Distributed Spectrum Trading via Dynamic Matching with Evolving Preferences

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***Abstract*—Spectrum trading benefits both primary users (PUs) and secondary users (SUs), while centralized spectrum trading designs need designated spectrum trader, incur extra control cost, and may miss lots of instantaneous spectrum trading opportunities. In this paper, a novel distributed frequency reuse based opportunistic spectrum trading (D-FRONT) scheme is proposed to further improve spectrum utilization, provide more accessing opportunities for SUs, and increase the revenues of PUs. Conflict graph is employed to characterize the SUs' co-channel and radio interferences. Based on the interference relationship, we formulate a centralized PUs' revenue maximization problem under multiple wireless transmission constraints. Due to the NP-hardness to solve the problem and no-existence of centralized trading entity, we develop the D-FRONT algorithms based on dynamic matching with evolving preferences. Through extensive simulations, we show that the proposed D-FRONT algorithm outperforms other distributed spectrum trading algorithms without considering spectrum reuse, yields results close to the centralized optimal one, and is effective in increasing PUs' revenue and improving spectrum utilization.**

***Index Terms*—Distributed Spectrum Trading; Spatial Reuse; Dynamic Matching with Evolving Preferences; Spectrum Utilization; Revenue**

I. Introduction

Nowadays, wireless services is an indispensable part of people's daily life. The large demand of wireless communication applications leads to a rapidly increase of the requirement for radio spectrum [1]–[3]. While the licensed spectrum bands are not fully utilized even in the most crowed region of bustling urban [4]. The dilemma between the proliferation of wireless users and the depletion of spectrum motivates FCC (Federal Communication Commission)to open up licensed spectrum bands and seek new dynamic spectrum access methods [1]. Cognitive radio (CR) technology is one of the most promising solution. It releases the spectrum from shackles of authorized licenses, and enables secondary users (SUs) to opportunistically access to the vacant licensed spectrum bands in either temporal or spatial domain [1]–[3].

Due to the economic values of frequency, the idea of opportunistic spectrum accessing has initiated the spectrum market, in which primary users (PUs) can sell/lease/auction their vacant spectrum for monetary gains, and SUs can purchase/rent/bid the available licensed spectrum if they suffer from the lack of radio resources to support their traffic demands [2], [5], [6]. Different from common commodities or resources, spectrum can be spatially reused, and this special feature of spectrum has promoted a lot of research on the centralized designs of spectrum trading [5], [7]. Although the centralized spectrum trading design has a joint consideration of spectrum reuse and the guarantee of economic properties, it needs the infrastructure deployment with extra economic and control cost, and the designated centralized spectrum traders (e.g., base stations or accessing points) may add huge energy consumption in existing networks. In addition, the centralized spectrum trading designs may not capture instantaneous accessing opportunities well, and have scalability issues, when the network size of SUs increases. Besides the centralized ones, there are also some interesting distributed spectrum trading schemes in existing literature. For example, Xing et al. in [8] and Niyato et al. in [9] investigated the spectrum pricing issues in the spectrum market, where multiple PUs, whose goal is to maximize the monetary gains with their vacant spectrum, compete with each other to offer spectrum access to the SUs. Leveraging models in game theory, Wang et al. in [10], Duan et al. in [11] and Zhang et al. in [12] proposed to construct spectrum trading systems with desired properties, such as power efficiency, allocation fairness, Pareto efficiency, collusion resistance and so on. Zhang et al. in [13] and Gu et al. in [14] employed many-to-one/student-project matching to share the spectrum trying to maximize the social welfare in CR networks/LTE-Unlicensed systems, respectively. However, most existing distributed spectrum trading designs have little consideration of frequency reuse, which might cost PUs to lose some monetary gains and SUs to miss many valuable spectrum accessing opportunities, and limit the improvement of spectrum utilization.

A distributed frequency reuse based opportunistic spectrum trading (D-FRONT) scheme is proposed in this paper. The scheme considers spectrum's special feature, spatial reuse, and allows spectrum trading between PUs and SUs in distributed manners. We employ matching theory to trade the spectrum with the objective to maximize PUs' revenues. In the proposed scheme, the PU's preference list evolves, which depends on

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both SUs' interference relationship observed by the PU. We mathematically model the problem, develop D-FRONT matching algorithm, and conduct performance evaluations. Compared with centralized spectrum trading designs, the proposed D-FRONT not only saves the cost for additional infrastructure deployment with extra power consumption, but also provides more accessing opportunities for SUs, increases the revenues of PUs, and improves spectrum utilization compared with existing distributed designs. Our salient contributions are listed as follows.

- A spectrum trading market consisting of PU and SU pairs are considered as shown in Fig. 1. Conflict graph is used to describe the interferences between SUs transmission pairs. Based on the conflict graph, centralized optimization problem with the goal to maximize PUs' revenues is formulated under constraints.
- To pursue achievable solutions in distributed way, a novel D-FRONT scheme is proposed, which jointly considers interference mitigation, reuse of frequencies and spectrum trading revenues in matching process. In D-FRONT, the SU, whose target is to maximize its transmission rate, lists its preferences over PUs' bands based on potential transmission rates it can recieve from those bands. According to frequency reuse, the PU, whose goal is to maximize its revenues, will accept as many SUs as possible, in case that those SUs have no interferences relationship. The PU lists its preferences over SUs according to their bidding values and their conflicts relationships. The preference lists of PUs evolve during the matching process. In this paper, the PUs' and SUs' utility functions are presented, the D-FRONT, which is a two-phase matching algorithm with PUs' evolving preferences is proposed.
- By extensive simulations, we show that the proposed D-FRONT is superior to other algorithms which do not consider frequency reuse. The feasible solutions obtained by the proposed algorithm are also close to the optimal one in terms of the PUs' revenues, the aggregated network throughput of SUs, and the spectrum utilization.

The rest of paper is organized as follows. Section II introduces the network model and related models in FRONT. In Section III, we centralized formulate the FRONT problem and show that it is hard to solve the problem in centralized way. In such a manner, we propose D-FRONT solution IV. Then the performance is evaluated and discussed in section V, and conclusion is drew in Section VI.

II. Network Model

A. Network Configuration

We consider a spectrum trading market consisting of $\mathcal{N} = \{1, 2, \cdots, n, \cdots, N\}$ SU transmission pairs, and $\mathcal{M} = \{1, 2, \cdots, m, \cdots, M\}$ PU transmission pairs on different spectrum bands. The words SU transmission pairs/SU pairs/SUs, and PU transmission pairs/PU pairs/PUs are interchangeably used in the rest of this paper to simplify. In this paper, we assume each SU transmitter/receiver has only one radio interface, and each PU pair owns one spectrum band, i.e., PU $k \in \mathcal{M}$ owns band k. Denote the unequal sized bandwidths of PUs' bands by $\mathcal{W} = \{W^1, W^2, \cdots, W^m, \cdots, W^M\}$. In our network model, each SU pairs can access to any PU pairs, i.e., let $\mathcal{M}_i \subseteq \mathcal{M}$ represent the set of available bands at SU pair $i \in \mathcal{N}$, then $\mathcal{M}_i = \mathcal{M}_j$, $j \in \mathcal{N}$.

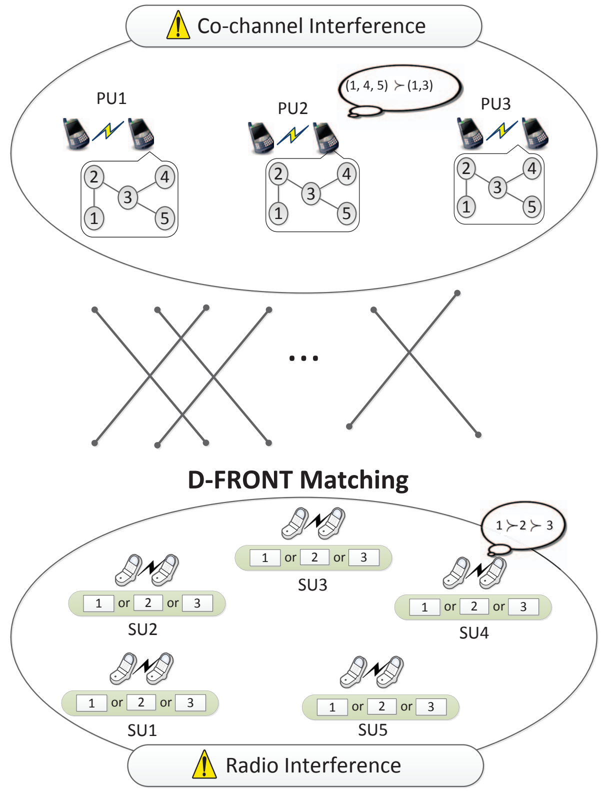


Fig. 1. Network Architecture for D-FRONT.

PUs sell available bands for monetary gains and the SUs purchase available bands of PUs to deliver their traffic. Here, SU $i \in \mathcal{N}$ is allowed to opportunistically access to a licensed band $k \in \mathcal{M}$ when the services of PU_k are not used, but SU i has to reduce their transmission when primary services become active over band k [15]. Suppose all the SUs have the same bidding value. Thus, from SU's perspective, SU_i would like to choose a band k over which band SU_i can access largest data transmission rate; from the PU's perspective, considering spatial reuse, it would like to accept as many SUs as possible to maximize its revenue, only if there are no co-channel interferences among those SUs as shown in Fig. 1.

B. Other Related Models in FRONT

1) SU's Interference Range: SUs can use a certain band with full power if PU is not active over this band. In our work we suppose all SUs have the same full transmission power P. For power propagation, we adopt a widely used model [16] shown as

$$g_i = \gamma \cdot d_i^{-\alpha} \quad (i \in \mathcal{N}), \tag{1}$$

where α is the path loss factor, γ is an antenna related constant, and d_i represents the distance of SU$_i$'s transmitter and reciever. In our assumption, SU$_i$ transmits data successful only under the condition that received power at the SU's receiver is larger than SU$_i$'s receiver sensitivity, i.e., a threshold power P_{Tx}. Moreover, we assume interference becomes non-negligible if it is over a threshold of P_{In} at the SU$_i$'s receiver. Hence, SU's transmission range is $R_{Tx} = (\gamma P/P_{Tx})^{1/\alpha}$, which comes from $\gamma \cdot (R_{Tx})^{-\alpha} \cdot P = P_{Tx}$. Similarly, the interference range for a SU is $R_{In} = (\gamma P/P_{In})^{1/\alpha}$. Since $P_{In} < P_{Tx}$, $R_{In} > R_{Tx}$. Normally, the interference range is 2 or 3 times of the transmission range [17], [18], i.e., $\frac{R_{In}}{R_{Tx}} = 2$. It is noted that if the interference range is properly set, the protocol model can transfer to the physical model as illustrated in [19].

2) Link Capacity/ Achievable Data Rate: The ON/OFF model [20] is used to represent the active/inactive status of PU in this paper. Suppose that PU$_k$ is "OFF" with probability β_k, it is obviously that PU$_k$ is on "ON" with the probability $(1 - \beta_k)$.

When band k is not used by PU$_k$, SU$_i$ can transmit with full power P over band k, in the meanwhile other SUs within SU$_i$'s interference range keep silent. The capacity of SU $i \in \mathcal{N}$ over band $k \in \mathcal{M}$ is

$$c_i^{k,\mathrm{OFF}} = W^k \log_2 \Big(1 + \frac{g_i P}{\sigma^2}\Big), \tag{2}$$

where σ^2 is the ambient Gaussian noise power at SU$_i$'s receiver according to the Shannon-Hartley theorem.

When band k is occupied by PU$_k$, SUs accessing to this band have to reduce their power to assure that the total interference is under the "interference temperature" of PU$_k$ [15]. We assume that the averaged interference tolerance power sensitivity for a SU is $P_\triangle^k$ at PU$_k$'s receiver. Let SU$_i$ accessing to band k transmit with power $P_i^{k,\mathrm{ON}}$. Then, $P_\triangle^k = P_i^{k,\mathrm{ON}} \cdot g_{ik} = P_i^{k,\mathrm{ON}} \cdot \gamma \cdot d_{ik}^{-\alpha}$, where d_{ik} is the distance between SU$_i$ and PU$_k$. Thus, when PU$_k$ is using the band, the capacity of SU$_i$ can transmit over band k is

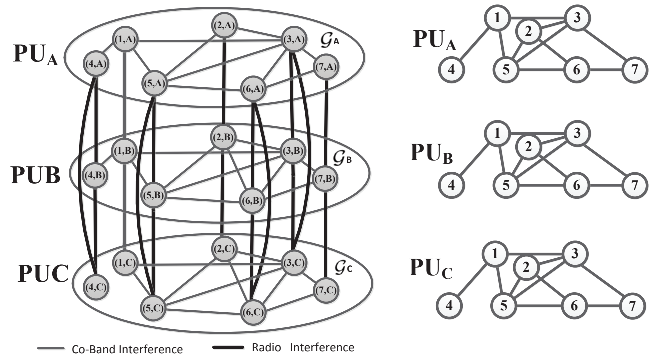
$$\begin{aligned} c_i^{k,\mathrm{ON}} &= W^k \log_2 \Big(1 + \frac{g_i P_i^{k,\mathrm{ON}}}{P^k \gamma d_{ik}^{-\alpha} + \sigma^2}\Big) && (3) \\ &= W^k \log_2 \Big(1 + \frac{g_i P_\triangle^k \gamma^{-1} d_{ik}^{\alpha}}{P^k \gamma d_{ik}^{-\alpha} + \sigma^2}\Big), && (4) \end{aligned}$$

where P^k is the transmission power of PU$_k$, $k \in \mathcal{M}$, and $P^k \gamma d_{ik}^{-\alpha}$ is the PU$_k$'s interference to SU$_i$ over band k.

Therefore, the expected capacity of SU$_i$ over band k can be written as

$$c_i^k = \beta_k c_i^{k,\mathrm{OFF}} + (1 - \beta_k) c_i^{k,\mathrm{ON}}. \tag{5}$$

While the achievable data is actually related to SNR at the receiver and receiver sensitivity, we use the approximation by (5) to calculate achievable data rate which is illustrated in most of existing [16], [17], [21] and will not affect the theoretical analysis.



(a) Conflict graph $\mathcal{G}$.

(b) Conflict graph $\mathcal{G}^k$, $k \in \{A, B, C\}$.

Fig. 2. Interference relationship represented by conflict graph in FRONT.

III. C-FRONT: Centralized FRONT Optimization Formulation

In this section, we first introduce conflict graph which describes the interferences relation between SUs, and formulate centralized FRONT optimization problem with the objective of maximizing PUs' benefit under multiple constrains.

A. Conflict Graph and Maximal Independent Sets

1) Conflict Graph: A conflict graph $\mathcal{G}(\mathcal{V}, \mathcal{E})$ is to characterize the interference among SUs in FRONT. In $\mathcal{G}(\mathcal{V}, \mathcal{E})$, each vertex corresponds to a SU opportunistically accessing to certain band [17]. Similar to the interference conditions in [16], [17], [21], there is interference if (i): two different SUs are using the same band and the receiver of one SU pair is in the interference range in the other SU pair, or (ii): a SU pair transmits over more than one band at the same time. These represent co-band interference and radio interface conflicts of SU, respectively. We connect two vertices in $\mathcal{V}$ with an undirected edge in $\mathcal{G}(\mathcal{V}, \mathcal{E})$, if there are interferes as shown in the conflict graph in Fig. 2(a).

Given $\mathcal{G}(\mathcal{V}, \mathcal{E})$, the impact of vertex $i \in \mathcal{V}$ on vertex $j \in \mathcal{V}$ are represented as follows,

$$\delta_{ij} = \begin{cases} 1, \text{ vertex } i \text{ and } j \text{ is connected by an edge} \\ 0, \text{ ertex } i \text{ and } j \text{ is not connected by an edge,} \end{cases} \tag{6}$$

i and j correspond to two SU-band pairs, respectively.

2) Maximal Independent Sets: If there is a vertex set $\mathcal{I} \subseteq \mathcal{V}$ and a SU $i \in \mathcal{I}$ satisfying $\sum_{j \in \mathcal{I}, i \neq j} \delta_{ij} < 1$, which means all SUs in the set $\mathcal{I}$ will transmit successful at the same time. If adding any one more SU-band pair into $\mathcal{I}$ there will appear edge between SUs pair, $\mathcal{I}$ is defined as a maximal independent set (MIS) [17], [21], [22].

B. The Formulation of C-FRONT Optimization

We use x_i^k to denote status of SU $i \in \mathcal{N}$ accessing to band $k \in \mathcal{M}$, where $x_i^k = 1$ indicates that SU$_i$ has opportunity to transmit over band k, on the other hand, $x_i^k = 0$. Given $\mathcal{G} = (\mathcal{V}, \mathcal{E})$ constructed from FRONT and all MISs as $\mathscr{I} = \{\mathcal{I}_1, \mathcal{I}_2, \cdots, \mathcal{I}_q, \cdots, \mathcal{I}_Q\}$, where $Q = |\mathscr{I}|$, and

$\mathcal{I}_q \subseteq \mathcal{V}$ for $1 \leq q \leq Q$. Based on the definitions, the fiscal benefit maximization optimization problem in FRONT can be formulated as follows.

$$\text{Maximize} \sum_{k\in\mathcal{M}} \sum_{i\in\mathcal{N}} x_i^k \tag{7}$$

s.t.:

$$x_i^k \in \{0,1\}, \qquad (i \in \mathcal{N}, k \in \mathcal{M}), \tag{8}$$

$$\sum_{k\in\mathcal{M}} x_i^k \leq 1, \qquad (i \in \mathcal{N}), \tag{9}$$

$$x_i^k \cdot x_j^k = 0, \qquad (i,j \in \mathcal{N}, k \in \mathcal{M}, (i,k) \in \mathcal{I}_u, (j,k) \in \mathcal{I}_v, \mathcal{I}_u, \mathcal{I}_v \in \mathscr{I} \text{ and } u \neq v) \tag{10}$$

where x_i^k is optimization variable, and since bidding value of all SUs are unit, we consider bidding value is 1 in the formulation. Here, binary value x_i^k indicates the accessing status of SU_i to band k, Eq. (9) presents radio interferences constraint and Eq. (10) presents the co-band interference constraint.This problem is a mixed-integer nonlinear programming (MINLP) problem, which means there is no classical optimal solution. That's why we propose a distributed FRONT matching scheme in the next section.

IV. D-FRONT: Distributed FRONT via Matching with Evolving Preferences

In this section, we describe some important definitions in D-FRONT and represent the procedure of D-FRONT scheme via matching with PUs' evolving preferences.

A. Definitions in D-FRONT Matching

1) SUs' interferences: As shown in Fig 2(a), PUs only know the interferences information of SUs who propose to it. To maximize its revenues while avoiding co-band interferences among the accessed SUs, the PU has to build up its preferences based on its own observations on SUs' relation. That is, by dividing $\mathcal{G}(\mathcal{V},\mathcal{E})$ into $\mid \mathcal{M} \mid$ layers, where $\mathcal{G}^k(\mathcal{V}^k,\mathcal{E}^k)$ is the conflict graph over band $k \in \mathcal{M}$, $\mathcal{G}^k(\mathcal{V}^k,\mathcal{E}^k)$ is the conflict graph observed by PU_k. While in our paper, since every PUs has same conflict graph, $\mathcal{G}^A = \mathcal{G}^B = \mathcal{G}^C$.

Similar to the definition of $\mathcal{I}_u \in \mathcal{G}$ and $\mathscr{I} \subseteq \mathcal{G}$, $\mathcal{I}_u^k \in \mathcal{G}^k$ and $\mathscr{I}^k \subseteq \mathcal{G}^k$ are defined as the MISs observed by PU_k, and all MIS. The SUs in $\mathcal{I}_u^k$ can transmit simultaneously over band k.

2) The Preferences of SUs and PUs: The objective for the SU_i is to maximize its data transmission rate, i.e.,

$$\text{Maximize} \sum_{k\in\mathcal{M}} x_i^k c_i^k \tag{11}$$

s.t.:

$$x_i^k \in \{0,1\}, \qquad (i \in \mathcal{N}, k \in \mathcal{M}),$$

$$\sum_{k\in\mathcal{M}} x_i^k \leq 1, \qquad (i \in \mathcal{N}),$$

where c_i^k is defined in Sec. II-B. Thus, for SU_i, $i \in \mathcal{N}$,

$$k \succ_i l \Leftrightarrow c_i^k \succ_i c_i^l, \quad k,l \in \mathcal{M}. \tag{12}$$

As for PU_k, the goal is to maximize its fiscal benefit. Since bidding price is unit, the number of SUs which accepted by PU is the total fiscal benefit the PU can earn. Thus we have

$$\text{Maximize} \sum_{i\in\mathcal{N}} x_i^k \tag{13}$$

s.t.:

$$x_i^k \in \{0,1\}, \qquad (i \in \mathcal{N}, k \in \mathcal{M}),$$

$$x_i^k \cdot x_j^k = 0, \qquad (i,j \in \mathcal{N}, k \in \mathcal{M}, (i,k) \in \mathcal{I}_u^k, (j,k) \in \mathcal{I}_v^k, \mathcal{I}_u^k, \mathcal{I}_v^k \in \mathscr{I}^k \text{ and } u \neq v).$$

So, given a group of SUs in $\mathcal{I}_u^k$ and another group of SUs in $\mathcal{I}_v^k$, the preferences of PU_k over those SUs can be shown as

$$\mathcal{I}_u^k \succ_k \mathcal{I}_v^k \Leftrightarrow \sum_{i\in\mathcal{I}_u^k} i \succ \sum_{j\in\mathcal{I}_v^k} j. \tag{14}$$

B. D-FRONT Matching with Evolving Preferences

The D-FRONT matching procedure with evolving preferences list is proposed in this section. This algorithm have four steps which is represented as follows[1].

1) D-FRONT Matching Procedure: There are four steps in *Phase I*: (i) constructing preference lists, (ii) listening SUs' bids proposing, (iii) PUs' unsattle matching with (i.e., accessing/rejecting) SUs, and (iv) PUs' preferences evolving.

First of all, all PUs and SUs will initiate the procedure by constructing their preference lists. According to (12), the SU_i builds its preference list $\mathbb{PL}(i)$. And PU_k constructs the conflict graph $\mathcal{G}^k$ based on (14).

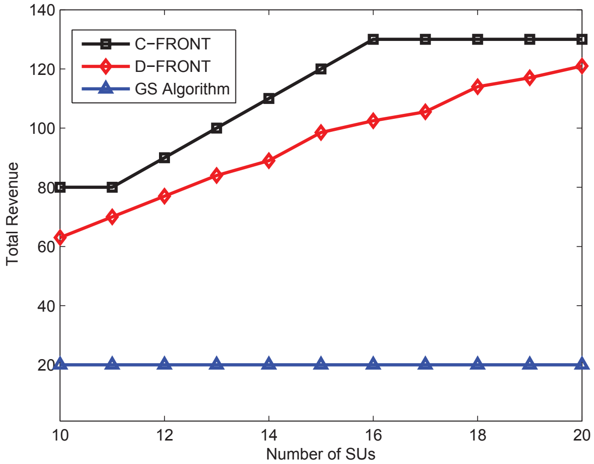
Then, having $\mathbb{PL}(i)$, SU_i proposes to the top PU of $\mathbb{PL}(i)$. Note that all the SUs propose to the PUs at the same time. Besides, because of the radio interference, a SU can only propose to one PU at a time .

After receiving the proposes from SUs, PU_k updates its $\mathcal{G}^k$, which includes the already accepted SUs and SUs newly proposing for PU_k from the 2nd round until the $|\mathcal{M}|$-th round. Based on the updated $\mathcal{G}^k$, PU_k will match with the SUs in $\mathcal{I}_u^k$, where $\mathcal{I}_u^k = \underset{\mathcal{I}_u^k \in \mathcal{G}^k}{\text{argmax}}\Big(\sum_{i\in\mathcal{I}_u^k} i\Big)$, and reject the SUs not in $\mathcal{I}_u^k$. If more than one MIS can reach the same maximal benefit of PU_k in the current round, PU_k would like to chooses the MIS which has the promising highest revenue, which means has largest number of SUs in the future rounds.

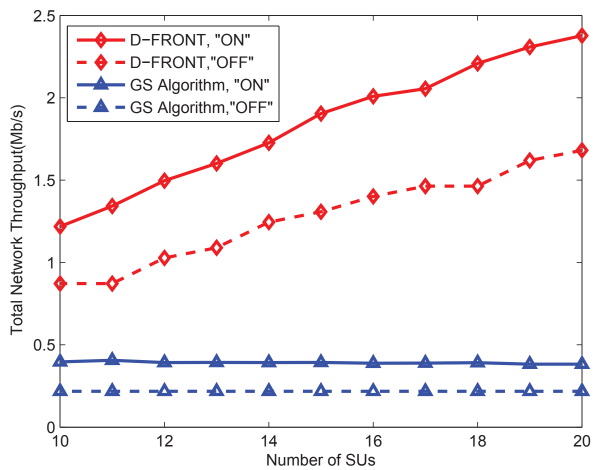
At last, based on the accepted $\mathcal{I}_u^k$, PU_k will evolve its preference list $\mathbb{PL}(k)$, which puts MISs/SUs who do not interfere $\mathcal{I}_u^k$ with higher priorities, and MISs/SUs who interefere $\mathcal{I}_u^k$ with lower ones. Then, the process goes back to *Step 2*, where SU_i who is not accepted by PUs starts to propose to the second highest PUs according to $\mathbb{PL}(i)$.

The iterations continues until the matching processing ends in the $|\mathcal{M}|$-th round.

[1]For the stability and complexity of the proposed D-FRONT, please refer to our technical report at http://www2.egr.uh.edu/~mpan2/TR/TR-DROST.pdf.

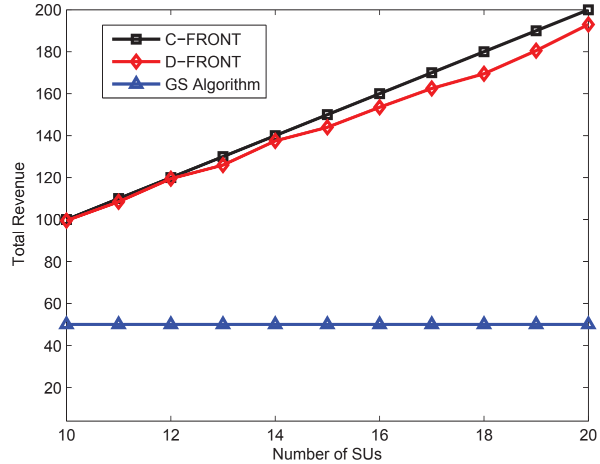


(a) Total revenues of PUs, M=2.

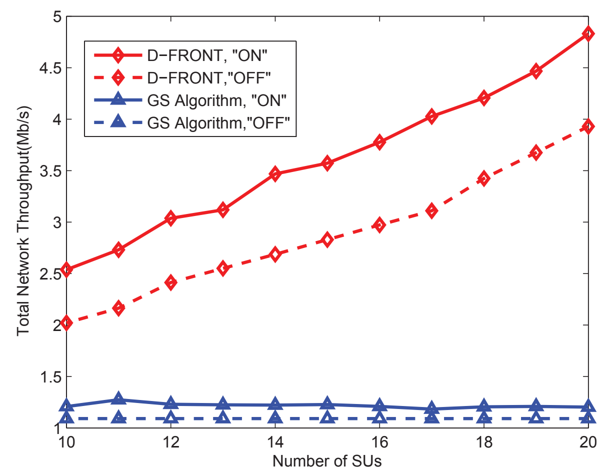


(b) Aggregated SU network throughput, M=2.

Fig. 3. Performance comparison of different spectrum trading algorithms, M=2.



(a) The number of accessed SUs/Spectrum utilization, M=5.



(b) Aggregated SU network throughput, M=5.

Fig. 4. Performance comparison of different spectrum trading algorithms, M=5.

V. Performance Evaluation

In this section, we consider a network consisting of PUs and 20 SUs randomly deployed in a 1000x1000 m^2 area, the noise power σ^2 is 10^{-10} W at all transmitters and receivers. Moreover, the path loss factor $\alpha = 4$, the antenna parameter $\gamma = 3.90625$, the receiver sensitivity $P_T = 100\sigma^2 = 10^{-8}$ W and the interference threshold $P_T = 6.25 \times 10^{-10}$ W. The transmission range R_T and the interference range R_I are equal to 250 m and 500 m according to Sec. II-B. All the bands are randomly selected from 10 MHz to 15MHz. We also assume transmission power of PU, SU and SU when PU coming back are 20×10^{-8} W, 15×10^{-8} W and 7×10^{-8} W, respectively. The distance between transmitter and receiver of SU is 20m, and the distances between PU and SU are randomly from 1m to 60m. The data transmission rates of SUs can be calculate by Eq. (5), where the probability values of PUs' coming back, i.e., β_k values, are randomly selected from 0 to 1. Every SU bid price is \$10, and we set $Z = 10000$ as a large enough number for the MISs.

The proposed D-FRONT scheme is compared with another two algorithms: C-FRONT and Gale-Shapley (GS) algorithms [23]. Here, by employing Z MISs found in multi-dimensional $\mathcal{G}$, C-FRONT can be obtained by CPLEX [24], and serve as a benchmark for the performance comparison.

The performance of total revenue under different number of PUs are compared in Fig. 3(a) and Fig. 4(a). GS has worst performance in terms of PUs' revenues, which is not surprised since it ignores the frequency reuse. Note that the revenue increase of C-FRONT generally stops when the number of SUs is beyond 16 as shown in Fig. 3(a). That is because there is only 2 PUs in the spectrum trading market, and there is still a cap for spectrum trading opportunities even though frequency reuse is considered. Taking spatial reuse into account, the number of revenue increases when there are more SUs in the network. As the number of SU increases, PUs' revenue under the D-FRONT algorithm increases rapidly and are much closer to the sub-optimal C-FRONT solution when there are 2 PUs and 5 PUs. Finally, Fig.3(b) and Fig.4(b) give some performance on the aggregated SU network throughput. The comparison is conducted under "ON" and "OFF" model. Here, "ON" mode means SUs decrease their power below "interference temperature" when PUs come back, while "OFF" mode means SUs absolutely shut down when PUs are working. Obviously, the performance of "ON" mode is better than that of "OFF" mode for all algorithms and the performance under D-FRONT model is much more better than GS algorithm. Here, the performance of GS under "ON" mode is not a constant because SUs' transmission power (thus their data rates) is affected by their distance from PUs' transmitters.

VI. Conclusion

In this paper, we have proposed a novel D-FRONT spectrum trading scheme, which considers spectrum reuse and trades the spectrum in distributed manners. In D-FRONT, we have employed conflict graph to characterize the SUs co-channel interference and radio interference. Based on the conflict graph, we have formulated centralized FRONT optimization. Due to the NP-completeness to solve this problem, we have developed the D-FRONT algorithm based on dynamic matching with evolving preferences. Through simulations, we have shown that the proposed D-FRONT algorithm is better than other distributed spectrum trading algorithms, yields sub-optimal solutions, and is effective in improving PUs revenues, the aggregated SU network throughput, and spectrum utilization.

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