TRANSMISSION POWER CONTROL FOR AVOIDING CELL OVERLAPPING IN MICRO-CELLULAR NETWORKS

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Abstract: In a cellular system, a base station can smoothly communicate with nodes in its cell by avoiding overlap of frequency range with its adjacent cells. From the viewpoint of graph theory, that needs to divide the original frequency range into at least four sub-ranges. This leads to deteriorate the transmission rate. To tackle this problem, we propose Complete Cell Partitioning (CCP) that enables a base station to use the whole of the original frequency range by avoiding overlap of its own cell with the adjacent cells. CCP is achieved by appropriately controlling the transmission power on base stations. We first analytically derive success probability of CCP when nodes are randomly located in the whole region. Then, we verify the analysis by comparing with simulation results. The analytical and simulation results show that CCP enables to use the original frequency range more effectively than the traditional cellular system regardless of the number of nodes in a cell.

1 INTRODUCTION

Mobile communication technologies (Schiller, 2000; Siau and Shen, 2003) which play important roles in ubiquitous networks have attracted extensive research efforts in recent years. In the traditional mobile communication services, voice and mail data occupied the large portion of traffic. Such data can be transmitted at a relatively low bit rate. In recent years, cellular phone service providers offer a flat-rate plan (Marcus, 2004) independently of the amount of consumed traffic. This new type of service plan enhances users to download short movies and music. In addition, a shop may want to distribute advertising information to people when they get close to it. In both types of service, network capacity and transmission rate become more important.

A cellular system (Lee, 1995; Castafieda-Camacho and Lara-Rodriguez, 2000) is an infrastructure used in a mobile communication between a cellular phone, called a node, and a base station. In the system, a service region is divided into multiple subregions, called cells. In every cell, a base station is located at the center and communicates with a node using a wireless connection. In the traditional cellular system, the size of a cell is as large as several kilometers. Such a large cell is called a macro-cell (I et al., 1993). A system administrator designs the size of a macro-cell so that the service area is fully covered by the macro-cells while allowing adjacent cells to overlap each other (Chen, 1994; Camp et al., 2000). This structure is effective for calling because a node can communicate wherever it is located in the service region.

However, to avoid the radio interference, a base station must use the radio wave whose frequency range is different from those of the adjacent base stations. From the viewpoint of graph theory, this needs to divide the original frequency range into at least four sub-ranges (Robertson et al., 1997). This leads the degradation of transmission rate. We expect that the transmission rate becomes more important in the information distributing service e.g., advertisement service with which a shop provides people who get close to it. If a system administrator does not need to divide the original frequency range, the transmission rate does not deteriorate. Appropriately controlling the transmission power leads the avoidance of cell overlapping and enables to use the whole of original frequency range. As a result, it achieves about four

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times higher transmission rate than the traditional cellular system. We call this scheme as "complete cell partitioning (CCP)."

In this paper, we propose CCP for information distributing service of a shop. A shop may want to distribute advertising information to people when they get close to it. On the occasion, it should not disturb the communication of its adjacent shops. Thus, it had better prevent radio interference among them. If a base station can achieve high-speed data transfer, it can distribute a large volume of multimedia contents that seems to be more attractive for people than text-based contents. In this case, CCP is accomplished when a base station can adjust the size of the cell so that a node belonging to an adjacent cell does not exist in the vicinity of border among adjacent cells.

We expect that CCP tends to succeed when the cell size becomes small. This is because nodes in the vicinity of the border among cells decrease in response to the reduction of the cell size. In recent years, various wireless technologies which have micro-cells (Lee, 1995), such as Bluetooth (Haartsen and Ericsson Radio Systems B.V., 2000) and ZigBee (Zigbee Alliance, 2007), have been widely deployed. Thus, CCP is expected to be one of key concepts achieved over these technologies.

We first propose CCP that is based on a radio interference model. Then, by using analytical approach, we derive the success probability of CCP, the probability that a node can communicate with a base station, under the following assumptions.

- The region is divided into multiple cells each of which shapes a regular hexagon.
- Nodes are located at random positions in the region.
- CCP is applied to download link, while upload link uses the traditional cellular system. In mobile communications, the size of download data is much larger than that of upload data. Therefore, download link requires much transmission rate.

Through simulation experiments, we verify the analysis and show the effectiveness of CCP.

The remainder of this paper is organized as follows. In Section 2, we introduce the radio interference model to explain CCP. In Section 3, we formulate the condition of CCP and analyze the success probability. Finally, Section 4 gives conclusions of this paper.

2 RADIO INTERFERENCE MODEL

We first introduce a model of radio interference in wireless networks. In general, a radio wave is attenuated in inverse proportion to α-th power of distance (Grossglauser and David N. C. Tse, 2002; Gupta and Kumar, 2000). Suppose that a base station *bs* emits a radio wave with transmission power P. Then, power $P(i)$ that a node X_i receives from *bs* is expressed as

$$P(i) = \frac{P}{|X_i - bs|^{\alpha}}. \quad (1)$$

As shown in Fig. 1, perceived radio quality at X_i is differentiated by the distance from *bs*.

- If $|X_i - bs| \leq r^c$, X_i is in a success zone where it can receive data from *bs* correctly.
- If $r < |X_i - bs| \leq \Delta r^c$, X_i in a noise zone where it receives data from *bs* as noise.
- If $\Delta r^c < |X_i - bs|$, X_i is in no interference zone where it does not receive data from *bs*.

Here, we call Δ as occupation ratio that determines the area occupied by *bs*. The radius of a success zone r^c is controlled by adjusting the transmission power.

3 COMPLETE CELL PARTITIONING

3.1 Formulation of Condition for CCP

In this section, we formulate the condition of CCP for information distribution service. In this case, a base station is responsible for the connections to available nodes in its maximum transmission range. We denote the nodes as X_i in an ascending order of the distance from the base station *bs*. X_i $(1 \leq i \leq n)$ is in its maximum transmission range while X_i $(n+1 \leq i)$ is out of the range. *bs* first finds maximum i that satisfies the following condition:

$$\begin{aligned} &|X_{n+1} - bs| \geq \Delta |X_i - bs| \\ &\quad \textit{and } |X_{n+1} - bs| < \Delta |X_{i+1} - bs|, \end{aligned} \quad (2)$$

then adjusts the radius of success zone as $|X_i - bs|$. Note that X_{n+1} is the nearest node out of the maximum transmission range of *bs*. Equation (2) indicates that *bs* can connect to nodes in its success zone only when there aren't any nodes belonging to other base

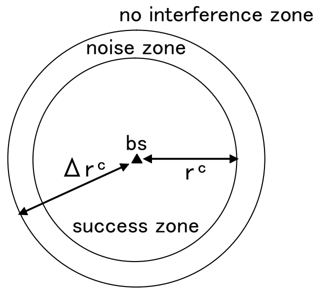


Figure 1: Relation between radio attenuation and occupation ratio.

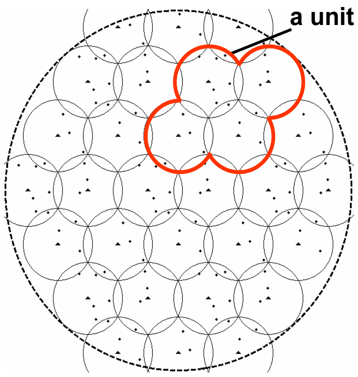


Figure 2: Sample distribution of nodes and base stations when $N_r = 4$.

stations in its noise zone. In CCP, *bs* generates the radio wave at the cost of nodes which is belonging to *bs* and in the noise zone. When each base station controls its transmission power by such a method, avoidance of radio interference leads CCP.

To realize this mechanism, each base station has to collect information on nodes in its maximum transmission range. In addition, it also needs to know every other node belonging to its neighboring base stations. This information can be obtained by exchanging node lists among neighboring base stations. The detail of the mechanism is a future work.

3.2 Analysis

In this section, we analyze the success probability of CCP. In the traditional analysis of a cellular system, the area is assumed to be a repeat structure of one cell. In this paper, we improve the precision of the analysis by making a unit of the repeat structure larger. In what follows, we explain the analysis in detail.

First, suppose that N_r adjacent cells are periodically located in the region. If N_r increases, we expect accuracy of the analysis grows up. Figure 2 displays a sample distribution of nodes and base stations when $N_r = 4$. A circle with dashed line and that with solid line express a region and a cell, respectively. Each cell that consists of the unit of the repeat structure is surrounded with a thick line. A triangle and a dot represent a base station and a node, respectively.

As mentioned in section 1, we assume a cell is shaped as a regular hexagon. Suppose that the length of each edge of the hexagon is R. The radius R_{eq} of the equivalent circle whose area is equal to that of the hexagon becomes $\sqrt{\frac{3\sqrt{3}}{2\pi}}R$. Note that we do not lose generality even if we set R_{eq} to 1. In the following analysis, we set R_{eq} to 1. Moreover, suppose that node density in a cell is n and the occupation ratio is Δ. We also define the success probability of CCP $P_{success}(n)$ as the probability that a node can communicate with a base station.

In what follows, we analytically derive $P_{success}(n)$ when $N_r = 1, 4$.

3.2.1 In the Case of $N_r = 1$

When $N_r = 1$, only one type of cell is lined with the region. We focus on the neighboring seven cells in the region, as illustrated in Fig. 3. A hexagon and a circle with solid line in these figures express a cell and a range of max transmission power of a base station, respectively. Define the center cell in the seven adjacent cells as a main cell and the others as neighboring cells. In what follows, we focus on the main cell.

Suppose a base station in one of the seven cells emits the radio wave so that a node whose distance from the base station is less than r can communicate with it. This distance in every cell equals to r since the position of a node is invariant among cells when $N_r = 1$. For successful communication, nodes in the main cell cannot exist in the noise zone of the adjacent cells. As a result, the node located at a distance of r from the base station *bs* in the main cell can exists on the thick lines in Fig. 3. When $r + \Delta r \leq \sqrt{3}R$, the thick line equals to the circle whose radius is r as in Fig. 3(a) because the success zone of the main cell does not intersect the noise zones of the adjacent cells. When $\sqrt{3}R \leq r + \Delta r$, the thick line becomes as in Fig. 3(b). Moreover, the thick line disappeared when r exceeds r_0. r_0 is derived from the following equation.

$$\left(\sqrt{3}R - \frac{\sqrt{3}}{2}r_0\right)^2 + \left(\frac{r_0}{2}\right)^2 = (\Delta r_0)^2. \qquad (3)$$

Therefore, we get

$$r_0 = \frac{\sqrt{3}R\sqrt{4\Delta^2 - 1} - 3R}{2(\Delta^2 - 1)}. \qquad (4)$$

Thus, the most distant node which can communicate with *bs* can exist in the area expressed as

$$S_1 = \int_0^1 S_b(r)dr, \qquad (5)$$

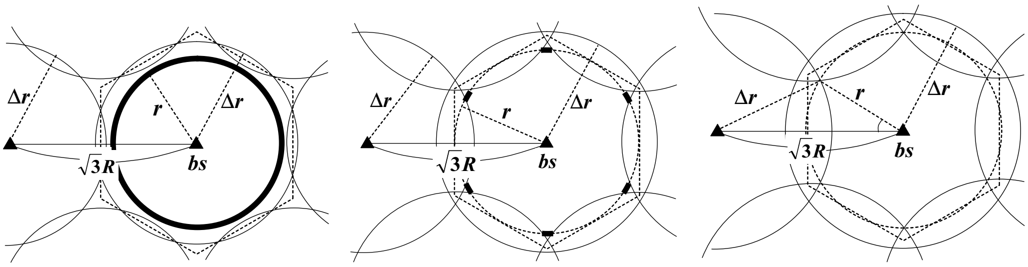
where $S_b(r)$ is the sum of the length of the thick lines and it is derived as

$$S_b(r) = \begin{cases} 2\pi r, & \left(0 \leq r \leq \frac{\sqrt{3}R}{\Delta+1}\right) \\ 12r\left\{\frac{\pi}{6} - \mathrm{acos}\left\{\frac{3R^2-(\Delta^2-1)r^2}{2\sqrt{3}Rr}\right\}\right\}, & \left(\frac{\sqrt{3}R}{\Delta+1} \leq r \leq r_0\right) \\ 0, & (r_0 \leq r \leq 1) \end{cases}$$

The success probability equals to the ratio of nodes in the area to all nodes in the main cell as follows:

$$P_{success}(n) = \frac{S_1}{\pi R_{eq}^2}. \qquad (6)$$

According to $R_{eq} = 1$, $P_{success}$ is derived as fol-



(a) $0 \le r \le \frac{\sqrt{3}R}{\Delta+1}$ (b) $\frac{\sqrt{3}R}{\Delta+1} \le r \le r_0$ (c) $r_0 \le r \le 1$

Figure 3: The area the most distant node from *bs* can exist when $N_r = 1$.

lows:

$$P_{success}(n) = \frac{1}{\pi}\int_0^1 S_b(r)dr. \tag{7}$$

3.2.2 In the Case of $N_r = 4$

We analyze the success probability in the case of $N_r = 4$. Define one cell from the four adjacent cells as a main cell and the others as neighboring cells. In what follows, we focus on the main cell. Suppose that there are $k \le 4n$ nodes in the main cell. In the case, the success probability of CCP is defined as follows:

$$P_{success}(n) = \frac{1}{n}\sum_{k=1}^{4n}\left\{k\, C_4(n,k)\, P_s(n,k)\right\}, \tag{8}$$

where $C_4(n,k)$ is the probability that k nodes are in the main cell and $P_s(n,k)$ is the mean success probability in the main cell.

First, we derive $P_s(n,k)$ to obtain $P_{success}(n)$. Figure 4 illustrates the main cell, $Cell_1$, and one of the neighboring cells, $Cell_2$, when the radius of the success zone in $Cell_1$ is r. $Cell_3$ is the neighboring cell of $Cell_2$ that faces $Cell_1$. When $N_r = 4$, node positions in $Cell_1$ and that in $Cell_3$ are same. Thus, in $Cell_3$, the radius of the success zone is r, too. In this case, for successful communication in $Cell_1$, the nodes in $Cell_2$ cannot exist in the noise zone of $Cell_1$ and $Cell_3$. Therefore, they must exist in the grey zone in Fig. 4. When $\Delta r \le \frac{\sqrt{3}R}{2}$, the circle with radius Δr does not invade $Cell_2$. Hence the nodes in $Cell_2$ can exist anywhere in $Cell_2$ as illustrated in Fig. 4(a). When $\frac{\sqrt{3}R}{2} \le \Delta r$, the grey zone becomes like Fig. 4(b) and Fig. 4(c). The nodes in the other neighboring cells must also exist in the grey zones of their belonging cells. As a result, the probability that $4n-k$ nodes in the three neighboring cells exists in the grey zones becomes

$$p_{adj}(r,n,k) = \left(\frac{S_4(r)}{\pi R_{eq}^2}\right)^{4n-k}, \tag{9}$$

where $S_4(r)$ is the area of the grey zone and it is defined as follows.

$$S_4(r) = \begin{cases} \pi, & \left(0 \le r \le \frac{\sqrt{3}R}{2\Delta}\right) \\ \pi - 4\left\{\frac{\mathrm{acos}\left(\frac{\sqrt{3}R}{2\Delta r}\right)}{2}(\Delta r)^2 - \frac{\sqrt{3}R}{4}\sqrt{(\Delta r)^2 - \left(\frac{\sqrt{3}R}{2}\right)^2}\right\}, & \left(\frac{\sqrt{3}R}{2\Delta} \le r \le \frac{R}{\Delta}\right) \\ \frac{\pi}{3}\left\{4 - (\Delta r)^2\right\}, & \left(\frac{R}{\Delta} \le r \le 1\right) \end{cases}$$

$p_{adj}(r,n,k)$ means the success probability when the radius of the success zone in $Cell_1$ is r. This equals to probability that a node whose distance from bs_1 is r succeeds in communication. Since $P_s(n,k)$ is the mean success probability in $Cell_1$, $P_s(n,k)$ becomes as

$$P_s(n,k) = \frac{1}{\pi}\int_0^1 2\pi r\, p_{adj}(r,n,k)dr. \tag{10}$$

Second, let's derive $C_4(n,k)$. Because the node density is n, the probability that the main cell includes k nodes is defined as

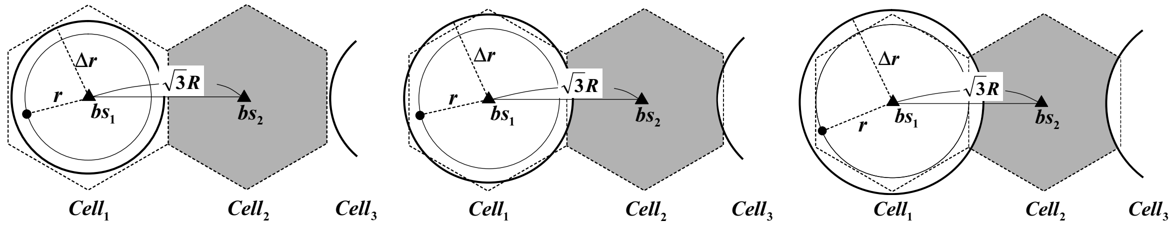
$$C_4(n,k) = {}_{4n}\mathrm{C}_k\left(\frac{1}{4}\right)^k\left(\frac{3}{4}\right)^{4n-k}. \tag{11}$$

By substituting Eq. (11) to Eq. (8), the success probability becomes

$$P_{success}(n) = \frac{1}{n}\sum_{k=1}^{4n}\left\{k\, C_4(n,k)\int_0^1 2r\left(\frac{S_4(r)}{\pi}\right)^{4n-k}dr\right\}. \tag{12}$$

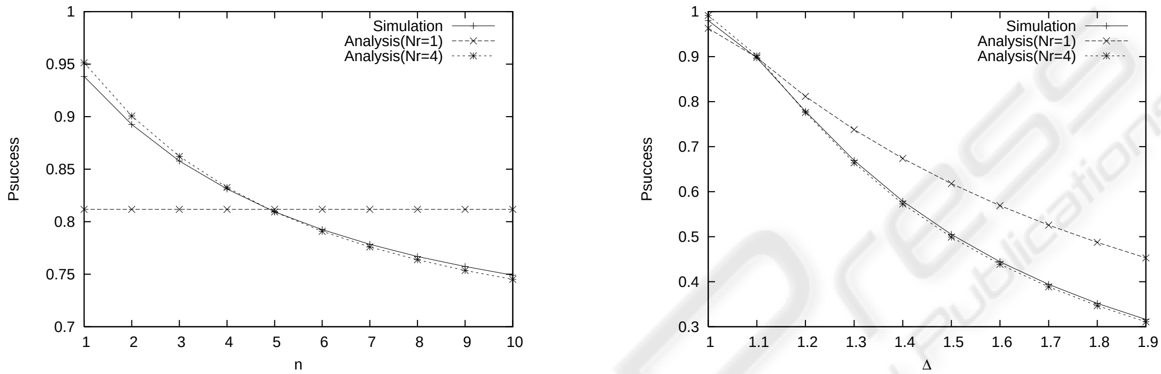
3.3 Simulation and Analytical Results

In this section, we verify the accuracy of our analysis and show the effectiveness of our proposal. In the following simulations, we set the number of base stations in the region to 250. We vary the number of nodes in the region from 250 to 2500. Thus, the average number of nodes in a cell, that is node density n, ranges from 1 to 10. Moreover, we suppose that nodes are located at random positions in the whole region. We define the success probability as the ratio of the number of nodes that success in communication to the whole number of nodes. Note that we ignore nodes near the border of the region because they cannot belong to any base stations regardless of the



(a) $0 \le r \le \frac{\sqrt{3}R}{2\Delta}$ (b) $\frac{\sqrt{3}R}{2\Delta} \le r \le \frac{R}{\Delta}$ (c) $\frac{R}{\Delta} \le r \le 1$

Figure 4: The area the most distant node from bs can exist when $N_r = 4$.



(a) In the case of $\Delta = 1.2$ (b) In the case of $n = 7$

Figure 5: Accuracy of analysis.

transmission power control. In the following results, we show the average of 1000 simulations.

3.3.1 Accuracy of Analysis

We verify the accuracy of our analysis by comparing simulation results. Figure 5 shows the transition of $P_{success}$ when $\Delta = 1.2$ and $n = 7$. The analytical results in the case of $N_r = 4$ are very close to the simulation results compared to those in the case of $N_r = 1$. As in Fig. 5(a), the average difference is only 0.5 % when $N_r = 4$ and $\Delta = 1.2$. Figure 5(b) also depicts that the average difference is at most 1.1 % when $N_r = 4$ and $n = 7$. Thus it is clear that increase of N_r contributes to reduction of difference between analytical and simulation results.

Furthermore, those figures show that N_r can be relatively small to improve the accuracy of the analysis. We use the analysis of $N_r = 4$ as $P_{success}$ in the following explanation.

3.3.2 Impact of Node Density and Occupation Ratio

We investigate the feasible area of CCP through analytical results. Figure 6 depicts the transition of $P_{success}$ for CCP with the node density n and the occupation ratio Δ. $P_{success}$ falls down with the increase of both of n and Δ. Now we examine the feasible area that our proposal is more efficient than the traditional cellular system. We define radio utilization as the product of available frequency range and the success probability. As mentioned before, our proposal can use about four times larger frequency range than the traditional cellular system. Thus, in terms of the radio utilization, our proposal is more effective than the traditional cellular system when $P_{success}$ is larger than 0.25. According to Fig. 6, CCP is more effective than the traditional cellular system since the radio utilization of CCP is constantly larger than 0.25 for every n and Δ. Especially when Δ is small, CCP can accomplish about 3-4 times higher radio utilization than the traditional cellular system while suppressing the sacrificed nodes.

3.3.3 Impact of Controlling the Transmission Power

In this section, we examine the effect of controlling the transmission power. First, we define the fixed transmission power to satisfy the condition of CCP. Suppose a base station emits the radio wave so that the radius of its success zone equals to r_{fix}. Since the radio wave cannot disturb the communication in its adjacent cells,

$$r_{fix} = \frac{\sqrt{3}R}{2\Delta}. \tag{13}$$

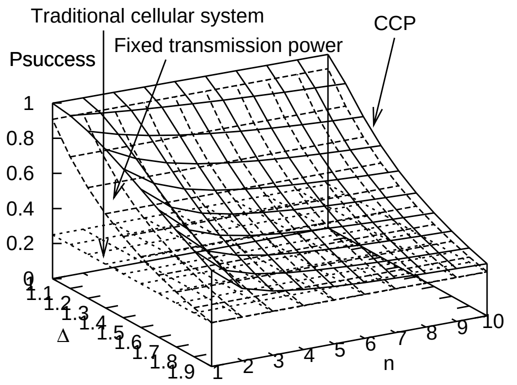


Figure 6: The success probability of CCP.

We define the scheme that every base station sets the radius of its success zone to r_{fix} as the fixed transmission power scheme. Then the success probability of this scheme becomes as follows:

$$P_{success} = \frac{\pi r_{fix}^2}{\pi R_{eq}^2} = r_{fix}^2. \tag{14}$$

Figure 6 also shows $P_{success}$ of CCP and that of the fixed transmission power scheme. CCP is more effective than the fixed transmission power scheme. When $\Delta = 1.2$, for example, the differences between $P_{success}$ of our proposal and that of the fixed transmission power scheme are up to 0.32.

4 CONCLUSION

In this paper, we proposed complete cell partitioning (CCP), a new scheme for transmission power control on base stations to avoid radio interference among adjacent base stations. CCP enabled a base station to use the whole of the original frequency range while a base station could use a quarter of it in the traditional cellular system. Then, we analyzed the success probability of CCP and verified the validity of the analysis. Several simulation and analytical results showed that the analysis was fully valid. Moreover, the results also showed that CCP was more effective than the traditional cellular system from the viewpoint of the radio utilization. For example, when the occupation ratio was 1.2, CCP accomplished about 3-4 times higher radio utilization than the traditional cellular system while suppressing the sacrificed nodes.

As future works, we have to consider implementation of CCP on a real system. For example, a base station needs to know the node positions in its maximum transmission range. We expect that Ultra Wide Band (UWB) realizes it because UWB can measure a position more accurately than GPS.

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