Joint Channel Assignment and Link Scheduling for Wireless Mesh Networks: Revisiting the Partially Overlapped Channels*

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***Abstract*—Despite all the encouraging reports on the benefit of Partially Overlapped Channels (POCs), the relative simple interference models and rather arbitrary network settings considered in the literature make those reports questionable. In order to gain proper engineering insights, we look into the problem of improving network throughput by making use of POCs in this paper. Our perspectives are novel in that we 1) adopt a more realistic model to capture the additive nature of interference, 2) apply efficient solution techniques to obtain the optimal solutions of the hard optimization problems, and 3) focus on a typical mesh networking scenario. The outcome of our investigations, though revealing interesting aspects of using multiple channels, contradicts the previous statements by exhibiting that only a marginal gain can be obtained if POCs are used.**

***Index Terms*—Wireless mesh networks, partially overlapped channels, channel assignment, scheduling.**

I. Introduction

As resource scarcity is a general challenge of wireless networking, radio frequency (RF), an important resource for wireless communications, needs to be fully utilized to improve the performance of wireless networks. Given the ability of many wireless NICs to operate on various RF channels, a conventional approach (e.g., [1]) is to smartly assign different links with those channels that have no overlap in their respective frequency domain (termed *Non-Overlapped Channels*, or NOCs), such that the network performance can be improved due to the enhanced spatial reuse. Inspired by the measurement results reported in [2], the community started to believe that network throughput can be improved by further use of *Partially Overlapped Channels* (POCs), as more simultaneous transmissions are allowed thanks to the attenuated interference compared with the co-channel ones. However, having more channels to assign may complicate the protocol design. In this paper, we intend to verify if the benefit of POCs justifies the added design complexity in a specific network scenario.

Many efforts have been made to theoretically study the network throughput improvement gained by using POCs along with NOCs (termed *POC scheme*), mainly focusing on the *Wireless Mesh Networks* (WMNs) scenario. Rad and Wong [3] formulated the channel assignment and scheduling problem concerned with the POC scheme as a mixed-integer linear program (MILP), and claimed a 90% increment of aggregate network throughput. A further step was made later in [4] and [5], where the authors addressed the flow allocation along with channel assignment. Their results show that the POC scheme notably outperforms the NOC-only deployment (termed *NOC scheme*) if enough POCs have been utilized. Apart from the optimization approaches, heuristics-based approaches were also proposed to handle the channel assignment and/or scheduling problem, e.g., [6], [7]. Their conclusions also show the POC scheme's promising enhancement of network throughput.

Although these extensive studies all report encouraging results, the models and formulations they used make the results misleading. Firstly, in most of the previous studies, the protocol interference model [8] (or its variances) was used to describe the interference between every pair of links, which leads to a binary interference matrix. As interference in practice is additive rather than binary, their results are not convincing from the engineering viewpoint. Secondly, most of the results obtained in the literature are not the optimal solutions to the respective optimization problems, as link scheduling is done by either using *sufficient scheduling condition*[1] [3], [5] or being decoupled from the channel assignment [6], [7]. Finally, the problem objectives were sometimes rather arbitrarily defined in the literature, which may not properly represent the actual needs for a WMN. For example, other than aggregated link data rates [3], [5], we are concerned with the throughput of the flows between mesh router and the gateway that links a WMN to the Internet.

In this paper, we revisit the *Joint Channel Assignment and Link Scheduling Problem* (JCSP), aiming at revealing the actual improvement of network performance introduced by POCs. Our work distinguishes itself from the literature in the following aspects. Firstly, as suggested in [9], we adopt the more **realistic** physical interference model [8] to characterize the additive interference from all the potentially interfering links. Secondly, We formulate the JCSP problem and obtain its optimal solutions using an extended version of the tools

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[1]The condition was used in [1] to obtain an approximate solution to the link scheduling problem. As the condition only states a sufficiency for a flow allocation to be feasible, the resulting solution can be suboptimal.

we developed in [10]. These optimal solutions allow us to truly evaluate the difference between the NOC scheme and the POC scheme. Finally, we focus on a practical situation that all the routers (nodes) in a WMN are sending traffic to the gateway, which is connected to the Internet. Our objective is maximizing the minimum node throughput, which is regarded as the bottleneck of the network.

Based on the numerical results by exactly solving JCSP, we obtain some novel insights that differ from those in the previous studies. First, as opposed to the significant boost in network throughput stated in some earlier works, however, our results show that the use of POCs, though beneficial, contributes only marginally to the network throughput improvement. Second, no matter for the POC scheme or the NOC scheme, involving more channels is always helpful not only to the network throughput, but also to the energy efficiency as well as the solution simplicity, as it is no longer needed to do joint routing and scheduling.

Our paper is organized in this way: we first introduce the network model that we are using in Section II, and then we present the formulation of JCSP in Section III. In Section IV, we derive our solution techniques to address the hard optimization problems. Numerical results and performance comparisons are presented in Section V. Finally we conclude our paper in Section VI.

II. Model Definition

We consider the following network model. Denote by $\mathcal{N} : |\mathcal{N}| = N$ the set of nodes in a WMN, with $g \in \mathcal{N}$ being the gateway. Let $\hat{\mathcal{L}} : |\hat{\mathcal{L}}| = \hat{L}$ be the set of physical links, and $\mathcal{H} : |\mathcal{H}| = H$ be the set of available channels. Each physical link $\hat{l} \in \hat{\mathcal{L}}$ is identified by its origin $\hat{l}_o \in \mathcal{N}$ and destination $\hat{l}_d \in \mathcal{N}$. In order to jointly perform link scheduling and channel allocation, we also define the logical link set as $\mathcal{L} : |\mathcal{L}| = L$ with each $l \in \mathcal{L}$ represented by $l = (l_o, l_d, h_l)$, where $h_l \in \mathcal{H}$ indicates the assigned channel. It is straightforward to see that each $\hat{l} \in \hat{\mathcal{L}}$ corresponds to a set of logical links $\{l : (\hat{l}_o, \hat{l}_d, h)\}_{h \in \mathcal{H}}$, we use $l \in \hat{l}$ to denote such a correspondence. We also denote by $\mathcal{P}(\mathcal{L})$ the power set of $\mathcal{L}$. Note that in later presentation, a link refers to a logical one unless otherwise specified. In the following, we describe modeling parameters that are specific to each layer in the network stack.

A. Physical Layer Model

Each link l is associated with three parameters: P_l the transmission power (used by l_o), c_l the data rate, and β_l the *Signal to Interference plus Noise Ratio* (SINR) threshold required by the modulation/coding scheme that yields c_l.

1) Interference Factor (I-Factor): To model the interference between links assigned with POCs, we use the theoretical model proposed in [2] and compute the I-Factor that represents the attenuated interference between such links. A typical channel model is shown in Fig. 1. We apply this model to all transmitters and receivers, offsetting it by certain center frequencies according to the assigned channels. We also assume that the channels are indexed by integers from 1 to H and their center frequencies are regularly spaced.

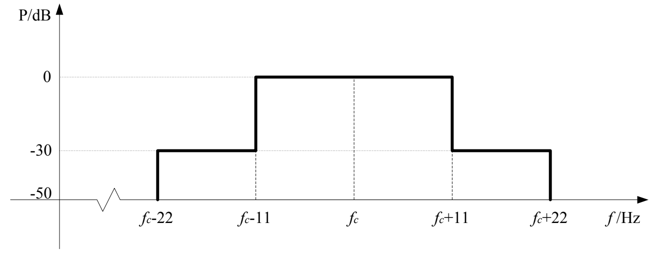

Fig. 1. Illustration of a spectrum mask $M(f)$ with center frequency f_c.

To characterize the extent of the spectrum overlap between any two POCs m and n, the following function is used to compute the I-Factor.

$$I(m,n) = \int_{-\infty}^{+\infty} S_T^m(f) B_R^n(f) df = \int_{-\infty}^{+\infty} M^m(f) M^n(f) df$$

where the first equality is the general form of calculating the received power, with $S_T^m(f)$ indicating the spectrum transform of the (normalized) signal at a transmitter operating on channel m, and $B_R^n(f)$ indicating the filter shape at a receiver operating on channel n. And the second equality follows by plugging in the corresponding spectrum masks of channel m and n, denoted by $M^m(f)$ and $M^n(f)$ respectively, regarding to the transmission signal on channel m and receiving filter on channel n. Let Δ denote the smallest separation in channel indices for two NOCs, we have $I(m,n) = 0$ for $|m-n| \geq \Delta$.

2) Multi-Channel Multi-Radio (MCMR): We assume that each node i is equipped with r_i radios. Let $A = [a_{ih}]_{i \in \mathcal{N}, h \in \mathcal{H}}$ be the channel assignment matrix, where $a_{ih} = 1$ indicates that node i is assigned with channel h; otherwise $a_{ih} = 0$. The channel assignment constraint on each node is

$$\sum_{h \in \mathcal{H}} a_{ih} \leq r_i \qquad \forall i \in \mathcal{N} \tag{1}$$

3) Physical (Interference) Model: Under this model, all links in a link set $\zeta \in \mathcal{P}(\mathcal{L})$ can be activated at the same time iff the following conditions are satisfied.

- The *node exclusion* constraint, i.e., no two links share the same origin and/or destination unless they are assigned with NOCs:

$$\Big((l_o \neq l_o^{'}) \cap (l_d \neq l_d^{'}) \cap (l_o \neq l_d^{'}) \cap (l_d \neq l_o^{'}) \Big) \bigcup \ (|h_l - h_{l'}| \geq \Delta) \qquad \forall l, l^{'} \in \zeta \tag{2}$$

- The *SINR* requirement, i.e., for each link in ζ, its destination receives an SINR exceeding some threshold:

$$\frac{P_l G_{ll}}{N_0 + \sum_{l' \in \zeta \setminus \{l\}} I_{l'l} P_{l'} G_{l'l}} \geq \beta_l \quad \forall l \in \zeta \tag{3}$$

  where $I_{l'l} = I(h_{l'}, h_l)$ is the I-Factor with respect to the channels used by link $l^{'}$ and l, and $G_{l'l}$ is the channel gain from $l_o^{'}$ to l_d. N_0 is the thermal noise power.

Here we adopt the popular channel gain formula that $G_{l'l} = k \cdot (\frac{d_{l'l}}{d_0})^{-\eta}$, with k representing a const factor, $d_{l'l}$ being the distance between $l_o^{'}$ and l_d, d_0 being the reference distance, and η denoting the path loss exponent.

4) Capture (Threshold) Model: For the comparison of different interference models, we also introduce the capture threshold model (named in [9]), which is widely used in the POC scheme related literature. Under this model, a link set ζ can be scheduled for transmission iff (2) is met along with

$$\frac{P_l G_{ll}}{N_0 + I_{l'l} P_{l'} G_{l'l}} \geq \beta_l \quad \forall l, l' \in \zeta \tag{4}$$

This model is similar to the physical model as they both employ the SINR condition. They differ from each other in that the physical model considers the cumulative interference from all other links belonging to ζ, whereas the capture model only considers the pairwise interference between two links. Their performances will be compared in Sec. V-D.

We call a link set that meets the conditions (1)–(3) (in terms of the physical interference model), or (1), (2), and (4) (in terms of the capture threshold model) an *independent set* (I-Set). The collection of all I-Sets is denoted by $\mathcal{I}$.

B. MAC Layer Model

We assume that the network is globally synchronized and the link transmissions are scheduled in a TDMA fashion. As only conflict-free scheduling may contribute to the improvement of network performance metrics, we only involve I-Sets in link scheduling. To this end, we use a transmission schedule vector $\boldsymbol{\alpha} = [\alpha_s]_{s\in\mathcal{I}}$ with α_s representing the *normalized time fraction* assigned to an I-Set s. Given the definition of α_s, we have $\alpha_s \geq 0$ and $\sum_{s\in\mathcal{I}} \alpha_s \leq 1$.

C. Network Layer Model

We consider two types of routing in this paper. The first type is a multi-path routing that is jointly optimized with link scheduling. In other words, the routing paths are not known a priori, they come as the optimal solution to the joint routing and scheduling problem. The second type is an interference aware single-path routing. It is computed separately from the link scheduling by the Dijkstra's shortest path algorithm. The interference awareness is achieved by defining the link length ℓ_l as the reciprocal of the total SINR that link l receives if all other links are transmitting at the same time, i.e.,

$$\ell_l = \frac{N_0 + \sum_{l'\in\mathcal{L}\setminus\{l\}} I_{l'l} P_{l'} G_{l'l}}{P_l G_{ll}} \tag{5}$$

III. Problem Formulation

Based on the model defined in Sec. II, we are ready to formulate the joint channel assignment and link scheduling problem. We assume that each node i generates data flow towards the gateway g at a rate of $\lambda_i \geq 0$, and the objective is to maximize the minimum positive flow rate among all the nodes, which is seen as the bottleneck of the network. We can always transform this objective into a more compact format by putting a lower bound on each λ_i, i.e., $\lambda = \min_{i\in\mathcal{N}}\{\lambda_i | \lambda_i > 0\}$, and by maximizing λ instead. As we consider two types of routing, we will formulate the two corresponding optimization problems separately.

A. Joint Routing, Channel Assignment and Link Scheduling Problem (JRCSP)

Denote by q_l the amount of data going through a link l. The JRCSP is formulated as

$$\max_{\mathbf{q},\,\boldsymbol{\alpha}} \quad \lambda \tag{6}$$

$$\text{subject to} \quad \sum_{l:l_o=i} q_l - \sum_{l:l_d=i} q_l \geq \lambda \quad \forall i \in \mathcal{N},\ i \neq g \tag{7}$$

$$c_l \sum_{l\in s\in\mathcal{I}} \alpha_s \geq q_l \quad \forall l \in \mathcal{L} \tag{8}$$

$$\sum_{s\in\mathcal{I}} \alpha_s \leq 1 \tag{9}$$

$$q_l,\ \alpha_s \geq 0 \quad \forall l \in \mathcal{L},\ s \in \mathcal{I}$$

where $\mathbf{q} = [q_l]_{l\in\mathcal{L}}$ is link load allocation vector. In the above constraints, (7) is the flow conservation for each node except the gateway (for which the constraint is redundant), (8) upper bounds the link load by the effective link capacity, and (9) restricts the normalized scheduling strategy. Here the effective link capacity is computed as the link data rate c_l multiplied by the fraction of time that the link is scheduled for transmission. Note that the physical layer constraints, e.g., (1), (2) and (3), are hidden behind in this formulation, as they are used to implicitly define an I-Set s.

B. Joint Channel Assignment and Link Scheduling Problem (JCSP)

Here we assume that the single path routing is predetermined by the Dijkstra's algorithm as discussed in Sec. II-C. The outcome of the Dijkstra's algorithm is a set of values that capture the number of paths going through each **physical link**; we represent them by a vector $\boldsymbol{b} = [b_{\hat{l}}]_{\hat{l}\in\hat{\mathcal{L}}}$. For the sake of clarity, we introduce the $\{0,1\}$ link–I-Set incidence matrix $U = [u_{ls}]_{l\in\mathcal{L},s\in\mathcal{I}}$ where $u_{ls} = 1$ iff l belongs to I-Set s, as well as the $\{0,1\}$ logical–physical link incidence matrix $V = [v_{l\hat{l}}]_{l\in\mathcal{L},\hat{l}\in\hat{\mathcal{L}}}$ where $v_{l\hat{l}} = 1$ iff $l \in \hat{l}$. We hereby formally present our JCSP formulation.

$$\max_{\boldsymbol{\alpha}} \quad \lambda \tag{10}$$

$$\text{subject to} \quad \sum_{l\in\mathcal{L}} v_{l\hat{l}} c_l \sum_{s\in\mathcal{I}} u_{ls}\alpha_s \geq b_{\hat{l}}\lambda \quad \forall \hat{l} \in \hat{\mathcal{L}} \tag{11}$$

$$\sum_{s\in\mathcal{I}} \alpha_s \leq 1 \tag{12}$$

$$\alpha_s \geq 0 \quad \forall s \in \mathcal{I}$$

Remarks: The above two formulations are both *linear programs* (LPs). However, owing to the huge size of $\mathcal{I}$, the problem may involve up to $O(2^L)$ variables $\{\alpha_s\}_{s\in\mathcal{I}}$. Fortunately, our novel solution technique reported in [10] along with its extension described in Sec. IV still allow us to obtain the optimal solutions to the two problems.

Note that our problems are indeed jointly optimizing over channel assignment and link scheduling, because the link scheduling is performed on a set of logical links that not only specify transmissions but also channel assignment. The resulting channel assignment is **dynamic**, in the sense that it is time-varying.

IV. Solution Techniques

We first briefly review the method we proposed in [10] to solve JRCSP, then we explain in detail how to extend that method to address JCSP. To facilitate the presentation, we define the Lagrangian multipliers of (9), (8), and (11) as ξ, ν_l, and $\nu_{\hat{l}}$, respectively.

A. A Column Generation Based Approach

The observation we made in [10] is that, though a huge number of variables are involved in constraint (8), only a small set of them are positive in an optimal solution. Therefore, a more efficient algorithm should, instead of solving a full scaled problem using an LP solver, start with a small set of variables and add those that may potentially increase the objective value gradually. We term a subproblem that only involves a subset of α_s as the *Restricted Master Problem* (RMP); it differs from the original JRCSP in (8) as the summation is only over an $\mathcal{I}' \subset \mathcal{I}$. The algorithm is as follows:

Algorithm *JRCSP Solver*

1. `JRCSP_solve`($\mathcal{N}$, $\mathcal{L}$)
2. $\mathcal{I}' \leftarrow \mathcal{L}$
3. **repeat**
4. solve RMP with $\mathcal{I}'$, and retrieve ξ and $\{\nu_l\}$
5. identify $s \in \mathcal{I}$, s.t. $p_s = \xi + \sum_{l \in s} \nu_l c_l > 0$
6. $\mathcal{I}' \leftarrow \mathcal{I}' \cup \{s\}$
7. **until** $p_s \leq 0, \forall s \in \mathcal{I}$
8. **return** λ

The rationale of this algorithm stems from the fact that $p_s = \xi + \sum_{l \in s} \nu_l c_l$ is the marginal contribution to the objective value if α_s is involved. Therefore, the termination condition $p_s \leq 0, \forall s \in \mathcal{I}$ states that no α_s is needed anymore. The difficulties in solving the problem lie in 1) finding an I-Set s with positive contribution (line 5) and 2) proving the termination condition holds. We proposed an algorithm that combines greedy heuristics and dynamic programming to address these two difficulties in [10]; we refer interested readers there for details.

B. Extension for JCSP

Apart from missing the flow conservation constraint, JCSP differs from JRCSP mainly in that two types of links are involved in (11): logical links on the LHS and physical links on the RHS. Consequently, the algorithm has to be modified accordingly for its correctness.

Let us write the Lagrangian of JCSP as follows:

$$L(\lambda, \boldsymbol{\nu}, \xi) = \lambda + \sum_{\hat{l}} \nu_{\hat{l}} \left(\sum_{l} v_{l\hat{l}} c_l \sum_{s \in \mathcal{I}} u_{ls} \alpha_s - b_{\hat{l}} \lambda \right) + \xi \left(\sum_{s \in \mathcal{I}} \alpha_s - 1 \right) \quad (13)$$

Then we can write down the marginal contribution of α_s as

$$p_s = \xi + \sum_{\hat{l}} \nu_{\hat{l}} \sum_{l} v_{l\hat{l}} c_l u_{ls} \quad (14)$$

This says that the Lagrangian multiplier corresponds to each physical link is replicated and assigned to each logical link associated with this physical link. It is worth pointing out that (14) differs from the usually used formula shown in *JRCSP Solver* (line 5). Whereas the dual vector corresponding to (11) has the cardinality of $\hat{L}$, which is the number of physical links, in column generation, each candidate s actually involves logical links. Therefore, the formula that computes the marginal contribution of α_s has to be extended to translate the dual vector associated with physical links to that associated with logical links.

V. Performance Evaluation

We first introduce the parameter settings, then we report the results we have obtained by solving both JRCSP and JCSP.

A. Experiment Setting

Our solver is developed in C++, using GLPK [11] as the underlying LP solver to handle the RMPs. For the network scenarios, we randomly deploy the nodes (or mesh routers) in a square area with the gateway at the center. In Sec. V-B, an identical network density is guaranteed for each scenario by letting the area of network proportional to the number of nodes; whereas nodes are distributed within the same area in Sec. V-C and Sec. V-D, making the network density proportional to the number of nodes. For each network, we require every node to send a flow to the gateway. We only consider this type of converging traffic because its counterpart, the diverging traffic sent from the gateway to all nodes, has usually no significant difference in the results, based on our previous experiences.

In terms of physical layer model, we assume $N_0 = -100$ dBm, $d_0 = 0.1$ m, and $\eta = 3$. We also assume that the transmission power and rate are identical for every link. The transmission power P_{tx} is used in some cases as a parameter, and it is tuned for other cases to guarantee connectivity. The rate is normalized to $c = 1$, with an SINR threshold $\beta = 6.4$dB. The channel parameters are taken from the IEEE 802.11 standard, where 11 channels are available, out of which only 3 (the first, sixth, and eleventh) are non-overlapped.

B. More Channels Are Beneficial

In this subsection, we assume that each node is equipped with only one radio, and we compare the throughput given different numbers of available channels. The throughput is obtained as the optimal solution of JCSP (10–12). The benchmark is a curve we have provided in [10], which shows that, with one radio and one channel, the optimal throughput of JRCSP (6–9) is an increasing function of P_{tx}. Besides one obvious conclusion that more channels yield higher throughput, our results actually lead to other interesting findings.

The results for two networks (one with 30 nodes and another with 50 nodes) are presented in Fig. 2. One immediate observation is that the improvement in throughput brought by having more channels is more evident in low power regime, as the bottleneck becomes the gateway in high power regime and

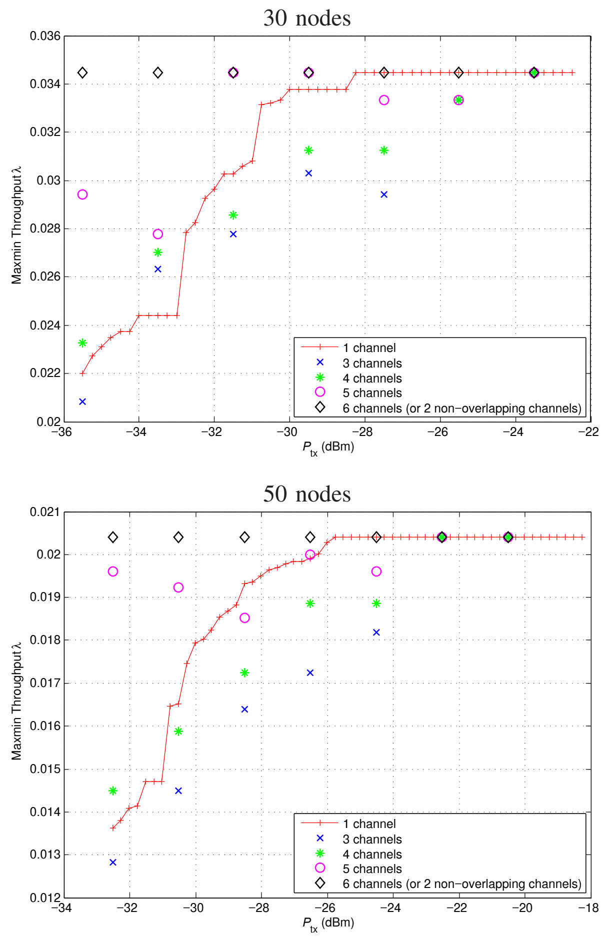

Fig. 2. The benefit of more channels (for both NOC and POC schemes) with one radio.

hence the throughput gets saturated. Really exciting benefits of having more channels are:

- It removes the need of joint routing and scheduling. As we explained, the throughput for multi-channel cases are obtained by solving JCSP, which does not jointly take routing into account, and the routing is computed separately by the Dijkstra's algorithm. As we have shown in [10], the throughput obtained from JCSP is much worse than that from JRCSP if there is only one channel available. However, what Fig. 2 shows is that, as far as there are a sufficient number of channels (no matter they are POCs or NOCs), the throughput can be improved even without involving routing in the optimization. This is a good news for practical protocol design, as joint routing and scheduling is very hard to achieve in practice.
- It may potentially reduce the total energy consumption of a network. In the best case, if we have two NOCs, the throughput achievable at the lowest power is the same as the maximum achievable throughput that is usually obtained by applying a very high transmission power. Detailed computations (omitted due to the lack of space) show that the total energy consumption in a network is at least halved at the lowest power, compared with running a network at a high transmission power.

Some negative news is that POCs do not help at all: using all the six channels is just as good as using non-overlapped channels 1 and 6. Though this can be partially attributed to the lack of more radios to fully utilize the channels, our results later show that the benefit of the POC scheme is marginal even with more radios.

C. POCs Are Hardly Beneficial

To see how much benefit can be obtained from the POC scheme, we compare the maximum network throughput of the POC scheme against that of the NOC scheme, with the use of the same spectrum band. For example, if a network is configured as $(2, 2, n)$, it implies that two NOCs (channel 1 and 6) are used and each node is equipped with two radios. This is compared against $(6, 2, p)$, which refers to the situation where the first six channels are in use and two radios for each node. Therefore, compared with $(2, 2, n)$, $(6, 2, p)$ does not need any additional spectrum resource. For the figures shown in Fig. 3, $(2, 2, n)$, $(3, 2, n)$, and $(3, 3, n)$ refer to the

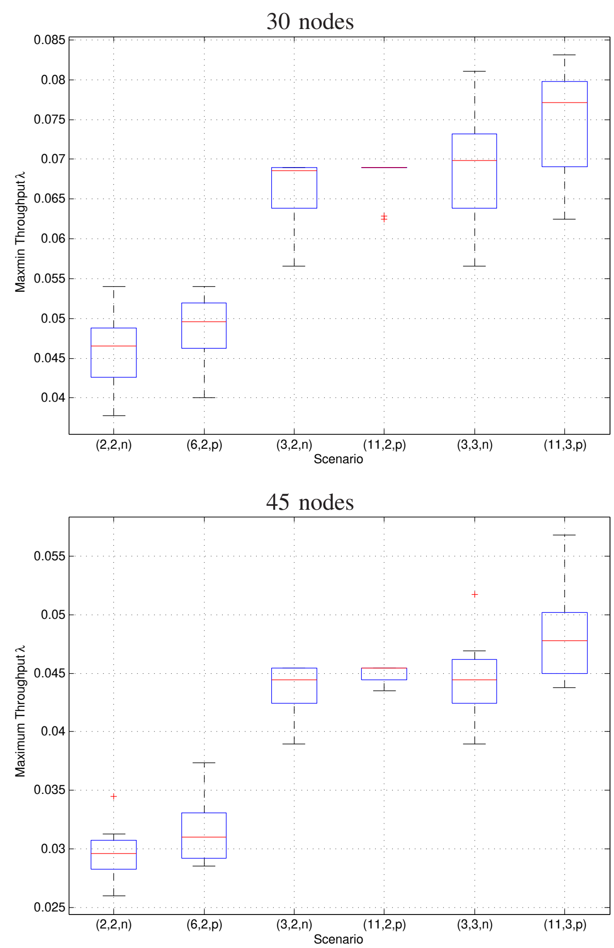

Fig. 3. Evaluating the benefit of the POC scheme against the NOC scheme.

configurations of the NOC scheme, while $(6, 2, p)$, $(11, 2, p)$, and $(11, 3, p)$ refer to those of the POC scheme, with each element bearing the meaning as explained earlier. Given each parameter setting, we perform computations for 10 random networks with the number of nodes indicated at the top of each figure. The boxplot is used to summarize the ten values, which involves five quantities: lower quartile (25%), median, upper quartile (75%), and the two extreme observations.

Unlike the studies before, our numerical results do not show a great boost in network throughput if POCs are used. Instead, as shown in Fig. 3, the improvement of the POC scheme with respect to the NOC scheme is actually marginal: lower than 10%. In fact, assigning 2 or 3 NOCs is much easier than doing that for 6 or 11 POCs in practice, our results call a careful evaluation of the tradeoff between a slightly higher throughput and a much higher design complexity. One might wonder why our results are so different from those reported in the literature, we will try to give some explanations in Sec. V-D. Note that we only consider up to 3 radios in this paper, as it can be easily shown that, with no more than 3 NOCs, having more than 3 radios does not benefit network throughput.

D. Capture Model Can Be Misleading

The capture model (Sec. II-A4) is widely used in the literature to evaluate the network throughput under the POC scheme. As stated before, however, capture model only considers pairwise interference between any two links, which fails to represent the additive nature of signals and interferences. One can see from the comparison we make in Fig. 4 that, the capture model always leads to radical results that are high

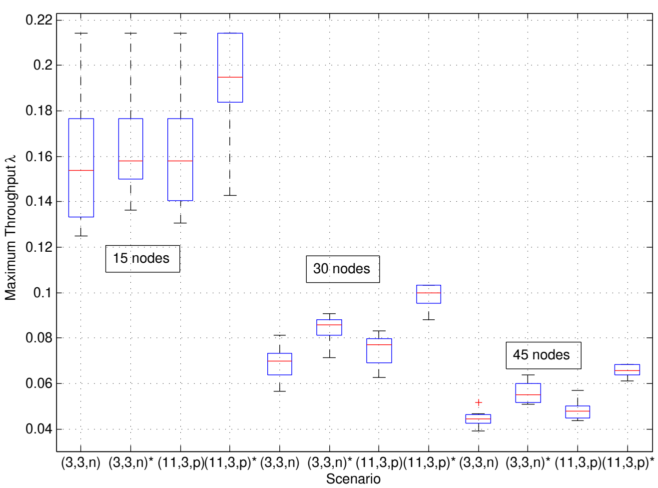

Fig. 4. Comparing the effects of two interference models, where * indicates the results corresponding to the capture threshold model, and the rest are those with the physical interference model.

beyond the optimal values resulted from the physical model. Specifically, the seemingly significant enhancement of spatial reuse brought by POC scheme may not be the case. Because though the attenuated interference would potentially lead to a larger I-Set under the capture model, the sum of the added interference is less likely to be tolerable under the physical model. Our solver has checked those solutions and it indicates that none of them satisfies the SINR threshold (3). This also means that in practice, those solutions are not feasible. One can easily see that, under the capture model, the POC scheme does bring substantial improvement in throughput compared with the NOC scheme, this partly explains the discrepancy between our results and those in the literature.[2] For this reason, we suspect that the previous reporting on promising improvement brought by POCs is misleading, and we believe our results reveal the practical enhancement that can be achieved.

VI. Conclusion

In this paper, we revisit the joint channel assignment and link scheduling problem, and we focus on the evaluation of network throughput improved by the POC scheme. We use the physical interference model to capture the additivity of link interference, and we formulate the corresponding joint optimization problem. With the help of a re-engineered column generation algorithm, we have been able to efficiently solve the problem to its optimality under a reasonable network size. Our numerical results first show that multiple channels may benefit, in addition to throughput, other network performance metrics such as energy efficiency. Our results also show that, as opposed to the promising enhancement of network throughput claimed before, the contribution of POCs is fairly marginal compared with the NOC scheme. We believe the discrepancy between our results and those in the literature is mainly attributed to the use of different interference models; we corroborate this by studying the impact of different interference models to network throughput. As we believe that the physical interference model we use is more realistic, we are convinced that our results indeed reveal the actual benefit can be gained from the POC scheme. Consequently, we caution that POCs, though beneficial, should be applied carefully in practice, as the resulting complexity of assigning these extra channels may offset the marginal improvement brought by them.

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[2]Other possible reasons may include the non-optimality of the previous results and the difference in defining the problem objectives. Due to the space constraints, we are not extending our discussion here.