A New Method of User Association in Wireless Mesh Networks

G Vijaya Kumar[1], C Shoba Bindu[2]

[1]Department of Computer Science and Engineering, G. Pulla Reddy Engineering College, Kurnool, A.P., India
[2]Department of Computer Science and Engineering, JNT University, Anantapuramu, A.P., India

***Abstract*:** The IEEE 802.11 based wireless mesh networks (WMNs) are becoming the promising technology to provide last-mile broadband Internet access to the users. In order to access the Internet through the pre-deployed WMN, the user has to associate with one of the access points (APs) present in the network. In WMN, it is very common that the user device can have multiple APs in its vicinity. Since the user performance majorly depends on the associated AP, how to select the best AP is always remaining as a challenging research problem in WMN. The traditional method of AP selection is based on received signal strength (RSS) and it is proven inefficient in the literature as the method does not consider AP load, channel conditions, etc. This paper proposes a new method of user association in WMN such that the user selects the AP based on achievable end-to-end throughput measured in the presence of other interfering APs. The proposed association metric is independent of routing protocol and routing metric used in WMN. The simulation results show that our method outperforms the RSS based AP selection method in WMN.

***Keywords*:** Wireless mesh networks, AP selection, User association.

1. Introduction

Nowadays, a large number of users are accessing the Internet through their mobile and portable devices. Every user wants to experience the better performance with the Internet accessible from the places like airports, hotels, and other public places. The IEEE 802.11 based wireless mesh networks [1-6] are the promising technology to provide last-mile broadband Internet access to the users. The WMN has a unique feature of complete wireless multihop backbone formed by a group of wireless routers. As shown in Figure 1, a few mesh routers are connected to the Internet with high speed wired links and are known as gateway nodes. In addition to the routing functionality, the mesh routers are able to provide the network access to the users, and so they are also called as mesh access points (MAPs). Normally, the user device has one wireless network interface whereas a MAP has multiple interfaces. Because of self-organizing and self-configuring nature of mesh routers, the WMN has a long list of applications such as enterprise networking, building automation, community and neighborhood networks, etc. One important application of WMN is providing wireless broadband Internet connectivity to the users. In order to access the Internet through the pre-deployed WMN, the user device needs to associate with one of the MAPs available in its vicinity. Since the user performance majorly depends on the associated MAP, how to select the MAP providing best performance is still an open research problem in WMN.

As defined by IEEE 802.11 standard [7], the most practical method of access point (AP) selection is based on the received signal strength (RSS) of management frames (beacon and probe response) and it is defined for infrastructure wireless local area networks (WLANs). The user selects nearest or strongest AP among all available APs. This traditional method of AP selection is good when the network load is uniformly distributed among all the APs in WLAN. But the greedy nature of each user in selecting the nearest or strongest AP to achieve higher performance causes non-uniform distribution of load in the network.

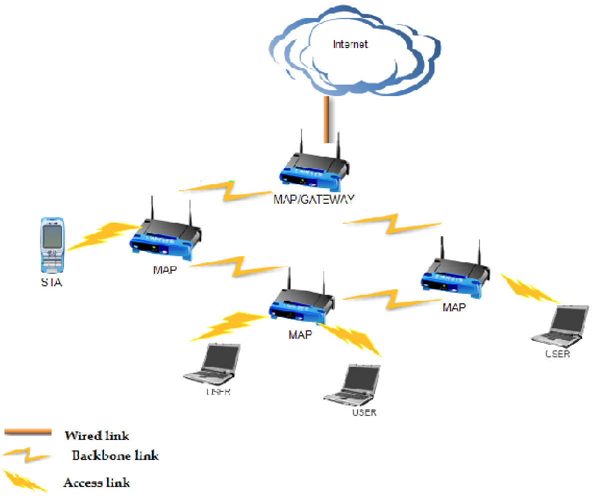

Figure 1 Wireless mesh network architecture

Some APs are overloaded and nearby other APs are lightly loaded or free. The user performance is not fair in this situation even though he is associated with the nearest or strongest AP. Therefore, many researchers have focused on achieving load balancing and user fairness [8-14] through AP selection method in WLAN. All these work done for WLAN are not efficient to implement in WMN as they have different architectures. The detailed comparative study between WLAN and WMN is presented in [15]. The WLAN has high speed wired backbone and only one wireless link, access link, is present between the user and the AP. On the other hand, the WMN has the multihop wireless backhaul. Therefore, in WMN, the user data traffic has to transmit through multiple wireless links before reaching the gateway.

The default RSS-based association method and the previous alternate methods are defined for WLAN with the assumption of the high speed wired backbone present in the network. Therefore there is a need to redesign the AP selection method for WMN by considering the quality of multihop wireless backhaul path from the MAP to the gateway in addition to the quality of access link present between user and the MAP.

Providing wireless broadband Internet access to the user is one of the applications of WMN and the dominant traffic of Internet user is in the downlink direction only (i.e., from the gateway to the user via multihop wireless backhaul) because most of the Internet servers are still present in wired infrastructure. With this observation, we formulate a novel metric of user association in WMN by considering the dominant wireless usage mode of downlink traffic along with the MAP capacity in the presence of other interfering MAPs. In our method, the user measures the potential throughput likely to achieve from the MAP after association by considering the MAP capacity in the presence of other interfering MAPs. The MAP selection process considers both access link quality and mesh backhaul routing path quality to ensure end-to-end communication quality. Unlike the previous work [16-22], the proposed association metric is independent of mesh routing protocol and routing metric used in WMN. We analyze the performance of proposed method through simulations and compare with RSS-based method. The results show that our method performs better than RSS-based method in improving the user performance in WMN.

The paper is organized as follows: the section 2 describes the related work and the proposed method is presented in section 3. The performance analysis of our method is presented in section 4 and the paper concludes with the section 5.

2. Related Work

In IEEE 802.11 infrastructure WLAN, the user-AP association process is defined with three phases: AP-scanning, AP-selection and AP-association. In the scanning phase, the user gets the information about all available APs in two different ways: active and passive scanning. In active scanning, the user broadcasts the probe request frame and all the available APs reply with probe response frame. In passive scanning, the user device listens to all channels to receive beacon frame transmitted periodically by AP. The user device measures the received signal strength (RSS) of beacon or probe response frame and determines the AP with highest RSS value. In the second phase, the user selects the AP with highest RSS value calculated in the first phase. Finally in the association phase, the user sends the association request message to the selected AP and the AP replies back with association reply message. The traditional RSS-based AP selection method is proven inefficient as important parameters like channel conditions, AP load, etc. are not considered in it. Moreover, the greedy nature of every user to select the nearest or strongest AP leads to uneven load distribution among all APs in the network. This situation causes unfairness in the user throughput and the overall system throughput is degraded.

Most of the researchers have focused on load balancing and user fairness [8-14] through AP selection in WLAN. In [24], the number of current active users of an AP is considered as a metric of user association. This is the simple metric to calculate but the actual network load is not the number of active users present in the network since they differ in their traffic load. In [25], the estimated delay between beacon schedule time and actual transmission time is used as AP selection metric. This kind of low level measurements cannot be applicable in all commercial AP products. Moreover, the researchers assumed that beacon frames are always transmitted before sending the data frames. Available bandwidth based association is proposed in [26]. Since the AP capacity is equally shared among all its associated users, the available bandwidth calculated before association may not be the same after association. The user measures the potential throughput achievable from AP and selects the one which provides highest throughput [27]. The user throughput must be calculated dynamically to get associated with the appropriate AP because of dynamic network conditions like varying user traffic demand, interference, channel conditions, etc. The user throughput calculated once before the association process cannot be taken as granted all the time. Moreover, the low rate user degrades the performance of high rate users that are already associated with the same AP [39]. User association based on channel busy time is proposed in [28]. Although the channel busy time is the practical metric, it cannot reflect the actual network load. For instance, if there are two APs, AP1 and AP2 which are configured at orthogonal channels such that there is no co-channel interference between them. Suppose that 10 users associated with AP1 and only one user associated with AP2. Since 10 users have to compete with each other to access the channel for communication, most of the time they wait for accessing channel instead of communication. On the other hand, the AP2 is busy in processing the frames of only user associated with it because the user always get the channel as the user has no competition in accessing the channel. When a new user wants to join the network based on channel busy time metric, the user selects the AP1 that has lesser busy time than AP2. In fact, AP1 is congested than AP2. Our previous work [29] analyzes all the related work in WLAN and presents the required parameters for AP selection metric design in WMN.

To mention the related work for WMN, the author in [16, 17] proposed two metrics of association: LAETT (Load Aware Expected Transmission Time) and CAETT (Contention Aware Expected Transmission Time). In [18], the airtime cost metric is proposed for AP selection in WMN. It is shown in [30] that the airtime cost metric does not always capture the channel conditions accurately. The authors in [19] enhanced the work [18] by considering the impact of packet size and hop count into the metric. In [20], dynamic association and reassociation oscillation avoidance mechanisms are investigated. Author in [21] enhanced the work [18] by measuring the mesh backhaul routing airtime cost in both directions between the MAP and the gateway. The most recent work [22] enhances [21] by adjusting the weighting parameter values assigned for access link metric and routing metric such that more users are associated with good-backhaul MAPs (MAPs with small hop count and/or high capacity) for a long time possible than bad-backhaul MAPs(MAPs with large hop count and/or less capacity). Also users mobility-aware reassociation control scheme is also proposed by same author [22]. The author in [36] proposes association control scheme to achieve utility fairness of users in wireless mesh networks. [37] presents a centralized optimal association in wireless mesh networks. Our previous work [38] presents a novel algorithm for MAP selection in WMN wherein a user selects the MAP such that the throughput of existing users already associated with the same MAP is not much degraded.

The WMNs are the promising technology to provide wireless broadband Internet access to the users. In WMN, the dominant traffic of user is in the downlink direction i.e., from the gateway to the user via multihop wireless backhaul because most of the Internet servers are still present in wired infrastructure. This fact motivates us to propose a novel method of user association in WMN by considering the dominant wireless usage mode of downlink traffic along with the MAP capacity in the presence of other interfering MAPs.

Considering the dominant wireless Internet usage in downlink direction while formulating the association metric keeps our work unique and different unlike other previous work mentioned [16-22, 36-38]. Moreover, our proposed association metric is independent of routing protocol and routing metric used in WMN whereas the previous work is limited to specific routing protocol with airtime cost metric. In our method, the user measures the potential end-to-end throughput likely to achieve from the gateway to all available MAPs and selects the MAP that provides higher throughput.

3. Association Metric Formulation

We consider the WMN model as shown in Fig. 1, where all the users communicate through their associated MAPs. The WMN has a multihop wireless backhaul connected to the Internet through one or more gateway nodes. The MAPs provide the network access to the users and also responsible for routing the user data through mesh backhaul to reach the gateway node. In our network model, each user device has a single wireless network interface and the MAP is provided with two interfaces: access and relay interfaces. The access interface provides the network access to the user and the relay interface connects the MAP to other MAPs on mesh backhaul to reach the gateway. These two interfaces of a MAP are configured with different radio technologies or different channels such that user data cannot interfere with routing data. The access interfaces of adjacent MAPs are configured to be operated in different channels to reduce the co-channel interference between the adjacent MAP cells.

The formulation of association metric is inspired from the work [31], which is defined for WLAN users and we extend the work for WMN environment. Since most of the Internet servers are still reside in the wired infrastructure, we assume that the major dominant mode of wireless usage is the downlink traffic. To simplify the derivation process of association metric, we consider the saturated WMN with Internet traffic flowing from the gateway to the users through their associated MAPs and each user is always waiting for a packet to receive. This situation simplifies the MAC layer modeling as the MAPs are the only senders in the network and the amount of interference caused by MAPs does not depend on the number of their users. Under these conditions, the long term average throughput measured at MAC layer is same for all users associated with a MAP [32].

We also assume that the MAP implements rate adaptation scheme. The user with poor quality link takes more time to receive a packet from the MAP compared to other users associated with the same MAP using good quality links if the packet size is assumed to be same for all users. As specified in [33, 34], a new user can estimate his/her instantaneous transmission rate using RSSI measurements.

We consider the WMN system with ‘m’ MAPs and ‘n’ users. The MAPs are represented as a_1, a_2, …, a_m and the users are u_1, u_2, …, u_n. A user is associated with only one MAP and a MAP provides the network access to few users. The user u_i associated with a MAP a_j is represented as u_i^j.

If the MAP, a_j, is sending information to all users in the packets of same size L, then the transmission delay experienced by a user u_i associated with MAP a_j is given by

$$T_{tx}(u_i^j) = \frac{1}{f(SINR(u_i^j)} \qquad (1)$$

where $f(SINR(u_i^j)$ gives instantaneous transmission rate of access link from MAP a_j to user u_i expressed usually in data units per second.

As per our model, the MAPs are the only senders and being as a wireless router, the MAP has to compete with other MAPs for accessing the radio channel. Hence the medium utilization of MAP a_j, MU(j), will not be 100% if other MAPs are present in its contention domain and the capacity of MAP a_j, C(j), will only be a fraction of the medium capacity. Under these assumptions, the long-term average throughput obtained by the user u_i associated with MAP a_j, $Th_{avg}(u_i^j)$ measured in a reference time period T is given by

$$Th_{avg}(u_i^j) = \frac{MU(j) * C(j) * T}{\sum_{i \in U_j} T_{tx}(u_i^j)} \qquad (2)$$

where U_j is the set of all active users associated with MAP a_j. The parameter C(j) is the nominal capacity of the MAP a_j which is based on the supporting physical layer and it is conveyed in the beacon/probe response frames. In order to measure the medium utilization, each MAP measures the number of slots it spends in the transmission/reception, backoff and idle states. The measurement period, T, can be defined with five transmissions/receptions as in [31]. The channel utilization fraction is estimated (busy slots/total slots) and maintained as a weighted moving average. Due to the performance anomaly of multirate users associated with the same MAP, the long-term average throughput is same for all users [39]. Since the low rate users degrade the performance of high rate users associated with the same MAP, the long-term average number of packets received by all users is same. In other words, the denominator of equation (2), $\sum_{i \in U_j} T_{tx}(u_i^j)$, is observed to be almost same for all users, u_i, associated with the same MAP a_j. We represent this denominator value as the aggregated transmission delay, ATD(j) of MAP a_j.

$$ATD(j) = \sum_{i \in U_j} T_{tx}(u_i^j) \quad (3)$$

The numerator of equation (2) represents the MAP aj capacity in the presence of other interfering MAPs for a measurement time period T and this value is represented as

$$APC(j) = MU(j) * C(j) * T \quad (4)$$

Each MAP a_j measures the values of ATD(j) and APC(j) for every reference period T and broadcast the values through modified beacon/probe response frames so that the interested users can determine the average throughput of existing users of the MAP a_j as shown in equation (2).

When a new user u_k wants to join the WMN to access the Internet through MAP a_j then the user can calculate the expected throughput $Th(u_k^j)$ as

$$Th(u_k^j) = \frac{APC(j)}{ATD(j) + T_{tx}(u_k^j)} \quad (5)$$

In WMN, the user needs to know the quality of wireless mesh backhaul path quality before associating with any MAP so that the user can select a MAP providing good end-to-end quality links. Since the users do not aware of mesh routing path, we assume that the MAP provides the information about the routing path used from the gateway to the user. Each MAP runs a routing protocol and finds multiple paths from the gateway node. Using certain routing metric such as hop count, the MAP selects a best path and makes this information available to the user. The user can make use of the routing information along with access link metric calculated in equation (5) to select a best MAP providing better end-to-end throughput. We consider that the MAP calculates the aggregate throughput (sum of individual link throughputs in the path) achievable from the gateway and provides this information to the user.

Accordingly, the MAP a_j provides the mesh backhaul quality in terms of aggregate throughput Th_b^j to the user u_k. Now the user u_k calculates the end-to-end throughput achievable from the MAP a_j as

$$ET_k^j = w(Th(u_k^j)) + (1-w)Th_b^j \quad (6)$$

where w is the weight assigned to access link quality and its value is chosen between 0 and 1(both inclusive). The value of w has the impact on MAP load balancing and the network throughput. We choose w=0.5 in our simulations to give equal weight to access link quality and backhaul path quality. To choose an optimal value of w, further study is required. A simulation study on the optimal value of w is presented in [17].

The user u_k calculates ET_k^j from each available MAP a_j and selects the MAP providing highest ET_k^j and only if it is acceptable throughput i.e. more than certain threshold value $Th_{threshold}$. The threshold value depends on the required quality of service of the application running on user machine i.e., threshold value varies with respect to application. We assume that the user device u_k knows the minimum throughput required for the application running on it. When the user throughput degrades below the threshold value, the user initiates re-association procedure.

Selection Algorithm is given below:

Initialization:

A={a_1,a_2,a_3,………………a_m} set of m MAPs in WMN.

U={u_1,u_2,u_3,…………….u_n} set of n users in WMN.

A_i : set of all available MAPs to the user u_i

U_j: set of all active users associated with MAP a_j

(i) begin
(ii) for every MAP $a_j \in A$ do /*for every T reference period */
(iii) begin
- (a) for all associated active users $u_i \in U_j$ do
- (b) calculate $ATD(j)$ as in equation (3) /*aggregate transmission delay is the amount of time required for the MAP a_j to send a packet of size L bits to all its current active users u_i^j */
- (c) calculate $APC(j) = MU(j) * C(j) * T$ /* APC(j) is the effective capacity of MAP aj in presence of other interfering MAPs in the network. */
- (d) calculate Th_b^j /* aggregate throughput achievable from the gateway node to MAP a_j */
- (e) broadcast ATD(j), APC(j) and Th_b^j values through modified beacon or probe response frames

(iv) end for
(v) a new user u_k scans for all available MAPs using either active or passive scanning
- (f) from every available MAP aj $\in A_k$, the user u_k receives ATD(j), APC(j) and Th_b^j
- (g) user u_k locally measures $T_{tx}(u_k^j)$ as in equation (1) after receiving beacon or probe response frames of MAP a_j
- (h) user u_k now calculates $Th(u_k^j)$ as in equation (5) and
- (i) $ET_k^j = w(Th(u_k^j)) + (1-w)Th_b^j$
- (j) user u_k selects MAP a_j with highest $ET_k^j \geq Th_{threshold}$

(vi) end

4. Performance Evaluation

The proposed method is evaluated using NCTUns 6.0 [35] simulator which is an open source, extensible network simulator and emulator. By using a novel kernel re-entering simulation methodology, it provides many unique advantages over traditional network simulators and emulators. NCTUns 6.0 is a Linux based network simulator/emulator upon which real world applications can be executed without modifications and a wide range of networking devices can be modeled using real TCP/IP network protocol stack to produce high-fidelity simulation results. In NCTUns, the configuration and operation for a simulated network are exactly the same as those for a real-life IP network. Using integrated GUI, it is easy for the user to create, edit and control the simulations/emulations and easily collect the results. The MAC protocol of NCTUns is ported from NS-2 network simulator which implements the complete IEEE 802.11 standard MAC protocol DCF to accurately model the contention of nodes for the wireless medium. Moreover, it supports more realistic wireless signal propagation models. In addition to providing the simple (transmission range = 250 m, interference range = 550 m) model that is commonly used in the ns-2, the NCTUns simulator provides a more realistic model in which the received bits BER is calculated based on the used modulation scheme, the bits received power level, and the noise power level around the receiver.

To analyze the performance of our method over RSS-based association method, we consider the simulation scenario with users and MAPs distributed randomly in the WMN as shown in Figure 2. We consider the IEEE 802.11b WMN with 9 MAPs and 20 users and one gateway node connected to the Internet with high speed (1 Gbps) wired link. As in previous work [16-22], we consider a simple channel model in which the data rate of a user depends on the distance between MAP and user. Accordingly, the data rates of user, 11Mbps, 5.5Mbps, 2Mbps and 1Mbps are in the range of 80m, 150m, 200m and 250m respectively. Each MAP is running Open Shortest Path First (OSPF) routing protocol with default routing metric hop count. Each MAP has two wireless network interfaces operating at orthogonal channels so that a user data cannot be interfered with backhaul routing data. Adjacent MAPs are configured to be operated on different channels such that co-channel interference is minimized. As most of the Internet Servers are still present in wired infrastructure, the dominant wireless usage is the downlink traffic. So we use User Datagram Protocol (UDP) saturated traffic with packet size 1000 bytes from the Internet via gateway to all users. The transmission rate of each traffic flow is set to 1Mbps and the simulation runs for 100 seconds.

We analyze the performance of our method by measuring the system throughput by gradually increasing the number of users accessing the Internet through WMN and compared with the default RSS-based method. In the traditional method, the user always selects the MAP based on received signal strength, so that sooner or later, the network load is unevenly distributed among the MAPs and this situation leads to degradation in user performance and system throughput. It is observed that our method performs better than RSS-based method because our method uses the association metric which measures end-to-end throughput achievable from the MAP in presence of other interfering MAPs. The signal strength alone is not a sufficient parameter to determine the user throughput because there are many other parameters like channel conditions, interference, medium contention, etc to estimate accurate throughput. Moreover, the delay sensitive applications like VoIP, Video Conference etc., are used majorly over the Internet, we also measured the average end-to-end delay of the users and the system. It is observed that our method outperforms the RSS-based method because selecting the highest signal strength MAP does not guarantee the highest throughput and required Quality of Service. The received signal strength cannot reflect the actual throughput because it not only depends on the distance between user and MAP but also on the transmission power of MAP. It might happen that a distant user can associate with the MAP that has highest transmission power and use low bit rate transmission. Therefore, the users already associated with the MAP and using higher bit rate might have to wait until the low bit rate and distant user communication is finished. In our proposed method, the user calculates the achievable throughput from all available MAPs by considering various parameters like channel conditions, MAP load, interference etc., and selects the MAP which is providing highest throughput and thereby providing required end-to-end Quality of Service. The results are averaged over 10 simulation runs and shown in Figure 3 and Figure 4.

Unlike the previous work, the proposed association metric is independent of wireless mesh routing protocol and routing metric. To observe the impact of routing metric on the user performance, the simulation is repeated with two different routing metrics: hop count and expected transmission count (ETX) [23], for the same routing protocol OSPF. The simulation results for different routing metrics are presented in Figure 5. As the hop count metric does not consider link conditions like ETX metric, the system aggregate throughput is more when ETX routing metric is used with OSPF routing protocol. As specified in [40], [41], when the routing metric optimized for WMN environment is used along with our association metric, a significant improvement in system throughput will be observed.

As the proposed method considers the MAP load into association decision, we analyzed the performance of our method by varying network traffic load. By gradually increasing the load for all users in the network, we measured system throughput and average end-to-end delay. The simulation results are shown in Figure 6 and Figure 7. Our method outperforms default RSS method because the default RSS method does not consider the MAP load into association decision and it solely depends on the received signal strength. Therefore the user associated with congested MAP cannot experience better performance compared to other users associated with nearby lightly loaded MAPs. Moreover, the RSS method cannot address the user unfairness problem. Our proposed method considers the MAP load, and the users are uniformly distributed over the network.

The RSS-based association method performs better as long as the network load is uniformly distributed among all MAPs in the WMN and fails when the load is non-uniformly distributed. In the previous simulation scenario, the MAPs and users are randomly placed in the WMN. We perform simulations with two more scenarios where the MAPs are placed as a grid and the users are distributed uniformly and non-uniformly. As shown in Figure 8, we consider 9 MAPs and 20 users in the WMN. The MAPs are separated by a distance of 200 meters from each other and the users are uniformly distributed in the network. In fact, the MAP load is not the number of users associated with it, but in order to capture the impact of load distribution, we simulate that each MAP is transmitting the packets of 1000 bytes and with a fixed rate of 1 Mbps to all users. The simulation runs for 100 seconds. The results are shown in Figure 10 and Figure 11 and the performance of our method is better than RSS-based method.

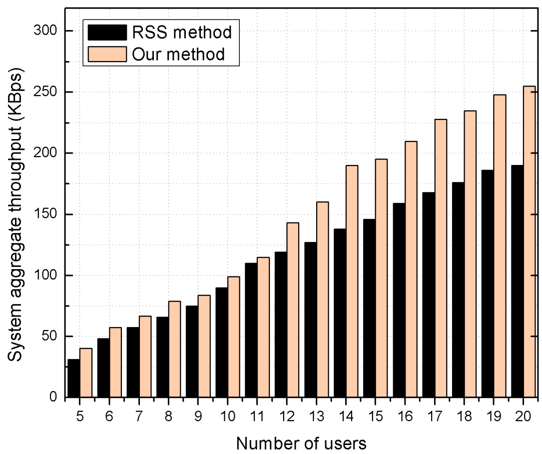

Figure 3 System throughput vs no. of users

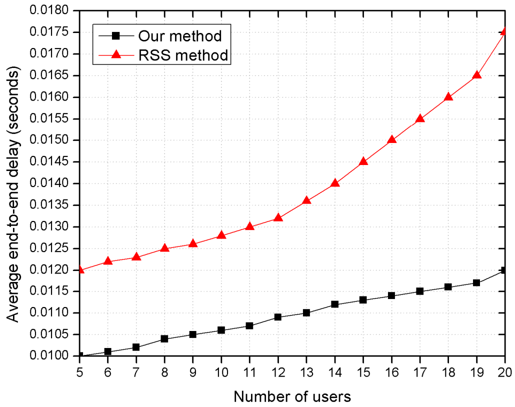

Figure 4 Avg. end-to-end delay vs no. of users

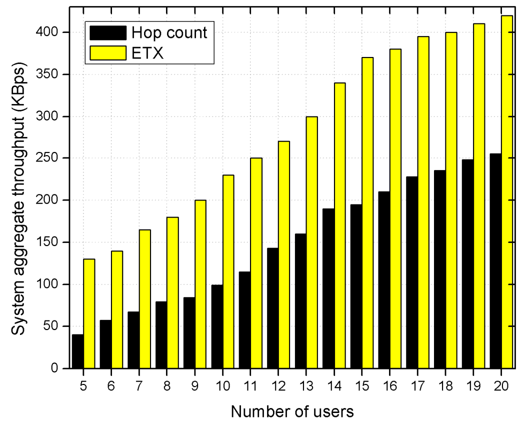

Figure 5 Impact of routing metric

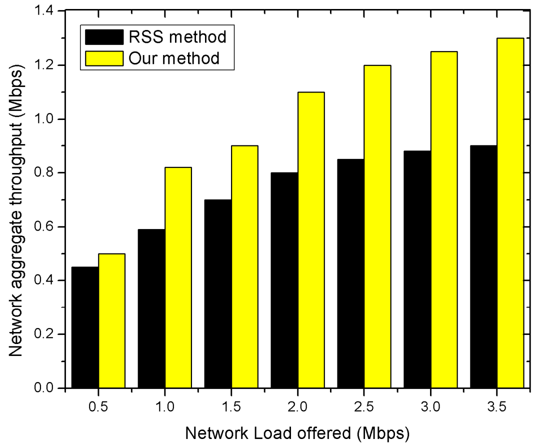

Figure 6 Aggregate throughput vs Network Load

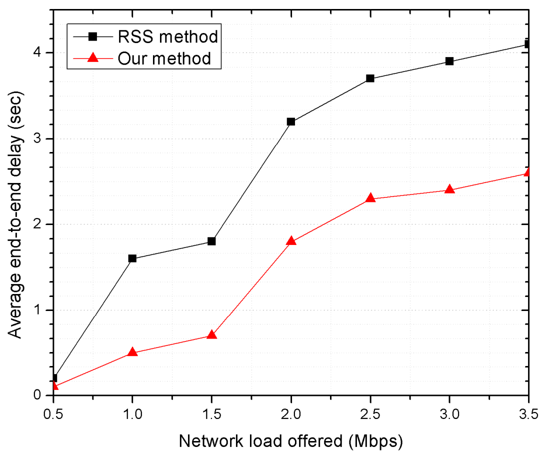

Figure 7 Average end-to-end delay vs network load

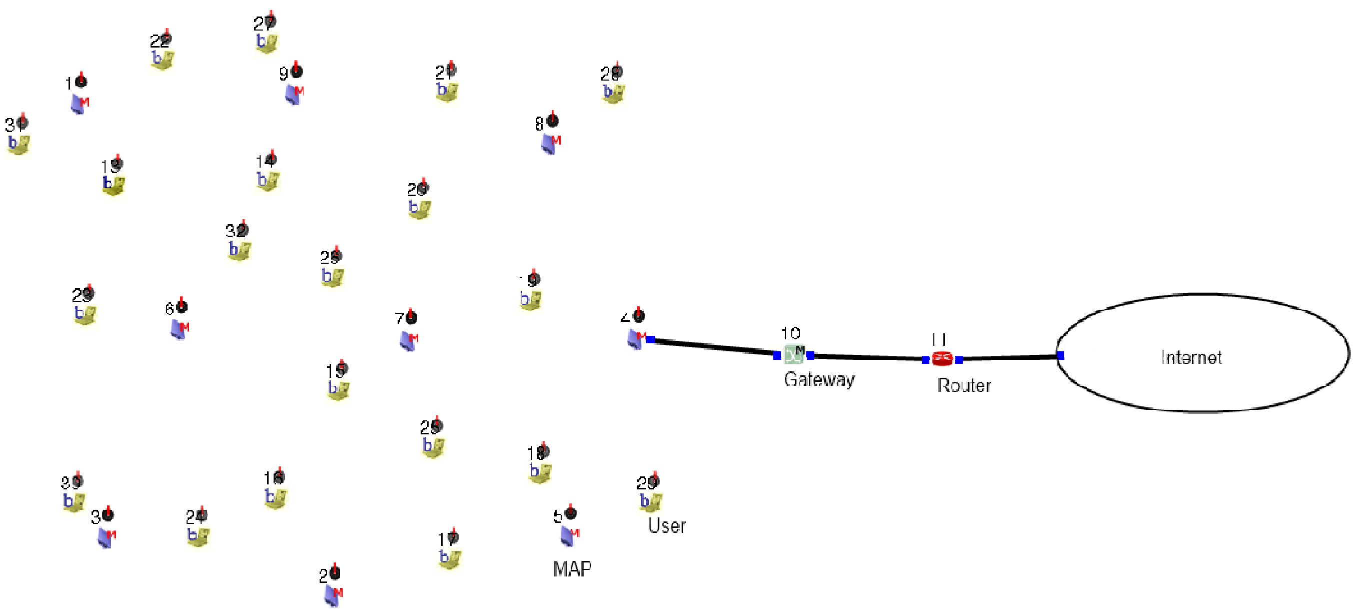

Figure 2 WMN with random distribution of users and MAPs

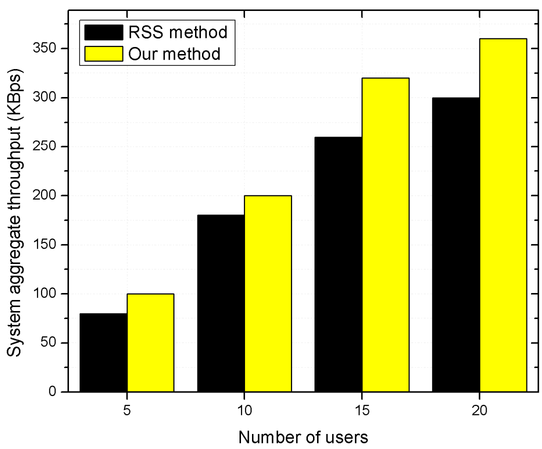

Figure 10 System throughput in uniform load distribution

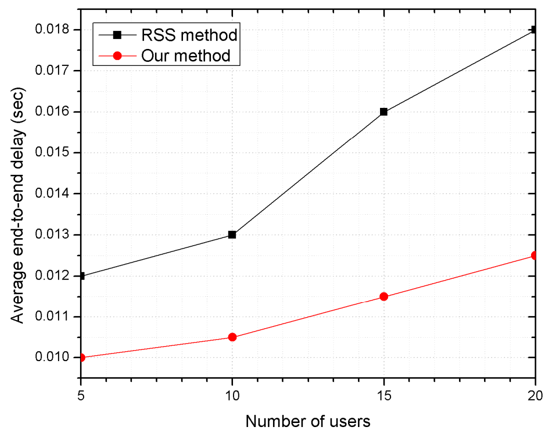

Figure 11 Delay in uniform load distribution

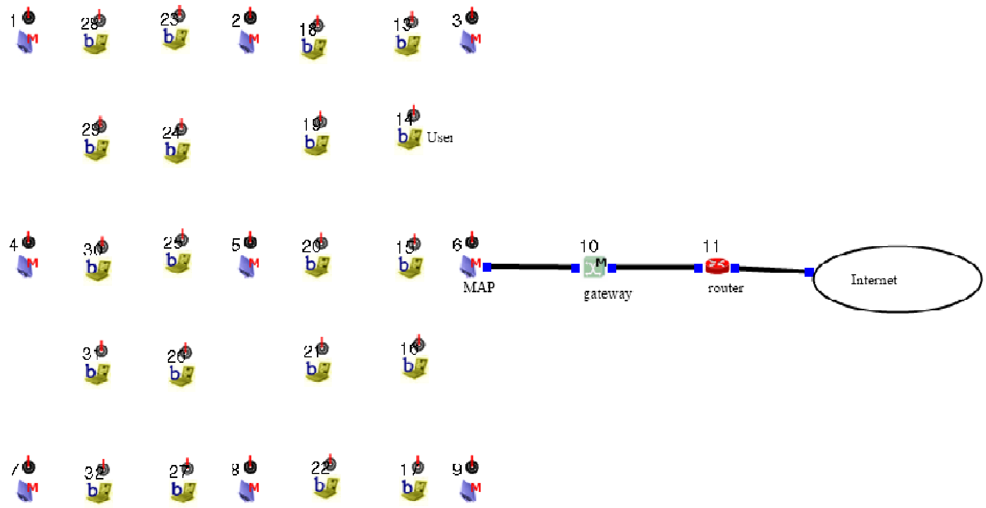

Figure 8 Uniform distribution of users in WMN

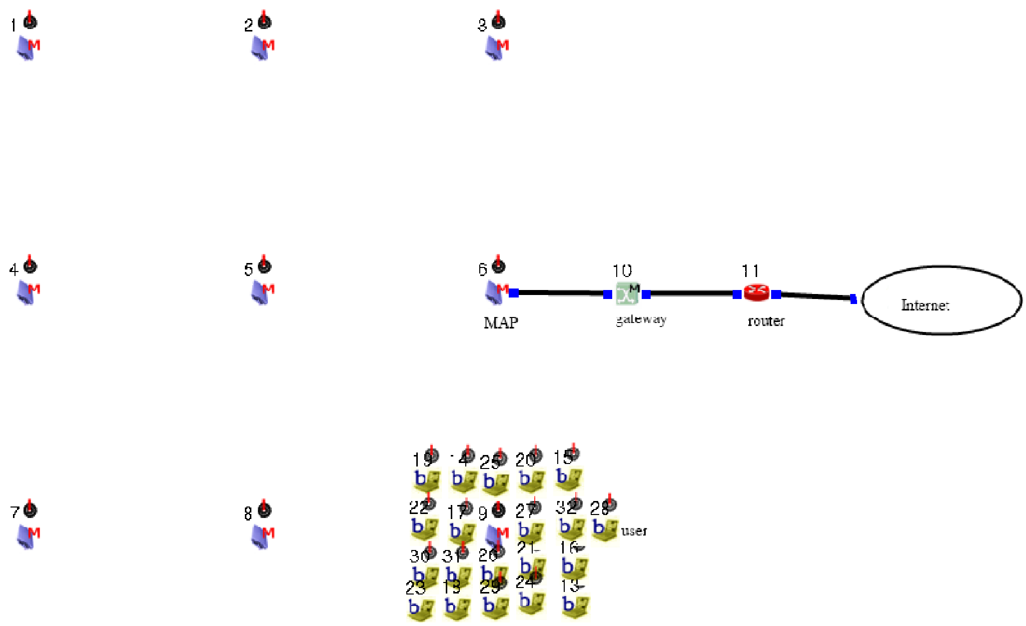

Figure 9 Non-uniform distribution of users in WMN

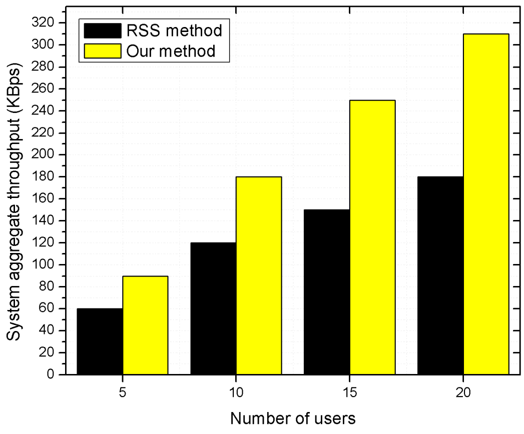

Figure12 Throughput in non-uniform load distribution

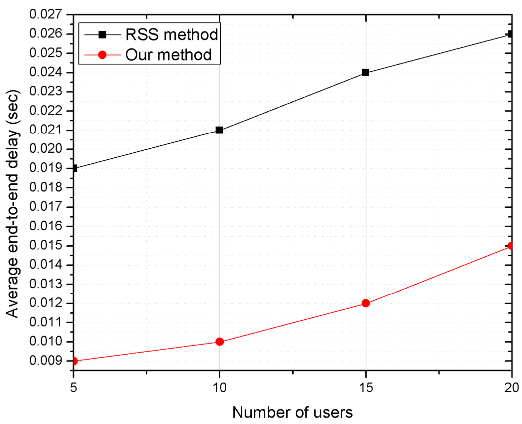

Figure13 Avg. end-to-end delay in non-uniform load distribution

In the default RSS-based method, the user selects the MAP with highest signal strength but the multihop wireless backhaul becomes the bottleneck of user performance. So the end-to-end throughput of user degrades. On the other hand, our method considers the MAP load, channel conditions and backhaul conditions which improves the network performance in terms of throughput and delay as shown in Fig. 10 and Fig. 11. Similarly, the results of non-uniform distribution of users in WMN are shown in Fig. 12 and Fig. 13. Clearly, the RSS-based method fails in achieving better user throughput in this hot-spot congested scenario. Our method alleviates the overloaded MAPs by suggesting the users to select the MAP based on achievable end-to-end throughput, and it outperforms the RSS-based method.

5. Conclusion

In WMN, the user performance majorly depends on the associated access point. As the traditional RSS based AP selection method is unable to address the load balancing and user unfairness problems, this paper proposed a new method of access point selection in WMN. The proposed method considers the MAP capacity in presence of other interfering MAPs along with wireless multihop backhaul path conditions. Moreover, the proposed AP selection method is independent of routing protocol and routing metric used in WMN. Through extensive simulations, it is shown that our method outperforms the default RSS method.

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