Multiple Radio Channel Assignement Utilizing Partially Overlapped Channels

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Abstract— Existing channel assignment algorithms designed for multi-radio multi-channel wireless mesh networks (MRMC-WMN) mainly deal with orthogonal or non-overlapped channels. But in reality, the limited availability of orthogonal channel is a major issue where the network is very dense in terms of inter-nodal distances. On the other hand, partially overlapped channels (POC) are currently considered as a great potential for increasing the number of simultaneous transmissions and eventually upgrading the network capacity; especially in case of MRMC-WMN. In this paper, we address the limited orthogonal channel problem by exploring the usable POCs. The key technique lies in the fact that the interference between adjacent channels has to be considered intelligently in order to increase the overall capacity. Our contributions include a new interference model I-Matrix that helps selecting channels with less interference and a POC-based channel assignment algorithm. We evaluate the performance of our POC based algorithm in terms of capacity by comparing with the one using only orthogonal channels. Our results show capacity improvement as the increased link assignments at an average of more than 15 percent. *(Abstract)*

Keywords-partially overlapped channels; orthogonal channels; adjacent-channel interference; Self-Interference; interference vector; I-matrix (key words)

I. INTRODUCTION

With recent advances in wireless technology, the utilization of multiple radios as well as multiple channels provides an opportunity to increase network capacity. Due to reasons such as price reduction and mass availability of wireless network interface cards (NIC), people can now easily afford to equip multiple NICs with notebooks and PDAs, not mentioning the wireless routers and mesh networks widely deployed. Equipped with multiple radios, nodes can communicate with multiple neighbors simultaneously over different channels, and thus can significantly improve the network performance by exploring concurrent transmissions.

In such a multi-radio multi-channel (MRMC) environment, the key challenging problem for capacity optimization is *channel assignment*. Consider a wireless mesh network operating with the interface devices built on IEEE 802.11b/g technology. Fig. 1 gives an overview of the frequency spectrum of this category which works in the 2.4 GHz frequency band having a total of 11 channels available for communication. The frequency bandwidth of each channel is 44 MHz and the dotted lines correspond to the centre frequencies of corresponding channels. The distance between the centre-frequencies of two consecutive channels is 5 MHz. Increasing channel separation for simultaneous transmissions corresponds to decrease in spectrum overlapping which lead to less interference. If two channels have a separation of 5 channels or more, then they work as orthogonal channels. For example, channel 2 is orthogonal with respect to channels 7 and above. The maximum number of available orthogonal channels in IEEE 802.11b/g is 3. These are channels 1, 6 and 11.

The reason why partially overlapped channels (POCs) are neglected is because they create a significant amount of interference which is often difficult to handle. On the other hand, as the number of orthogonal channels is very limited, it now becomes infeasible to design an efficient channel assignment algorithm without the aid of POCs for MRMC environment. Recent works show that a systematic approach to exploit POCs can lead to better spectrum utilization and maximize network capacity and throughput. Experiments by Mishra *et al* in [5] have proved that two simultaneous transmissions with a channel separation of 3 can give the same level of throughput derived from two orthogonal channels. Their research also reflects that the effect of interference from adjacent channels is reduced as the geographical distance is increased. Therefore, instead of prohibiting the usage of channels with overlapped spectrum, POC based design makes a smart compromise between geographical positioning of neighboring nodes and interference tolerance level of radio interfaces. The primary idea is to provide nodes with full access of all working channels in the available spectrum let it decide whether a specific channel is usable or not. This increases channel diversity and upgrades overall network capacity. In this way, network capacity can be improved up to 90% if all the 11 channels can be utilized in 802.11b. [1]

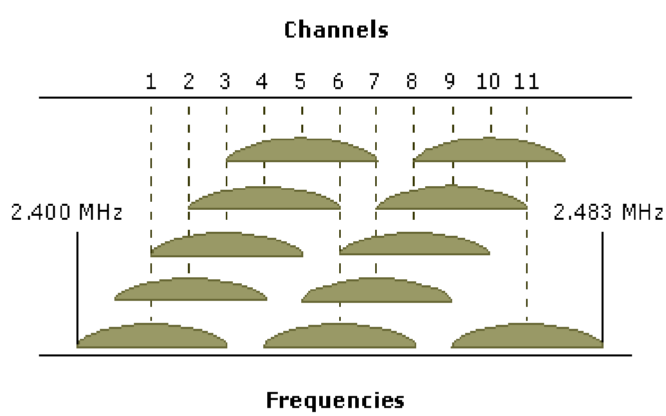

Figure 1. Partially Overlapped Channels (POC) in IEEE 802.11b/g.

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In this paper, we study the issue of channel assignment with POCs in consideration for MRMC environments. We attempt to provide an estimation of the workability of POC based channel assignment schemes on various topologies in wireless mesh networks (WMNs). To the best of our knowledge, this is the first algorithm for this targeted issue. Our main contributions include:

1) Given the topology of an MRMC-WMN, we propose a heuristic algorithm to allocate channels to maximum number of links such that it minimizes interference.

2) We consider the issues of efficient spectrum utilization by considering both POCs and orthogonal channels.

3) We had shown the effect of different topological factors influencing the channel assignment results, such as node density, network load etc.

4) Finally we evaluated the capacity improvements by comparing the performance of our POC based algorithm with the one using only orthogonal channels.

The rest of the paper is organized as follows. Section II describes the problems associated with channel assignments. In section III we introduce our interference model with innovative concept of I-Matrix. Section IV gives the sketch of the channel assignment algorithm followed by performance evaluation in section V. The related works comes in section VI and finally we conclude in section VII with our future improvement plans.

II. PROBLEM FORMULATION

The fundamental problem to be addressed in an MRMC mesh network architecture is the channel assignment problem that involves mapping channels to radios with a goal to achieve maximum channel utilization with minimum interference. The distance within which two transmissions interfere with each other is called the *interference range*. Due to *adjacent channel interference,* a transmission on channel 4 will interfere with channel 3 or 5 if they are within the interference range. In order to avoid such interference, network designers usually tend to use only non-overlapping channels in their wireless network.

The interference range of a transmission depends on the transmission power used. Therefore, the choice of transmission power also determines the amount of spatial re-use of the same channel. In channel allocation schemes that only use orthogonal channels, it is often unavoidable to assign neighboring nodes with the same channel due to limited number of orthogonal channels. The *co-channel interference* restricts the nodes from parallel communication. Though POCs can also interfere with each other, it is observed that the interference range of POC is often much smaller than the typical co-channel interference range. Such reduced interference range of POCs enables more parallel transmissions and lead to increased network capacity.

A number of challenging issues have to be tackled in our POC-aware channel assignment algorithm. Generally speaking, the "goodness" of a channel assignment rests on two factors: connectivity and interference. Each has a few more considerations. We shall focus on each of these constraints elaborately.

A. Connectivity

With multiple radio interfaces operating on different channels, two nodes *a* & *b* can communicate only if

a) they are within the transmission range; and

b) each of them has an interface assigned to a common channel (let this common channel be i);

B. Inteference

The most significant issues related to this factor include:

1) Co-channel Interference:

Co-channel intereference refer to the interefernce generated from concurrent use of the same channel. To overcome this problem: *none of the two communicating nodes (a & b) can use the common channel i for any other adjacent links.*

2) Self-Interference

One of the most critical challenges is to overcome self-interference problem. Links connected to a single node cannot be assigned to channels with overlapping frequency bandwidth due to this problem. This important issue, addressed by Feng *et al* in [3], has been taken into account very well in our work. To overcome this problem:

a) the maximum number of parallel transmission from a single node must be restricted to the number of maximum orthogonal channels available, which is 3 in our case.

b) To ensure that within a single node the channels assigned to the incident links are mutually orthogonal.

3) Adjacent-channel Interference (ACI)

ACI refers to the interference perceived by node *a* or *b* from any of their neighboring nodes communicating on a channel which has partial overlapping with channel *i.* Fortunately, POCs do not have the same interference range as co-channel interference. As experimented by previous research works, the effect of interference from adjacent channels is reduced as the channel separation or geographical distance is increased. This is the basis of our POC based design.

To utilize the property that ACIs of POCs reduces with the increase of channel separation and geographical distances in our algorithm, we introduce an innovative concept of Interference-Matrix (which we shall hereafter refer to as *I-Matrix*) to measure the ACIs among different POCs. The details about the I-Matrix and the algorithm are given in the following sections.

III. INTERFERENCE MODEL

The I-Matrix at each node is the ultimate measurement that helps our channel assignment algorithm in determining whether a channel is assignable or not. It measures the interferences from all the possible channels for each channel with the node's current radio usage. We describe here the steps that lead to generate the matrix. They include the calculations of the interference factor, interference vector and the I-Matrix.

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A. Interference factor

We define the interference factor, $f_{i,j}$ to provide a measure of the effective spectral overlapping level between channels *i* and *j*. This interference factor takes into account both the geographical distance and the channel separation between the two transceivers using these two channels. Our definition of interference factor refers to the effective interference from adjacent channels considering the *Interference Range* as a reference distance metric.

To be noted, our definition of interference factor is different from the normalized I-Factor defined by Mishra *et al* in [5]. The I-Factor measures the *extent* of overlap between channels *i* and *j* given by the fraction of a transmitted signal's power on channel *i* that will be received on channel *j*. On the other hand, we quantified our metric as a ratio of *interference range* and geographical distance between the operating radios. If the geographical distance is greater than the *interference range* associated with the channel separation, we consider the two channels *i* & *j* as non-interfering, even though they have spectrum overlapping. This gives us the opportunity of better spatial reuse of channels with overlapping bandwidths. Since the *interference range* depends on the signal strength of the receiver, we may say, in a broad sense, that ours is a derived metric from the I-Factor mentioned in [5].

A good number of prior experiments have been done to measure the *interference ranges (IR)* for different channel separations. For our algorithm, we utilized the experimental results showed by Zhenhua Feng and Yaling Yang [3] &[4]. The IR table used for our algorithm is as follows:

TABLE I. INTERFERENCE RANGE

δ	0	1	2	3	4	5
IR(δ)	13.26	9.21	7.59	4.69	3.84	0

Here $IR(\delta)$ refers to the interference range for a channel separation of δ, where $\delta = |i - j|$.

Let, *d* refer to the distance between the two radios operating on channels *i* & *j*. If the two radios tuned to channels *i* & *j* belong to the same node then the value of *d* will be zero. We define the interference factor as follows:

1) $f_{i,j} = 0$: when $\delta > 5$ *or* $d > IR(\delta)$

When channels *i* & *j* do not have overlapping spectrum or their operating distance is beyond the interference range; the corresponding value of interference factor is equal to zero, which implies that channels *i* & *j* are *non-interfering*.

2) $1 < f_{i,j} < \infty$: when $0 \leq \delta < 5$ and $d < IR(\delta)$

When two radios communicating on channels *i* & *j* are within the interference range and the channel separation is less than 5, they interfere with a factor inversely proportional to the distance between two operating radios. In this case we calculate the interference factor from the following equation:

$$f_{i,j} = IR(\delta)/d \quad \ldots \ldots \ldots (1)$$

Equation (1) indicates that $f_{i,j}$ decreases as the geographic distance increases.

3) $f_{i,j} = \infty$: when $0 < \delta < 5$ and $d = 0$.

Due to the *self-interference* problem discussed in the previous section, two parallel transmissions on channels *i* and *j* within the same node will fully interfere with each other if their channel separation is less than 5.

B. Interference Vector

After calculating the interference factors for all the distinct 11 channels with respect to a specific channel within a particular node, we tabulate the values as below (table II) which we refer to as an *interference vector*. Clearly, an interference vector signifies the effect of interference from each of the 11 channels with respect to a particular channel *i*. The table also keeps track of the distance (d_i) to the nearest radio operating on channel *i* from the current node. Therefore, if the node itself has a radio tuned on channel *i* then d_i will be equal to zero. Table II below shows the *interference vector* corresponding to channel 3.

TABLE II. INTERFERENCE VECTOR

Ch#	d_i	Interference Factor										
		1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*
3	d_3	$f_{3,1}$	$f_{3,2}$	∞	$f_{3,4}$	$f_{3,5}$	$f_{3,6}$	$f_{3,7}$	0	0	0	0

C. I- Matrix

Combining all the interference vectors for each channel, the I-Matrix (table III) is formed. Each node keeps track of its own I-Matrix. Either a column or a row corresponding to channel *i* refer to the interference effects from all other channels. After each link assignment, each node updates the I-Matrix for the newly assigned channel.

TABLE III. I-MATRIX

Ch#	d_i	Interference Factor										
		1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*
1	d_1	∞	$f_{1,2}$	$f_{1,3}$	$f_{1,4}$	$f_{1,5}$	0	0	0	0	0	0
2	d_2	$f_{2,1}$	∞	$f_{2,3}$	$f_{2,4}$	$f_{2,5}$	$f_{2,6}$	0	0	0	0	0
3	d_3	$f_{3,1}$	$f_{3,2}$	∞	$f_{3,4}$	$f_{3,5}$	$f_{3,6}$	$f_{3,7}$	0	0	0	0
4	d_4	$f_{4,1}$	$f_{4,2}$	$f_{4,3}$	∞	$f_{4,5}$	$f_{4,6}$	$f_{4,7}$	$f_{4,8}$	0	0	0
5	d_5	$f_{5,1}$	$f_{5,2}$	$f_{5,3}$	$f_{5,4}$	∞	$f_{5,6}$	$f_{5,7}$	$f_{5,8}$	$f_{5,9}$	0	0
6	d_6	0	$f_{6,2}$	$f_{6,3}$	$f_{6,4}$	$f_{6,5}$	∞	$f_{6,7}$	$f_{6,8}$	$f_{6,9}$	$f_{6,10}$	0
7	d_7	0	0	$f_{7,3}$	$f_{7,4}$	$f_{7,5}$	$f_{7,6}$	∞	$f_{7,8}$	$f_{7,9}$	$f_{7,10}$	$f_{7,11}$
8	d_8	0	0	0	$f_{8,4}$	$f_{8,5}$	$f_{8,6}$	$f_{8,7}$	∞	$f_{8,9}$	$f_{8,10}$	$f_{8,11}$
9	d_9	0	0	0	0	$f_{9,5}$	$f_{9,6}$	$f_{9,7}$	$f_{9,8}$	∞	$f_{9,10}$	$f_{9,11}$
10	d_{10}	0	0	0	0	0	$f_{10,6}$	$f_{10,7}$	$f_{10,8}$	$f_{10,9}$	∞	$f_{10,11}$
11	d_{11}	0	0	0	0	0	0	$f_{11,7}$	$f_{11,8}$	$f_{11,9}$	$f_{11,10}$	∞

D. Threshold Interference (Th)

We define a threshold (*Th*) value which specifies the tolerance level of interference for the radios. By limiting the value of *Th* to 1, we can disregard any channel within $IR(\delta)$ from being considered for assignment. If we want to increase the tolerance level, we may specify $Th > 1$.

IV. Channel Assignment

Our channel assignment algorithm uses the knowledge of offered traffic load. The offered load is specified as an input file to the algorithm which describes all the links that need to be assigned with suitable channels. The input links are assigned to specific radios of both the incident nodes. Then the nodes are sorted in descending order of the degree of the nodes so that the channel assignment starts with the most constrained node having maximum neighbors and links to be assigned. The I-Matrix of each node are initialized with zero. During the channel assignment procedure, the I-Matrixes will be updated accordingly.

For each node, whenever any link incident to that node is found unassigned, a suitable channel is sought for assignment based on the information from the I-Matrix. To check whether a channel c is assignable to a link or not, the algorithm visits the two I-Matrixes of the incident nodes of this link, and sums up the total interference factors corresponding to the channel c. For example, if a link e connecting nodes u and v needs to be assigned a channel c, it computes the total interference factor with respect to channel c for both the nodes. The process repeats for all 11 channels. Whichever channel gives the minimum value of total interference factor will be selected for the assignment. If this value is less than the threshold value (*Th*), the channel is finally assigned to the link.

After each link assignment, the interference vectors corresponding to the assigned channel are updated for each node. To update the I-Matrix, each of the nodes computes the distance from the node with the newly assigned link. With this distance (d), the interference factors are calculated for each channel with respect to the newly assigned channel (c), based on the conditions specified in section III. Then the values of I-Matrix are updated as follows.

$$F_{c,i}{}^{new} = F_{c,i}{}^{prev} + f_{c,i} \qquad 1 \leq i \leq 11$$

where c is the newly assigned channel..

A. Channel Assignment Algorithm

for each Node *n* in the sorted list:
  for each link *e* incident to Node *n*:
    if *e* is not assigned then:
      ch = **Get_Channel** (*e*);
      if (*ch*=Valid channel)
        e - > Assign_channel(*ch*);
        for all nodes: Update I-Matrix(*ch*);
      else cannot assign channel;

B. Algorithm for Get_Channel(e)

Get two adjacent nodes of link e: *n1* & *n2*
Initialize *min*=INFINITE;
For each channel *i* from 1 to 11:
  Calculate total I-Factor for channel *i* for both *n1* & *n2*:
  if *min* > [*n1*.total_i_factor(*i*) + *n2*.total_i_factor(*i*)]
    min = *n1*.total_i_factor(*i*) + *n2*.total_i_factor(*i*);
  if (*min* < *Threshold_Interference*)
    ch = *i*;
return *ch*;

V. Performance Evaluation

Our evaluation studies the workability and efficiency gain for the POC based channel assignment scheme. We compare the two sets of usable channel inputs, one is the conventional orthogonal channels (denoted as OC) only; the other is all the channels (denoted as POC). To maintain consistency, we specified the threshold interference value, *Th* = 1 for both the schemes. This implies that we disregarded any partially interfering channel within the interference range (IR) from assignment. We are interested in the influence on the channel assignment algorithm from radio resources (implying feasible traffic load) and node density. Very low traffic load demands less channels, thus, could be sufficiently handled by OCs. Very high traffic load will saturate the media, leading to high interference at POC channels, thus can provide less help.

The area dimension for our topology is within 100m × 100m. Nodes are equipped with multiple radios of similar capability. Each node has the information of physical distance from each of its neighbors. We considered different types of node placements for our simulation, but due to page limitation we only present the results from random topology in this paper. The total number of nodes is varied in the simulation. And we test two cases, 2 and 3 for the number of radios. According to our traffic load assignment scheme presented early, we assign sets of links for channel assignment as input load. We use the number of the links as a baseline to measure the improvement offered by POCs. In measuring the performance, we use the percentage of assigned link for a given link load.

A. Illustrations of Channel Assignment Outputs

Fig. 2 shows the channel assignment output for a random topology with 45 nodes and 54 total links, where maximum load is 3. Our results show that, POC based scheme is capable of assigning 35 links with 11 different channels whereas OC based scheme could only assign 29 links. This gives an overall capacity improvement of more than 20%. Similarly Fig. 3 shows the output for a random topology with 35 nodes and 30 links, where maximum load is for a node is 2. In this case POC based scheme was able to increase the number of assigned links from 19 to 25, which corresponds to 31% increase in the overall network capacity.

B. Total Link Assignment vs. NodeNumber

The performance of POC improves as the number of node increases. Fig. 4a and 4b demonstrates the total link assignment comparison between OC and POC scheme for different number of nodes with load 2 and 3. For both the cases, the figures show that increasing the number of total nodes results in increase of link assignments. The figures also show that saturation exists, after which the network is unable to assign more links even with POC. This saturation point occurs early in case of load 3. But there is not a single point where the POC based scheme is exceeded by OC scheme.

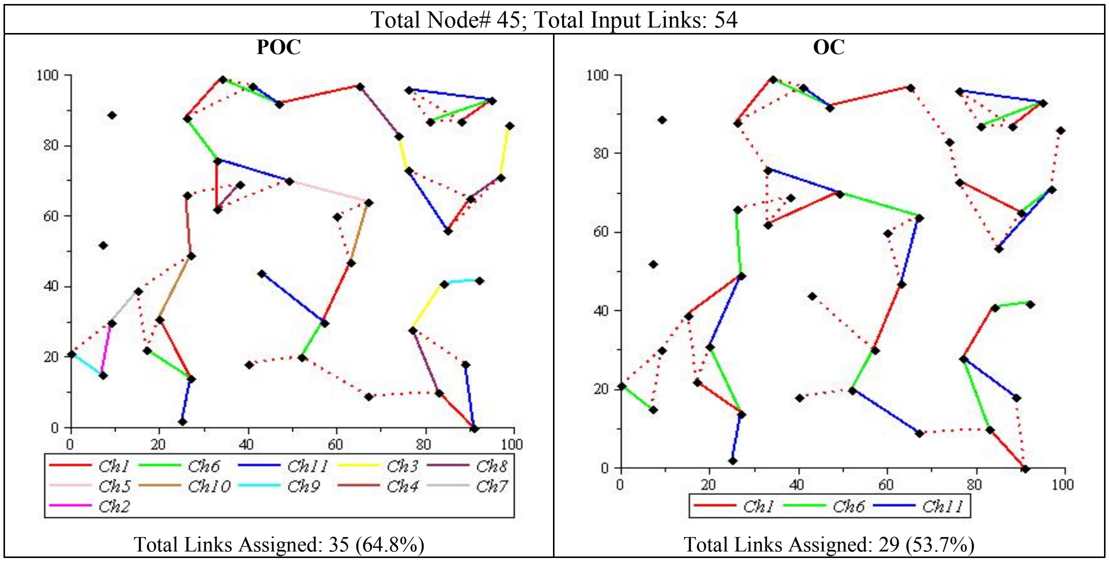

Figure 2. Channel Assignment Output for Random Topology (Input load=3)

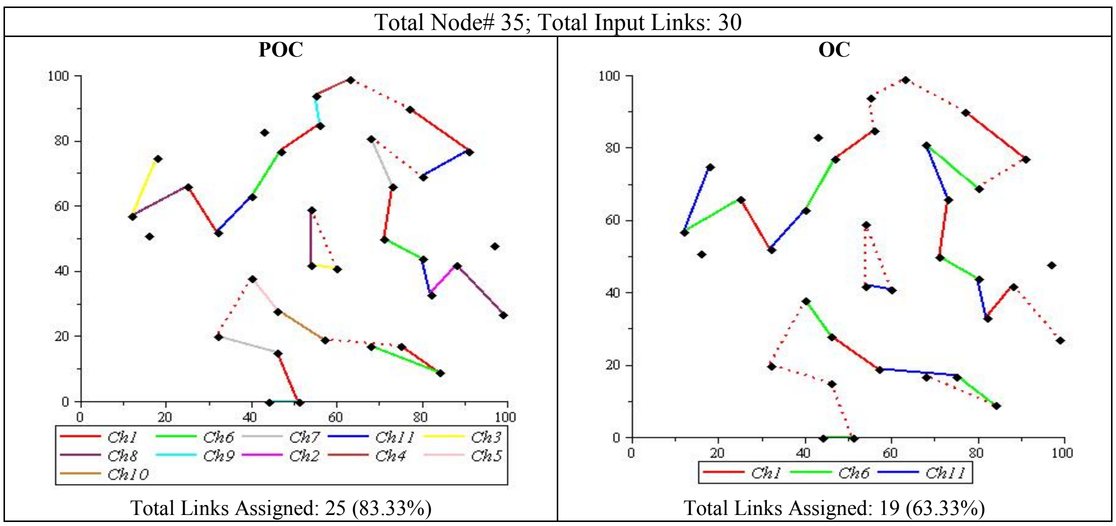

Figure 3. Channel Assignment Output for Random Topology (Input load=2)

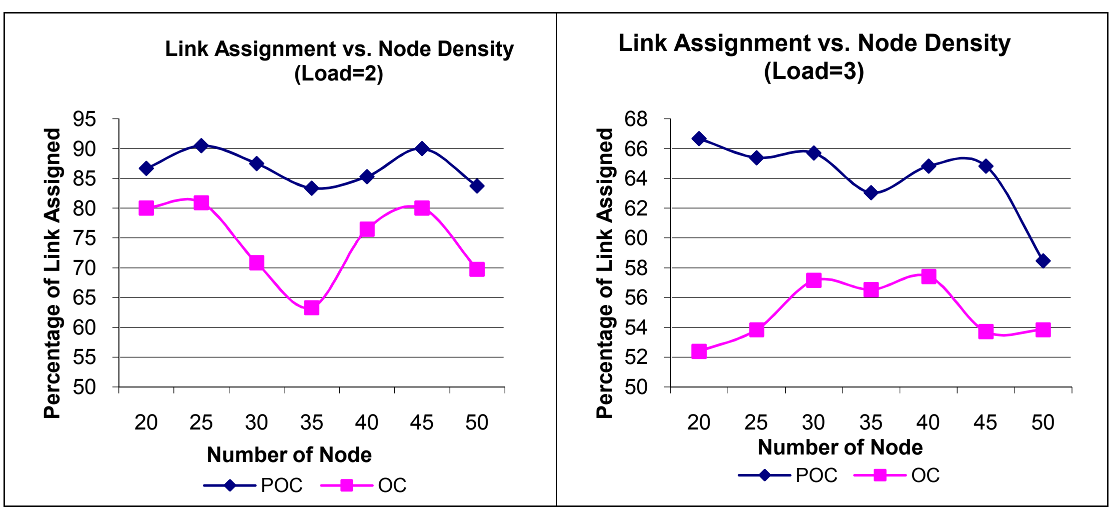

Figure 4. Comparison of Link Assignment Percentage: (a) Load=2 & (b)Load=3

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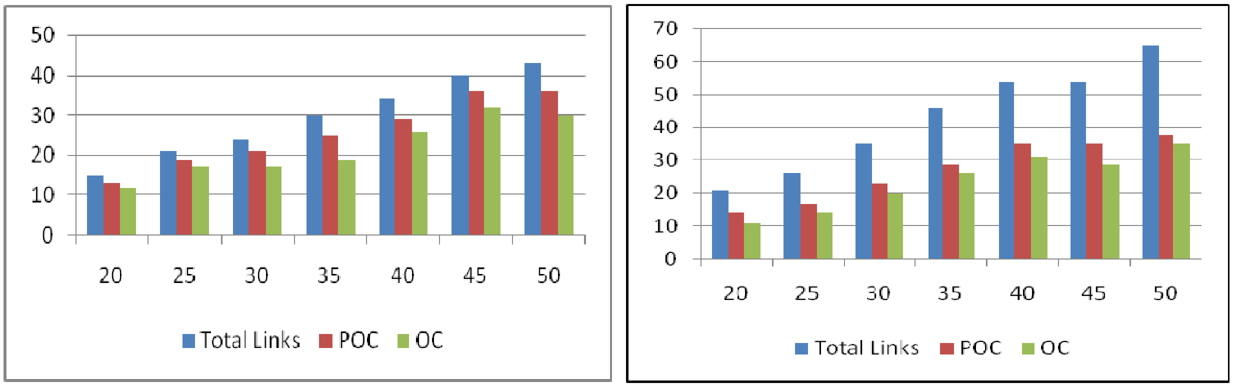

Figure 5. Number of link assignments for (a) load=2 (b) load=3

C. *Percentage Link Assignment vs. Node Density*

Fig. 5 shows the comparison of the percentages of the link assignments for both types of inputs. As our system can handle maximum 3 concurrent links in order to negotiate with the self interference problem, it is interesting to notice that an input link set with load =2 is capable of assigning channels with a higher percentage than that with load=3. But the POC still assigned more links in load=3 as seen in Fig. 4a and 4b.

D. *Capacity Improvement*

If we assume each link with equal bandwidth then the more number of links is assigned with channels, the higher capacity is gained. This capacity improvement is directly proportional to the difference of number of links assigned between POC and OC. We present the percentage of capacity improvement in Fig. 6. It is measured with respect to the OC based scheme. From Fig. 6 we can see the variation of capacity improvement for different node densities and loads. This is due to the randomness in the topologies. On average, with either load=2 or 3, our POC based algorithm can give an increase of capacity by more than 15%.

In summary, our POC based channel assignment algorithm shows significant increase in channel assignment outputs for different random networks varying the number of total nodes and input load.

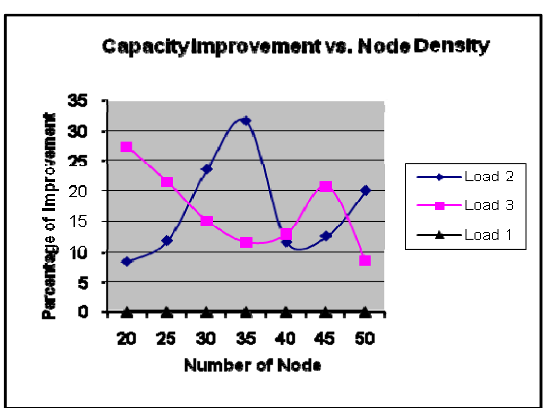

Figure 6. Capacity Improvement

VI. RELATED WORKS

Early work that closely relates to ours includes modeling interferences and capacity improvements of POCs and designing channel allocation and scheduling schemes using POCs.

The first systematic model of the POC based network design was introduced by Mishra, *et al.* in [5] and [6]. Their discovery showed that POC based design can improve network capacity up to three times in IEEE 802.11b-based networks compared to using only orthogonal channels. However, the authors did not mention any particular algorithm for channel assignment using POCs.

In [14], Garcia *et. al*, presented a new frequency management scheme as well as channel assignment algorithm for IEEE 802.11b that minimizes interference and increases the throughput. Their algorithm takes both co-channel and adjacent channel interference into account, and makes use of all available channels instead of only 3 orthogonal channels. The results obtained from their simulations, justified the use of POCs for channel assignment.

The usability and performance improvements by POCs in WLAN were also experimented using real test-beds by Feng *et al.* in [3] and [4]. They proposed two separate optimization models for one hop and multi-hop networks for POC-based design. They are the first to identify one of the most vital constraints for channel assignment in multi-radio multi channel WMN, that limit the number of parallel transmissions. We referred to this constraint in our paper as *self-interference* constraint. We also utilized their experimental results on interference range in our paper as an input to our algorithm for constructing I-Matrix.

A few more existing works focused on designing POC-aware channel allocation and scheduling schemes by applying variants of classic network resource allocation schemes. In [2], Liu *et al.* proposed a genetic algorithm scheme for joint channel allocation and link scheduling using POCs in single radio based wireless mesh networks. Their simulation results also showed that POC works better in denser networks. The authors mentioned the extendibility of their algorithm in multi-radio environment, but they failed to mention about the different types of interference issues (like self-interference) that arises while considering

MRMC networks. Hence their algorithm, though improved system throughput for single radio environment, may not be feasible in multi-radio environments.

In [1], Rad, et al., formulated the joint channel assignment and link scheduling problem in multi-radio environment as a linear mixed integer problem. Their simulation results showed that there was a significant performance improvement in terms of a higher aggregate network capacity and a lower bottleneck link utilization when all the POCs were used. But unfortunately, their algorithm also lacks the concept of self-interference.

Our study utilizes the promising results from the early work about the potential of POCs in increasing network throughput, and applies them to the channel assignment scheme for multiple radio and multiple channel networks. Our algorithm integrates all the related interference issues which are missing in most previous works.

VII. CONCLUSION AND FUTURE WORKS

This work presented a channel assignment algorithm that uses the partially overlapped channels in addition to conventional orthogonal channels for multi-radio multi-channel wireless mesh networks. We developed the new I-Matrix interference model to provide metric for the assignment decisions. Our algorithm has shown capacity improvements of more than 15% on average and up to 30% in some cases with random topologies. Along this line, we will consider dynamic assignments of channels for mobile nodes in the future and evaluate in mobile network scenarios (instead of the static topology used here). We do believe that this work started a novel approach to introduce the usability of POCs for channel assignment in an MRMC mesh network.

REFERENCES

[1] A. Hamed Mohsenian Rad and Vincent W.S. Wong, "Partially overlapped channel assignment for multi-channel wireless mesh networks," Proceedings of IEEE International Conference on Communications, ICC 2007, pp. 3770-3775.

[2] Haiping Liu, Hua Yu, Xin Liu, Chen-Nee Chuah, Prasant Mohapatra, "Scheduling Multiple Partially Overlapped Channels in Wireless Mesh Networks," Proceedings of IEEE International Conference on Communications,ICC 2007, pp.3817 - 3822.

[3] Zhenhua Feng and Yaling Yang, "How Much Improvement Can We Get From Partially Overlapped Channels?," Proceedings of IEEE WCNC 2008, pp. 2957 – 2962.

[4] Zhenhua Feng and Yaling Yang, "Characterizing the Impact of Partially Overlapped Channel on the Performance of Wireless Networks," Proceedings of IEEE GLOBECOM 2008, pp.1 –6.

[5] A. Mishra, V. Shrivastava, S. Banerjee, and W. Arbaugh, "Partially overlapped channels not considered harmful," in *Proc. of ACM SIGMetric*, Saint Malo, France, June 2006.

[6] Arunesh Mishra, Eric Rozner, Suman Banerjee, William Arbaugh, "Exploiting partially overlapped channels in wireless networks: Turning a peril into an advantage," Internet Measurement Conference, Berkeley, CA, October 2005.

[7] B. Ko, V. Misra, J. Padhye, D. Rubenstein, "Distributed channel assignment in multi-radio 802.11 mesh networks," *in Proc. WCNC*, 2007.

[8] M. Alicherry, R. Bhatia, and L. Li, "Joint channel assignment and routing for throughput optimization in multi-radio wireless mesh networks," in *ACM MobiCom*, 2005.

[9] Kai Zing, *et al*. "Superimposed code based channel assignment in multi-radio multi-channel wireless mesh networks." Proceedings of the 13th annual ACM international conference on Mobile computing and networking,2007.

[10] Pradeep Kyasanur and Nitin Vaidya, "Routing and interface assignment in multi-channel multi-interface wireless networks," in *Proceedings of IEEE WCNC*, 2004.

[11] Jungmin So and Nitin Vaidya, "Routing and channel assignment in multi-channel multi-hop wireless networks with single network interface," *Technical Report, University of Illinois at Urbana Champaign*, 2005.

[12] Ashish Raniwala, Kartik Gopalan, and Tzi cker Chiueh, "Centralized channel assignment and routing algorithms for multi-channel wireless mesh networks," *ACM Mobile Computing and Communications Review*, April 2004.

[13] Ka-Hung Hui, Wing-Cheong Lau and On-Ching Yue, "Characterizing and Exploiting Partial Interference in Wireless Mesh Networks" Proceedings of IEEE International Conference on Communications, ICC 2007.

[14] Garcia E, Lo´pez-Aguilera E, Vidal R, Paradells J. "Effect of adjacent-channel interference in IEEE 802.11 WLANs." Proceedings of the 2nd International Conference on Cognitive Radio Oriented Wireless Networks and Communications, CROWNCOM'07, August 2007; pp. 118–125.

[15] EG Villegas, RV Ferre, J Paradells, "Frequency assignments in IEEE 802.11 WLANs with efficient spectrum sharing" Wireless Communications and Mobile Computing, 2008.

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