MASS: Multiple ASSociation Scheme in IEEE 802.11 Wireless Mesh Networks

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Abstract. Traditional association mechanism in IEEE 802.11 is in the form of one-to-many. It indicates that an access point (AP) can associate with many clients at the same time, while one client is capable to be associated with only one AP at a time. Such policy is inefficient and inflexible in the context of wireless mesh network (WMN). In this paper, we propose a many-to-many association scheme called Multiple ASSociation (MASS) for IEEE 802.11 WMN. The MASS allows a Mesh Client (MC) to be associated with multiple Mesh APs (MAPs) simultaneously. The most appropriate MAP is selected adaptively from a group of MAPs to actually serve the MC based on its correspondence node. Consequently, when the MC communicates with different nodes, probably distinct MAPs are employed to forward its packets. The protocol is compatible with current IEEE 802.11 standards and does not need any modification on the MC. We conduct extensive experiments which demonstrate the effectiveness and flexibility of the proposed scheme.

Keywords: multiple association, MASS, IEEE 802.11, wireless mesh networks, WMN.

1 Introduction

As an emerging technology to provide last few miles connectivity, Wireless Mesh Network (WMN) [1] [2] has received considerable attention from both academic and industrial communities in recent years. In IEEE 802.11 based WMN, there usually exist two types of nodes: Mesh Routers (MRs) and Mesh Clients (MCs). The MRs are interconnected to form a multi-hop infrastructure to forward packets for the MCs. The MR who can provide access service for the MCs is referred to as Mesh Access Point (MAP). The MC (e.g. laptop, PDA, WiFi IP phone, etc.) can access the WMN after being associated with an MAP. With the assistance of the infrastructure, each MC can communicate with other MCs within the same WMN, as well as access the Internet through an Internet GateWay (IGW) of the WMN. Hence, both of these two traffic types should be considered.

The association procedure defined in IEEE 802.11 standards uses the Received Signal Strength Indication (RSSI) value as the sole metric. Namely, the MC scans

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all available channels and selects the MAP that has the strongest RSSI to be associated with and would not change its decision until the RSSI becomes below a certain threshold. However, this scheme is prone to severe traffic load imbalance as well as inefficient utility of network resources in WLAN environment [3] [4] since the RSSI-based metric cannot reflect the traffic load of access points. The problem is even more serious in the context of the WMN where association decision can affect routing selection in the backhaul and both access link and routing path should be taken into account [5] [6].

Previous works, such as [7] [8] [9], have proposed some new association metrics. G. Athanasiou et al. [10] argued that the backhaul latency should be considered for association in the WMN, and used the airtime cost defined in the IEEE 802.11s draft [11] to evaluate link quality. In [5], two different metrics for access link and backhaul are proposed. Recent research work [12] used end-to-end airtime cost to determine the MAP to be associated with. But all approaches mentioned above inevitably require a modification to the IEEE 802.11 standards or the wireless interface driver at both MAP and MC sides, which result in the infeasibility in practical applications.

Actually, traditional association mechanisms have a potential rule that a MC is capable to be associated with only one MAP at one time. But the fixed access point cannot always be optimal when correspondence nodes are changed. The paper [13] breaks the rule and proposes a network-leading association scheme which allows the MC to be associated with a group of MAPs. On one hand, the MAPs can adaptively elect the one having the optimal performance to cater for the MC. On the other hand, from the MC's point of view, there seems only one MAP around to serve it, and it cannot perceive the handoff even it moves across different MAPs' coverage. Furthermore, the scheme is compatible with current widely used IEEE 802.11 standards and do not need any modification at the MC side. This scheme is only designed for the traffic from/to the IGW, however, it does not take the internal peer-to-peer traffics into consideration.

When an enterprise or a community builds a WMN not only for Internet accessing but also for internal information sharing, the traffics among MCs within the same WMN are also dominating. Take the scenario shown in Fig.1 for example. A_1 to A_5 are five MAPs that constitute the backbone of the WMN while C_1 to C_3 are three MCs. According to the RSSI-based association scheme, the three MCs are associated with A_1, A_3 and A_5 respectively. Under such circumstances, a four-hop routing path C_1-A_1-A_2-A_3-C_2 is established to support communication between C_1 and C_2. But obviously the performance of the two-hop routing path C_1-A_2-C_2 may be better than the four-hop one and A_2 may be the optimal access point for C_1 to communicate with C_2 although it is not with the strongest RSSI for both C_1 and C_2. If C_1 wants to transmit data to C_3 at the same time, maybe A_1 is the best choice for C_1 this time. Therefore, the MC can benefit from being associated with multiple MAPs at the same time rather than with only one fixed MAP, especially when internal peer-to-peer traffic is dominating.

In this paper, we propose a novel association scheme called Multiple ASSociation or MASS for the WMN which supports both two traffic types. We configure

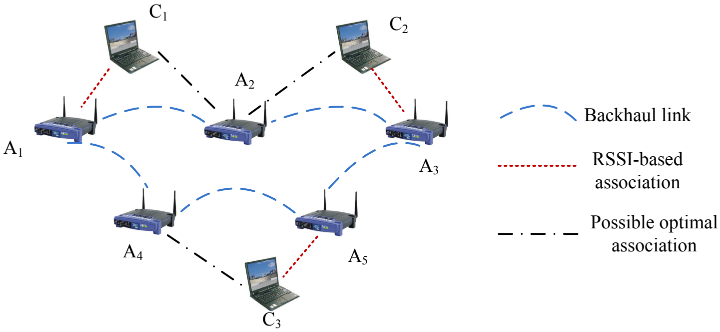

Fig. 1. A Sample Scenario of Association in WMN

the interfaces serving as access points of all MAPs in the WMN with same MAC address, same IP address, same ESSID and same channel. An MC will be associated with a group of MAPs rather than a specific one. The MAPs which associate with the MC will cooperate with each other to elect the most appropriate one to serve the MC on the basis of its correspondence node. Unlike prior works to select the optimal MAP for the MC (such as [14]), in our MASS scheme, an MC can be associated with multiple MAPs simultaneously. The MC does not need to trigger a handoff to the other optimal MAP when its correspondence node changes.

Our novel design mainly achieves the following three advantages:

(1) The multiple association scheme can adaptively assign an optimal MAP to the MC according to its correspondence targets respectively, which is able to improve the performance of the WMN.

(2) The multiple association scheme can help MCs to achieve seamless handoff in dynamic circumstances.

(3) The multiple association scheme is totally transparent to the traditional MC. The MC can be associated with our MAP as normal without any modification.

The rest of this paper is organized as follows. The next section will describe the system model. In Section 3, we will discuss the MASS scheme in detail. The performance evaluation based on simulations is given in Section 4. Finally, we summarize our work in Section 5.

2 System Model

In this paper, we mainly focus on the infrastructure/backbone WMN in which MCs must access the WMN by direct association with MAPs rather than by relays of other MCs through multi-hop paths. And only MAPs in the backhaul of the WMN are considered in our research. The MRs without access function work normally. We assume that each MAP has two radios. One radio works in Ad-Hoc mode to form the backbone of the WMN. The backbone uses AODV routing protocol to find destinations and forward data packets. The other radio operates in AP mode to provide access service for MCs. They are assigned non-overlapping channels from different frequency bands. Only end-to-end link is considered in this paper. The IGW will be treated as a special MC.

$$C_{ij} = \alpha AC_{ia} + (1 - \alpha)BC_{ab} + \alpha AC_{bj} \quad (1)$$

We employ the airtime cost introduced in the 802.11s draft [15] as the serving MAP election metric in MASS. Equation (1) is the end-to-end airtime cost used in our proposed association scheme. C_{ij} is the total airtime cost from MC_i to MC_j, which includes the access link airtime cost AC_{ia} between MC_i and MAP_a, the backhaul airtime cost BC_{ab} between MAP_a and MAP_b and the access link airtime cost AC_{bj} between MAP_b and MC_j. The alterable weighting coefficient $\alpha(0 \leq \alpha \leq 1)$ indicates the respective influence of AC and BC. The α value can be adjusted to improve the accuracy of the association scheme. Here we set 0.5 as its default value in our experiments. The equation contains two ACs. Although both of these two ACs indicate the access link airtime cost, there are still some differences between them. The first AC is the airtime cost from an MC to an MAP, i.e. "uplink" channel, and the second one is for the "downlink" channel.

2.1 Access Link Airtime Cost Calculation

$$AC_{ia} = [O_{ca} + O_p + \frac{B}{r_i}]\frac{1}{1 - e_{pt}^i} \quad (2)$$

In Equation (2), O_{ca} is the channel access time overhead and O_p is the time overhead caused by protocols. Both of them are constant values. B is the dominant size in bit of the test traffic. r_i is the available bandwidth that MC_i can acquire from MAP_a. e_{pt}^i is the frame error rate between MC_i and MAP_a.

Equation (2) is for the uplink channel. The downlink channel airtime cost is calculated similarly, but the e_{pt}^i is a little different for each downlink associated for every MC. In our MASS scheme, we do not want any modification on the MCs. It means that the airtime cost between MC and MAP cannot be calculated on the MCs. Thus it only should be operated on the MAPs. Since the difference of airtime costs between uplink and downlink cannot be too far, we can use the downlink airtime cost calculated on the MAP instead of which computed on the MC. In other words, we can calculate AC_{ia} on MAP_a instead of MC_i.

The calculation equation is same as Equation (2), but all the test traffics and calculations are operated on the MAP. The rate r_i depends on the local implementation of rate adaptation. The estimation of e_{pt}^i is also a local implementation choice.

2.2 Backhaul Airtime Cost Calculation

We use ETT [16] as the routing metric in the communication infrastructure. Therefore, the backhaul airtime cost calculation can use the ETT calculation.

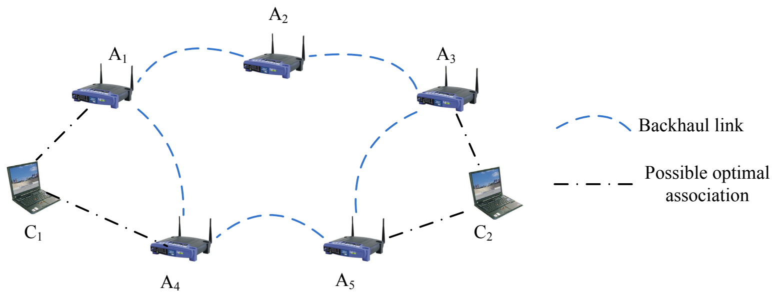

Fig. 2. A Sample Scenario For MASS

ETT is the expected time to successfully transmit a packet at the MAC layer. According to the ETT measured in link of a real network, the calculation equation is as follows:

$$BC = \frac{S}{B} \cdot \frac{1}{D_f \cdot D_r} \tag{3}$$

In Equation (3), S denotes the average size of packet and B represents current link bandwidth. We define that P_f is the packet loss probability in forward direction and P_r is the packet loss probability in the reverse direction. Then D_f is the forward delivery ratio (1-P_f) and D_r is the reverse delivery ratio (1-P_r). The delivery ratios D_f and D_r are measured by broadcasting dedicated link probe packets of a fixed size every average period from each MAP to its neighbors.

3 MASS: The Multiple Association Scheme

3.1 Basic Setting

Take Fig.2 for example. All the interfaces providing accessing function of all the MAPs are set to the same MAC address, the same IP address, the same ESSID and the same channel. When an MC scans channels, it will only find a single MAP around. After its association with the MAP in its view, in fact it is associated with a group of MAPs. All the data emitted by the MC will be received by all of these MAPs normally. But if all the MAPs reply with the ACKnowledgment frame (ACK) to MC normally, there will be conflict occurred at the receiver. In order to avoid such collision, the wireless driver on the MAP needs a little modification to control the ACK transmission. The MAP should be able to handle the ACK reply for every MC. When it replies the ACK to an MC, it acts as a normal MAP communicating with MC. When it doesn't reply ACK to an MC, it just works as a sniffer. In order to guarantee the normal communication between an MAP and an MC, there should be only one MAP replying ACK to a specific MC at one time.

S_MAC	T_MAC	Airtime_Cost	Nexthop	Flag	Seq

Fig. 3. Route Table Design

3.2 Protocol Specifications

The MAP should maintain a routing table to record both source and target MCs' MAC addresses, the airtime cost, next-hop node, serving flag, sequence number and so on.

The format of the entry in the routing table is depicted Fig.3. S_MAC is the MAC address of the source MC while T_MAC refers to which of the target MC. The item of Airtime_Cost is the airtime cost from this MAP to the MC. The value is calculated by the MAP itself. The field of Nexthop tells the MAP to whom the packets should be forwarded. The Flag item indicates whether the MAP replies ACK frame to the MC and the Seq item is used to avoid outdated messages. The routing table is maintained by the MAP for every MC being associated with it, and is updated periodically. According to this table, an MAP decides to calculate the airtime, update the route table, forward the packet or just keep silence. Thus, the MAP can have four states to a specific MC which are *idle*, *calculating*, *silence* and *serving*. The idle state means the MC is out of the MAP's range and there is no entry of the MC in the MAP's routing table. When an MC is associated with the MAP, the MAP turns into the calculating state. It calculates the airtime from the MC to the target MC or the IGW. The MAPs exchange their routing table information through broadcasting only in the backbone. Truly, it may incur some overhead, but the influence can be weakened by establishing high bandwidth backbone. The best MAP with lowest airtime cost will be selected to serve the MC. It will turn into serving state and the others will be in silence state. The unique MAP in serving state will forward the data to the next-hop node as a normal MAP. The other silent MAPs just drop the packet from the specific MC. The MAP can stay in distinct states to different MCs. The state transition diagram is illustrated in Fig.4.

Next we will describe the complete process when two MCs in MASS WMN communicate with each other.

Association. In the beginning, the MAPs are idle and broadcast beacons normally. Because of the special settings of the MAC address, ESSID and channel, an MC considers that there is only one MAP after scanning all available channels. When the MC find an available AP, it will send an association request frame to the MAP. All the MAPs that receive this request add a new entry into its routing table and set the S_MAC field with the MC's MAC address. The MAP will calculate the *AC* (access link airtime cost) by sending some testing packets to the MC and fill the Airtime_Cost field. All the MAPs exchange the information through broadcasting the routing table. The best one with lowest airtime cost will be selected to reply the association request, and its state turns into serving and the others keep in silence to this MC. At this time, the MC

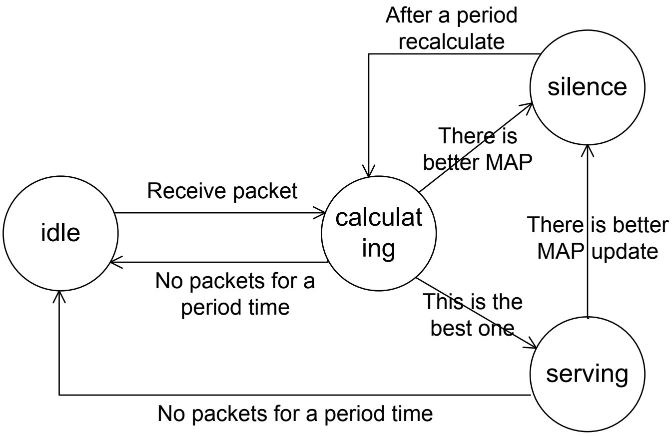

Fig. 4. State Transition Diagram

associates with the MAP successfully. Because there is only one MAP serving for the MC, the authentication and IP assignment can be operated as usual. The MC can either be pre-assigned a unique IP address or require the IP address through DHCP service.

Communication. When the MC wants to communicate with another MC or IGW, the MAP will check its route table firstly. If there is no route path to the target. The MAP will add a new entry for it and send airtime request packet to get the *BC* and the other *AC* value. Notice that all the MAPs hearing the MC's data will do it including the silent MAPs for the MC and then add them together and fill the Airtime_Cost field of the item. After calculation, it broadcasts its routing table to each other. To avoid the outdated message, the MAP pluses the route table entry's Seq value with 1 and then broadcasts it. When an MAP receives an updated table entry with lower Seq, it will be considered out of date and will be dropped directly. If the MAP receives an updated entry with a better routing path, it turns itself into silence state for the MC. If there is no better route received by the MAP before a timer expires, then it will be the best MAP for this data flow. And this MAP will enable its ACK function for the MC and serve to forward the data from the MC to its destination.

Recalculation. Owing to the MCs' mobility, the variable link quality and the unstable traffic load, the serving MAP cannot always be the best one. Therefore, recalculation will be operated when a timer expires or the serving MAP loses the connection with the MC. In the recalculation process, the MAPs in silence state turn into the calculating state and elect the best MAP serving for the MC again. If the MAP doesn't receive any data from the MC for a period of time, it will delete the route table entry of the MC and move back to the idle state because the MC may have been out of communication scope or powered off.

3.3 Further Discussion

In our proposed scheme MASS, an MC can be associated with a group of MAPs but it believes to connect to a single MAP because all MAPs are transparent to the MC. The MC will not be conscious of the alteration of the serving MAP when it communicates with other MCs. This means there is no handoff when the MC re-associates from an old MAP to a new MAP indeed. Hence, the MC can achieve seamless handoff within the whole coverage area of the WMN in this way.

It may inhibit concurrent transmission to configure all the access links into the same channel. Actually, our approach can be easily extended to multi-channel access links. When multi-channel configuration is applied, the MAPs with the same access link channel will operate as MASS. Hence the entire WMN will be viewed as several overlays.

Because of the broadcast updating scheme, MASS is just suite for the WMN with limited scale. But we will design an effective routing table exchange scheme next step. The new exchange process will only operate among the MAPs associating with the MC. MASS will be improved for large scale WMNs.

4 Performance Evaluation

In this section, we conduct simulations using the NS-3 network simulator [17] to evaluate the performance of MASS.

We generate a WMN of 16 MAPs and 5 MCs. The MAPs are placed in a 600m×600m rectangular area to form a 4×4 grid and their locations are fixed. The distance from any MAP to its nearest neighbor is 200m. Each MAP is equipped with two radios, one is connected with other MAPs to constitute the infrastructure and the other provides access function for MCs. The MCs are distributed uniformly and we consider the static scenario only, which is the same to the mobility scenario. The topology of the simulation test is illustrated in Fig.5.

To show the improvements of the multiple association scheme MASS, we compare it with the traditional RSSI-based mechanism. Our simulations include two independent parts. In the first part, we evaluate the performance of a single data flow. While in the second part, we evaluate the overall performance of multiple data flows. The following three metrics are considered. The throughput is the end-to-end traffic being successfully transmitted. The average delay is the packet transmission time in the access link and the mesh backhaul. And the packet loss rate is calculated as the lost packets number divides the total transmitted packets number.

4.1 Experiment 1: Single Flow Performance

In this subsection, we evaluate the end-to-end performance of one flow between two MCs.

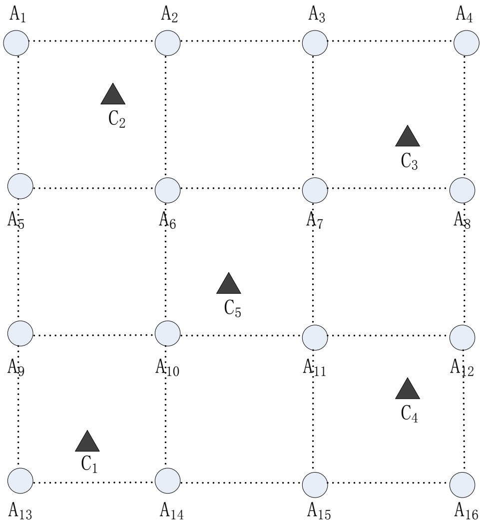

Fig. 5. WMN Topology of the Simulation

In simulation, a single flow from C_1 to C_2 is set up. The nearest MAPs to them are A_{13} and A_2 respectively. Suppose for an MC, the nearest MAP is just the one with the highest RSSI. In the light of RSSI-based scheme, C_1 will be associated with A_{13} and C_2 will be associated with A_2. But in our MASS scheme, C_1 will likely select A_{10} or A_9 to be associated with according to the airtime cost between C_1 and C_2.

Fig.6 shows the results of the comparisons between MASS and RSSI-based scheme on the above three metrics. We can see that, the throughput is improved by 30% and the average delay is reduced by 50%. The average packet loss rate is also reduced in MASS scheme by as much as 30%.

Obviously, the results reveal that, in the single flow situation, the proposed MASS achieves a significant higher performance than the RSSI-based scheme.

4.2 Experiment 2: Multiple Flows Performance

Consider the scenario in Fig.5 again. C_1 to C_5 are five independent MCs, and the nearest MAPs to them are A_{13}, A_2, A_8, A_{12} and A_{10} respectively. C_1, C_2, C_3 and C_4 all establish a data flow to C_5. According to the RSSI-based method, these five MCs will be associated with the respective nearest MAPs, and A_{10} is the unique MAP serving C_5. The link A_{10}-C_5 is prone to be the bottleneck of the entire WMN. In MASS however, C_1 to C_4 will select the MAP with the lowest airtime to C_5 to be associated with, which may be A_{10}, A_6, A_7 and A_{11} respectively. In addition, C_5 will get aid from four MAPs when communicating with different targets.

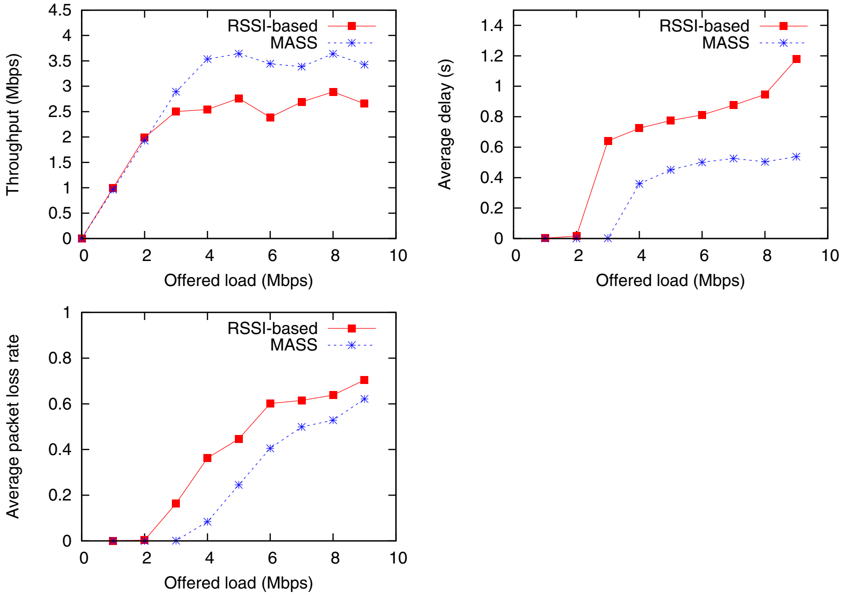

Fig. 6. Single Flow Performance Evaluation

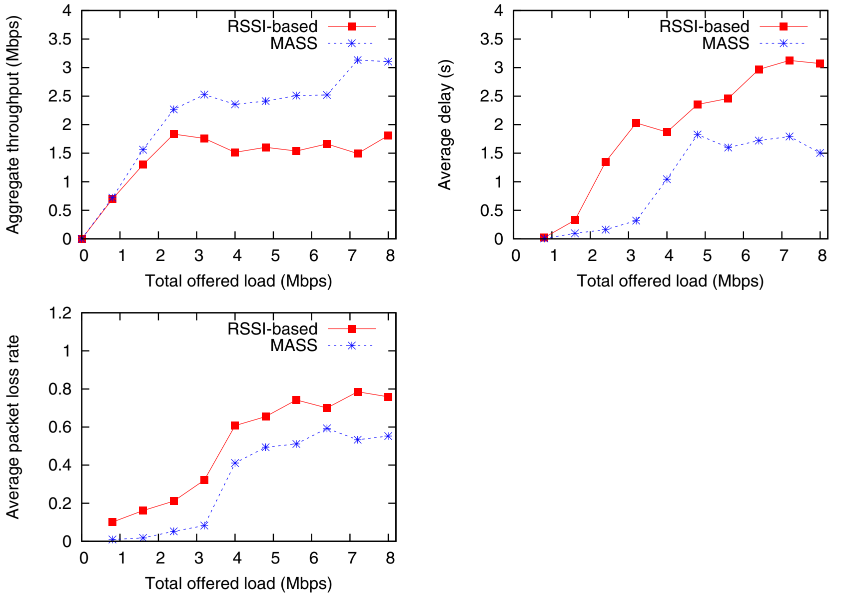

Fig. 7. Multiple Flows Performance Evaluation

Fig.7 demonstrates the results of the performance comparisons between MASS and RSSI-based strategy. Note that, in this experiment part, we measure the aggregate throughput, the average delay and the average packet loss rate, which represent the overall performance of the multiple flows. Compared with traditional 802.11 mechanism, the throughput of MASS is improved by 50% while the average delay is reduced by 45%. In MASS scheme, the average packet loss rate is also reduced by 35%. The results explains that the proposed MASS also performs better than the RSSI-based scheme when multiple flows exist in the WMN.

5 Conclusion

In this paper, we proposed Multiple ASSociation (MASS) scheme in IEEE 802.11 wireless mesh networks. The MASS scheme is a MAC layer protocol and does not need any modification on MCs and is completely transparent to the MCs. Different from the traditional methods, in MASS, an MC can set up association with multiple MAPs simultaneously, and the optimal MAP can be elected adaptively from these MAPs to serve the MC according to its correspondence node. Simulation results reveal that our MASS scheme performs significant better than the RSSI-based scheme on metrics such as throughput, delay and packet loss rate. Our extensive simulation-based experiments also demonstrate the effectiveness and flexibility of the proposed MASS scheme.

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