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A Cross-Layer Scheduling Technique for Low-Latency Wireless Mesh Networks

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ABSTRACT

The growth of smart phone technology have resulted in increased number of multimedia application which requires low latency service delivery and coverage which the existing wireless technology could not handle due to power limitation imposed by Wireless Local Area Network (WLAN) regulatory body. To address this wireless mesh networks (WMNs) was standardized by task group S to support multichip based communication. Reducing packet delivery latency in existing multichip WMN is one of key issues that need to be addressed. The existing methodology induces high data delivery latency due to inability to address the hidden and exposed node problem in multichip WMN environment. Many approaches have been developed to optimize the Medium Access Control (MAC), hidden node and exposed node detection algorithm in recent time to better utilize slot and reduce latency. The existing method adopts contention based method to address the collision caused by the hidden node problems which result in improper utilization of slot, which result in bandwidth wastages. Node classification technique for reutilizing slot will aid in improving network performance by reducing latency. As it is seen the latency plays a significant part in improving the performance overall throughput of a network. This work proposes an efficient device classification based MAC scheduler by adopting a cross layer design to reduce the data delivery latency. The experiments are conducted to evaluate mean network latency and data delivery latency by varying depth of tree for varied network size and density. The outcome shows that the proposed approach perform better than existing CSMA/OCA in term of network data delivery latency.

Key words: Cross-Layer, IEEE 802.11, Scheduling, WMN. Diabetes Mellitus, Prediction

1. INTRODUCTION

WMN is considered to be the future paradigm of wireless access technology due to its low cost of deployment and high coverage. The WMN can support various application services are as follows intelligent public transportation system, wireless internet broadband services, disaster management etc… The IEEE 802.11WLAN (wireless local area network) is a most sorted standard due to its unlicensed operating bands of 2.4 GHz and 5 GHz. Due to the regulatory enforcement limitation of transmission power result in limiting the transmission range of WLAN [1, 23]. Nevertheless the requirement of such large wireless network is in huge demand in various areas such as office, home, university, campuses etc… The demand for growth of low latency service cannot be addressed by existing single hop communication of IEEE 802.11WLAN. To achieve a low latency service delivery it requires a multihop services, to achieve this Task Group S [1, 2] has been working to standardize the IEEE 802.11 to achieve multi hop association by optimizing the routing capabilities and frame forwarding at medium access control layer. The 802.11s standardization brings a new cost effective and secure communication.

WMN establishes an ad-hoc infrastructure as in Figure 1, i.e. it is self-configured and self-organized, with the devices in the network can join and leave a network and still maintaining the mesh connectivity. The 802.11s mesh networks are made of two forms of devices namely mesh clients and mesh routers. Like the 802.11 wireless device it also support routing proficiency for gateway tasks along with that the mesh router contain an added routing functionalities to provision mesh infrastructure. The WMN adopts a multi-hop transmission [2]; which can achieve a better coverage by a mesh router with reduced power for transmission. To provide flexibility of WMN the wireless mesh router are fitted with multiple wireless interfaces built on various wireless access technologies.

Though the mesh network provides cost effective network coverage backhaul solutions it has numerous challenges [2, 3] [23], particularly when bandwidth per user is increased for number of concurrent sessions among multi-hop wireless mesh devices in providing service as backhaul Wireless LAN technologies. Due to shared medium access some challenges occurs in 802.11's at the time of communication service considering multi hop nature of mesh network.

The provisioning of multimedia based communication services in multi-hop Wireless Mesh Networks is a service which is important for the future perspective of Internet technology [4], but providing multimedia service contained some issues and new challenges when it deployed over a multihop WMN such as losses of packet and an increased communication delay because of interference in a multi hop network can significantly degrade the quality of end-to-end multimedia services. In multi-hop communication load of traffic cause very high medium contention which leads to loss of packet rate as it compared with single hop communication [5].

The presence of hidden devices or failure to identify the presence of hidden devices will result further increase of packet loss rate and induces a high overhead in MAC (Medium access control) layer which result in low capacity for multimedia based services over internet over IEEE 802.11 based WMNs [5]. In recent there has been several approaches is been modelled for performance enhancement of IEEE 802.11s wireless mesh network that adopt CSMA/CA MAC protocol [6, 7] that include tuning the carrier-sense range [8] by adopting out of band control message [9] and local coordination [10] in order to improve the channel slot utilization. The MAC protocols based on distributed scheduling [11, 13, 14] have been modelled to cater the interference free [12] TDMA scheduler technique. Yet these models allocate equal slot access on time basis for each user request irrespective of traffic demand or load which affect the end to end performance. Along with this there has been various cross layer design have been adopted to solve the routing, interference and MAC contention for better path selection [15] but they suffer in identifying alternative path and failed to address the interference due to hidden and exposed node problem.

Here [16] they considered link and bandwidth aware scheduling metric has been considered to address the problem of bandwidth wastage in TDMA based protocol. The hidden node problem are solved by giving time slot but the signaling message will cause channel overhead and the bandwidth are estimated based RSSI and improper measurement of RSSI will result in degraded throughput due to collision. To address the throughput degradation due to signaling overhead in [17] aim to avoid or block the device which is hidden but cause for data loss due to collision in other hand author transmit the data through visible device and utilize the available capacity of network. They obtained better throughput than existing methodology [18-21]. As seen from [17] allowing the exposed to reuse the slots helps improving the throughput performance of the network. Therefore, it is important to identify the hidden devices in the network for designing an effective MAC scheduler. The architecture if wireless Mesh Networks shown in Figure 1.

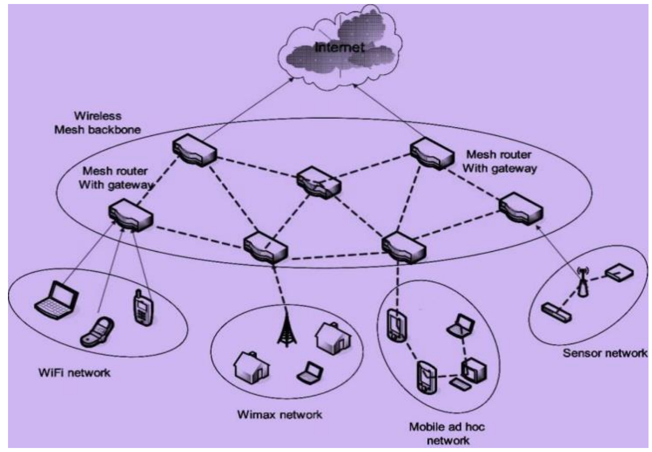

Figure 1: The Architecture of Wireless Mesh Networks

It is seen that handling hidden node problem and reducing latency play a significant part in improving performance of network. The existing models induce high collision due to inefficiency in handling hidden devices in Mesh network. The existing model does not use slot reutilization technique thus induces data delivery latency which affects the overall throughput performance of Mesh network. To address the hidden node problem and latency issue this work present a slot reutilization technique by adopting devices classification method. The device is classified into four types CIRP (Connected inner relay device pair), DIRP (Distant inner relay device pair), CLRP (Connected leaf relay device pair) and NCLRP (Non-connected leaf device pair). The proposed model adopts a cross-layer design for efficient MAC scheduler. No prior work has considered device classification method for slot reutilization of DIRP, CLRP and NCLRP pairs. Latency plays a significant role in improving the throughput performance of mesh network hence we consider this has main performance parameter in our work.

Design issues and challenges in 802.11s wireless mesh network:

The difficulties faced at the time of Mesh network designing process given as [2, 3, 23]. Mesh Connectivity is an important factor in order to guarantee network self-organization, reliable connectivity, and topology control protocols are required. Topology conscious routing and *MAC* protocols can efficiently enhance the performance of mesh networks. At the different interval of network predication of number of subscriber is an important issues and difficult task. For that reason predication of load which is generated on the mesh network also get difficult. Channel capacity and performance varying according to the system parameters.
Scalability is an important factor and necessities of Wireless mesh networks. The network performances will degrades badly without provision of scalability i.e. for varying network sizes and density. For instance, routing strategy may not be suitable or find difficulties in finding a cost effective routing path, loss of connectivity, and *MAC* protocols may see degradation in throughput performance. To ensure the scalability in Wireless mesh networks, all strategies from the medium access layer to the application layer need to be designed considering scalability.

The paper organization is as follows: In Section two the literature review are briefly described. In section three, the proposed scheduling techniques are discussed. Section four the simulation result are obtained and evaluated with existing methodologies. The last section the paper is concluded with future works.

2. LITERATURE SURVEY

Providing an end-to-end low latency service delivery guarantee for end user in multi hop wireless mesh network is one of major challenges that need be addressed. Various methodologies have been proposed in recent time to address the issue such finding bandwidth or low latency link for transmission, addressing the hidden node problem in multihop environment to reduce collision and *QoS* delivery for end user since the *WMN* has large coverage area.

In recent years routing in *WMN* to achieve high throughput and low latency service delivery in multi hop wireless environment is been a hot research trend [24, 25]. In multi-hop environment the packet are forwarded through multiple intermediate devices when the source and destination are not within the range of communication area. Many approaches have been proposed to route the packet in an efficient manner from source to destination [26, 27]. The performance of these methodologies is not efficient since these strategies did not consider the hidden and exposed node problem that exists in multi-hop wireless mesh networks.

The hidden node problem in multi-hop wireless mesh networks depends on carrier sense of source devices and the device within the communication range of particular end devices [28, 29]. If the carrier sense of source device [29] are within the interference range destination device will result in packet collision at the destination devices due to hidden node problem. Due to large coverage of wireless mesh network will result in increased rate of collision of packet as compared with $WLAN$ as a result the network capacity is affected.

The *IEEE 802.11s* protocol adopt *CSMA/CA* as its *MAC* protocol [30] which significantly degrades the performance of methodology that adopted *CSMA/CA* as it's *MAC* due to hidden node problem. To address the hidden node problem that underlying *IEEE 802.11s* employs the Clear to Send/Request to Send (*CTS/RTS*) mechanism, but this increases the communication overhead in the mesh network due to transmission of beacon update packets [31]. To address the latency due to hidden node in contention-based protocol, the contention less based *TDMA* based approach have been adopted in recent times which consider fixed traffic pattern for scheduling but the drawback this protocol is over allocation of bandwidth.

To address [32] proposed a two-stage link scheduling which adopted a dynamic link scheduling mechanism to overcome the NP-Hard problem of optimal throughput algorithm [33]. They did not consider slot reutilization technique and when network become large it suffers from linear search problem in associating links which induces high network overhead. In [17] they proposed special reuse for hidden and exposed node; they adopted power optimization mechanism to address the interference caused by hidden and exposed nodes, there model improved the throughput but implementation of such model requires the *MAC* layer to be altered, and continuous measurement of signal interference to noise ratio (*SINR*) and channel error transmission result in communication overhead in control channels thus induces latency for channel access.

To overcome all these problems that exists in designing a low latency wireless mesh network, this work present a low latency scheduling technique by adopting slot reutilization technique strategy based on device classification methodology [22] which is presented in section 3 below.

3. PROPOSED NODE CLASSIFICATION BASED SLOT REUTILIZATION SCHEDULING MODEL

To provide a low latency Quality of Service (QoS) for WMN's which suffer from hidden node problem due to its large coverage area, slot reutilization is an effective method to reduce latency for channel access for data delivery but will induces channel collision. To address this work present a scheduling technique by adopting slot reutilization technique based on device classification method [22] to reduce the latency of the mesh network.

The benefit of slot reutilization is that it utilizes the unutilized slot of its neighbour devices for transmission of its packets. The utilization of this unutilized slot will aid in improving the utilization of bandwidth more efficiently. This help in providing a cost effective service delivery platform as bandwidth availability is very limited. Though slot reutilization improves in utilizing bandwidth more efficiently but it induces collision due to hidden device problem. As both devices might try to access same channel or deny channel access thus incur collision and increases latency. The latency is the most critical part in providing efficient service delivery (improving throughput). Minimizing latency for channel access is most desired. Device classification plays a significant role in addressing hidden node problem for efficient slot reutilization and minimizing latency.

Classification of device pair is done based on tree structure and neighborhood and parenthood relationship. Device pair classification is done below in terms of *x* and *y* and this device pair classification is shown in Figure 2.

CIRP (Connected inner relay device pair):

- x and y may behave as an adjacent node that occur physically in the WMN,
- May x and y are not an adjacent node
- May x or y has a child, but x and y have a conjoint an DIRP (Distant inner relay device pair):
- x and y are not adjacent devices physically but have a common conjoint an adjacent physical device
- But these common adjacent physical devices are neither x's nor y's children.

CLRP (Connected leaf relay device pair):

- x and y are adjacent devices that exist physically in the WMN,
- Both x and y don't have any child. NCLRP (non-connected leaf device pair):
- x and y are not adjacent physical devices
- They don't have any adjacent physical devices in common.

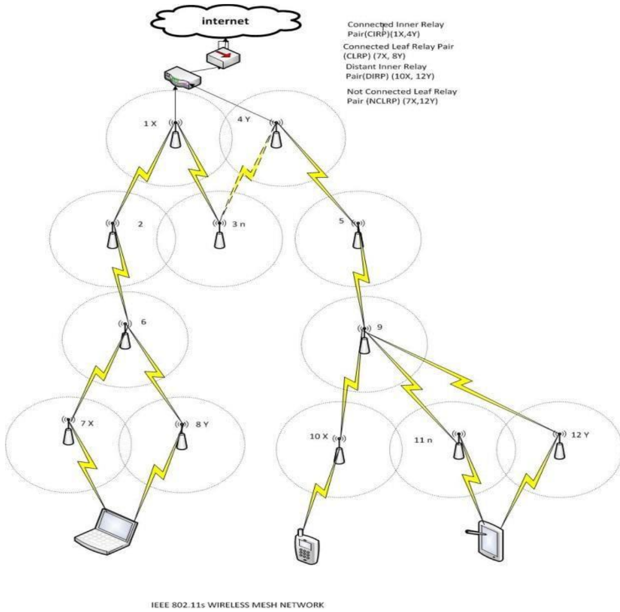

Figure 2: The proposed device classification model for *IEEE 802.11s* wireless mesh network

In [22] proved that slot reutilization of *CLRP* is having higher probability of having risk in slot reutilization as compared with DIRP and slot reutilization of *DIRP* is having higher probability of having risk in slot reutilization as compared with NCLRP. The slot reutilization of *CIRP* is not considered in our work. The probability of having risk in slot reutilization is as follows *CLRP≥DIRP≥NCLRP*. Here author propose concept of *CLRP*, *DIRP* and *NCLRP* for channel slot reutilization when the probability of risk is small.

3.1 Proposed Node Classification based Scheduling approach

The mesh router slot is set to zero initially for node join operation. When a device *x* needs to a join a wireless mesh network it primarily needs to search the node join operation of adjacent mesh router which are currently present in the wireless mesh tree. Let ***α*** represent a collection of root contenders of wireless mesh router. The mesh router that cannot allow a leaf node is removed first by using ***α***. The root selection strategy is then applied by node *x* to sort. In this case the *x* root device must be the adjacent wireless mesh router that hast the least depth parameter. In our strategy to break the ties, the adjacent mesh router is chosen that has highest number of slot and depth parameter. Once the ***α*** is sorted, the device *x* choose a root device form ***α*** by following strategy. Firstly, get the first *α* of ***α***, compute weather *x* can join with *α* as mesh router. If *α* has lesser than the maximum number of leaf node of wireless mesh router or gateway amongst its leaf, and has a depth of maximum depth of tree -2 or lesser, and *selectTranSlot(α,x)* which gets a transmission slot *t*, then *x* joins with *α*. If it fails to join the first *α*, it checks the next devices of ***α*** till all the devices of *α* is computed. To verify whether a device *x* can join as mesh router or as a mesh router end device the depth check is considered. Secondly, the device *x* will join a mesh network as mesh router end device of ***α'****s* first device if it fails to identify device in ***α***. Below the flow diagram of the proposed node classification based slot reutilization based scheduling is shown, where flow diagram 4 shows the slot selection *selectTranSlot(α,x)* and flow diagram 3 represent device pair classification computation *retPairClass(x,y)*.

3.2 Transmission Latency Optimization Algorithm

Let us consider a WMN of m nodes. Let $\mathscr{R}$ represent a set of MAP's and Access routers. The active user nodes of the WMN are (m –R). The WMN is represented using a tree structure and number of possible children of any node is $\mathscr{L}$. The tree structure is defined as Gm ($\mathscr{R}$, $\mathcal{D}$, $\mathscr{L}$), where $\mathcal{D}$ represent tree depth. The user nodes communicate to the nearest access router and data is transmitted using a hop based mechanism over the tree structure of $\mathscr{R}$ nodes. Probability that a communication from the x^{th} to y^{th} node suffers due to slot-reutilization is $P(x, y)$: $\forall x,\ y \in \mathscr{R}$. The slot success probability is therefore , $(1 - P\ (x, y))$. Transmission latency is dependent of slot success prabability. Higher successful slot transmission probabilities reduce latency. Hop to hop transmission is considered for WMN here. Let $\mathrm{N}(x) \subset \mathscr{R}$, represents the physical neighbors of xth node. The next hop node amongst (x) nodes is selected using following objective function

$$p_x = \max_{k \in N(x)} (1 - p(x, k)) \quad (1)$$

Transmission latency of i^{th} transmission from x^{th} to p_x node is represented as $p_x^i(t)$. The total transmission latency observed is computed using

$$\sum_{i=1}^{I} \sum_{j=1}^{J} p_j^i(t) \quad (2)$$

where *I* represents the total transmissions considered and *J* represents the total hops per transmission. Explanation of simulation study is presented below for our proposed approach over existing *CSMA/OCA*.

Table 1 describes the symbols and notations used in the system. Figure 3 represents the Flow diagram for *retPairClass(x,y)* and Figure 4 represents the Flow diagram for *selectTranSlot(α,x)*.

Table 1: List of Symbol and Notation Used

Notation	**Representation**
$CIRP$	Connected inner relay device pair
$DIRP$	Distant inner relay device pair
$CLRP$	Connected leaf relay device pair
$NCLRP$	Non-connected leaf device pair
P_x	$P(x, y)$ for the instance of $P(x, y) \in NCLRP$
P_y	$P(x, y)$ for the instance of $P(x, y) \in CLRP$
P_z	$P(x, y)$ for the instance of $P(x, y) \in DIRP$
$P(x, y)$	It is the probability risk expected for future device being a victim of slot re-utilization among x and y
$V(x, y)$	Area of a region jointly covered by device x and y
$l(x, y)$	Represent physical distance among (x, y)
t	Number of slot for each devices
α	Set of root devices

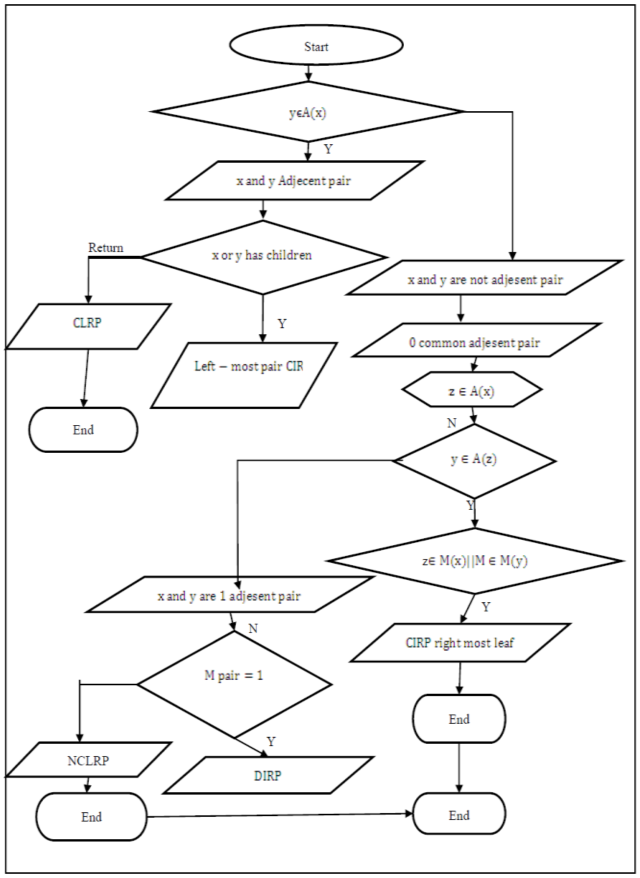

Figure 3: Flow diagram for *retPairClass(x,y)*

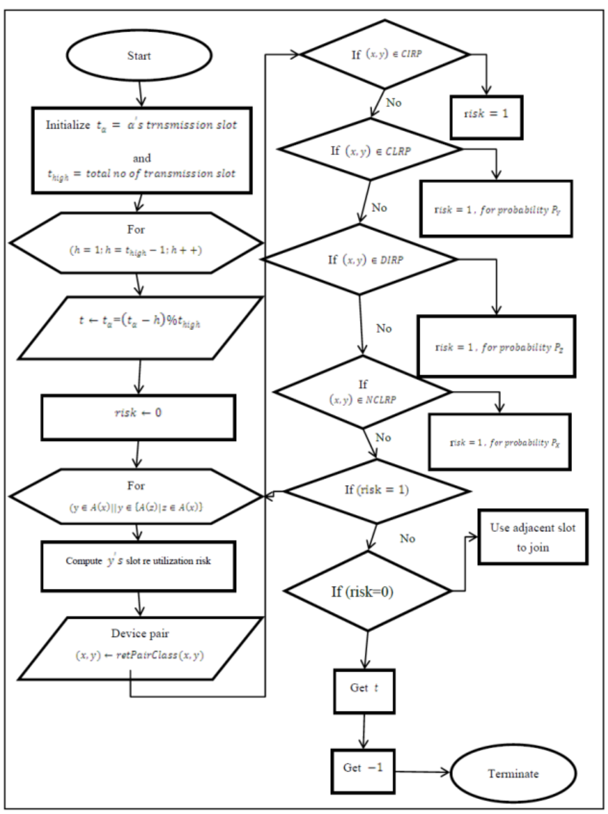

Figure 4: Flow diagram for *selectTranSlot(α,x)*

In this final phase, we will test our classification model on our prepared image dataset and also measure the performance on our dataset. To evaluate the performance of our created classification and make it comparable to current approaches, we use accuracy to measure the effectiveness of classifiers.
After model building, knowing the power of model prediction on a new instance, is a very important issue. Once a predictive model is developed using the historical data, one would be curious as to how the model will perform on the data that it has not seen during the model building process. One might even try multiple model types for the same prediction problem, and then, would like to know which model is the one to use for the real-world decision-making situation, simply by comparing them on their prediction performance (e.g., accuracy).

To measure the performance of a predictor, there are commonly used performance metrics, such as accuracy, recall etc. First, the most used performance metrics will be described, and then some famous estimation methodologies are explained and compared to each other. Performance Metrics for Predictive Modeling In classification problems, the primary source of performance measurements can be calculated by finding the accuracy.

4. EXPERIMENTAL ANALYSIS

The Simulation study is done using windows 7 enterprises has 64-bit operating system it contain i-5 class Intel processor with 8GB of RAM. Visual Studio 2015, Dot net frame work 4.0 and the programming language used is VC++ and C#. This work conducted simulation study for mean latency and means maximum latency for channel slot re-utilization by varying the network size and network density, and also for packet delivery latency by varying depth of mesh tree and is compared with the existing *CSMA/OCA* [17]. In experimental study network size is varied as 100, 200, 300, 400 and 500 meter and network density is varied as 100, 200, 400, 800 and 1000 devices. The mean latency is the mean of mean latency of all run and mean maximum latency (*MML*) is the mean of maximum latency with respect to simulation run which can be defined as follows

$$MML = \sum_n N_n / \max(n) \quad (3)$$

In Figure 5, mean latency for varied network sizes is computed considering 1000 wireless mesh devices. The mean latency achieved for proposed approach when network size is 100m is reduced by 57.186%, for 200m it is 56.893%, for 300m is 58.88%, for 400m is 59.462%, and for 500m is 54.82%. From result obtained we can see when network size is increased the latency also increases linearly for both proposed and existing approach. The average latency of proposed approach is reduced by 58.19% over existing *CSMA/OCA* considering varied network sizes.

In Figure 6, mean maximum latency for varied network sizes is computed using Eq. (6) considering 1000 wireless mesh devices. The mean maximum latency achieved for proposed approach when network size is 100m is reduced by 52.2%, for

200m it is 53.25%, for 300m is 56.56%, for 400m is 56.744%, and for 500m is 57.13%. From result obtained we can see when network size is increased the latency also increases linearly for both proposed and existing approach. The mean maximum latency of proposed approach is reduced by 55.17% over existing *CSMA/OCA* considering varied network sizes.

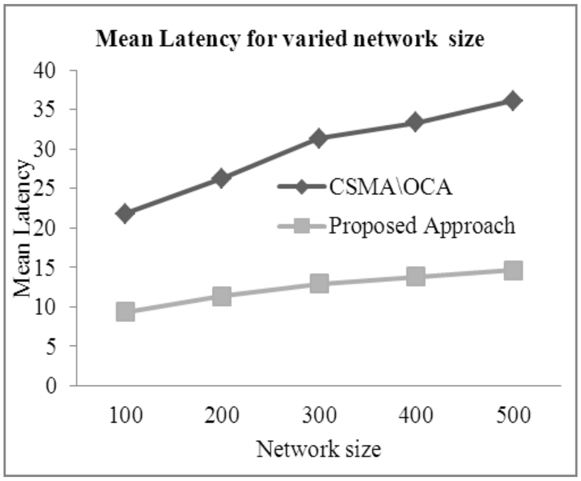

Figure 5: Mean latency achieved for varied network size

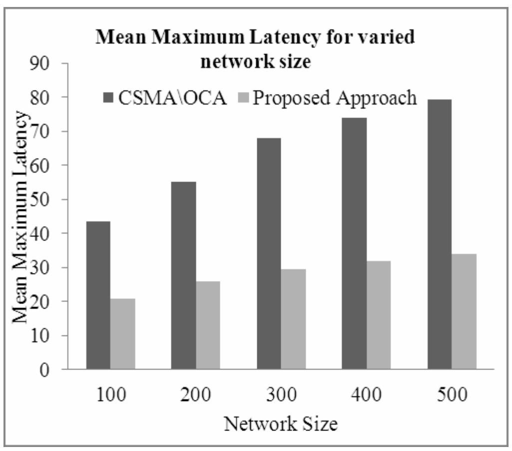

Figure 6: Mean Maximum Latency for varied network size

In Figure 7 below, mean latency for varied network density and considers 500meter as the network size. The mean latency achieved for proposed approach when network density is 100 is reduced by 55.114%, for 200 it is 58.1%, for 400 is 59.24%, for 800 is 59.48%, and for 1000 is 59.65%. From result obtained we can see when network density is increased the latency also increases linearly for both proposed and existing approach. The mean latency of proposed approach is reduced by 58.32% over existing *CSMA/OCA* considering varied network density. In Figure 8 below, mean maximum latency is computed using Eq. (3) for varied network density and considers 500meter as the network size. The mean maximum latency achieved for proposed approach when network density is 100 is reduced by 53.17%, for 200 it is 56.33%, for 400 is 56.12%, for 800 is 57.12%, and for 1000 is 58.12%. From result obtained we can see when network density is increased the latency also increases linearly for both proposed and existing approach. The mean maximum latency of proposed approach is reduced by 56.13% over existing *CSMA/OCA* considering varied network density.

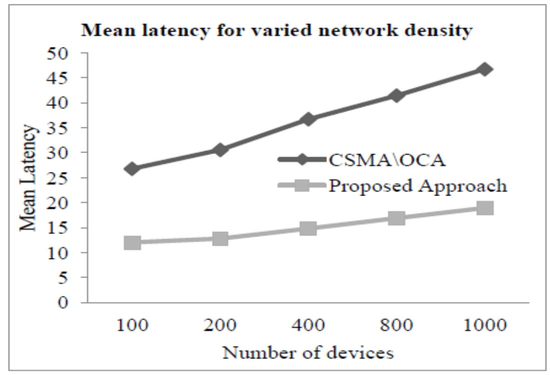

Figure 7: Mean Latency achieved for varied network density

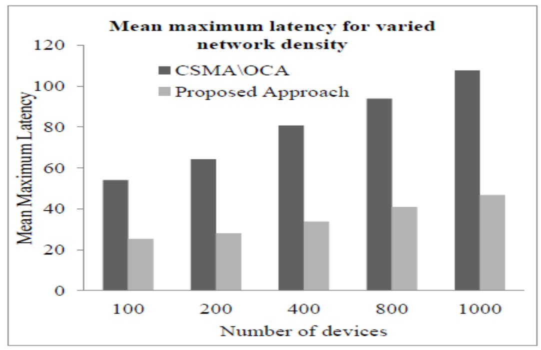

Figure 8: Mean maximum latency achieved for varied network density

The packet delivery latency in mesh network depends on length of the tree and number of associated devices that are connected to these devices. This work conducted simulation study considering following simulation parameter as follows, mesh tree depth is varied as 5, 7, 9 and the wireless mesh gateway router are fixed as 10 and each router can accommodate 14 devices.

In Figure 9, the packet delivery latency is computed for mesh tree depth of five for varied network density. The packet delivery latency achieved for proposed approach when network density is 100 is reduced by 47.687%, for 200 it is 60.97%, for 400 is 65.63%, for 800 is 72.5%, and for 1000 is 72.66%. From result obtained we can see when network density is increased the latency also increases linearly for both proposed and existing approach. The mean packet delivery latency of proposed approach is reduced by 64.32% over existing *CSMA/OCA* considering varied network density.

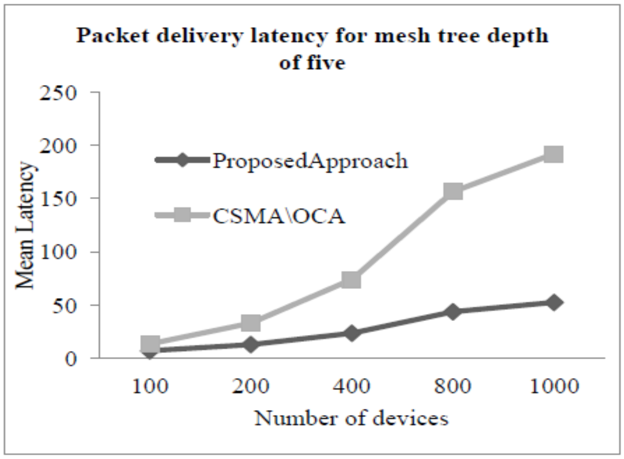

Figure 9: Packet delivery latency for tree depth size of five

In figure 10, mesh tree depth of seven for varied network density. The packet delivery latency achieved for proposed approach when network density is 100 is reduced by 65.55%, for 200 it is 77.42%, for 400 is 81.93%, for 800 is 84.42%, and for 1000 is 85.57%. From result obtained we can see when network density is increased the latency also increases linearly for both proposed and existing approach. The mean packet delivery latency of proposed approach is reduced by network density

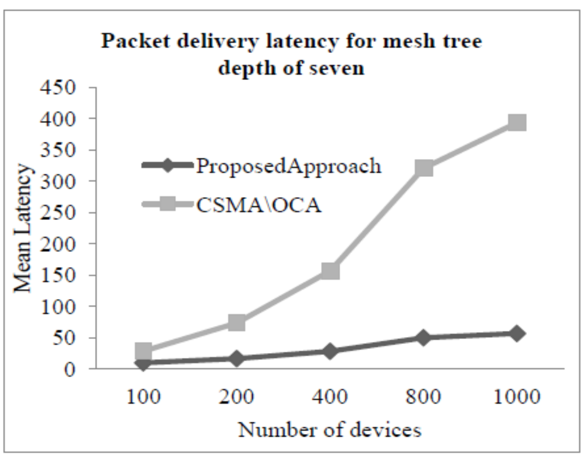

Figure 10: Packet delivery latency for mesh tree depth size of seven

In Figure 11, the packet delivery latency is computed for mesh tree depth of seven for varied network density. The packet delivery latency achieved for proposed approach when network density is 100 is reduced by 67.1%, for 200 it is 78.96%, for 400 is 81.96%, for 800 is 85.42%, and for 1000 is 85.77%. From result obtained we can see when network density is increased the latency also increases linearly for both proposed and existing approach. The mean packet delivery latency of proposed approach is reduced by 80.004% over existing *CSMA/OCA* considering varied network density

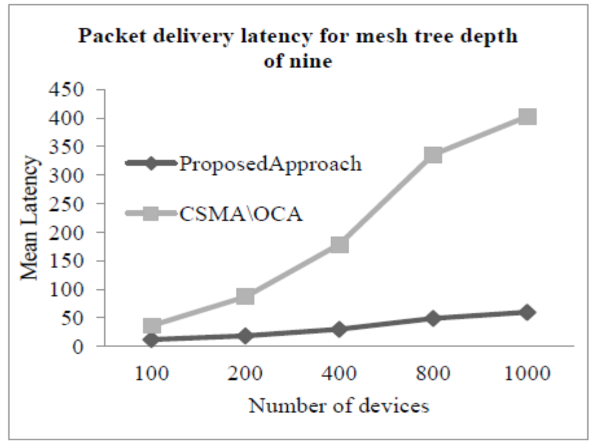

Figure 11: Packet delivery latency for mesh tree depth size of nine

It is seen from the Figures 9, 10 and 11. The packet delivery latency performance of proposed approach is linearly improved over existing *CSMA/OCA* when the depth of the mesh is increased which shows that the proposed model is scalable. The result archived proves Eq. (2), when the number of hop devices is increased the packet delivery latency is also increased.

5. CONCLUSION

This work presented a low latency service delivery model for wireless mesh network. As demand for multimedia based application service is growing at rapid pace which requires a low latency service delivery. In wireless mesh network reducing the latency is a key factor to meet *QoS* necessities of the end user. This work presented a Low latency cross layer based *MAC* scheduling scheme by adopting a node classification technique for slot reutilization. The slot reutilization model addresses the hidden node problem by adopting node classification method which reduces collision thus improving the performance of service delivery of proposed model. Experiment are conducted to evaluate the performance of latency of network by varying network size and density and also packet delivery latency for varied depth of mesh tree size is compared with existing *CSMA/OCA*. The outcome shows the proposed model reduce the network mean maximum latency by 55.17%, mean latency by 58.19% for varied network size scenario, and reduce mean maximum latency by 56.13% and mean latency by 56.32% for varied network density and reduce mean packet delivery latency by 74.34% for varied mesh tree depth size over *CSMA/OCA*. In future work considers evaluating the performance of proposed model in hybrid wireless mesh network and also simulation study of throughput analysis.

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