to the communication requirement with the help of cooperative game theory based channel assignment.

In order to form the channel assignment game, set of finite number of players or nodes is considered where each player follows common strategy for communication. Finite set of players are given as $\mathcal{A} = \{a_1, a_2, \dots, a_N\}$ and communication strategy is given as $S = S_i$. According to this stage, channel mapping is performed by considering any given mesh router and its working strategy. Strategy of i^{th} player is denoted as

$$s_i = \{k_{i,1}, \dots, k_{i,c}, \dots, k_{i,|C|}\}$$

Where $k_{i,c}$ denotes whether channel is assigned or not and $|C|$ denotes total number of channel set present in the network. The value of $k_{i,c}$ is always in the binary form, if the value is set to 1 then channel is assigned to its corresponding radio otherwise it remains unassigned.

By creating this game, we try to solve the optimization problem as we have discussed in previous section that channel assignment can be considered as an optimization problem. Our main aim is to achieve better end-to-end throughput for the network by solving this game based optimization problem. In order to do this, we define a parameter joint metric as J_i for each player which is present in the formulated game strategy. This metric performs correlation between link configuration and link topology for better analysis of game. Rate of data transmission for each link is evaluated based on the total number of interfering links. Furthermore, here we have included two another parameters for topology controlling application. These factors are denoted as k and h , main aim of introducing these factors are that network performance evaluation should be performed based on link capacity and its performance towards gateway

$$J_i = k \frac{\sum_{t \in C} \frac{R}{n_t}}{h}$$

Where R denotes link data rate in Mbps, total interfering links are denoted by n , total hop count is given as h and connectivity factor is given as k which is assigned to 1 or 0.

With the help of these assumptions, utility function of each player is computed based on the strategy. Utility function of each player is denoted by $U_i(\psi)$ and network utility is denoted by $U_{NET}(\psi)$. This relationship can be denoted as follows

$$U_{NET}(\psi) = U_i(\psi) = \sum_{i \in A} J_i, \forall_i$$

During communication in mesh network, each node or player change their strategy to obtain the optimal solution in network utility function. In order to obtain the optimal solution, we need to analyze that utility function for any particular node is achieving a steady state scenario and the performance of steady state scenario. These issues can be resolved by obtaining Nash Equilibrium for any given state of game. Here we try to find Nash Equilibrium for the formulated game based on the mesh network concepts. As discussed before that each node having their own strategy during communication which is denoted as $s^* \in S$. We try to find Nash Equilibrium state for this model which can be represented as

$$U_i(s^*) \geq U_i(s_i', s_{-i}) \forall s_i' \in S_i, \forall_{i \in A}$$

According to Nash Equilibrium theory, if any player is deviating from the defined strategy then it cannot be benefitted and performance cannot be improvised in wireless mesh network scenario. To address this issue, players start negations to obtain optimal performance and network fairness with the help of potential games which consists Nash Equilibrium stats. Potential game can be denoted with the help of potential function as

$$P(s^{\dagger\prime}, s_i(-i)) - P(s^{\dagger\prime\prime}, s_i(-i)) - U_i i\,(s^{\dagger\prime\prime}, s_i(-i)) \forall\, i, s^{\dagger\prime}, s^{\dagger\prime\prime}$$

Where s' and $s^{\dagger\prime\prime}$ denotes two random strategies for communication in WMN.

To address this issue of Nash Equilibrium and potential games, here we develop a new approach for convergence of Nash Equilibrium based on the negotiation. Let us assume that each mesh router has a unique identity number for routing purpose. Further performance of the WMN is improved by introducing finalization criteria for meeting the requirement of negotiations by considering maximum number of negotiations, time limitations and threshold for utility function.

Proposed game theoretic approach is based on the cooperative game theory modeling which has coordination among various nodes in the network and try to meet the requirement specifications for potential game formulation and Nash Equilibrium. This approach is performed into two steps called as strategy negotiation and operation. According to the first stage of operation, nodes are operated in given frequency bands and packets are transmitted through ho-by-hop communication based on the node cooperation scheme. This stage shows the cooperation between mesh routers or communicating nodes. In some communication scenarios, each node is operated in different frequency band. While during communication, nodes exchange their control message but due to channel diversity control message is received by the destination resulting in network performance degradation. Hence, negotiation phase, decision phase is applied for strategy selection where the nodes have a time window of 250 ms for decision broadcasting. This process is performed until the finalization criteria is met then operation phase is initiated where nodes switch their channels on the other radios. This algorithm is described in below section:

Algorithm 1: Proposed algorithm

Step 1: initiate random strategy as $s_i = \{0\} \forall_{a_i} \in A$

Step 2: finalization criteria evaluation as $F = false$ do

Step 3: random selection of players with probability $\frac{1}{N}$

Step 4: random strategy $s_i^{rand} \leftarrow \{k_{i,1}, \ldots, k_{i,c}, \ldots, k_{i,|C|}\}$

Step 5: evaluate selected strategy from step 4.

Step 6: if strategy is invalid i.e. $s_i^{rand} \neq invalid$ then select another random strategy

Step 7: if strategy $s_i^{t+1} > s_i^t$ then assign strategy as $s_i^{t+1} = s_i^{rand}$

Else

$s_i^{t+1} > s_i^t$

Step 8: decision selection

Step 9; decision broadcasting

Step 10: Update finalization criteria

Aforementioned algorithm is applied for decision making and channel selection for mesh routers based on the finalization criteria. In the next section we present the simulation study of proposed work.

IV. EXPERIMENTAL STUDY

In this section, we present the description of experimental analysis of proposed work. This approach is implemented using MATLAB simulation tool. For simulation study, we have considered a grid topology of 5x5 for wireless mesh networks where the network grid length is taken as 250m. Transmission range and grid lengths are similar to each other. For interference consideration, we have considered co-channel, adjacent channel and self-interference scenarios.

For each vertex, static router is considered and Omni-directional antennas are deployed for packet transmission and receiving purpose. For experimental analysis, 24 mesh nodes are distributed in the coverage area of 1000 m x 1000 m where each mesh client is having only one interface. For better complexity analysis, direct communication is not allowed to mesh clients i.e. mesh clients communicates with neighboring nodes.

Here, system bandwidth is conisdered as 2 Mbps according to 802.11b with a constant bit rate packet generation source scenario. Packet transmission rate is taken as 200Kbps where eacch packet size is considered as 512 bytes.

System performance is evaluated in terms of performance metrics as mentioned below:

- End-to-end throughput: This is the performance metric for any network which shows overall efficient of the network. This metric can be obtained by considering total number of received packet and time taken to receive first packet to last packet. It can be expressed as

$$Throughput = \frac{total\ received\ packets}{time\ taken\ \ between\ first\ and\ last\ packet}$$

- End-to-end delay: it is the measurement of time taken for a packet to reach at destination from source node to destination node. Average end-to-end delay is computed by measuring the delay for all packets.
- Packet drop rate: this metric is measurement of packets delivery ratios as packets delivered at receiver end and actual number of packets to be delivered at receiver end.

Simulation parameters are presented in table I.

Table. ISimulation parameters

Simulation parameter	**Considered Value**
Total time for Simulation	100 ms
Network area	1000m x1000m
Network Topology	Grid topology with 5x5 grid
Bandwidth of 802.11b	2 Mbps
Total Number of Mesh clients	24
Traffic Source	CBR traffic
Packet Transmission rate	200 kbps
Packet size	512 bytes
Interference range	250 m
Range of transmission	250 m
Communicating antennas	Omni-directional

Performance of this work is compared with existing partially-overlapped channel scheme for wireless mesh networks [14]. In [9], Wang et al. presented a new approach for wireless mesh network performance improvement considering partially overlapped channels. In this work authors presented three approaches which are named as: ELIA-POCA, EPOCA and ELIA-OCA. ELIA-POCA illustrated best performance when compared with other schemes. Still there are some performance improvement can be done in these approach. To improve the performance of WMN, we proposed game theory based approach and compared it with existing schemes.

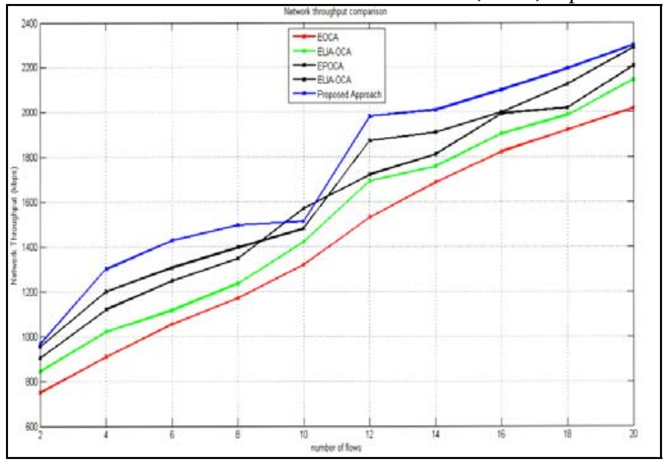

Figure 1. Throughput Comparision

Figure 1 shows the comparative study of proposed approach and existing approach in terms of throughput. In order to obtain this analysis, we have varied number of flows and based on the flow rate obtained throughput performance is reported. According to this study it is concluded that proposed approach provides better performance in terms of network throughput for varied number of traffic flows also.

In next analysis, we present the performance evaluation and comparison of proposed and existing approaches in terms of end to end delay. For this analysis also similar simulation parameters are considered here.

In figure 2, we show end –to-end delay comparison of proposed and existing models. In this analysis it is reported that proposed model provides better performance in terms of delay. This delay performance is evaluated by varying number of flows and considered delay in seconds for each packet. It shows that as number of flows are increasing delay is decreasing but according to comparative analysis, proposed approach provide less delay when compared to state-of-art technique.

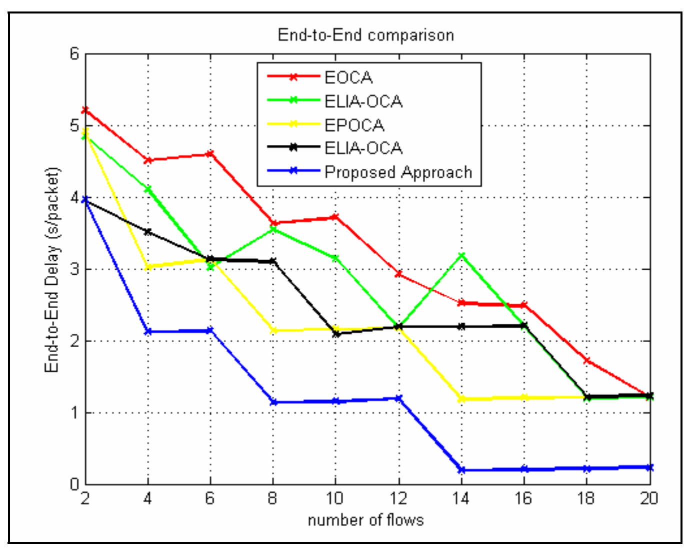

Figure 2. End-to-end delay performance

Another performance matrix is evaluated in terms of average packet loss ratio. This analysis is presented in figure 3.

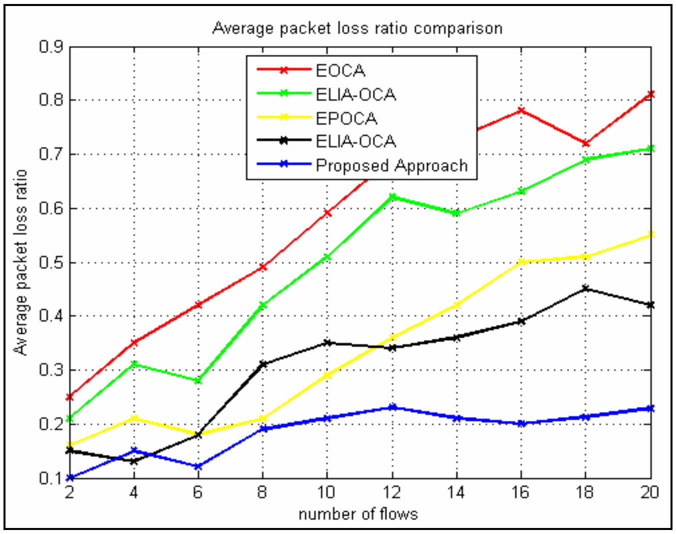

Figure 3. Average packet loss ratio comparison

In this experimental study, it is reported that proposed approach reports better performance when compared with other state of art techniques. However, existing techniques are based on the utilization of partially overlapped channels but still interference is a challenging task. To overcome this issue, we have developed a robust approach for wireless mesh network.

In next simulation scenario, we have evaluated the delay performance by varying the snot size. This analysis is shown in figure 4.

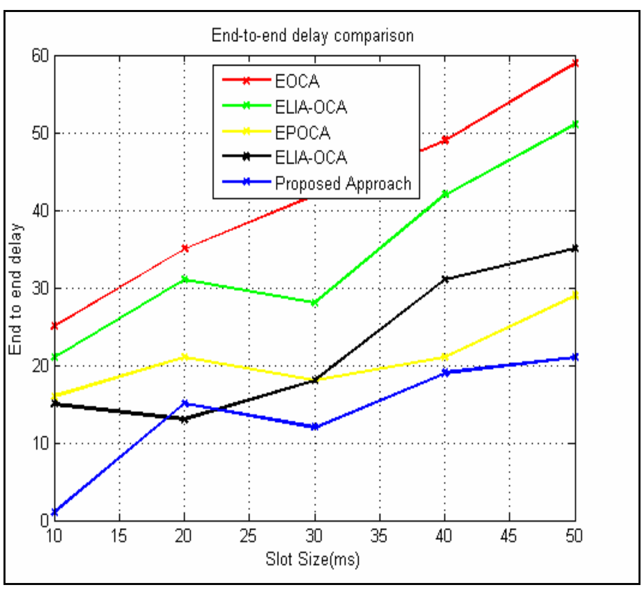

Figure 4. End-to-end delay analysis

In figure 4 we show the comparison of proposed approach with state-of-art techniques where existing approach EOCA results in more delay whereas proposed approach outperforms in terms of delay based on the slot size variations.

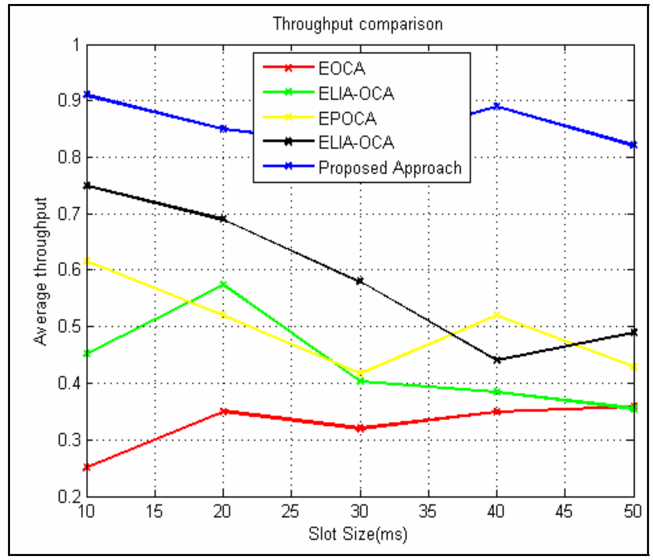

Figure 5. Throughput analysis

With similar simulation scenario, we analyze the throughput performance of proposed approach. This study is presented in figure 5, which shows that proposed approach provides better results when compared with existing schemes.

V. CONCLUSION

In this work we have studied about the wireless mesh network, their impact on wireless communication and performance analysis. A literature study is also carried out which shows that efficient channel utilization approach need to be developed for better performance of wireless mesh network. In this work, we developed cooperative game theory based channel assignment approach by considering partially overlapped channel scenario.

An extensive simulation study is carried which shows that proposed approach can efficient manage overlapping channels and improve the performance using orthogonal channels by minimizing the interference. Simulation performance is measured in terms of network throughput, end-to-end delay andpacket drop ratio. Proposed approach reported significant performance of wireless mesh network when compared with existing models for channel assignment.

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