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A Client-Assisted and Distributed Channel Assignment Scheme For Dense IEEE 802.11 WLAN

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ABSTRACT
Due to huge popularity, the WLANs (Wireless Local Area Networks) have gained in recent years, especially based on IEEE 802.11 family of standards, dense deployment of AP (Access Point) can be found in many places. However, these dense deployments can severely affect the aggregate throughput of the network due increased contention and interference between different APs using same channel. This often leads to decreased overall throughput of a local wireless network, such as in a university campus or city-wide Wi-Fi network. In this paper, a simple client-assisted and distributed channel assignment scheme has been proposed for minimizing such adverse affects of interference in dense WLANs. Client-assisted means the resources of clients are also used for measurements of some parameters to increase the performance of the scheme. Distributed schemes are those schemes which can easily be used where AP belongs to different owners and administrative domains. This scheme will be shown to have better throughput performance than other prominent distributed schemes through simulation results.
Keywords – Channel assignment scheme, DCF-MAC, IEEE802.11, and WLAN.

I. Introduction

The WLAN has become a ubiquitous networking technology worldwide for wireless communication. Highly dense WLAN networks can be found in many cities of the world. One important characteristics of such dense WLAN is closely spaced APs, which leads to interference among them, if they are using same channel for transmissions with their respective clients. This may results in limiting the value of maximum throughput achievable.

Fortunately IEEE standard 802.11 has specified an efficient MAC protocol, called DCF (Distributed co-ordination function), which uses CSMA/CA (Carrier sense multiple access/Collision avoidance) technique. Using this technique, a station in WLAN system transmits, only after sensing the medium to be idle for certain DIFS (distributed inter-frame space) amount of time. This makes it effective in presence of other transmissions and interference.

In an infrastructure BSS (Basic Service Set), each transmission in the network will be only via the AP of that BSS. This means that the AP is either the source or destination in each transmission. In case of an infrastructure BSS (Basic Service Set) and dense WLAN, even CSMA/CA is unable prevent the adverse effect of increased contention. This increased contention is a result of several APs transmitting on same channel, when numbers of channel available are very few to choose from (for example, 3 in case of IEEE 802.11b). This problem is further aggravated by the use of non-overlapping and unlicensed use of spectrum specified in IEEE 802.11 family of standards. This forms the basis of channel assignment problem where a scheme is applied so that each neighbouring AP in a dense WLAN has different channel or atleast there is optimal channel assignment which can maximize the throughput for a given number of channels.

Channel assignment schemes can be broadly classified into two categories; Centralised [1-4] and Distributed [5-7]. Centralised schemes are applied to centrally managed deployments, usually seen in places such as university campuses, offices or airports where all APs and associated clients are managed by a central entity [8]. On the other hand, distributed schemes are used in uncoordinated WLANs, which operate in the absence of a central control and are typical in places such as residential neighborhoods or private hotspots managed by different service providers [8]. In distributed schemes each AP perform its own channel assignment based on the localized information available to it, without interacting with neighbouring APs.

Centralized scheme's greatest weakness is that these techniques require information of the whole network, which is not feasible in the majority of the WLAN networks. Majority of WLAN networks belong to distributed category. Hence the main focus of this paper is to develop a distributed channel assignment scheme.

In [5], a weighted variant of graph-colouring problem was proposed. The weights for each channel are set according to interference information reported from the client nodes to their associated AP. A simple and effective minimum neighbour (MINE) scheme was proposed in [6]. In the MINE scheme, each AP only needs to choose the channel with the minimum number of active neighbour nodes to maximize the expected throughput. Also a client-assisted Minimum conflict pairs (MICPA) scheme is proposed in [7]. This scheme has identified conflict pairs as its metric, based on which channel assignment is done, i.e., each AP chooses channel having minimum number of conflict pairs.

The client-assisted schemes perform better than AP only schemes as clients are better placed, owing to their location, to perform measurements in the network. Hence they can also be utilized to get better results.

In this paper, the transmission range of each node is not assumed to be same because practically the transmission range of each node in a network varies according to their environment and other factors. Hence this scheme is assumed to present better alternative to the channel assignment problem, which will be verified in the later segment of this paper through simulation results.

Rest of the paper is organised as follows. In section II, impact of interference on throughput will be studied. Based on this study, a metric called interference value will be proposed. Next, in section III, the proposed channel assignment scheme will be described. Then, in section IV extensive performance evaluation of the scheme and comparisons with other simple and effective schemes, namely MINE and MICPA schemes are performed. Finally, Section V concludes this paper.

II. Impact of High Contention on Throughput

To effectively study the impact of high contention on throughput performance of a dense WLAN interference scenarios are classified into 3 categories, namely Scenario I, Scenario II and Scenario III, as shown in fig.1. The proposed interference scenarios are simple to identify, even in a large network.

Before describing each scenario in detail, several notations used needs to be introduced. In our classification of interference scenarios two BSS are considered, BSS1 and BSS2. Each BSS has a single access point denoted by AP1 and AP2, respectively. The clients in BSS1 are denoted by $Cl_1{}^{\chi}$. Similarly clients in BSS2 are denoted by $Cl_2{}^{\chi}$. The transmission between an AP^{χ} and its client $Cl_{\chi}y$ will be denoted by $TR_{\chi}y$. For example, using fig.1 as a reference, transmission between AP1 and $Cl_1 3$ will be denoted by $TR_1 3$. N_{χ} will denote the set containing all the clients of BSS^{χ}. For example, with reference to fig. 1(b), $N_1 = \{Cl_1 1, Cl_1 2, Cl_1 3\}$ and $N_2 = \{Cl_2 1, Cl_2 2, Cl_2 3, Cl_2 4\}$.

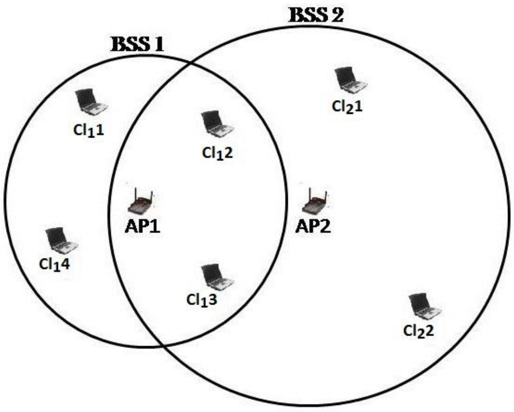

Fig. 1(a)

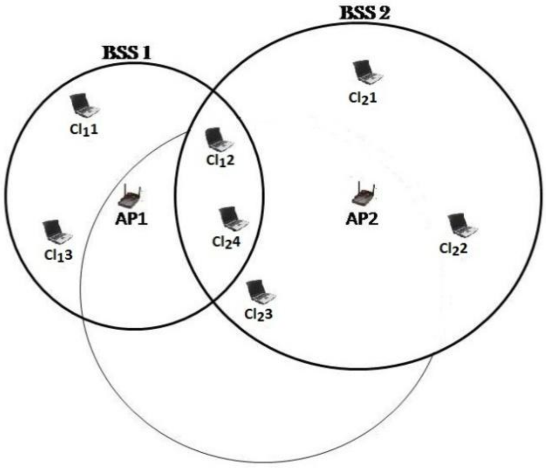

Fig. 1(b)

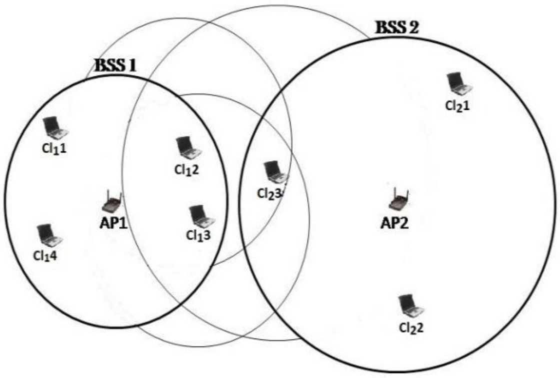

Fig. 1(c)

Fig.1 All three interference scenario. (a).Scenario I. (b) Scenario II. (c) Scenario III.

A BSS is said to be interfered by another BSS if any of its members (AP or clients) suffers from interference due to transmissions originating from any member of the interfering BSS. The proposed interference scenarios are classified from the viewpoint that BSS1 is interfered by the BSS2 (Although BSS2 may also suffer interference due to transmissions of BSS1). Hence, in case of Scenario I, AP1 being in the transmission range of AP2, directly suffers interference from AP2. In case of scenario II, only some clients of BSS1 will be in the range of AP2. Such clients will belong to a set denoted by Ni_1. AP1 also might be in the transmission range of some of the clients of BSS2. Set of such clients of BSS2 will be denoted by Ni_2. For example, with reference to fig. 1(b), $Ni_1 = \{Cl_12\}$ and $Ni_2 = \{Cl_23, Cl_24\}$. And finally in case of scenario III, some clients of BSS1 are in the range of only some clients of BSS2. For example in fig. 1(c), Cl_12 and Cl_14 are in the range of Cl_23. Set of such interfering clients of BSS2 in Scenario-III will be denoted by Ni_2. Remember that number of elements of any set A will be denoted by |A|. For example in fig. 1(a) $|N_1| = 4$ and $|N_2| = 2$.

In such interference scenarios, a metric called interference value (IV) has been identified, which approximately reflects the amount of interference a BSS suffers from its neighbouring BSS. IV is here defined as the number of transmissions of a BSS which can possibly get interfered from transmissions of its neighbouring BSS. Take for example fig 1(b), the transmission TR_23 can interfere with all four transmissions of BSS1, as range of Cl_24 encircle AP1. Therefore the IV of TR_23 is 4. Similarly with reference to fig. 1(c), the transmission TR_23 can interfere with TR_12 and TR_14, hence the IV of TR_23 is 2.

For Scenario I, because AP1 is in the range of AP2, transmission without interference in BSS1 is not possible when there is any ongoing transmission in BSS2. Also as each transmission of BSS2 interferes with all the transmissions of BSS1, the IV of all $TR_2\chi$ will be equal to $|N_1|$. And there are $|N_2|$ numbers of $TR_2\chi$, therefore total IV for BSS1 due to BSS2 for Scenario-I will be given by,

$$IV_{(1,2)} = |N_1| \times |N_2| \quad (1)$$

In Scenario-II, when any of the interfering clients from the set Ni_2 is transmitting, it interferes with all transmissions of BSS1, as AP1 is in the range of all these interfering clients. Hence IV for BSS1 due to transmissions of all such clients of BSS2 will be equal to $|N_1| \times |Ni_2|$. Also, the clients of BSS1 belonging to the set Ni_1 suffers interference, not only from transmissions of clients belonging to set Ni_2, but also from all other clients $(N_2 - Ni_2)$ of BSS2, as all these clients from the set Ni_1 are in the range of AP2. Hence IV for BSS1 due to all such transmission of BSS2 will be equal to $(|N_2| - |Ni_2|) \times |Ni_1|$. Therefore total IV for BSS1 due to BSS2 for Scenario II will be,

$$IV_{(1,2)} = |N_1| \times |Ni_2| + |N_2| \times |Ni_1| - |Ni_1| \times |Ni_2| \quad (2)$$

Finally, for Scenario-III, only $|Ni_2|$ number of clients of BSS2 can interfere in the transmission of some of the clients of BSS1. And each of such transmission has different IV depending on number of transmission of BSS1 they interfere with. Hence total IV for BSS1 due to BSS2 in case of Scenario III will be,

$$IV_{(1,2)} = \sum_{i=0}^{|Ni_2|} IV_i \quad (3)$$

Now, having described the metric interference value and calculating it for each of the scenarios, it is necessary to find that how this metric correlates to the throughput of the network before proceeding further. It is now shown that interference value is a good indicator of interference experienced by each BSS due to the transmission of other BSS using the same channel. To validate this observation, packet-level simulations of all the three scenarios have been performed using NS-2. In each of the scenario two BSS having an AP and three clients for each AP has been taken. The IEEE 802.11b direct-sequence spread-spectrum (DSSS) specifications have been used in the simulations. All nodes are in saturated condition. Each topology has been simulated for 100s. Also the Basic-access mechanism of DCF has been used instead of RTS/CTS, as Basic-access mechanism has been found to provide better throughput even in presence of hidden nodes [9]. Fig.2 shows the plot between Normalised Throughput v/s Interference Value for BSS1 for all three scenarios.

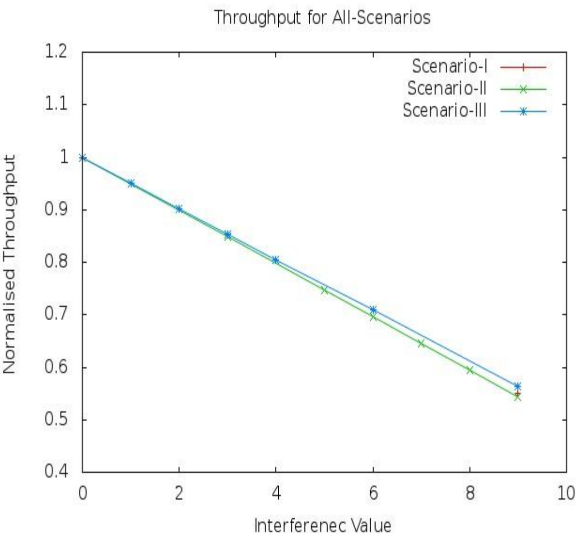

Fig.2 Normalised Throughput vs. Interference value

For each of the interference scenarios, it can be seen that the throughput obtained is somewhat inversely proportional to the interference value. In other words, higher throughputs can be achieved by selecting topologies that have lower interference value. Keeping this in mind, the MIV (Minimum Interference Value) scheme is proposed in the next section.

III. MIV Scheme

Having defined the relationship between Interference value and Throughput in previous section, it is easy to predict the fact that MIV scheme works by choosing the channel having minimum interference value, at each AP of the network so that expected throughput is maximum. IEEE 802.11b has specified a set of 13 channels in 2.4 GHz ISM band. Out of these 13 overlapping channels, only 3 non-overlapping channels are used for transmission in most countries. IEEE 802.11a has specified a set of 12 OFDM channels in 5 GHz UNII band. Therefore for each AP, there are 3 and 12 alternatives to choose from in 802.11b and 802.11a, respectively.

In the MIV scheme, an AP first calculates IV (Interference value) of each of the neighbouring interfering BSS and adds them up to get total IV. For example, if there are N numbers of interfering BSS, then total IV for an AP_i will be,

$$IV_i = \sum_{j=0}^{N} IV_{(i,j)} \qquad (4)$$

This Total IV is calculated on each channel and then the AP simply chooses the channel which has minimum IV, so that its throughput can be maximized. And if each AP in a large and dense WLAN runs this scheme, the throughput of the whole system can be significantly increased.

Now the main issue in the implementation of this scheme is that how an AP calculates this metric IV. For example, in case of Scenario-I, what is required to calculate IV are two sets N_1 and N_2. And in case of Scenario-II, sets of N_1, N_2, Ni_1, and Ni_2 are required. And finally in case of Scenario-III, only the set of interfering nodes Ni_2 with their IVs is required to calculate total IV. For calculating these values, addressing fields of a typical IEEE 802.11 MAC frame (shown in Fig. 3) can be used.

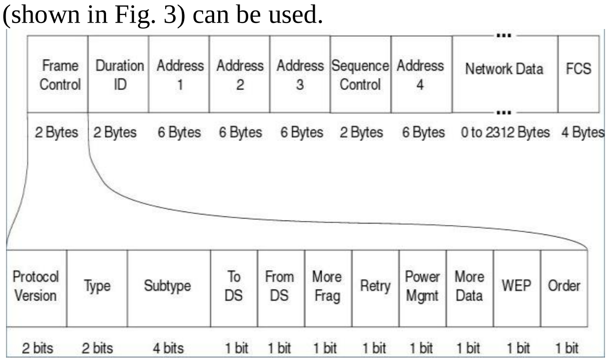

Fig. 3 IEEE 802.11 MAC frame.

Therefore, the 4 address fields and " *To DS* " and " *From DS* " fields of a MAC frame can be used for identifying all those parameters required for calculating IVs. For example, taking Fig. 1 as a reference, in Scenario-I AP1 can directly sense all transmissions of BSS2 originating from AP2. Hence AP1 can observe MAC frames of BSS2 over a time and identify all active clients of that BSS to get N_2. Similarly in case of Scenario-II, AP1 can observe MAC frames of BSS2 to identify interfering clients to get Ni_2. Some clients of BSS1, which are being interfered upon by AP2, can similarly identify total clients of BSS2 over a period of time and report them to its access-point, i.e. AP1. AP1 then will use this information to identify Ni_1 (Set of clients of BSS1 getting affected by interference) and N_2 (Total number of clients of BSS2). And finally in Scenario-III, similar observation of MAC frames of BSS2 by clients of BSS1 will help AP1 in identifying Ni_2 and their IVs.

IV. Simulation Results

This section presents performance evaluation of the MIV scheme on the basis of the metric Total IV (Interference Value). Simulations have been performed using a model created using C++ programming language. Simulation scenario consists of a network of 100 APs, each having random number of clients from 1 to 10. The transmission range of each BSS is also set randomly between 75m and 125m to account for variable transmission range of each BSS. Deployment density of the network will be denoted by a metric Y (same as used in MICPA scheme [13]), where Y is the average number of interfering APs each node have within its transmission range. This parameter Y will decide dimensions of the topology of whole network of 100 APs. The number of channels for IEEE 802.11b and IEEE 802.11a are C=3 and C=12, respectively. All results shown are obtained using the average of 1000 independent realizations with randomly generated initial channels and number of clients. The performance of MIV scheme will also be compared with other two simple and effective distributed schemes, MINE and MICPA scheme. The results of other schemes have also been generated in a similar manner and using the same model as the MIV scheme.

Performance evaluation of these 3 schemes (MINE, MICPA and MIV) has also been performed under different levels of client spread and different AP deployment densities. Three levels of client spread have been used, which are low, moderate, and high client spreads. In low client spread, the client's locations are normally distributed around AP with a standard deviation of 25m. For moderate client spread, the standard deviation is 50m. And for high client spread, the client's locations are uniformly distributed around AP.

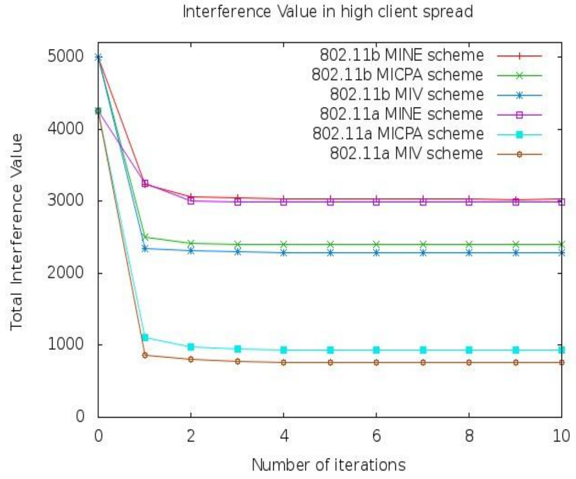

Fig.4 Total interference value for all three schemes for high client spread

In Fig. 4, the total interference value of whole network of 100 BSSs is plotted against the number of iterations. The number of iterations is chosen to be 10, because all three schemes were found to be able to converge into their best channel assignments before 10 iterations in saturated load conditions. 0_{th} iteration here denotes initial random channel assignment in the network before any scheme is applied. Also these results have been generated for IEEE 802.11a and IEEE 802.11b with a normalized density of unity Y /C = 1 (Y is the average number of interfering APs and C is the number of channels) and with high client spread.

From the fig. 4, these schemes result in significant improvement in terms of reduction in interference value of a large and dense network. Also it is evident from Fig. 4 that MIV scheme outperforms both MINE scheme and MICPA scheme with a significant reduction in interference value. Reductions of up to 25% and 5% for interference value can be achieved by the MIV scheme over MINE scheme and the MICPA scheme respectively in case of IEEE 802.11b. In case of IEEE 802.11a, this reduction in interference value by MIV scheme is even better, i.e. 75% over MINE scheme and 19% over MICPA scheme. Also the reduction by MIV scheme over initial random channel assignment is 55 % for IEEE 802.11b and 82% for IEEE 802.11a. The relatively larger improvement in the case of IEEE 802.11a was also found in case of MICPA scheme which points to the fact as number of channels available is greater; these two schemes provide better performance.

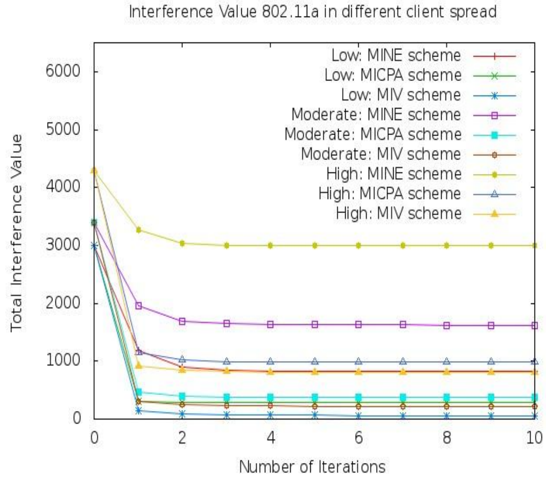

Fig.5 Total interference value for all three schemes for different client spread

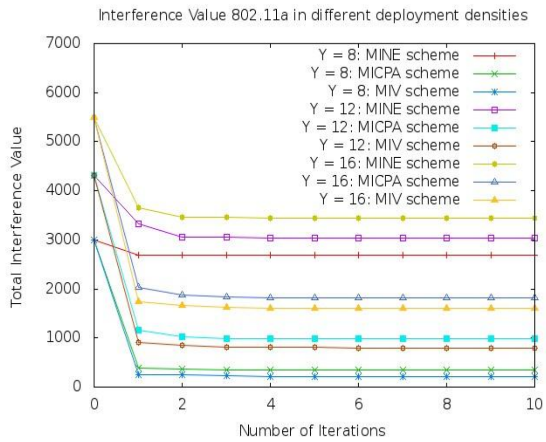

Fig.6 Total interference value for all three schemes for different deployment density

Fig. 5 shows the total interference value for all three schemes with different levels of client spread for IEEE 802.11a with a normalized density of unity. These results show that as the client spread increases, IV also increases. This is expected because clients which are located farther away from their APs, not only are more exposed to, but also create more interference to other APs. Nevertheless, MIV scheme was able to reduce interference value by 98%, 94%, and 82% for low, moderate and high client spread respectively. Also significant reductions in the interference value were observed by the MIV scheme over MICPA scheme and the MINE scheme for all levels of client spread. Reductions in interference value of 93%, 87%, and 75% over MINE have been observed for low, moderate, and high client spread, respectively. Also the reduction by MIV scheme over MICPA scheme is observed to be 79%, 43%, and 19% for low, moderate, and high client spread respectively.

The interference value for all three schemes with different deployment densities for IEEE 802.11a with high client spread is plotted in Fig.6. From the results, it can be seen that the interference value is larger when the deployment density is higher signifying the point that as deployment density increases, interference increases. In all the considered cases of deployment densities, significant reductions in interference value of 92%, 75%, and 54% by the MIV scheme over the MINE scheme and of 40%, 19%, and 12% over MICPA scheme can still be observed for Y = 8, Y = 12, and Y = 16, respectively.

V. Conclusion

In this paper, the channel assignment problem has been tackled first by classifying interference environment of dense deployment of WLAN system into three interference scenarios. Based on these interference scenarios a metric, called interference value has been identified. Then this metric was shown to be almost inversely proportional with the throughput obtained for all interference scenarios. Employing this metric, the MIV scheme was proposed.

Simulation results have shown that the MIV scheme can provide a significant reduction in interference value of a large and dense network for both IEEE 802.11b and IEEE 802.11a. Also in comparison with MINE and MICPA scheme, MIV scheme performs better for all considered cases of client spread and deployment density. Several implementation issues of MIV scheme was also discussed in this paper.

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