Efficient multicast association to improve the throughput in IEEE 802.11 WLAN

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Abstract—This paper deals with the problem of optimal association of stations (*STAs*) to access points (*APs*) for mulicast services in *IEEE* 802.11 *WLAN*. In a multicast session, all the subscribed *STAs* receive the multicast data packet at the same data rate (R_{min}) from their respective serving *APs*. A higher value of R_{min} improves the multicast throughput by completing the ongoing multicast session in lesser time. This also improves the unicast throughput as the cycle duration is shared by the unicast and multicast sessions. To provide multicast services to the *STAs*, we need to select a minimum cardinality subset of *APs* as the system message overhead depends on this cardinality. However, such a minimum cardinality subset of *APs* may not be possible to activate simultaneously due to the limited number of available orthogonal frequency channels. In this paper, we develop a combined greedy algorithm that selects a subset of *APs* with minimum cardinality for which a conflict-free frequency assignment exists and finds an association between the *STAs* and the selected *APs* that maximizes the R_{min} value. Through simulation we have shown that the proposed algorithm selects significantly less number of *APs* for different R_{min} values in comparison to the well-known metrics for multicast association like *RSSI*, *minimum hop-distance*, *normalized-cost* and *in-range STA number*.

1 INTRODUCTION

In an electronic communication system, multicasting is a technique in which a message or information can be delivered from a host user to a group of destination users simultaneously in a single transmission. In recent years, the multicasting of multimedia applications such as live lecture, online examinations, share market information, *IPTV* (Internet Protocol Television) streaming, and video conferences are increasingly being used in several sectors. The *IEEE* 802.11 wireless local area network (*WLAN*) has become the most popular and widely used wireless Internet access technology because of its low-cost and high-speed connectivity to the users. It is very crucial to efficiently manage the network resources and to reduce the transmission message overhead for a *WLAN* with a dense deployment of access points.

The networking model used in our study can be described as follows. We have considered an infrastructure based *WLAN* where n number of *APs* are directly or via multi-hop connected through a wired backbone network to the main access point (*MAP*). The *MAP* is nothing but a special *AP* which has the backbone Internet connection. There are m numbers of *STAs*, which are accessing this network through these *APs*. An *AP* establishes a cell and co-ordinate all the communications that take place within that cell's area. We have considered the coverage and interference ranges of all the *APs* are equal and known. An area is covered by several *APs*, where a single *STA* can be associated with at most one *AP* for any time instance but a single *AP* may serve multiple *STAs*. An *STA* may request different kind of services from the service provider such as *unicast services* and *multicast services*. An *STA* can send/receive data frames via an *AP* only when the *STA* is associated to that *AP*. When an *STA* maintains an association with an *AP* to get its unicast services then that kind of association is known as *unicast association*. Similarly, an association that is maintained by an *STA* with an *AP* to get its multicast services is known as *multicast association*. In traditional-association, an *STA* maintains both the unicast and multicast associations with the same *AP*. Whereas, in multi-association, an *STA* maintains unicast and multicast associations with two different *APs* [9]. Time is divided into cycles, where a cycle duration is shared by both the unicast and multicast sessions. The cycle duration as well as the unicast and multicast session intervals are configured by the network provider. The network provider advertises these system information inside their network by means of beacon signals. In a realistic scenario, some *STAs* may maintain traditional-association and while others may use multi-association. At the beginning of a multicast session, the *APs* and the *STAs* need to switch from the unicast mode to the multicast mode at a fixed time interval. Such time-synchronization with respect to both *APs* and *STAs* may be achieved by network time protocol (*NTP*) [12]. In accordance with the current *IEEE* 802.11 standard, multicast packets are transmitted to all the subscribed *STAs* at the same basic data rate (R_{min}). The feasibility of transmitting multicast packets at data rate higher than the basic rate has been established and studied by several authors [4], [7], [10]. In this work, we have assumed that the unicast association is fixed and know a priory and our primary focus is on the multicast association. Specifically, our main objective is to reduce the multicast session duration by increasing the value of R_{min}. This in effect increases the unicast session duration and hence the overall system throughput is improved. Since the unicast association is fixed, in the rest of the paper, by association we mean to say multicast association.

Although multicast communication is possible with both

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single channel and multiple channels, research has indicated that single channel network suffer from serious capacity degradation and self interference due to the multi-hop nature of wireless mesh network [6]. Hence we consider multiple channels for multicasting in this work. An *AP* needs to be allocated a frequency channel to provide multicast services to all its associated *STAs*. Let r_{ij} be the data rate obtained by *STA* i from *AP* j if it is associated with *AP* j. Here $r_{ij} \in \tau$ and τ is a finite data rate set. For example, $\tau = \{1, 2, 5.5, 11\}$ *Mbps* for *IEEE* 802.11*b* *WLAN* which operates in the unlicensed *ISM* band at 2.4 *GHz*. Let $F = \{1, 2, \ldots, k\}$ be the set of available non-overlapping frequency channels. A very limited number of non-overlapping frequency channels are available to activate the set of *APs* on the specified area. For example, in *IEEE* 802.11*b* *WLAN*, though there are 14 channels available, due to inter-channel interference, only 3 of them (1, 6 and 11) can be considered to be non-overlapping. The interfering *APs* require the allocation of different frequency channel to satisfy the co-channel interference. Two *APs* are interfering to each other if they are within the interference range of each other. Thus all the *APs* in a given area may not be possible to activate simultaneously due to limited number of non-overlapping frequency channels.

For a multicast session, the network provider has to select a subset of *APs* from the set of available *APs* in order to provide multicast services to the subscribed *STAs*. An inappropriate selection of *APs* may cause multiple *APs* to transmit the same multicast packets to the *STAs*. This in turn increases the overhead for multicast services and hence wasting the system resources. So for efficient multicast services, we have to select as few *APs* as possible that cover all the subscribed *STAs*. This results a reduction in control and data packets overhead, leading to a higher packet delivery ratio [10]. Since the number of non-overlapping frequency channels is limited, all such *APs* may not be possible to activate using the available number of frequency channels. Thus we need to select a subset of *APs* for which there exists a conflict-free frequency assignment to them using the available number of frequency channels and the cardinality of the selected subset is as minimum as possible. By activating those selected *APs*, the network provider serves all the subscribed *STAs* for that particular session. Here, a conflict-free frequency assignment of a subset of *APs* means that any pair of interfering *APs* belong to that subset will get different frequency channels to avoid the co-channel interference among them.

In this paper, we develop a combined greedy algorithm that selects a subset of *APs* with minimum cardinality for which a conflict-free frequency assignment exists and also finds an association between the *STAs* and the selected *APs* that maximizes the R_{min} value. Simulation results show that the proposed algorithm selects 69%, 43.8%, 36.8% and 21.6% less number of *APs* to cover all the *STAs* in comparison to the well-known metrics for multicast association like *RSSI*, *minimum hop-distance*, *normalized-cost* [9] and *in-range STA number* respectively, for $R_{min} = 1.0$ *Mbps*. Similar improvement are also found for higher values of R_{min}.

The rest of the paper is organized as follows: Section 2 summarizes the related works. Section 3 provides a motivational example. The proposed greedy is presented in Section 4. We also compute the time complexity of the proposed greedy in this section. The simulation results are presented in Section 5. Finally, Section 6 concludes the paper.

2 RELATED WORKS

The problem of association control and channel assignment in *WLAN* for both unicast and multicast has received enormous attention from network researchers. Many researchers have studied the various aspects of multicasting in *WLAN*. Friedman and Kogan [5] explored a novel approach to utilizing multiple channels for reliable multicasting in wireless networks. In [18], Ruiz and Gomez-Skarmeta have studied the problem of computing minimal cost multicast tree in multi-hop wireless mesh networks. In [14], [15], authors consider an architecture called Hyacinth and proposed a centralized channel assignment and routing algorithms for multi-channel mesh networks. In [3], Chieochan et al. have discussed several exiting channel assignment schemes for *WLAN* which are applicable to either centrally managed or uncoordinated environments. In *WLAN*, several algorithms for proper assignment of available frequency channels based on graph coloring technique are discussed in [11], [13], [16], [17].

The association control in *WLAN* has been studied by many researchers. An association control mechanism to balance the network load and provide max-min fairness among *STAs* has been studied in [1]. In [8], Kumar et al. studied the problem of optimal association of *APs* and *STAs* and shown that the objective of load balancing may not always be the correct solution. However, the effect of co-channel interference is ignored in their study. In [19], Tewari et al. proposed an integrated model to solve the joint unicast association and frequency assignment problem by taking care of the co-channel interference. In [2], Bejerano et al. have proposed an association strategy for supporting real-time multicast services in *WLANs*. In [10], the authors have considered multi-association in *WLAN* and they have independently chosen the *AP* for unicast traffic and the multicast traffic to optimize the overall network load. In [4], [7], [10], authors have studied the multi-rate multicasting in wireless networks.

The work which is similar to our work is reported in [9], where the authors have proposed a distributed association control based solution for multicasting in wireless mesh networks. A metric called normalized-cost is proposed and based on which an *STA* distributively selects an *AP* to receive its multicast services. They have used the basic rate for multicasting and the objective was to reduce the multicast load in the mesh network. The authors have considered a tree based structure to connect the selected *APs* with the *MAP* and the issue of frequency assignment was not considered explicitly. In our work, we have considered a more general k-colorable structure in place of the tree structure, where k is the number of available non-overlapping frequency channels. This flexibility in the structure leads to select more appropriate subset of *APs* depending on the value of k. Moreover, our proposed greedy deals with the selection of *APs*, frequency assignment to the selected *APs* and finding association between the *STAs* and the selected *APs* in a combined way with a view to maximizing the R_{min} value. We have compared our algorithm with other well-known metrics including the normalized-cost and showed that our algorithm selects significantly less number of *APs* for different values of R_{min}.

3 A MOTIVATIONAL EXAMPLE

Our primary objective is to select an appropriate subset of *APs* for providing multicast services to the subscribed *STAs* satisfying the co-channel interference and at the same time to find an association between the *STAs* and the selected *APs* such that the value of R_{min} is maximized. To demonstrate our approach, we consider an example as shown in Figure 1. The figure shows 8 *STAs* and 7 *APs* as represented by empty and filled circles respectively. An edge between two *APs* represents that they are within the interference range of each other and hence require different frequency channel to operate simultaneously. In this example, an *STA* is allowed to associate with any *AP* from which it gets at least 1 *Mbps* data rate. We assume that all *STAs* have the subscription to the concern multicast session and there are three orthogonal frequency channels available. The data rate matrix $R = (r_{ij})$ is shown in Table 1 where non-zero r_{ij} represents the data rate that can be obtained by $STA\ i$ if it is associated with $AP\ j$. Here $r_{ij} = 0.0$ implies that $STA\ i$ is out of the communication range of $AP\ j$ and hence can not be associated to $AP\ j$. $STA\ i$ is said to be covered by $AP\ j$ if r_{ij} is greater than or equal to 1 *Mbps*. In this context, a dominating set is a subset of *APs* that covers all the subscribed *STAs*. Given an association between the *STAs* and the selected *APs*, the value of R_{min} is defined as the minimum of the data rates that the *STAs* get from their respective associated *APs*. That is, $R_{min} = \min_{i,j}\{r_{ij}\colon STA\ i\ is\ associated\ to\ AP\ j\ and\ r_{ij} \geq 1\}$.

TABLE 1
Data rate matrix $R = (r_{ij})$.

	AP 1	AP 2	AP 3	AP 4	AP 5	AP 6	AP 7
STA 1	5.5	0.0	0.0	0.0	0.0	0.0	0.0
STA 2	5.5	0.0	0.0	0.0	0.0	0.0	0.0
STA 3	0.0	2.0	0.0	2.0	0.0	0.0	0.0
STA 4	0.0	0.0	5.5	0.0	0.0	0.0	0.0
STA 5	0.0	0.0	5.5	0.0	0.0	0.0	0.0
STA 6	0.0	0.0	0.0	5.5	0.0	2.0	0.0
STA 7	0.0	0.0	0.0	2.0	0.0	0.0	2.0
STA 8	0.0	0.0	0.0	0.0	1.0	5.5	2.0

Consider the following four dominating sets (i) $\{AP\,1, AP\,3, AP\,4, AP\,6\}$, (ii) $\{AP\,1, AP\,3, AP\,4, AP\,5\}$, (iii) $\{AP\,1, AP\,2, AP\,3, AP\,6, AP\,7\}$ and (iv) $\{AP\,1, AP\,3, AP\,4, AP\,7\}$.

The first dominating set contains four *APs* and there exists an association ($AP\,1 \leftarrow STA\,1$, $AP\,1 \leftarrow STA\,2$, $AP\,4 \leftarrow STA\,3$ and $AP\,3 \leftarrow STA\,4$, $AP\,3 \leftarrow STA\,5$, $AP\,4 \leftarrow STA\,6$, $AP\,4 \leftarrow STA\,7$ and $AP\,6 \leftarrow STA\,8$) that achieves the R_{min} value of 2.0 *Mbps*. But it can be seen from Figure 1 that all the four *APs* belonging to this dominating set are in the interference range of each other. Hence we need at least four orthogonal frequency channels to activate all of them simultaneously in order to satisfy the co-channel interference criteria. Since we have only three orthogonal frequency channels available, this dominating set is not a feasible solution to our problem, although there exists a feasible association resulting a R_{min} value of 2.0 *Mbps*.

The second dominating set contains four *APs* and there exists a conflict-free frequency assignment ($AP\,1 \leftarrow 1$, $AP\,3 \leftarrow 2$, $AP\,4 \leftarrow 3$ and $AP\,5 \leftarrow 1$) using 3 orthogonal frequency channels 1, 2 and 3. It is evident from Table 1 that $STA\,8$ gets 1.0 *Mbps*, 5.5 *Mbps* and 2.0 *Mbps* data rates from $AP\,5$, $AP\,6$ and $AP\,7$ respectively. Since this dominating set does not include $AP\,6$ and $AP\,7$, the only option for $STA\,8$ to get associated with is $AP\,5$ and from which it gets only 1.0 *Mbps* data rate. Thus the value of R_{min} can not be greater than 1.0 *Mbps* for this dominating set. There exist an association ($AP\,1 \leftarrow STA\,1$, $AP\,1 \leftarrow STA\,2$, $AP\,4 \leftarrow STA\,3$ and $AP\,3 \leftarrow STA\,4$, $AP\,3 \leftarrow STA\,5$, $AP\,4 \leftarrow STA\,6$, $AP\,4 \leftarrow STA\,7$ and $AP\,5 \leftarrow STA\,8$) that achieves a R_{min} value of 1.0 *Mbps*.

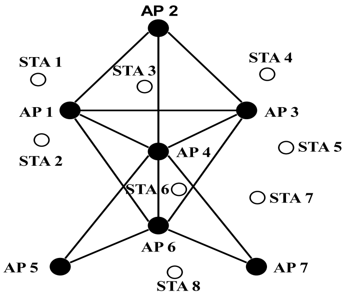

Fig. 1. Motivational Example.

The third dominating set contains five *APs* and there exists a conflict-free frequency assignment ($AP\,1 \leftarrow 1$, $AP\,3 \leftarrow 2$, $AP\,2 \leftarrow 3$, $AP\,6 \leftarrow 3$ and $AP\,7 \leftarrow 1$) using 3 orthogonal frequency channels. For this dominating set, however, there exits an association ($AP\,1 \leftarrow STA\,1$, $AP\,1 \leftarrow STA\,2$, $AP\,2 \leftarrow STA\,3$ and $AP\,3 \leftarrow STA\,4$, $AP\,3 \leftarrow STA\,5$, $AP\,6 \leftarrow STA\,6$, $AP\,7 \leftarrow STA\,7$ and $AP\,6 \leftarrow STA\,8$) that results a R_{min} value of 2.0 *Mbps*.

The fourth dominating set contains four *APs* and there also exists a conflict-free frequency assignment ($AP\,1 \leftarrow 1$, $AP\,3 \leftarrow 2$, $AP\,4 \leftarrow 3$ and $AP\,7 \leftarrow 2$) using 3 orthogonal frequency channels. There also exits an association ($AP\,1 \leftarrow STA\,1$, $AP\,1 \leftarrow STA\,2$, $AP\,4 \leftarrow STA\,3$ and $AP\,3 \leftarrow STA\,4$, $AP\,3 \leftarrow STA\,5$, $AP\,4 \leftarrow STA\,6$, $AP\,7 \leftarrow STA\,7$ and $AP\,7 \leftarrow STA\,8$) that results a R_{min} value of 2.0 *Mbps*.

Though the second, third and fourth dominating sets give feasible solutions to our problem, the third and fourth dominating sets provide higher R_{min} value than the second one. Note that the third and fourth dominating sets contain five and four *APs* respectively. Thus the fourth dominating set is our desire solution as it has the lower cardinality than the third one and it achieves higher R_{min} value. In the following section, we now present a greedy algorithm to find such a desire subset of *APs*.

4 THE PROPOSED GREEDY

We now describe our proposed greedy solution to select an appropriate subset of *APs* for providing multicast services to the subscribed *STAs* without neglecting the co-channel interference effects and at the same time we find an association between the *STAs* and the selected *APs* such that the value of R_{min} is maximized. We have introduced the notion of essential *AP* to establish our greedy. Before going to present the proposed greedy, we first consider the following definitions and an important observation based on the notion of essential *AP*.

Definition 1: *STA i* is said to be covered by *AP j* if $r_{ij} \geq \tau$.

Let C_i be the set of *APs* from which *STA i* gets at least τ data rate. That is, $C_i = \{AP\ j : r_{ij} \geq \tau \text{ and } j \in S_{AP}\}$ for all $i \in S_{STA}$. Note that in order to cover *STA i*, we must have to select at least one *AP* in C_i. In other words, an *STA i* can be covered if and only if $|C_i| \geq 1$. If $|C_i| = 0$, *STA i* can not be covered by any *AP* of the network. Such an *STA* is considered to be outside the network. Hence we have eliminated all such *STAs* from S_{STA}.

Definition 2: EAP_i is said to be *essential AP* of *STA i*, if EAP_i belonging to C_i and $|C_i| = 1$.

It is important to note that an *AP* can be an essential *AP* for multiple *STAs*. Let $S_{EAP} = \{EAP_i : i \in S_{STA}\}$ be the set of all essential *APs*.

Observation 1: We must have to select at least $|S_{EAP}|$ many *APs* from S_{AP} to cover all the *STAs* in S_{STA}.

TABLE 2

List of variables used in the proposed greedy.

Symbol	Meaning
n	Number of *APs*.
m	Number of subscribed *STAs*.
F	Set of available frequencies.
S_{AP}	Set of all *APs*.
S_{STA}	Set of all *STAs*.
R	Data rate matrix.
I	Interference matrix.
τ	Threshold data rate in *Mbps*.
S_{SAP}	Set of all selected *APs*.
F^{SAP}	The frequency assignment vector, where F_k^{SAP} represents the frequency assigned to *AP k*.
S_{CSTA}	Set of all covered *STAs*.
S_{EAP}	Set of all essential *APs*.
S_{RAP}	Set of all remaining *APs*.
S_{RSTA}	Set of all remaining *STAs*.
A^{CSTA}	The association vector, where A_i^{CSTA} represents the *AP* to which *STA i* is associated.
$NumAP_j$	The number of *APs* within the interference range of *AP* j, $j \in S_{AP}$.
$MinHop_j$	The minimum hop-distance to reach the *MAP* from *AP* j, $j \in S_{AP}$.
$CovSTA_j$	The set of *STAs* that can be covered by *AP j*.
$NumSTA_j$	Number of *STAs* that can be covered by *AP j*. That is, $NumSTA_j = \lvert CovSTA_j \rvert$.
r_j^{min}	The minimum data rate that *AP j* provides to its covered *STAs*. That is, $r_j^{min} = \min\limits_i \{r_{ij} : r_{ij} \geq \tau \text{ and } i \in S_{RSTA}\}$.
$BestAP^i$	The *AP* from which *STA i* gets the maximum data rate among all *APs* in S_{SAP}.
R_{min}	Minimum data rate for the current multicast session. That is, $R_{min} = \min\limits_i \{r_{iBestAP^i} : i \in S_{CSTA}\}$

The different sets and variables used in the proposed greedy are listed in Table 2. The proposed greedy works as follows. Initially, no *APs* are selected, no *STAs* are covered, no frequencies are being assigned, and no association has been made. It is evident from Observation 1 that we must have to select the essential *APs* in order to cover all the *STAs*. Among all the essential *APs*, we will first choose that essential *AP* which covers maximum number of *STAs*. If multiple such essential *APs* exist, we choose the one for which the value of r_j^{min} is maximum. We term this resulted *AP* as the temporarily selected *AP*. We will now try to find a frequency for assigning to this temporarily selected *AP*. This frequency must satisfy the frequency separation criteria with the previously allocated frequencies. If multiple such frequencies exist, we choose the least one among them. Assign the selected frequency to the temporarily selected *AP* and save it. We now consider this temporarily selected *AP* as permanent and insert it into the set of selected *APs*. We include its in-range *STAs* in to the set of covered *STAs*. The set of remaining *APs* and the set of remaining *STAs* are updated accordingly. We now consider the association between the so far covered *STAs* and the so far selected *APs*. An *STA* will be associated with that *AP* among the so far selected *APs* from which it gets the maximum data rate. We now compute the value of R_{min}, which is the minimum value of the data rate that the so far covered *STAs* get from their respective associating *APs*. If, however, no frequency satisfying the frequency separation criteria is found then that temporarily selected *AP* is not considered to be selected. Such *AP* is then removed from the network but its covered *STAs* remain in the set of remaining *STAs*. We repeat this until all the essential *APs* are being considered. If all *STAs* are not covered by these essential *APs*, we consider the non-essential *APs* for covering the remaining uncovered *STAs* by following the similar approach as has been done for essential *APs*. The detail step by step description of the proposed greedy is described in Algorithm 1.

Time complexity of the proposed greedy: Time complexity of the different steps of the algorithm have been shown in Algorithm 1. The complexity of one iteration of the while loop in line 10 is $\mathrm{O}\big(m^2 + mn + n|F|\big)$. In general, $m \geq n$ and $m \geq |F|$. Thus, complexity of one iteration becomes $\mathrm{O}\big(m^2\big)$. Since in each iteration one *AP* is considered, the while loop can be executed at most n times. Therefore, the worse case complexity of the algorithm is $\mathrm{O}\big(nm^2\big)$.

5 PERFORMANCE EVALUATION

5.1 Simulation set-up

We have considered an infrastructure based *IEEE* 802.11*b* *WLAN*. In our simulation, 50 *APs* and 210 *STAs* are uniformly placed in a 1000×1000 $meters^2$ area. The *MAP* is placed at $(0,0)$ which is the lower left most corner of the considered area. The coverage and interference range of each *AP* are set to 210 and 240 meters respectively. The data rate obtained by an *STA* depends on the distance of it from the serving *AP*. The *STAs* those are within 60 meters from an *AP* will get 11.0 *Mbps*, 5.5 *Mbps* between 60 and 110 meters, 2.0 *Mbps* between 110 and 160 meters and when the distance is between 160 and 210 meters the data rate is 1.0 *Mbps*. An *STA* will get 0.0 data rate from an *AP* if it is located beyond the distance of 210 meters from it. An *STA* is not considered to be part of the network if no *AP* is there within 210 meters from it. Two

Algorithm 1. *The proposed greedy*

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Input: $S_{AP}$, $S_{STA}$, $R$, $I$ and $\tau$
Output: $S_{SAP}$, $F^{SAP}$, $S_{CSTA}$, $A^{CSTA}$ and $R_{min}$
Initialization: $S_{SAP} = \emptyset$, $S_{CSTA} = \emptyset$, $F^{SAP} = \emptyset$, $A^{CSTA} = \emptyset$ and $R_{min} = 0.0$;
Calculate $NumAP_j$ for all $j \in S_{AP}$ using the interference matrix $I$. // $O(n^2)$;
Calculate $MinHop_j$ for all $j \in S_{AP}$ using the breadth first search algorithm.// $O(n+|E|) = O(n^2)$ in the worse case;
Compute $S_{EAP}$, the set of essential $APs$.// $O(mn)$;
if $S_{EAP} = \emptyset$ then // Essential $AP$ does not exist
    Set $S = S_{AP}$;
else // Essential $APs$ exist
    Set $S = S_{EAP}$;
Set $S_{RAP} = S_{AP}$;
Set $S_{RSTA} = S_{STA}$;
while $S \neq \emptyset$ and $S_{RSTA} \neq \emptyset$ do // Until all $APs$ are considered or all $STAs$ are covered.
                                                  // This loop will be executed at most $min(n,m)$ times.
    Compute $CovSTA_j = \{STA\ i : r_{ij} \geq \tau \text{ and } i \in S_{RSTA}\}$ and set $NumSTA_j = |CovSTA_j|$ for all $j \in S$. // $O(mn)$;
    Set $r_j^{min} = \min_i \{r_{ij} : r_{ij} \geq \tau \text{ and } i \in S_{RSTA}\}$ for all $j \in S$. // $O(mn)$;
    Find the $AP$ for which the value of $NumSTA_j$ is maximum. If multiple such $APs$ exist, break the ties according to the higher value
    $r_j^{min}$ and the lower value of $AP$ index. The resulted $AP$ (say $AP\ k$) is considered as the temporarily selected $AP$. // $O(n)$;
    if $S_{SAP} = \emptyset$ then // No $APs$ are selected yet
        Set $F_k^{SAP} = 1$ and make $AP\ k$ as permanently selected $AP$;
        Update $S_{SAP} = S_{SAP} \cup AP\ k$, $S_{RAP} = S_{RAP} \setminus AP\ k$ and $S = S \setminus AP\ k$. // $O(n)$;
        Update $S_{RSTA} = S_{RSTA} \setminus CovSTA_k$ and $S_{CSTA} = S_{CSTA} \cup CovSTA_k$. // $O(m^2)$;
        Compute $BestAP^i$ and set $A_i^{CSTA} = BestAP^i$ for all $i \in S_{CSTA}$. // $O(mn)$;
        Compute $R_{min} = \min_i \{r_{iBestAP^i} : i \in S_{CSTA}\}$. // $O(m)$;
    else // Some $APs$ are already been selected
        Choose a frequency $f \in F$ for assigning to $AP\ k$. Before assigning $f$ to $AP\ k$, we check weather $f$ satisfies the frequency
        separation criteria with the previously allocated frequencies to the $APs$ in $S_{SAP}$. // $O(n|F|)$;
        if frequency/frequencies satisfying the said criteria is/are found then
            if only one frequency $f$ is found then
                $F_k^{SAP} = f$;
            else // Multiple frequencies are found
                Choose the least frequency $f^*$ among all such frequencies that satisfy the required criteria and set $F_k^{SAP} = f^*$.
                // $O(|F|)$;
            Mark $AP\ k$ as permanently selected $AP$;
            Update $S_{SAP} = S_{SAP} \cup AP\ k$, $S_{RAP} = S_{RAP} \setminus AP\ k$ and $S = S \setminus AP\ k$. // $O(n)$;
            Update $S_{RSTA} = S_{RSTA} \setminus CovSTA_k$ and $S_{CSTA} = S_{CSTA} \cup CovSTA_k$. // $O(m^2)$;
            Compute $BestAP^i$ and set $A_i^{CSTA} = BestAP^i$ for all $i \in S_{CSTA}$. // $O(mn)$;
            Compute $R_{min} = \min_i \{r_{iBestAP^i} : i \in S_{CSTA}\}$. // $O(m)$
        else // No frequency satisfying the said criteria is found
            Update $S_{RAP} = S_{RAP} \setminus AP\ k$ and $S = S \setminus AP\ k$. // $O(n)$

    if $S = \emptyset$ but $S_{RSTA} \neq \emptyset$ then // Some $STAs$ remain uncovered after considering all $APs$ in $S_{EAP}$
        Set $S = S_{RAP}$;
```

APs are considered to be interfering to each other and hence require different frequency channel to activate simultaneously if their intermediate distance is less than or equals to 240 meters. These values are common with that provided by IEEE 802.11 vendors. The number of frequencies vary from 1 to 11 to show the effect of co-channel interference. We consider all the *STAs* as subscribed *STAs* for the multicast session under consideration.

5.2 Simulation results

In this section, we consider some well-known metrics and a metric namely *normalized cost* [9] to compare the performance of our proposed greedy. In *RSSI* metric, an *STA* is associated with an *AP* from which it gets the maximum data rate. Let C_i be the set of *APs* from which *STA i* gets at least τ data rate. The *minimum hop-distance* metric tells that *STA i* will be associated with an *AP* belongs to C_i, which has the minimum hop-distance to reach the *MAP*. The *in-range STA number* of an *AP* is the number of *STAs* within its coverage range. In *in-range STA number* metric, *STA i* is associated with an *AP* belongs to C_i, which has the maximum *in-range STA number*. Apart from these three well-known metrics, we also consider a metric namely *normalized cost* used in [9]. The *normalized cost* of an *AP* is defined as the ratio $\frac{H}{N}$, where H is the minimum hop-distance to reach the *MAP* from it and

TABLE 3
Comparison of results with different metrics.

Metric	R_{min} $(Mbps)$	Selected APs (%)	Covered $STAs$ (%)
$RSSI$	1.0	100	100
	2.0	100	100
	5.5	100	98.48
	11.0	100	50.81
Minimum Hop-distance	1.0	74.8	100
	2.0	86.4	100
	5.5	99.2	98.48
	11.0	100	50.81
Normalized Cost	1.0	67.8	100
	2.0	81	100
	5.5	97.8	98.48
	11.0	100	50.81
In-range STA Number	1.0	52.6	100
	2.0	69	100
	5.5	95.8	98.48
	11.0	100	50.81
Proposed Greedy	1.0	31	100
	2.0	48.8	100
	5.5	92.6	98.48
	11.0	100	50.81

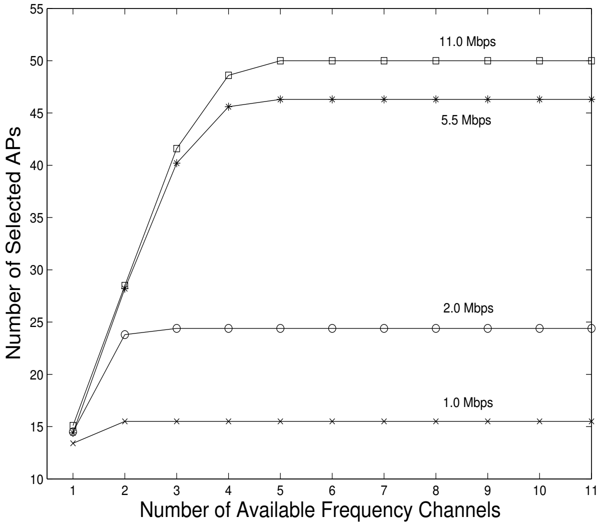

Fig. 2. Frequency Vs Selected APs.

N is the *in-range STA number* of that AP. In *normalized cost* metric, an STA will be associated with that AP which has the minimum *normalized cost*.

Table 3 shows the comparison of the results obtained by Algorithm 1 against the said metrics. Note that in the metrics $RSSI$, minimum hop-distance, normalized cost and in-range STA number, any subset of APs can be activated simultaneously as the co-channel interference is not taken into consideration. In our proposed greedy, however, we have considered the general k-colorable structure of the selected APs. In order to compare the performance of Algorithm 1 with these metrics and for fair comparison, we have assumed that enough frequency channels are available in the results presented in Table 3. In the later part of simulation, we have shown the effect of number of frequency channels on both the number of selected APs and number of served $STAs$. We have considered ten different runs and report their average value in this table for all metrics. It can be seen from Table 3 that Algorithm 1 selects 69%, 43.8%, 36.8% and 21.6% less number of APs than the metrics $RSSI$, minimum hop-distance, normalized cost and in-range STA number, respectively, when $R_{min} = 1.0$ $Mbps$. When $R_{min} = 2.0$ $Mbps$, Algorithm 1 selects 51.2%, 37.6%, 32.2% and 20.2% less number of APs than these metrics, respectively. Note that for these values of R_{min}, all $STAs$ are served. For $R_{min} = 5.5$ $Mbps$ and 11.0 $Mbps$, 98.48% and 50.81% of $STAs$ are served by all these metrics and Algorithm 1. However, Algorithm 1 selects 7.4%, 6.6%, 5.2% and 3.2% less number of APs than these metrics, when $R_{min} = 5.5$ $Mbps$. For $R_{min} = 11.0$ $Mbps$, all metrics and Algorithm 1 selects all the available APs but serve only 50.81% of $STAs$. Effect of number of frequency channels on the number of selected APs and number of served $STAs$ has been shown in Figures 2 and

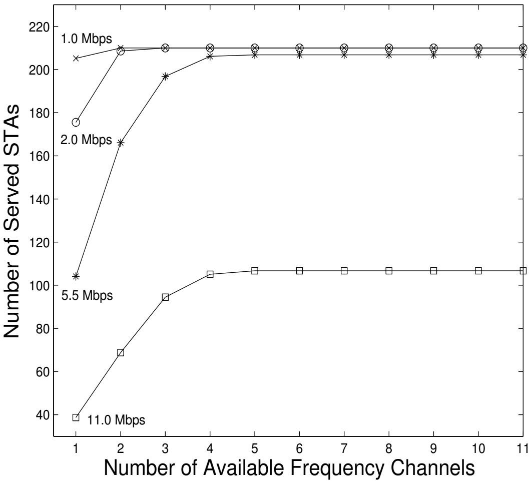

Fig. 3. Frequency Vs Covered $STAs$.

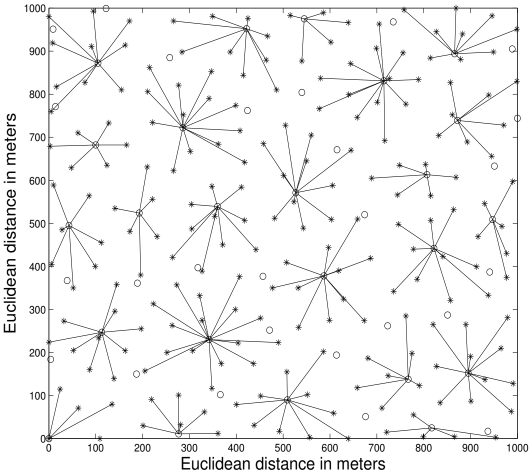

Fig. 4. An AP-STA association for 2.0 $Mbps$ data rate with 3 frequency channels.

3 respectively. Figure 2 shows how the number of selected APs vary with the number of frequency channels for different data rates. Whereas, Figure 3 shows the corresponding number of covered $STAs$ with the number of frequency channels for different data rates. From all these figures we observe that the number of selected APs as well as the number of covered $STAs$ increases with the increase in number of frequency channels but get saturated at when number of frequencies is 5. This is because in the considered network, 5 frequency channels may be enough to activate any subset of APs satisfying the co-channel interference. Figure 4 shows an association between the selected APs and the subscribed $STAs$ for $R_{min} = 2.0\,Mbps$ and 3 available frequency channels.

6 CONCLUSION

We have presented a greedy algorithm that jointly selects an appropriate subset of APs with minimum cardinality for which a conflict-free frequency assignment exists and also finds an association between the $STAs$ and the selected APs that maximizes the R_{min} value. Higher value of R_{min} improves both the multicast and unicast throughput. We have considered general k-colorable structure of the selected APs instead of tree structure. The simulation results show that the proposed greedy selects significantly less number of APs than the well-known metrics for serving the subscribed $STAs$. This in effect reduces the multicast overhead and hence improves the packet delivery ratio.

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