Link-Preserving Interference-Minimization Channel Assignment in Multi-Radio Wireless Mesh Networks

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***Abstract*—In a wireless mesh network, an efficient utilization of multiple radios with multiple channels involves the assignment of channels to radios/links. This becomes an optimization problem for which various objectives can be defined with various conflicting constraints and requirements. We present a novel channel assignment strategy based on predicted upper-bound and lower-bound of interference associated with particular assignments. An additional design is also proposed to prevent the possibility that two ends of any designated link are not assigned a common channel. Simulation results indicate that the proposed algorithm outperforms existing approaches in the number of operative links when only few channels or sufficiently many radios are provided.**

I. Introduction

A wireless mesh network (WMN) is an infrastructure that provides data access services to mobile stations equipped with wireless interface. It enhances wireless local area network (WLAN) in that dozens of mesh access points (MAPs), which provide wireless access service to mesh clients, are deployed in a large geographical area and linked together by a wireless backhaul network. The backhaul network, which may adopt a wireless transmission technology different from that used by wireless access links, allows for multiple gateways to wired network and multiple frame forwarding paths between any pair of MAPs.

In planning the backhaul network, one MAP may be demanded to establish several wireless links, one to each neighboring MAP. Transmitters that operate on the same channel in close proximity cause co-channel interference which degrades link capacity. A simple way to prevent such degradation is to equip each MAP with several standalone wireless interfaces (radios) such that several non-overlapping channels can be utilized in parallel. In such a multi-radio, multi-channel WMN, how to assign channels/radios to links becomes an optimization problem for which various objectives can be defined with various conflicting constraints and requirements. Variants of this problem have been proven NP-hard and many heuristics have been proposed [1], [2], [3], [4].

A general setting of the channel assignment problem is to equip each MAP with multiple radios for the utilization of several channels and the establishment of one link to each neighboring MAP. The problem can be formulated as a mapping from radios to channels/links (radio-centric) or from links to channels/radios (link-centric). Channel assignments can be traffic-aware [1], [5], [2] or traffic-independent [6], [7]. The former assumes that different links bear different amount of traffic load while the latter does not have such assumption. Existing approaches may assume overlapping [6] or non-overlapping channels [8], [7]; they may also assume different interference models (Protocol or Physical [9]).

The primary goal of channels assignments may be minimizing local interference [6], minimizing overall interference [3], minimizing maximum interference [4], maximizing total operative links [7], or maximizing total network goodput [1], [2]. Despite of the diversity, existing approaches still share some common properties. For example, almost all existing approaches assume a limited number of radios (radio constraint). It is also a common requirement to preserve every link in the physical topology (link-preserving requirement) or, at least, guarantee that the network remains connected (connectivity requirement) after channel assignments. A typical technique to satisfy the connectivity requirement is by way of default channel [10], [8], [5], [6]. To guarantee the link-preserving requirement, on the other hand, channel switching [11] or other complicated techniques may be needed to deal with possible violation of the radio constraint [3].

This paper assumes non-overlapping channels and Physical interference model. The number of radios allocated to each node is assumed fixed (i.e., the radio constraint) and known, and all radios are identical. We propose a traffic-independent, link-centric channel assignment algorithm with a goal to meet the link-preserving requirement while minimizing overall network interference.

Our contribution. We summarize the unique features that set us apart from existing channel assignment approaches on multi-channel, multi-radio environment as follows.

- We have proposed a coordination-free design that simply *prevents* potential violations of the link-preserving requirement. The correctness of this design has been proven.
- We have designed a greedy channel assignment strategy which estimates both upper-bound and lower-bound of

interference that may occur to an assignment. This information significantly helps decide which channel to use throughout the whole decision process as the worst-case and best-case performance of any particular decision can be predicted.

The remainder of this paper is organized as follows: Background information and related work are presented in Section II. In the following section we present a greedy channel assignment approach with a special treatment to deal with the link-preserving requirement. In Section IV, simulation results of the proposed approach are evaluated and compared with other alternatives. Section V concludes this paper.

II. Preliminaries

Wireless access network and wireless backhaul network coexist in a WMN. We assume that wireless access networks use a wireless technology or spectrum different from that used in the wireless backhaul network (the former 802.11g and the latter 802.11a, for example) such that no communication in an access network can interfere with that in the backhaul network. We only consider channel assignments for the backhaul network and assume all channels are non-overlapping, i.e., no interference from adjacent channels is expected.

As an effort towards a clear formulation of channel assignment problem, we formally define three entities in a WMN: nodes, radios, and links. A *node* is a mesh point (MP) in the wireless backhaul network that forwards frames for other nodes. A *radio* is a wireless interface that can operate on one channel at a time. A node can be equipped with multiple radios, allowing for parallel communications with several other nodes.

Link is an ambiguous term in the literature. Most researchers consider only *physical links*. A physical link exists between two nodes when these two nodes are within the transmission range of each other. This definition only takes account of signal strength. We explicitly define *designated links* (generally paraphrased as virtual links [1], [5]), which is a given subset set of physical links to be assigned channels. Many studies implicitly assume the identity between physical links and designated links, but that may not always be the case.

A physical link is *operative* if it functions correctly after channel assignments. There are two reasons for a physical link to be inoperative after channel assignments. More specifically, a bidirectional physical link $l(u, v)$ between nodes u and v is operative only if the following two conditions are both met.

- *Common-channel constraint*. $K_u \cap K_v \neq \phi$, where K_u and K_v are the sets of channels used by u's radios and v's radios, respectively.
- *Interference constraint*. The interference experienced by u and v must not exceed some threshold level.

Physical links that satisfy the common-channel constraint are said to be *committed*. Only a subset of committed links are operative (Fig. 1).

The common-channel constraint and the interference constraint may be conflicting when several nearby links are under consideration. The interference constraint suggests that we should take advantage of channel diversity on allocating channels to nearby links to minimize co-channel interference. On the other hand, the common-channel constraint suggests that channel assignments should maintain some convergence, allowing for two ends of a link to tune to a common channel. When the number of radios are limited, we may not be able to find a channel for some link without interfering with some other links and making them inoperative.

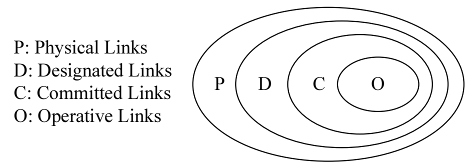


Fig. 1. Relationship among different types of links

Link-preserving requirement demands that every designated link must also be a committed link. An alternative is *connectivity* requirement, which demands that the whole network must remain connected (not partitioned) despite possible existence of some inoperative links. This requirement is weaker than the link-preserving requirement provided that the given set of designated links comprise a connected network.

There are constraints other than the common-channel constraint and the interference constraint. *Channel constraint* assumes that the number of available channels is limited while *radio constraint* places a quantity constraint on radio interfaces. In practice, the assignment problems are usually subject to *tight radio constraint*, *i.e.*, the number of radio interfaces each node has is less than either the number of channels available to the node or the number of designated links incident on the node.

Two commonly-adopted models for the analysis of link interference are the *Protocol Model* and the *Physical Model* [9]. In the Protocol Model, a unidirectional transmission from i to j is considered successful if no other transmitters are located within some physical distance (the *interference range*). Most researchers further consider bidirectional communication and assume several variants for which two links are considered interfering with each other. For example, a link can be considered interfering with another if these two links share a common end [12] or one end of the former link is within some hop count from one end of the latter [6]. Regardless of the variety of definition, a common property associated with these variants is that the interference relation is Boolean, binary, and symmetric. Consequently, whether a link is operative can be checked by examining the interference relation between this link and all others in a pair-wise manner.

In the Physical Model, a unidirectional transmission from i to j is considered successful only if the ratio of the signal strength to the aggregated interference intensity from all other transmitters plus background noise (i.e., signal to interference and noise ratio or SINR) exceeds some threshold. The SINR can be obtained by theoretical modeling [9] or field measurements. When considering bidirectional communication, whether a link is operative depends on aggregated interference intensity from all other links, not only determined by the presence of a single link. Interference relation defined by this model is usually asymmetric.

Tam *et al*. [11] assumed that each node has single radio interface while multiple channels are available. These channels are utilized by dividing link-layer transmission time into fixed-size time slots and scheduling the transmission and reception slots to reduce possible co-channel interference among nearby transceivers. This approach demands network-wide tight time synchronization, which is not easy to achieve. The incurred channel switching delay may not be neglected for some applications.

The simplest approach to multi-channel multi-radio channel assignment is Common-Channel Assignment (CCA) (assumed in [13]), which assigns channel 1 to the first radio interface of each node, channel 2 to the second radio interface of each node, and so on. This approach demands no coordination among nodes and retains network connectivity (when committed links are of concern). However, it also leads to a high degree of interference. For this reason CCA usually serves as a baseline for performance comparison.

Ko *et al*. [6] considered interference due to overlapping channels and modeled it by the Protocol Model. They proposed a distributed algorithm to minimize local interference level subject to the channel constraint, the radio constraint, and the connectivity requirement. To guarantee network connectivity, each node is required to reserve a radio interface to operate on a default channel.

The study in [7] assumes the Physical Model and considers both the interference and the channel constraints. A channel is assigned to a link if and only if the resultant interference is below a threshold. After channel assignment is completed, all designated links that are not yet assigned channels are to be replaced by free-space optical links. The authors apply generic algorithm to minimize the number of required optical links. However, this work does not consider the radio constraint, and it is untold how to deal with the case when the number of channels assigned to a node exceeds the number of radio interfaces the node has.

Reference [4] considers the radio constraint, the channel constraint, and the link-preserving requirement. Its goal is to minimize maximum interference in the network. The authors have shown that this problem is NP-hard, and proposed a heuristic approach called CLICA that assigns channels to radios in a node-by-node manner. Each node in this approach is associated with a priority that determines the order of this node in the assignment. The priority may be altered during the assignment procedure to meet the link-preserving requirement.

Subramanian *et al*. [3] assumed the Protocol Model and used conflict graphs [2] to represent interference between pairwise links. They modeled interference-free channel assignment as a node coloring problem in a conflict graph, which has been shown NP-hand, and proposed a heuristic algorithm based on tabu search [14]. The goal is to minimize overall network interference subject to the link-preserving requirement with the channel constraint and the radio constraint. When the number of channels assigned to a node is larger than the number of radio interfaces the node has, channels will be merged to meet the radio constraint. This is in contrast to [7].

III. The Proposed Approach

A. Problem Formulation

We model link-centric channel assignment as a composition of two mappings (functions). For each node i in the WMN, let R_i be the set of i's radios, K_i be the set of channels available to i, and L_i be the set of designated links incident on i which are to be assigned channels. Link-centric channel assignment can be modeled as a composition of two mappings (functions) $g_i \circ f_i$, where functions $f_i : L_i \to K_i$ and $g_i : K_i \to R_i$ are defined for each node i.

Let $r_i = |R_i|$, $k_i = |K_i|$, and $l_i = |L_i|$. The tight radio constraint states that $r_i < \min(k_i, l_i)$ for each i. If there is any f_i for which $|f_i(L_i)| > r_i$, then the mapping from $f_i(L_i)$ to R_i cannot be one-to-one and we must face the difficulty of letting these $|f_i(L_i)|$ channels share r_i radios. Therefore, we intentionally limit the number of channels that can be assigned to links of node i by r_i. This limitation ensures that $|f_i(L_i)| = r_i$ and the mapping from $f_i(L_i)$ to R_i can be one-to-one for each i. The exact mapping from $f_i(L_i)$ to R_i does not matter in terms of interference when all radios are identical. It can be defined by simply assigning a different radio to each channel in $f_i(L_i)$. In this way, we can skip the definitions of g_i and focus on those of f_i in our problem formulation.

Define N to be the set of all nodes and

$$D_{i,j} = \begin{cases} 1 & \text{if } l(i,j) \text{ is a designated link,} \\ 0 & \text{otherwise.} \end{cases}$$

Clearly, $L_i = \{(i,k)|D_{i,k} = 1\} \cup \{(k,i)|D_{k,i} = 1\}$. Given N, $\{D_{i,j}\}$, $\{r_i\}$ and $\{K_i\}$, the Minimal Interference Problem is to define f_i for each node i such that overall signal quality

$$\sum_{i \in N} \sum_{j \in N - \{i\}} \sum_{k \in K_i \cap K_j} (D_{i,j} \cdot F_{i,j}(k) \cdot I_{i,j}(k)) \tag{1}$$

is maximized subject to $\forall i \in N : |f_i(L_i)| = r_i$ and the link-preserving requirement

$$\forall i, j \in N : D_{i,j} = 1 \Rightarrow \sum_{k \in K_i} F_{i,j}(k) \geq 1, \tag{2}$$

where $F_{i,j}(k)$ is an indicator variable defined as

$$F_{i,j}(k) = \begin{cases} 1 & \text{if } k \in f_i(L_i) \cap f_j(L_j), \\ 0 & \text{otherwise} \end{cases} \tag{3}$$

and $I_{i,j}(k)$ denotes the SINR value of i's transmission received at node j when $l(i,j)$ operates on channel k. In the Physical Model, $I_{i,j}(k)$ is defined by [9]

$$I_{i,j}(k) = \frac{S_{i,j}}{\sum_{l \in N - \{(i,j)\}} (S_{l,j} \cdot F_{l,j}(k)) + N_a}, \tag{4}$$

where $S_{i,j}$ is the signal strength of i's transmission received at j and N_a denotes background noise. In this paper, we assume the use of Friis Free Space Model [15] to compute signal strength $S_{i,j}$, but other models or estimations can also be used.

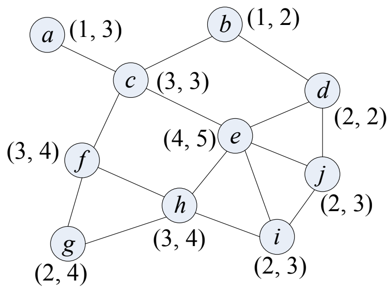


Fig. 2. An example of applying the link-preserving rule to a WMN. Number pair (r, u) associated with each node indicates the number of radios the node is given (r) and the maximum channel number the node can use (u) as indicated by (5).

B. On the Link-Preserving Requirement

To meet the link-preserving requirement indicated by (2), $f_i(L_i) \cap f_j(L_j)$ must not be empty for every designated link $l(i, j)$. Our approach already limits *the number of* channels to be allocated to links of a node to meet the tight radio constraint. However, we does not yet specify *the range of channels* that can be used in an allocation. We shall show that a proper range setting can further guarantee the link-preserving requirement.

Recall that our approach ensures that $f_i(L_i) \to R_i$ is one-to-one for all node i to meet the radio constraint. This mapping must be onto as well to fully utilize radio bandwidth. In other words, every radio of a node is assigned to a different channel. With this property, the following theorem shows a rule to guarantee the link-preserving requirement.

Theorem 1: Assume that every radio of the same node is assigned to a different channel. If each node i limits the set of channels that it can use to $K'_i = \{c_1, c_2, \cdots, c_u\}$, where

$$u = \min_{j \in N - \{i\}} \{D_{i,j} \cdot (r_i + r_j - 1)\}. \tag{5}$$

then the link-preserving requirement is met.

Proof: Suppose, by way of contradiction, that every node limits the available channel set to that as indicated by (5) but the common-channel constraint is not met for some designated link $l(i, j)$. Let $m = (r_i + r_j - 1)$, $K'_i = \{c_1, c_2, \cdots, c_u\}$, and $K'_j = \{c_1, c_2, \cdots, c_v\}$. By definition, $|K'_i| = u \leq m$, $|K'_j| = v \leq m$ and $K'_i \cup K'_j \subseteq \{c_1, c_2, \cdots, c_m\}$. Since every radio of the same node is assigned to a different channel, node i must choose r_i out of u channels from the set $\{c_1, c_2, \cdots, c_u\}$ and node j must choose r_j out of v channels from the set $\{c_1, c_2, \cdots, c_v\}$. Let the sets of channels chosen by i and j be C_i and C_j, respectively. We have $|C_i| = r_i$ and $|C_j| = r_j$. Violating the common-channel constraint implies that $C_i \cap C_j = \phi$. By the inclusion-exclusion principle

$$\begin{aligned} |C_i \cup C_j| &= |C_i| + |C_j| - |C_i \cap C_j| \\ &= r_i + r_j. \end{aligned} \tag{6}$$

On the other hand, since $C_i \subseteq K'_i$ and $C_j \subseteq K'_j$, we have $|C_i \cup C_j| \leq |K'_i \cup K'_j| \leq m = r_i + r_j - 1$, which contradicts (6). We thus have the proof. ■

Figure 2 shows an example of our rule applying to a given WMN.

The closest related work to ours is the Tabu-based approach [3], which is also link-centric. The Tabu-based approach consists of two phases. The first phase assigns channels to links with a goal to minimize interference but without worrying about the radio constraint. All nodes where the radio constraint is violated after the first phase are then processed in the second phase, undergoing a channel-merging procedure that may cause chain reactions to other nodes. In contrast, our proposal simply *prevents* any violation of the radio constraint during the assignments of channels to links.

C. On Channel Assignment

The proposed approach assigns channels to links on a link-by-link basis. Among all available channels, the channel that leads to the highest signal quality will be assigned to the link under consideration. This strategy seems sound, but we have to accurately gauge the quality of channel assignments and determine the assignment order of links.

Gauging the quality of channel assignments becomes an issue because typically only partial information is available to an assignment. Assume that $S_{i,j}$ for every nodes i and j is known (which can be achieved by field measurements or theoretical modeling). For any physical link $l(i, j)$ and channel k, $I_{i,j}(k)$ stands for the quality of assigning channel k to link $l(i, j)$. The computation of $I_{i,j}(k)$ considers interference from all other links $l(u, v)$ for which $F_{u,v}(k) = 1$, as indicated by (4). However, as channel assignments are done in a link-by-link manner, $\{l(u, v)|F_{u,v}(k) = 1\}$ only represents a set of links *already known* to introduce interference to $l(i, j)$ on channel k. A link $l(u, v)$ for which $F_{u,v}(k) = 0$ either has been assigned a channel other than k or has not yet been assigned any channel. The latter possibility can degrade the eventual value of $I_{i,j}(k)$ if $l(u, v)$ is assigned channel k later. Therefore, an assignment based on $I_{i,j}(k)$ is *optimistic* as it ignores such possibility, and the resultant SINR of $l(i, j)$ on channel k can be less than $I_{i,j}(k)$ after the channel assignment is completed.

To address this concern, we also study a pessimistic estimation of link SINR that takes account of all potential interference. We first define $G_{i,j}(k)$ as follows:

$$G_{i,j}(k) = \begin{cases} 1 & \text{if } F_{i,j}(k) = 1 \text{ or } \sum_k F_{i,j}(k) < r_i, \\ 0 & \text{otherwise.} \end{cases} \tag{7}$$

Then a *pessimistic* estimation can be defined by

$$J_{i,j}(k) = \frac{S_{i,j}}{\sum_{l \in N - \{i,j\}} (S_{l,j} \cdot G_{l,j}(k)) + N_a}. \tag{8}$$

It represents the SINR of $l(i, j)$ under the assumption that all other links not yet assigned channels will take channel k.

$I_{i,j}(k)$ (resp. $J_{i,j}(k)$) is generally different from $I_{j,i}(k)$ (resp. $J_{j,i}(k)$). Since we consider bidirectional links, we actually take $N_{i,j}(k) = \min\{I_{i,j}(k), I_{j,i}(k)\}$ and $M_{i,j}(k) = \min\{J_{i,j}(k), J_{j,i}(k)\}$ as the quality metrics in use. $M_{i,j}(k)$ and $N_{i,j}(k)$ are the lower bound (or the worst-case) and upper bound (or the best-case) SINR of $l(i,j)$ on channel k, respectively. The final SINR value after assignment is completed will fall into the range between these two extremes.

As we have mentioned, the proposed approach assigns channels to links on a link-by-link basis. The order in which channels are assigned to links does affect the final result. Given $\{N_{i,j}(k)\}$ and $\{M_{i,j}(k)\}$ for every link $l(i,j)$ on every available channel k, how should we determine the order of links in assigning channels? This is a question because the values of $N_{i,j}(k)$ and $M_{i,j}(k)$ may diverge. Initially, $\forall i,j,k : F_{i,j}(k) = 0$, so $\forall i,j,k : G_{i,j}(k) = 1$. Therefore, the maximal value of $N_{i,j}(k) - M_{i,j}(k)$ for all $l(i,j)$ occurs in the very beginning. As channels are assigned to links, the difference between $N_{i,j}(k)$ and $M_{i,j}(k)$ diminishes. For the last link $l(i,j)$ in assignments, $N_{i,j}(k) = M_{i,j}(k)$ for all k.

We define $C_{i,j}(k)$ as below for the priority of links in channel assignment. Formally,

$$C_{i,j}(k) = \left(\frac{\alpha-\beta}{\alpha}\right) M_{i,j}(k) + \left(\frac{\beta}{\alpha}\right) N_{i,j}(k), \qquad (9)$$

where α is the total number of designated links and β is the number of links that have already been assigned channels. When picking up a link to assign channel, the one with the highest $C_{i,j}(k)$ value will be chosen, and it will be assigned channel k.

The rationale behind (9) is that $N_{i,j}(k)$ and $M_{i,j}(k)$ are not always of the same importance to $l(i,j)$. When most links are not yet assigned channels ($\beta \ll \alpha$), the worst-case estimation, $M_{i,j}(k)$, is given more weight than the best-case estimation $N_{i,j}(k)$ to reflect our major concern of risk as there is still a lot of uncertainties in the future. On the other hand, when most links have been assigned channels ($\beta \approx \alpha$), the worst-case estimation is given less weight than the best-case estimation. This setting tries to maximize the best-case performance, which is hopeful as not many links are left unassigned.

After a channel k is assigned to $l(i,j)$, associated F and G variables should be updated to reflect the new status. For all nodes $l \in N - \{i,j\}$, $F_{i,l}(k)$ and $F_{j,l}(k)$ are set to 1. If i (resp. j) has all its radios assigned channels, $G_{i,l}(c)$ (resp. $G_{j,j}(c)$) should be reset to 0 for all $c \neq f_i(L_i)$ (resp. $c \neq f_j(L_j)$). The assignment process is then repeated.

IV. Simulation Results

We study the performance of the proposed algorithm through simulations. The proposed algorithm was compared with CCA [13], Tabu-based [3], and CLICA [4]. These approaches were chosen because they all meet the link-preserving requirement (just like ours)[1]. For this common property, comparisons can be made on a fair basis. All the algorithms under comparison require a set of designated links as inputs. The counterparts all assume the notion of transmission range to obtain physical links and take physical links as designated links. We take the same assumption though our algorithm does not rely on such assumption. Tabu-based and CLICA additionally require the setting of interference range. In that case we assume identical transmission and interference ranges as in [3], [4].

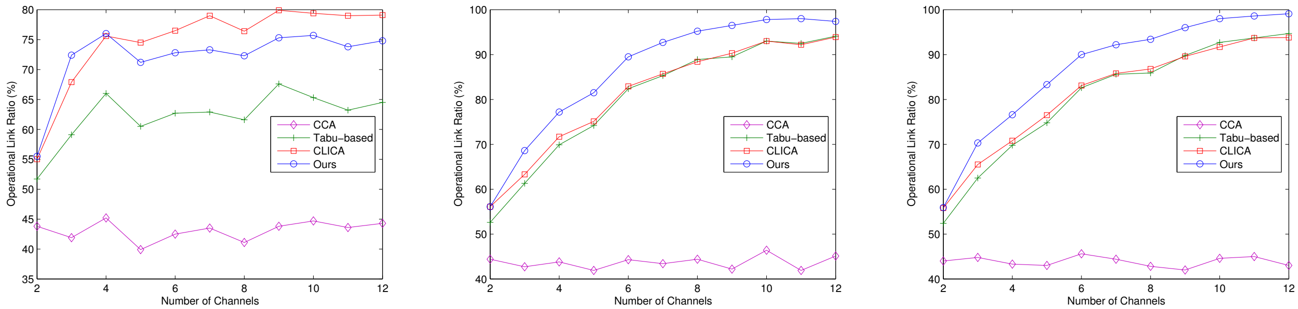
We are interested in how many operative links can be yielded by different approaches. To this end, we define *operational link ratio* (OLR) to be the number of operative links divided by the number of total designated links. Concerning the interference constraint, OLR is surely affected by the setting of SINR threshold. The threshold value t_s in the simulations is set to the minimum one that still makes the link with the most distant end points operative (disregarding any interference). This is to ensure that all designated links are operative if and only if no designated link experiences any interference. Since interference is unavoidable under our simulation settings, the chosen t_s makes 100% OLR impossible, and the OLR value can be considered a gauge of effective interference.

We assumed a 100×100 m^2 area, within which 20 MAPs were randomly placed. We measured OLR by varying the number of available channels k and the number of radio interfaces per node r. Transmission range was set to 25 m in all trials. Each result is an averages over 100 trials.

We first fix r and observe how OLR changes with k. Fig. 3a shows the results with $r = 2$. We can see that the performance of CCA is irrelevant to k, which is justifiable as CCA does identical channel assignment at all nodes, and at most one designated link counts between any pair of nodes. Similar results have been reported by other researchers [4]. Both the proposed approach and CLICA outperform Tabu-based. CLICA results in higher OLRs than our approach does when $k \geq 5$. The reason is that our algorithm limits the number of channels to be used by $(2 + 2 - 1) = 3$ regardless how many channels are available. This trend changes when we have more radios per node. Fig. 3b shows the results with $r = 6$. When $r = 6$, the number of channels used by our algorithm is limited by $(6+6-1) = 11$. Therefore, every channel is usable except for the case of $k = 12$. Our algorithm outperforms all counterparts except for the case of $k = 2$, where the OLR value of CLICA is equal to ours. The superiority of our algorithm over the counterparts remains the same when r is increased up to 12 (Fig. 3c).

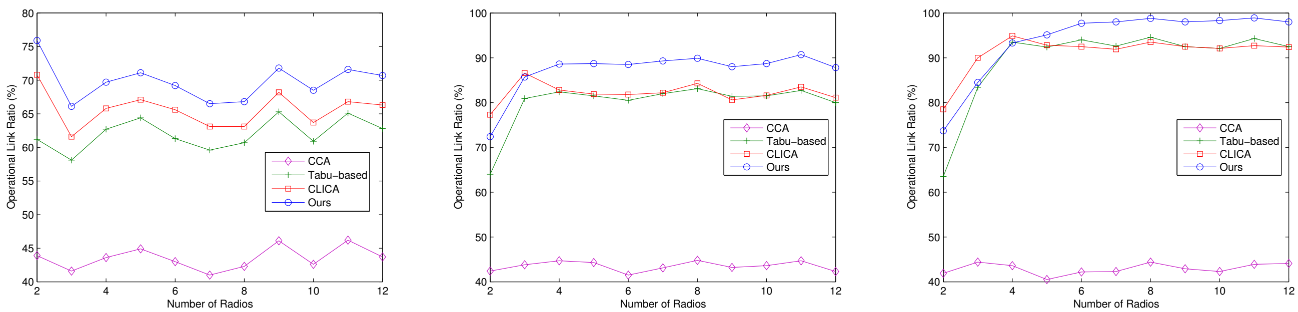
In the next set of simulations, we fix k to 3, 6, and 12, respectively, and study the relation between r and OLR. When $k = 3$, more radios ($r \geq 3$) do not necessarily lead to increased OLR due to the lack of channel resource (Fig. 4a), and the proposed algorithm performs the best. When the number of available channels is increased to six (Fig. 4b) or 12 (Fig. 4c), both CLICA and Tabu-based exhibit an increase in OLR initially and a marginal improvement thereafter ($r \geq 4$), which suggests that these two approaches do not fully exploit all radios. The proposed approach can use up to $\min(k, 2r-1)$ channels, so its performance is next to that of CLICA when r is small. However, OLRs with the proposed algorithm surpass those of the others when $r \geq 4$ in Fig. 4b and when $r \geq 5$ in Fig. 4c. When $r \geq (k+1)/2$, OLRs yielded by the proposed approach are hardly increasing, as the performance is upper

[1]The simulations results confirm that all the four algorithms meet the link-preserving requirement.



(a) (b) (c)

Fig. 3. OLR versus the number of channels with (a) $r_i = 2$ (b) $r_i = 6$ and (c) $r_i = 12$ for all node i



(a) (b) (c)

Fig. 4. OLR versus the number of radios with (a) $k = 3$ (b) $k = 6$ and (c) $k = 12$

bounded by the fixed k. Remarkably, these OLRs are close to 100% when $r > 6$ in Fig. 4c.

We conclude from the simulation results that the proposed algorithm is able to increase the number of operative links when only few channels or sufficiently many radios are provided. Its performance is still acceptable when many channels but few radios are available.

V. Conclusions

Our proposal for the link-preserving requirement is simple as it prevents possible violation of the radio constraint during channel assignments rather than resolves violations associated with assignments. The proposed link-centric channel assignment strategy selects channels based on predicted upper-bound and lower-bound of interference. Simulation results have confirmed the efficiency of this design. The proposed approach performs the best in terms of the number of operative links particularly when only few channels or sufficiently many radios are provided.

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