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Dynamic Frequency-Intelligent Reserve-and-Switch Technique (D-FIRST) to Combat Inter-Operator Interference

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***Abstract*— In this paper, a spectrum sharing scheme that will coordinate among different co-existing cellular operators competing for the same spectrum band is proposed. Based on this scheme, the cell of an operator can be divided into several sub-regions, and mobile stations (MSs) inside each sub-region form one subset. The whole frequency band assigned to a cell is partitioned into slots dedicated to the subsets based on the Quality of Service (QoS) demand. When interference from other operators is detected, the victim operator can switch the frequency of the interfered MSs with the MSs in the *safe region*, and/or switch to the *reserved band*. In this way, the inter-operator interference (IOI) can be reduced. From the simulation results, it is shown that with the proposed protocol, the total power consumption of both operators can be reduced significantly. Furthermore, it has been demonstrated that in order to reduce the IOI in a high-density area, the operator should reserve more bandwidth for potential frequency-switching.**

I. Introduction

As the demand for wireless cellular services keeps increasing in nowadays, meanwhile the wireless spectrum becomes much more crowded than in the past, how to optimally utilize the limited spectrum resources to provide high Quality of Service (QoS) has attracted a lot of attention. Without an efficient spectrum access scheme, cellular users will experience heavy interference, for example the co-channel interference (CCI) and neighbor-channel interference (NCI) from both intra-cell and inter-cell mobile users. Novel spectrum/channel access schemes are necessary to suppress the interference in order to ensure satisfying QoS and thus accomplish efficient spectrum utilization.

Several channel allocation schemes are previously proposed in order to manage different types of interference and to improve the spectrum usage efficiency. In [1], a multi-cell coordinated radio resource management scheme is applied to Orthogonal Frequency Division Multiple Access (OFDMA) cellular systems, in which each cell has its own sequence for allocating radio sub-channels. Higher spectrum efficiency can be achieved by inter-sector scheduling in multi-user OFDM [2], where the amount of buffered data at each base station (BS) is exchanged within a small group of BSs. An adaptive dynamic slot allocation strategy is proposed in [3] that resolves the crossed-slot interference in multi-cell environments by dividing the coverage area of each cell into a number of distinct service zones and studying the level of mutual interference between the service zones. A decentralized interference aware medium access in cellular OFDMA-Time Division Duplex (TDD) networks is proposed in [4], which enables the transmitter to determine the level of interference it would cause to already active links prior to transmissions. In [5], a distributed spectrum allocation algorithm is developed by employing principles of mutual exclusion pertaining to distributed computing systems. An efficient fault-tolerant distributed channel allocation algorithm for cellular networks is proposed in [6], where the limited spectrum resources are efficiently utilized with control on the CCI from neighboring cells. In [7], the capacity of cellular systems with interference-adaptation dynamic channel allocation (DCA) is studied with the knowledge of the mobiles' locations.

However, most of the above DCA approaches assume that all mobile users in different cells subscribe to a single operator. Under this assumption, all the users would cooperate with each other and coordinate the channel allocation by sharing the information about their spectrum usage. Therefore, such approaches are not directly applicable to the scenario where multiple cellular operators compete for a common band, whereby each operator performs frequency spectrum planning independently and would not reveal the spectrum usage information to other operators.

In this work, we propose an on-demand dynamic spectrum access scheme in order to combat inter-operator interference (IOI) when multiple cellular providers co-located in the same area share the same frequency band. Such an on-demand DSA is not required in the conventional and current cellular networks since each operator has been pre-assigned with a specified frequency band. The proposed mechanism can jointly allocate the spectrum resources based on users' QoS demand, and dynamically switch the frequency upon detection of uplink interference. Since MSs closer to the BS is least sensitive to uplink interference, their frequency planning can be made flexible in order to compensate for the MSs with high sensitivity to uplink interference. The ratio of the reserved bandwidth can be selected in order to balance the tradeoff between meeting the QoS demand from current active users and possible band-switching requirements from potentially interfered users. The simulation results show that with the

[1]This work was done when Beibei Wang was an intern in DoCoMo USA Labs.

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proposed method, the power consumption can be reduced significantly while maintaining the same QoS requirement. Generally in higher user density area, the ratio of reserved bandwidth should be higher for future frequency switching.

This paper is organized as follows: In Section II, the system model is described. In Section III, the optimal bandwidth allocation inside one cell is analyzed, then spectrum sharing between two cells by aid of location information is studied, and the Dynamic Frequency-Intelligent Reserve-and-Switch Technique (D-FIRST) is proposed. Simulation results are given in Section IV and conclusions are drawn in Section V.

II. System Model and Description

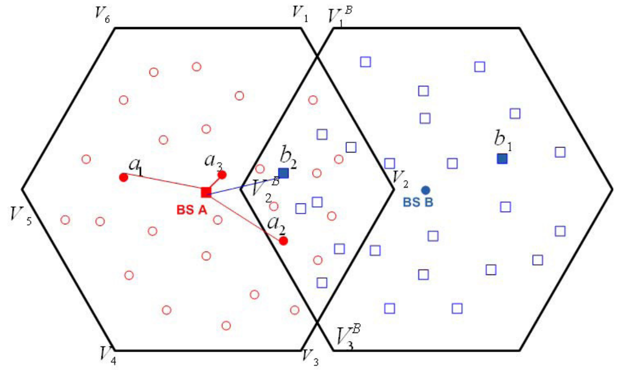
In an area where multiple cellular operators that compete for the same chunk of spectrum band place competing cells together, it is of high potential for uplink interference when MSs subscribing to different operators share the same sub-channels. Hence, it is very important for each cellular operator to investigate the uplink interference level so that it can dynamically access the spectrum in order to alleviate the QoS degradation or additional power consumption due to such undesired interference.

Fig. 1(a) illustrates the scenario where two equal-size cells, Cell A and Cell B, belonging to two cellular operators, Operator A and Operator B, have part of its coverage area overlapped by the other cell. The centers of the two cells are the BSs, i.e., BS_A and BS_B, respectively. The two competing cellular operators occupy the same frequency band, so the bandwidths allocated to Cell A and Cell B are overlapped as well. Here, we can view that Operator A and Operator B are overlapped two dimensionally, i.e., frequency and space. Fig. 1(b) depicts an example of the spectrum occupation for the two cellular operators. Here, we assume B is the interferer, and A is the victim; A and its subscribed MSs, a_i, $i = 1, \cdots, I$, have no explicit information about the interfering MSs subscribing to B, b_j, $j = 1, \cdots, J$. When MSs of Cell A are interfered by MSs of Cell B, Operator A has to adopt some methodology to ensure its subscribed MSs to maintain the same QoS demand, without deteriorating the QoS for MSs of Cell B. Without loss of generality, if the neighboring cells are far away, practically speaking, it can be said that there is insignificant amount of IOI. Therefore, we assume that interference to a_i's is due to b_j's located inside or very close to the overlapping region generated by boundaries $V_1V_2V_3$ and $V_1^BV_2^BV_3^B$ (see Fig. 1(a)).

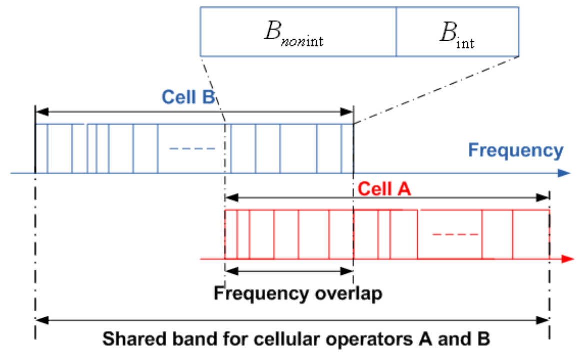
For MS a_i, let's define W_{a_i} as the assigned bandwidth, P_{a_i} as its uplink transmitting power, and $G_{a_i,A}$ as the channel gain from a_i to BS_A. Thus, the maximal uplink transmission rate of a_i when there is no interference from Cell B is expressed as follows

$$R_{a_i} = W_{a_i} \log_2 \left(1 + \frac{P_{a_i} G_{a_i,A}}{N_0}\right), \tag{1}$$

where N_0 is the noise power. If some MS of Cell B, b_j, begins to occupy the same sub-channel as a_i is transmitting



(a) System model



(b) Spectrum occupation

Fig. 1: Two operators share a spectrum band.

information to BS_A, then the maximal transmission rate for a_i is as the following

$$\tilde{R}_{a_i} = W_{a_i} \log_2 \left(1 + \frac{P_{a_i} G_{a_i,A}}{P_{b_j} G_{b_j,A} + N_0}\right), \tag{2}$$

where P_{b_j} is the transmitting power from b_j to BS_B, and $G_{b_j,A}$ denotes the channel gain from b_j to BS_A. Here, we use the transmission rate as the QoS criterion.

In order to maintain the same transmission rate under the interference environment and the given bandwidth assignment, a_i can increase its transmitting power from P_{a_i} to a greater value. However, b_j may also be interfered by a_i, e.g., when a_2 and b_2 share the same sub-channel as shown in Fig. 1(a). If b_j also needs to maintain its required rate, P_{b_j} will need to increase to a greater one. According to (2), this will cost a great amount of additional power to satisfy both a_i and b_j's QoS demand. Let's denote the increased power of a_i and b_j under mutual interference as P'_{a_i} and P'_{b_j}, by equating R_{a_i} (or R_{b_j}) to $\tilde{R}'_{a_i}$ (or $\tilde{R}'_{b_j}$), we will have the following equations

$$\log_2 \left(1 + \frac{P_{a_i} G_{a_i,A}}{N_0}\right) = \log_2 \left(1 + \frac{P'_{a_i} G_{a_i,A}}{P'_{b_j} G_{b_j,A} + N_0}\right),$$
$$\log_2 \left(1 + \frac{P_{b_j} G_{b_j,B}}{N_0}\right) = \log_2 \left(1 + \frac{P'_{b_j} G_{b_j,B}}{P'_{a_i} G_{a_i,B} + N_0}\right), \tag{3}$$

where P'_{a_i} and P'_{b_j} are solved as

$$P'_{a_i} = \frac{P_{a_i}N_0^2 + P_{a_i}P_{b_j}G_{b_j,A}N_0}{N_0^2 - P_{a_i}P_{b_j}G_{a_i,B}G_{b_j,A}}, \quad P'_{b_j} = \frac{P_{b_j}N_0^2 + P_{b_j}P_{a_i}G_{a_i,B}N_0}{N_0^2 - P_{a_i}P_{b_j}G_{a_i,B}G_{b_j,A}}. \tag{4}$$

Here, we view Cell A and its subscribed MSs as the victims, and assume they have no information about the instantaneous channel allocation inside Cell B. Therefore, in order to achieve a new channel allocation for the victim Cell A with small P'_{a_i}'s, i.e., with reduced additional power to maintain QoS, the only way is to investigate the influence of the interference from Cell B to all the a_i's with different locations and transmission power levels. In the next section, we will analyze in detail how to design the spectrum access scheme of MSs in Cell A by frequency switching and reservation, assuming Cell B will not alter its channel allocation if P'_{b_j} can also be reduced after Cell A adopts the proposed spectrum access scheme.

III. Dynamic Frequency-Intelligent Reserve-and-Switch Technique (D-FIRST)

In this section, we first analyze the optimal bandwidth allocation inside one cell, and study the optimal spectrum sharing criterion between two operators by the aid of location information. Then, by considering a scenario where more than one operator overlapped in both frequency and space, we propose the Dynamic Frequency-Intelligent Reserve-and-Switch Technique (D-FIRST) in order to combat the IOI.

A. Optimal Spectrum Allocation Within A Cell

Let MSs inside Cell A share the total bandwidth W_A in a Frequency Division Multiple Access (FDMA) fashion, and there are in total of I active MSs. In order to maintain satisfactory communication quality, the QoS requirement for a_i is the minimal transmission rate R^i_{min}. Moreover, the transmission power for each a_i can not exceed the maximum value P^i_{max}. Therefore, the optimization goal of the channel allocation for Cell A is to design the bandwidth $\mathbf{W} = [W_{a_1}, \cdots, W_{a_I}]$, so that all users' minimal rate requirements are satisfied and the total transmission power is minimized, which is expressed as follows

$$\min_{\mathbf{W}} \quad \sum_{i=1}^{I} P_{a_i}, \tag{5}$$

$$\text{s.t.} \quad R_{a_i} \geq R^i_{\text{min}}, \quad P_{a_i} \leq P^i_{\text{max}}, \quad \sum_{i=1}^{I} W_{a_i} = W_A. \tag{6}$$

Re-organizing (5) by substituting (1), we have

$$\min_{\mathbf{W}} \quad \sum_{i=1}^{I} \frac{N_0}{G_{a_i,A}}(2^{\frac{R^i_{\text{min}}}{W_{a_i}}} - 1), \tag{7}$$

$$\text{s.t.} \quad W_{a_i} \geq \frac{R^i_{\text{min}}}{\log_2(1 + \frac{P^i_{\text{max}}G_{a_i,A}}{N_0})}, \quad \sum_{i=1}^{I} W_{a_i} = W_A. \tag{8}$$

It can be shown that (7) is convex and Slaters condition holds, so there is no duality gap. Therefore, the optimal solution is characterized by the Karush-Khun-Tucker conditions [10]. Then the Lagrangian of (7) is given by

$$L(\mathbf{W}, \lambda, \nu) = \sum_{i=1}^{I} \frac{N_0}{G_{a_i,A}}(2^{\frac{R^i_{\text{min}}}{W_{a_i}}} - 1) + \nu(\sum_{i=1}^{I} W_{a_i} - W_A) + \sum_{i=1}^{I} \lambda_i(\frac{R^i_{\text{min}}}{\log_2(1 + \frac{P^i_{\text{max}}G_{a_i,A}}{N_0})} - W_{a_i}), \tag{9}$$

where the Lagrangian multipliers $\lambda_i \geq 0$, $i = 1, \cdots, I$, and $\nu \geq 0$. Optimizing over $\mathbf{W}$ given ν and λ_i yields

$$\nu = \lambda_i + \frac{N_0 \ln 2}{G_{a_i,A}} 2^{\frac{R^i_{\text{min}}}{W_{a_i}}} \frac{R^i_{\text{min}}}{W^2_{a_i}}. \tag{10}$$

Then for any two MSs, a_i and a_j, from (10), we get

$$\lambda_i + \frac{N_0 \ln 2}{G_{a_i,A}} 2^{\frac{R^i_{\text{min}}}{W_{a_i}}} \frac{R^i_{\text{min}}}{W^2_{a_i}} = \lambda_j + \frac{N_0 \ln 2}{G_{a_j,A}} 2^{\frac{R^j_{\text{min}}}{W_{a_j}}} \frac{R^j_{\text{min}}}{W^2_{a_j}}. \tag{11}$$

In general cases where a_i and a_j are assigned a bandwidth large enough to meet the minimal requirement R^i_{min} (or R^j_{min}), from (11) and by the complimentary slackness [10], $\lambda_i = \lambda_j = 0$, and we can get the following simplification

$$\frac{2^{\frac{R^i_{\text{min}}}{W_{a_i}}} \frac{R^i_{\text{min}}}{W^2_{a_i}}}{2^{\frac{R^j_{\text{min}}}{W_{a_j}}} \frac{R^j_{\text{min}}}{W^2_{a_j}}} = \frac{G_{a_i,A}}{G_{a_j,A}}. \tag{12}$$

If we assume that the MSs of Cell A have similar rate requirements, i.e., $R^i_{\text{min}} \in [\bar{R} - \epsilon, \bar{R}]$, $\forall i = 1, \cdots, I$, where $0 < \epsilon \ll \bar{R}$, we can conclude that

$$\begin{aligned} W_{a_i} < W_{a_j},\ P_{a_i} < P_{a_j},\ \text{if} \quad G_{a_i,A} > G_{a_j,A}, \\ W_{a_i} > W_{a_j},\ P_{a_i} > P_{a_j},\ \text{if} \quad G_{a_i,A} < G_{a_j,A}. \end{aligned} \tag{13}$$

If the channel undergoes large-scale fading, i.e., $G_{a_i,A} = D^{-\gamma}_{a_i,A}$, where γ is the path loss exponent, then (13) indicates that for a_i that is closer to BS_A than a_j, it will be allocated a bandwidth W_{a_i} smaller than W_{a_j}, and will transmit with a smaller power level P_{a_i}, since $P_{a_i} = \frac{N_0}{G_{a_i,A}}(2^{\frac{R^i_{\text{min}}}{W_{a_i}}} - 1)$.

B. Spectrum Sharing Between Two Operators

According to [9], it is not preferred that two MSs of A and B, a_i and b_j, share the same sub-channel, if

$$G_{a_i,B}G_{b_j,A} > G_{a_i,A}G_{b_j,B}, \tag{14}$$

which indicates that for a_i and b_j, the product of the channel cross gains $G_{a_i,B}G_{b_j,A}$ is greater than the product of the channel direct gains $G_{a_i,A}G_{b_j,B}$. Therefore, if there is high spectrum demand for both Operator A and Operator B, and some b_j has to share the same band with some a_i, intuitively, it is better to have

$$G_{a_i,B}G_{b_j,A} \ll G_{a_i,A}G_{b_j,B} \quad \text{or} \quad \frac{G_{a_i,B}}{G_{a_i,A}} \ll \frac{G_{b_j,B}}{G_{b_j,A}}. \tag{15}$$

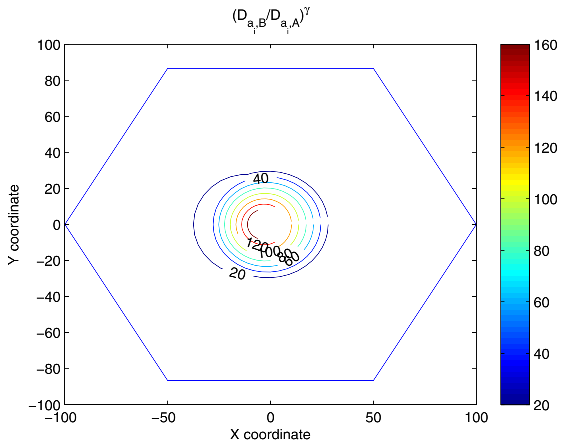


Fig. 2: Contour of $(\frac{D_{a_i,B}}{D_{a_i,A}})^{\gamma}$ when a_i moves inside Cell A, with BS_A at (0m,0m), BS_B at (120m,0m), and $\gamma = 3.5$.

Otherwise, heavy IOI will degrade the quality of the desired signals for the two MSs. In other words, both of them need to greatly increase their transmission power in order to maintain a satisfying QoS.

Condition (15) can be justified as follows. Without loss of generality, we view (4) as functions of the channel cross gains, $G_{a_i,B}$ and $G_{b_j,A}$. By taking the first order derivative of P'_{a_i} and P'_{b_j} with respect to $G_{a_i,B}$ and $G_{b_j,A}$, we can get

$$\frac{\partial P'_{a_i}}{\partial G_{a_i,B}} > 0, \ \frac{\partial P'_{a_i}}{\partial G_{b_j,A}} > 0, \ \frac{\partial P'_{b_j}}{\partial G_{a_i,B}} > 0, \ \frac{\partial P'_{b_j}}{\partial G_{b_j,A}} > 0. \tag{16}$$

Therefore, in order to reduce the transmission power P'_{a_i} and P'_{b_j} under interference, it is better to have smaller $G_{a_i,B}$ and $G_{b_j,A}$, and thus, a smaller $G_{a_i,B}G_{b_j,A}$.

If we assume large-scale fading and γ is the path loss exponent, then (15) becomes

$$\left(\frac{D_{a_i,B}}{D_{a_i,A}}\right)^{\gamma} \gg \left(\frac{D_{b_j,B}}{D_{b_j,A}}\right)^{\gamma}, \tag{17}$$

where $D_{a_i,B}$ denotes the distance between a_i and BS_B.

As we mentioned in the system model, Cell A is the victim and it has no information about the spectrum allocation inside Cell B. So when a MS a_k is interfered by b_j, a_k has no knowledge of where b_j is located nor the transmission power of b_j and the ratio $\left(\frac{D_{b_j,B}}{D_{b_j,A}}\right)^{\gamma}$. In order to reduce the transmission power for both two MSs under interference, according to (17), the controller of victim Cell A should select another non-interfered a_i that has the largest ratio $\left(\frac{D_{a_i,B}}{D_{a_i,A}}\right)^{\gamma}$, instead of a_k, to share the spectrum with b_j.

We depict the plot of $\left(\frac{D_{a_i,B}}{D_{a_i,A}}\right)^{\gamma}$ when a_i moves inside Cell A in Fig. 2. We set the radius of Cell A as 100 m, the distance between BS_A and BS_B as 120 m, and $\gamma = 3.5$. As a_i moves farther away from BS_A, $\left(\frac{D_{a_i,B}}{D_{a_i,A}}\right)^{\gamma}$ decreases rapidly. For instance, when $D_{a_i,A}$ is about 10 m, the ratio is about 120; however, when $D_{a_i,A}$ increases to 20 m, the ratio drops to only 60. This indicates that when a_i is not close enough to BS_A, the interference level is higher, and thus the QoS degradation of a_i is greater. For a_i's that are very close to BS_A, they are the most robust to uplink interference from other operators. So we name the small circular area with BS_A as the center the "*safe region*", meaning that the MSs inside the safe region are the least sensitive to uplink interference (see Fig. 4). As a rule of thumb we set the radius of the *safe region* to be $\frac{1}{5}$ of the cell radius.

Moreover, from the conclusion in (13), in general, a_i's that are close to BS_A use smaller power P_{a_i}. According to (4), taking derivative of the adjusted power P'_{a_i} and P'_{b_j} with respect to P_{a_i}, we find that

$$\frac{\partial P'_{a_i}}{\partial P_{a_i}} > 0, \quad \frac{\partial P'_{b_j}}{\partial P_{a_i}} > 0. \tag{18}$$

This indicates that for those a_i's closer to BS_A, since they are using smaller transmission power P_{a_i}, the increased power level to combat performance degradation due to interference will also be lower. Therefore, concluding from the above analysis, a_i's inside the safe region are the most proper ones to share spectrum bands with the other operators, since they will save most power under mutual interference. If MSs outside the safe region in victim Cell A are interfered by the other operators, the controller of Cell A can switch the frequency of the interfered MSs with those MSs inside the safe region to maintain QoS, without deteriorating the interferer's performance. In the next, we will develop the dynamic frequency-intelligent reserve-and-switch technique (D-FIRST) to combat IOI based on the above conclusions.

C. Proposed Protocol

As shown in Section III, if MSs of Cell A share the total bandwidth W_A in a FDMA fashion and are interfered by the competing Operator B, the controller of Cell A should switch the frequency of the interfered MSs with MSs located within the safe region of Cell A to save power. However, from (13), we can see that the bandwidth assigned to MSs located within the safe region of Cell A is small. Therefore, if the competition with Operator B is severe, and many MSs inside Cell A are being interfered, the amount of bandwidth available to perform frequency switching might not be sufficient. One option is to increase the coverage area of the safe region so that a larger amount of MSs can be included in the safe region and thus, more spectrum is available for switching. However, due to the effect of path loss, (17) may not hold. Hence, a better solution for Operator A to combat the unpredicted interference from other operators is to reserve a part of W_A for future frequency-switching. The proposed D-FIRST is illustrated in Fig. 3, and the partition of Cell A is shown in Fig. 4.

From Fig. 4, the controller of Cell A first groups the MSs of Cell A into subsets based on their geographical locations, and divide the spectrum band allocated to Cell A into slots according to the aggregated QoS demand of the dedicated subsets, as shown in Fig. 3. When uplink interference from Cell B occurs due to spectrum competition, the controller of

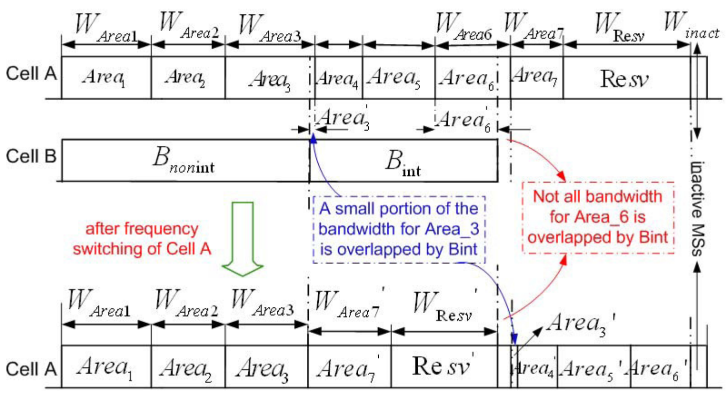


Fig. 3: The proposed D-FIRST.

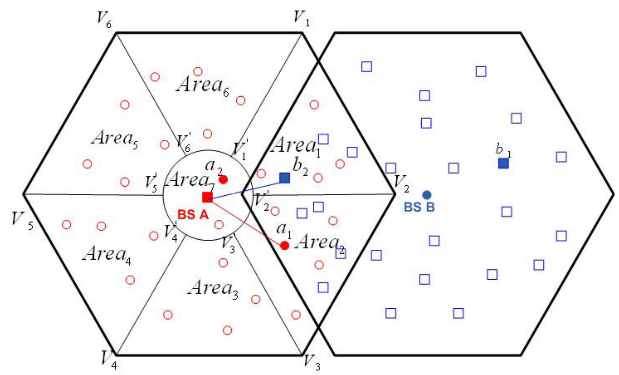


Fig. 4: The illustration of partition of Cell A.

Cell A will dynamically switch the interfered MSs' currently allocated sub-channels with MSs of Cell A located in the safe region (i.e., $Area_7$ in Fig. 4). Alternatively, it can also switch to the reserved bands W_{Resv} that are not currently occupied. Hence, the Operator A can maintain satisfying QoS and improve the spectrum efficiency with little extra cost (e.g., power).

The amount of frequency allocated to the reserved band can be determined by the environment and scenario under consideration. For example, environment with high user densities such as urban metropolitan, a larger segment of reserved band can be set in order to guarantee active users always achieving their QoS requirements. However, in low user density areas, e.g., rural environment, a smaller segment of reserved band can be set in order to avoid the waste of bandwidth. The impact of the ratio of the reserved bandwidth over W_A will be discussed in more detail in the next section.

IV. Simulation Results

In order to evaluate the performance of the proposed protocol and investigate the impact of the ratio of the reserved band, we performed simulations for a two-cell case in the following section.

A. Comparison of Power Consumption with D-FIRST

In the first part of the simulation, we show how the proposed protocol can reduce the total power consumption in order to satisfy all MSs' QoS demand in a cell under interference. We consider the spectrum sharing between Cell A and Cell B, as shown in Fig. 4, where the radii of both cells are 100 m. There are in total of 48 active MSs uniformly distributed within Cell A and share a bandwidth of $W_A = 10$ MHz. Let's assume that the minimum QoS requirement for a_i is $R^i_{\min} = 1$ Mbps, and the maximal power constraint is $P^i_{\max} = 1$ mW, $\forall i$. We consider the case when there are 16 active MSs randomly distributed in the overlapping area, which will cause interference to Cell A. The total sharing bandwidth for these MSs is 3.2 MHz. The goal of channel allocation for Cell B is assumed to be the same as Cell A (see Eq. (5)), with $R^j_{\min} = 100$ kbps and $P^j_{\max} = 1$ mW. The noise power N_0 is set to be 10^{-12} W, and the pass loss exponent $\gamma = 3.5$. The ratio of the used bandwidth over W_A is fixed as 90%. The spectrum allocation pattern for Cell A is as shown in Fig. 3 in which we randomly allocate the assigned spectrum for b_j's within the range of W_A, and assume that if b_j occupies the reserved bandwidth W_{Resv} of Cell A or W_{Area_7} for the safe region, frequency-switching is not performed. We vary the distance between BS_A and BS_B from 125 m to 150 m, and observe the total power consumption with the proposed protocol under different interference levels. In Fig. 5, we show the comparison of the total power for Cell A before and after the frequency-switching. We can see that as the distance between the two BSs decreases, the mutual interference becomes higher, thus the transmission power increases greatly. With the proposed protocol, when the interference level is high, i.e., when the distance is 125 m, the total power consumption can be reduced by 40%.

Here we consider Cell A as the victim, and Cell B as the interferer. We assume that Cell B will not alter its channel allocation if the frequency-switching of Cell A can also improve its performance. Furthermore, we also need to ensure that the total power consumption for Cell B will be reduced if deploying the proposed protocol. From Fig. 6, we can see that Cell B will also gain benefit from the proposed D-FIRST.

B. Impact of the Ratio W_{Resv}/W_A

In the second part of the simulation, we show how much bandwidth should be reserved to minimize the total power consumption of Cell A under interference. In particular, two interference levels are studied: i) low-interference case in which the distance between the two BSs is set at 140 m with 16 MSs in Cell B interfering Cell A; ii) high-interference case in which the distance is set at 120 m, with 48 MSs in Cell B. The minimum QoS requirement for a_i and b_j is assumed to be $R^i_{\min} = 500$kbps and $R^j_{\min} = 50$kbps, respectively. Other parameters are kept unchanged as in Section IV-B. From Fig. 7, we can see that as the active MSs occupy an increasing ratio of W_A from 70%, the total power consumption will decrease. Therefore, the reserved bandwidth should be set to less than 30% of W_A to avoid the waste of spectrum resources. However, when they occupy around 85% of W_A, there is a jump in the power consumption. This indicates that if the active MSs

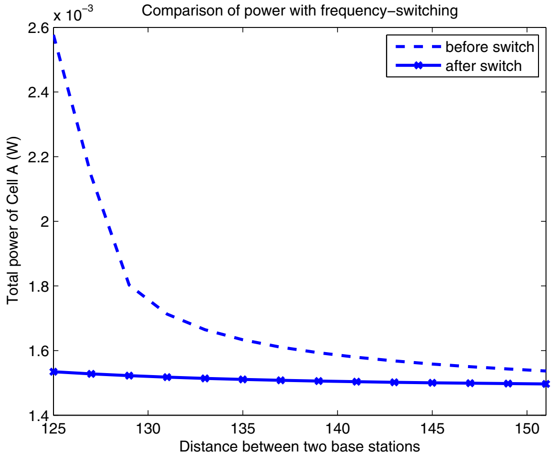


Fig. 5: Comparison of total power consumption for Cell A (the victim operator).

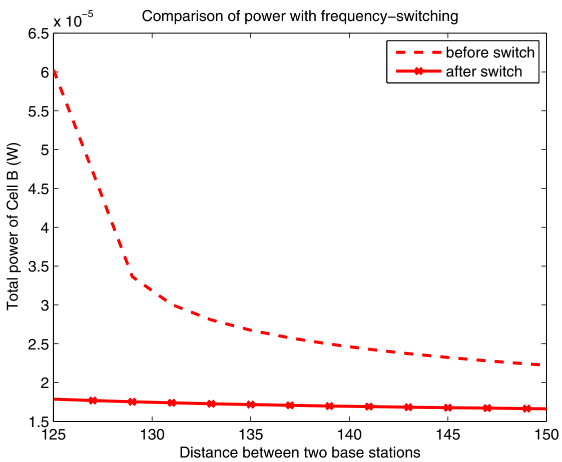


Fig. 6: Comparison of total power consumption for Cell B (the interferer operator).

use too much spectrum, the reserved bandwidth is insufficient to support frequency-switching. However, as the ratio of used bandwidth over W_A keeps increasing and approaches unity, the total power consumption decreases again, since the effect of a larger bandwidth overwhelms that of the IOI. But in this scenario, the total power consumption is still higher than that where the active MSs occupy about 85% of W_A, and the spectral efficiency is also lower. From Fig. 7, we can also see that when the IOI level is higher, Cell A should reserve more bandwidth for frequency switching.

V. Conclusions

We have proposed a spectrum sharing scheme that will coordinate among different co-existing cellular operators competing for the same spectrum band. When interference from other operators is detected, the victim operator can switch the frequency of the interfered MSs with the MSs in the *safe region*, which is shown to be a small circular area

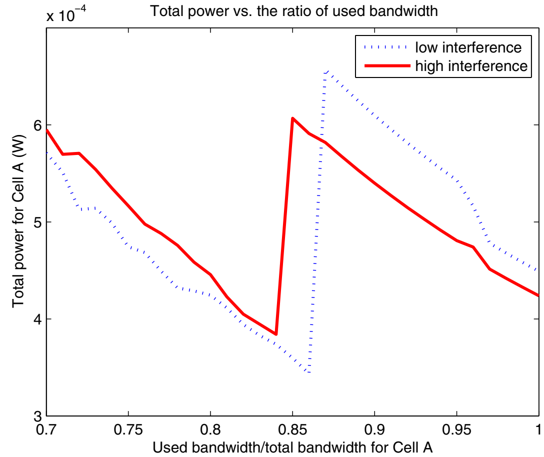


Fig. 7: Total power vs. ratio of used bandwidth.

around the cell center, and/or switch to the *reserved band*. The simulation results show that with the proposed protocol, the total power consumption of both operators can be greatly saved which effectively reduced the IOI. Therefore, such a scheme can serve as a potential spectrum sharing mechanism for the future cellular networks such as IMT-Advanced in which “win-win” situation can be guaranteed for both sharing operators. Furthermore, it has been shown that in a high-density area, the operators should reserve more bandwidth for potential frequency-switching to ensure reliability of the spectrum sharing scheme.

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