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A New Network Architecture for Wireless Communications

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Current cellular systems are based on the concept of the *cell*. Although the cell allows channel reuse, it has also become a metaphor for channel confinement and leads to the thorny problem of handoff and call dropping. The problem will get much worse as wireless networks move toward smaller cells and multirate. A new network architecture for wireless communications is presented in this paper. The architecture—called MAWCC for its main characteristic, MAcrodiversity Without Channel Confinement—has no ping-pong effect in handoff. Furthermore, its capacity gain from macrodiversity can be freely converted into handoff reduction. The new architecture offers many options to handle mobility which are not possible in a conventional cellular architecture.

KEY WORDS: DCA; macrodiversity; MAWCC.

1. INTRODUCTION

Current cellular systems are based on the concept of the cell. We divide the entire region into cells and use the same channel repetitively in different cells so long as the interference requirement is not violated. Although the “cell” offers channel reuse, it also leads to the vexing handoff and call-dropping problem: A call might be handed over again and again during its lifetime and could be dropped in each handoff step. The problem will get much worse as the network moves toward smaller cells and multirate services. Studies have shown that high-bandwidth connections have high blocking probabilities [1]. If handing over one voice connection is problematic, imagine the chance of success of handing over a call ten times that rate. Call dropping has become a major hurdle for delivering *multirate* wireless services.

A new network architecture for wireless communications is proposed in this paper. The new architecture—called MAWCC for its main characteristic: MAcrodiversity Without Channel Confinement—can freely convert its capacity gain from macrodiversity into handoff reduction. In MAWCC, requesting the network to support a higher mobility is the same as requesting more bandwidth; conversely, the network’s capacity will rise if the mobilities of its customers are reduced. The convertibility between the two offers more options to tackle the mobility issue than possible in a conventional wireless network.

2. MAWCC ARCHITECTURE

In a cellular system, the effects of the surrounding buildings, terrain, and trees cause a large variation in the mean square envelope of the received signal power. The variation degrades the system’s performance and the resulting degradation is called the shadowing effect. To mitigate the shadowing effect, we can use two (or even three) sites to serve a connection, since the probability that two paths are shadowed is much smaller than that of one being shadowed. This technique, called *macrodiversity*, can achieve a more homogeneous coverage and has long been recognized as an effective tool for combating shadowing [2, 3].

One example of macrodiversity implementation is given in Fig. 1 [3]. Each cell is divided into three zones and each zone is covered by a separate antenna.

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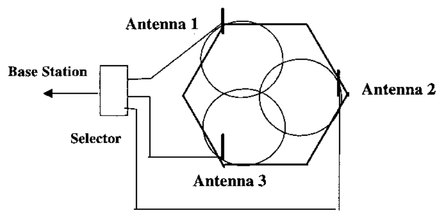

Fig. 1. The zone concept described in [1].

The selector chooses the best zone and its antenna to send and receive signals from and to the base station. Although this macrodiversity architecture improves the performance of the system, it does not address the coverage between cells and the ping-pong problem during handoff remains. An entirely different concept to implement macrodiversity is described below [4]. It achieves a goal well beyond the conventional advantages of macrodiversity.

2.1. Macrodiversity in MAWCC

Instead of using three antennas, we can use *sectoring*—already commonly deployed in the field—to implement macrodiversity. Figure 2 shows a three-sectored hexagonal cellular system; at the center of each cell are three directional antennas. Figure 3 shows the same topology with dashed lines added. As can be seen, the areas surrounded by the dashed lines are also hexagons. The difference between the two is just a coordinate shift. Conventionally we call the area surrounded by the solid lines a cell. We are equally correct to call the area surrounded by the *dashed lines* a cell. Since nothing is changed, how we define a cell is only a matter of convenience. But the two views offer drastically different interpretations about the network's structure. According to the first view, each cell has three directional antennas located at the center. According to the second view, however, each cell has three antennas sitting

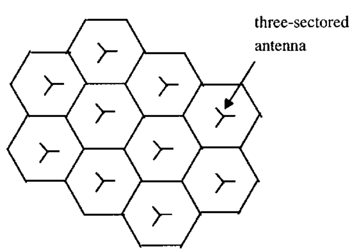

Fig. 2. A sectored cellular system.

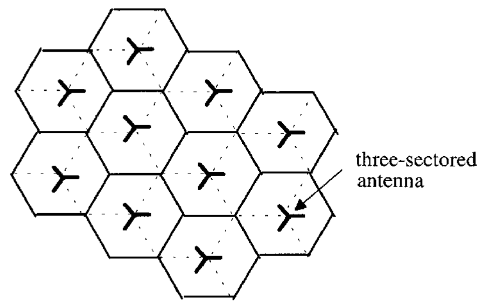

Fig. 3. If we consider the areas surrounded by dashed lines as cells, then each cell has antennas sitting at the three corners.

at the corners—just as in a macrodiversity cell (Fig. 1). Sectoring, as can be seen, already has the makings of macrodiversity.

The second key element in MAWCC's implementation is dynamic channel allocation (DCA). Unlike a fixed-channel-assignment (FCA) network, where each base station is assigned a fixed number of channels, a DCA network allows its base stations to access any channel in the network. Many DCA schemes have been proposed. They differ in degree of network planning and the required communication among base stations. For example, the DCA schemes in [14–16] require no network planning or communication among base stations. Other types of DCA schemes [e.g., 17] require limited communication among base stations. Although studies have demonstrated DCA's advantage of higher trunking efficiency over FCA, DCA is not without its problems: it requires more circuits in each cell and a more complicated channel assignment scheme than an FCA scheme. Tradeoffs can be made among these factors (efficiency, complexity of channel assignment, and number of circuits required) and, as a result, various variations have been proposed. Their pros and cons can be found in refs. 18–21.

To simplify our discussion, we assume a general DCA scheme for MAWCC in which every channel can be accessed by every cell. Besides higher trunking efficiency [5, 6], DCA in MAWCC serves another major purpose: it breaks the conventional cell boundary so that adjacent cells can simultaneously serve the connection with the same channel (Fig. 4). When the mobile unit moves into other cells, it carries the same channel with it and no immediate handoff is required. This continues until the cochannel interference requirement is violated. More discussion on handoff is provided in the following section.

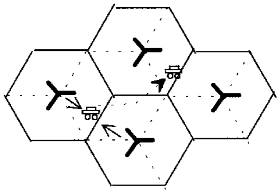

Fig. 4. The mobile unit will carry the same channel as it moves into a new cell.

2.2. Call Setup and Handoff in MAWCC

In call setup, the mobile unit will identify the best and the second-best stations and their sectors to serve the connection. We call one *active* and the other *standby*. Identifying the two can be done with one power scanning. For the uplink, the signal from the mobile unit is received by both serving base stations and the selection can be done at either the base station or the switch. For the downlink, only the active station—the stronger of the two—transmits the signal to the mobile unit. Periodically, the two stations measure their signal strengths and report that information to the switch. Based on that information, the switch decides which station should be active or standby.

When the mobile unit enters another cell, it carries the same channel into the new cell as if nothing had happened (Fig. 4). This is possible because there is no boundary for a particular channel in MAWCC, due to its use of DCA. In contrast, a handoff is immediately required in a conventional cellular network when the mobile unit enters a new cell. If the signal strength of the *standby* station drops below a predetermined value, the switch will identify a new standby station. For TDMA, it is preferable to have the mobile unit assist the process to alleviate the processing demand for the base stations and the switch.

It is important to note that the change of the standby station is not the same as a conventional handoff. A conventional handoff has two elements that lead to call dropping: (1) no channels available in the new cell, and (2) not enough time to process the handoff. These two elements do not apply to the case of changing the standby station because in the latter the channel is guaranteed (the same channel) and the task does not need to be done immediately—the standby station is only standing by. Certainly there are times when two mobile units using the same channel get close enough to violate the cochannel interference requirement. Then one of them must switch its channel and a traditional handoff is required. Such activities, as shown later, are significantly less frequent than in a conventional cellular architecture.

Although the WCC (without-channel-confinement) feature can still be implemented without macrodiversity, it will not work well. First, without macrodiversity the connection must be handed over immediately to the neighboring cell as the mobile unit crossing the cell boundary (although the channel is still the same). The time-critical characteristic of a conventional handoff remains. Second, without macrodiversity the system will be plagued by the ping-pong problem as a mobile unit zigzagging on the cell boundary. More important, the capacity gain created by macrodiversity can be traded for further handoff reduction (Section 3).

The MAWCC concept also differs from that of soft handoff in a CDMA system. Although macrodiversity is also used in soft handoff of a CDMA system, the WCC characteristic sets them apart, WCC allows a mobile user to move into a new cell without requesting new network resources. This feature, not possible for CDMA, is the key element of MAWCC's mobility management strategy.

3. MACRODIVERSITY GAIN AND HANDOFF REDUCTION

This section offers a comprehensive study of the performance gain from macrodiversity. We then study how that gain can be converted into handoff reduction.

3.1. Capacity Gain from Macrodiversity

In a traditional macrodiversity system, the number of diversity branches is almost fixed in order to have a homogeneous coverage, and is determined by the topology of the network—for example, three branches for hexagons, four-branch grids, and two-branch linear arrays. But the proposed architecture does not have this restriction. For example, we have described a two-branch diversity for the hexagonal topology. With a higher cost, we can use three branches to achieve a better performance. To better understand the design tradeoff, we offer an analysis in the following. The performance improvement of macrodiversity is represented as a reduction in cochannel interference (CCI) probability, defined as the probability that the desired signal level is less than the required receiver threshold due to excessive interference.

3.1.1. Analytical Model

Suppose a conservative DCA policy is adopted in which a minimum reuse distance is imposed for every channel. Under the worst-case scenario, the locations of the first-tier interferers are similar to that in a fixed channel assignment (Fig. 5). In the following we analyze the performance gain as a function of number of macrodiversity branches for the case shown in Fig. 5. The performance gain of macrodiversity is strongly affected by the link-quality evaluation scheme. Various schemes have been proposed and each has a different implementation complexity. In the following we study the performance gain of macrodiversity under three link-quality measurement schemes:

1. *SIR*-diversity: The signal-to-interference ratio (SIR) is constantly computed and the branch with the largest SIR is selected.
2. *S*-diversity: The signal power *S* is constantly measured and the branch with the largest *S* is selected.
3. *S* + *I*-diversity: The signal mixed with interference, i.e., *S* + *I*, is constantly measured. The branch with the largest *S* + *I* is selected.

As implementation goes, $(S+I)$-diversity is the easiest to implement and only the received signal, $(S+I)$, is monitored. *S*-diversity requires interference be separated from the received signal, which obviously is a difficult task. Because $S \gg I$, *S*-macrodiversity can be considered as an approximation for the $S + I$ case. Among the three, the most desirable one is SIR-diversity. But it is also the most difficult to implement.

There are some results in the literature related to the $(S+I)$-*micro*diversity [7, 8]. As for macrodiversity, the *S* type has been discussed in ref. 9. We are going to compute and compare the cochannel interference of all three forms of macrodiversity mentioned previously. As in ref. 9, we ignore fading and only consider shadowing in the analysis. We assume that the uplink and downlink channels are symmetric and have the same statistics. For the ease of presentation, we discuss *S*-macrodiversity [9] and SIR-macrodiversity first. We then present the analysis for *S* + *I*-macrodiversity.

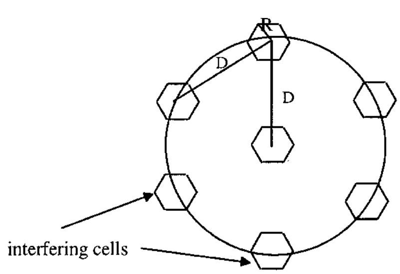

Fig. 5. The locations of the interferers under the worst-case scenario, where *D* is the minimum reuse distance and *R* is the radius of the cell.

S-Macrodiversity. For *S* macrodiversity, the branch with the largest desired signal power is selected to the receiver. The desired signal power at the receiver is expressed as

$$S = \max(S_1, \ldots, S_L) \tag{1}$$

where S_k is the signal power from the *k*th branch and L is the number of the diversity branches. Let $F_k(x)$ and $f_k(x)$ be the *cdf* and *pdf* of S_k. Assume the signal powers from each branch are i.i.d. random variables. Then the *pdf* of *S* is

$$f_S(x) = L[F_k(x)]^{L-1} f_k(x) \tag{2}$$

Furthermore, the total interference power of each branch has a distribution identical to that of another branch. The total interference power of a branch is also independent of the desired signal power *S*. Let f_I be the *pdf* of the total interference power *I* of some branch. The CCI probability of *S*-diversity is then equal to

$$\begin{aligned} F_S(\lambda_{th}) &= \text{Prob}\left(\frac{\max(S_1, \ldots, S_L)}{I} \le \lambda_{th}\right) \\ &= 1 - L \int_0^{\infty} \left[\int_{-\infty}^{x/\lambda_{th}} f_I(y)\, dy\right] \\ &\quad \times [F_k(x)]^{L-1} f_k(x)\, dx \end{aligned} \tag{3}$$

Under the effect of shadowing, $f_K(x)$ is log-normal distributed, which is written as

$$f_k(x) = \frac{1}{\sqrt{2\pi}\,\sigma_k x} \exp\left[\frac{-(\ln x - \ln \Upsilon_k)^2}{2\sigma_k^2}\right] \tag{4}$$

where σ_k is the shadowing spread and Υ_k is the area mean power. Yeh *et al.* [10] offered an approach to determine the composite *pdf* of the sum of the independent log-normal random variables, which is approximated by another log-normal random variable. We apply this approach to represent the total interference power by an approximate log-normal random variable. Let σ_I represent the logarithmic variance and Υ_I the area mean of the approximate log-normal *pdf*. Then substituting Eq. (4) into Eq. (3), we obtain the CCI probability with S-macrodiversity as

$$F_S(\lambda_{th}) = 1 - L \int_0^{\infty} \left[\int_{-\infty}^{x/\lambda_{th}} \frac{1}{\sqrt{2\pi}\,\sigma_I y} \times \exp\left[\frac{-(\ln y - \ln \Upsilon_I)^2}{2\sigma_I^2} \right] dy \right] \times \left[1 - Q\left(\frac{\ln x - \ln \Upsilon_k}{\sigma_k} \right) \right]^{L-1} \frac{1}{\sqrt{2\pi}\,\sigma_k x} \times \exp\left[\frac{-(\ln x - \ln \Upsilon_k)^2}{2\sigma_k^2} \right] dx \tag{5}$$

where

$$Q(x) = \int_x^{\infty} \frac{1}{\sqrt{2\pi}} \exp\left(\frac{-x^2}{2} \right) dx$$

Let $w = (\ln x - \ln \Upsilon_k)/(\sqrt{2}\sigma_k)$ and transform Eq. (5) into the Hermite integration form, which can be calculated by the Hermite polynomial approach. We have

$$F_S(\lambda_{th}) = 1 - \int_{-\infty}^{\infty} f(w) \exp(-w^2)\, dt = 1 - \sum_{i=1}^{\infty} f^n(w_i) h \tag{6}$$

where

$$f(w) = \frac{L}{\sqrt{\pi}} \left[1 - Q\left(\frac{\sqrt{2}\,\sigma_k w + \ln(\Upsilon_k/\Upsilon_I \lambda_{th})}{\sigma_I} \right) \right] \times [1 - Q(\sqrt{2}w)]^{L-1} \tag{7}$$

and w_i and h_i are roots and weight factors of the nth-order Hermite polynomial.

SIR-Macrodiversity. Assume SIR in each branch $(S_K/I_K,\ k = 1, \ldots, L)$ are i.i.d. random variables. Then the average CCI probability with SIR selection diversity is

$$F_{\mathrm{SIR}}(\lambda_{th}) = \mathrm{Prob}\left(\max\left(\frac{S_1}{I_1}, \ldots, \frac{S_L}{I_L} \right) \le \lambda_{th} \right) = \left[\mathrm{Prob}\left(\frac{S_k}{I_k} \le \lambda_{th} \right) \right]^L \tag{8}$$

In the case of no macrodiversity, the CCI probability formula is the same as for S-diversity, S/I-diversity, and $(S+I)$-diversity. By letting $L = 1$ in Eq. (5), we can simplify the CCI probability with no diversity as

$$F_{\mathrm{SIR}_B}(\lambda_{th}) = Q\left(\frac{\ln(\Upsilon_K/\lambda_{th}\Upsilon_I)}{\sqrt{\sigma_k^2 + \sigma_I^2}} \right) \tag{9}$$

According to Eqs. (8) and (9), the CCI probability of the SIR-macrodiversity in the presence of log-normal shadowing is then written as

$$F_{\mathrm{SIR}(\lambda_{th})} = \left[Q\left(\frac{\ln(\Upsilon_k/\lambda_{th}\Upsilon_I)}{\sqrt{\sigma_k^2 + \sigma_I^2}} \right) \right]^L \tag{10}$$

$(S+I)$-Macrodiversity. Following a similar procedure given in ref. 11, we derive the performance of the $(S+I)$-macrodiversity as follows. It is easy to see that the L-branch CCI probability can be written as

$$F_{S+I}(\lambda_{th}) = 1 - \sum_{i=1}^{L} \left[\mathrm{Prob}\left(\frac{S_i}{I_i} \ge \lambda_{th} \middle| S_i + I_i \ge S_j + I_j,\ j = 1, \ldots, L,\ j \ne i \right) \times \mathrm{Prob}(S_i + I_i \ge S_j + I_j,\ j = 1, \ldots, L,\ j \ne 1) \right]$$

Let $U = S_i + I_i$ and $V = S_i/I_i$. Then the above equation is reduced to

$$F_{S+I}(\lambda_{th}) = 1 - L \int_0^{\infty} \int_{\lambda_{th}}^{\infty} f_{U,V}(u, v) \times [\mathrm{Prob}(S_j + I_j \le v)]^{L-1}\, du\, dv \tag{11}$$

Note that $\text{Prob}(S_i + I_i \le v)$ is just the cdf of U and $f_{U,V}(u, v)$ is the composite pdf of random variables U and V. The relation between $f_{U,V}(u, v)$ and the composite pdf of random variables S_i and I_i is

$$f_{U,V}(u, v) = \frac{v}{(u+1)^2} f_{S_i, I_i}\left(\frac{uv}{u+1}, \frac{v}{u+1}\right) \tag{12}$$

As in the case of S-diversity, we use a log-normal random variable with area mean Υ_I and logarithmic variance σ_I to approximate the composite pdf of the sum of multiple log-normal interferers. Combining the pdf of the desired signal power [described in Eq. (4)], we then express Eq. (12) as

$$f_{U,V}(u, v) = \frac{1}{2\pi\sigma_k\sigma_I uv} \exp\left[\frac{-\{\ln[uv/(u+1)\Upsilon_k]\}^2}{2\sigma_k^2}\right] \times \exp\left[\frac{-\{\ln[v/(u+1)\Upsilon_I]\}^2}{2\sigma_I^2}\right] \tag{13}$$

Since both S_j and I_j are log-normal distributed, we again use a log-normal random variable with area mean Υ_c and logarithmic variance σ_c to approximate $S_j + I_j$. Then

$$\text{Prob}(S_j + I_j \le v) = 1 - Q\left(\frac{\ln(v/\Upsilon_c)}{\sigma_c}\right) \tag{14}$$

Substituting Eqs. (13) and (14) into (11), we express the CCI probability in a Hermite form as follows:

$$F_{S+I}(\lambda_{th}) = 1 - \int_{-\infty}^{\infty} f(w)\exp(-w^2)\, dw = 1 - \sum_{i=1}^{i=n} f(w_i)h \tag{15}$$

where

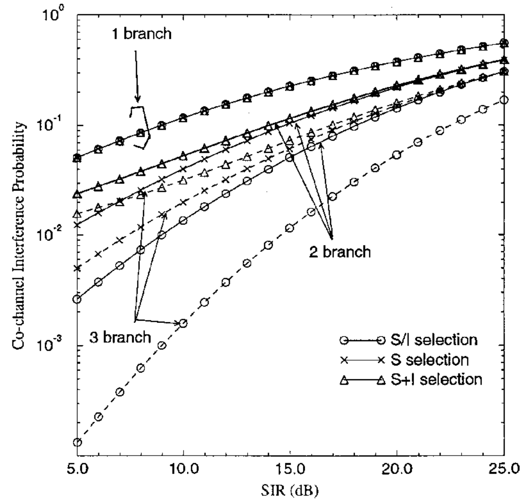

Fig. 6. Performance comparison of SIR-, S-, and $(S+I)$-macrodiversity in the presence of one log-normal shadowed interferer, where the shadowing spread is 8 dB for both the desired and the interferer.

w_i and h_i are the roots and weight factors of the nth-order Hermite polynomial.

3.1.2. *Results*

Consider a dual slope path loss model, $P_r/P_t = 1/[r^a(1 + g/r)^b]$, where P_r/P_i is the ratio of received power to the transmitted power, r is the distance, $a = b = 2$, and $g = 0.6$ times the cell radius in our case. Assume the receiver is located at the cell boundary R and the interferers are $4.6R$ away, although Fig. 5 shows that under the worst-case scenario, the first-tier interferers can be as large as six. In reality, however, the number of interferers is usually small, since we have a sectored system. Even if we assume that all cells on the circle have an interferer, there are, on average, only two interferers. Figure 6 compares, in the presence of one interferer with 8 dB shadowing spread, the S-macrodiversity, $(S+I)$-macrodiversity, and SIR-macrodiversity, i.e., Eqs. (6), (10), and (15).

$$f(w) = \frac{L}{\pi}\int_{(\ln\lambda_{th})/\sqrt{2}\sigma_k}^{\infty} \exp\left[-\left(z - \frac{\ln(\Upsilon_k/\Upsilon_I)}{\sqrt{2}\,\sigma_k} + \frac{\sigma_I w}{\sigma_k}\right)^2\right] \times \left[1 - Q\left(\frac{\ln(\exp(\sqrt{2}\sigma_k z) + 1) - \ln(\Upsilon_c/\Upsilon_I) + \sqrt{2}\,\sigma_I w}{\sigma_c}\right)\right]^{L-1} dz \tag{16}$$

The results show that under a 5% CCI probability, the SIR thresholds for the SIR-, S-, and $(S+I)$-diversity are 15, 11, and 10 dB, respectively. In other words, with a probability of 0.95 the SIR of the network exceeds 15, 11, and 10 dB, respectively, for the three types of macrodiversity. Compared with the case of no diversity (5 dB), the gains of the three diversity schemes are 10, 6, and 5 dB, respectively. If the CCI probability is set to 10%, then the SIR thresholds for SIR-, S-, and $(S+I)$-diversity become 18, 15, and 14 dB, respectively. Compared with the case of no diversity (9 dB), the gains are 9, 6, and 5 dB for the three diversity schemes, respectively. The results indicate that all three diversity schemes have significant performance gains over the case of no diversity. The gains of $(S+I)$– and S-diversity are similar. $(S+I)$-diversity can be considered as a good approximation for the S-macrodiversity. The gain of SIR-diversity is significantly higher. But a precise SIR measurement is difficult to achieve.

Since $(S+I)$-macrodiversity is the simplest to implement, we show some additional results based on this scheme. Figure 7 shows, in the presence of two interferers, the performance gain of the $(S + I)$-diversity as a function of the number of diversity branches. At the 5% CCI probability, the 2-branch case has a 4 dB gain over the case of no diversity; the 3-branch case has a gain of 6 dB. Figure 8 describes how the performance gain is affected by the number of interferers. The case we study is a 3-branch $(S+I)$-diversity. Compared with the case of one interferer, two interferers degrade the performance by 1.7 dB, and three interferers degrade the performance by 4.5 dB.

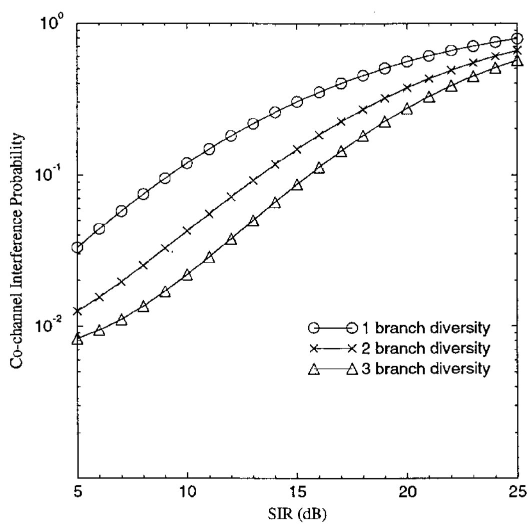

Fig. 7. Comparison of L-branch ($L = 1, 2, 3$) $(S+I)$-macrodiversity in the presence of two log-normal shadowed interferers, where the shadowing spread is 8 dB for all parties.

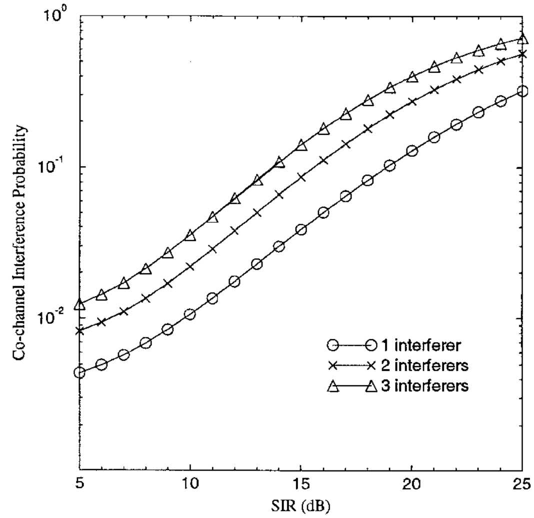

Fig. 8. Effects of the number of interferers on the performance of a 3-branch $(S+I)$-macrodiversity, where the shadowing spread is 8 dB for all parties.

3.2. Converting Capacity Gain into Handoff Reduction

In a traditional cellular system, a mobile unit immediately requires a handoff as it crosses a cell boundary. But a mobile unit in MAWCC can travel a much longer distance before a handoff is needed. There are two reasons for this.

1. The inherent imperfect packing of DCA allows a mobile unit to travel a greater distance before violating the reuse distance constraint. For example, suppose a cellular system imposes a reuse distance of 4 during call setup. Due to imperfect packing, the real average reuse distance is increased to 5 (Fig. 9).[4] (The maximum packing efficiency depends on the complexity of the algorithm [12].) In a conventional DCA system, this is just bandwidth waste. But in MAWCC, this lost bandwidth is converted into handoff reduction and allows a mobile unit to travel one more cell without violating the interference requirement.

[4]This does not imply the overall capacity is less than a conventional system. The capacity loss due to imperfect packing in DCA is well compensated by a higher trunking efficiency [6, 12].

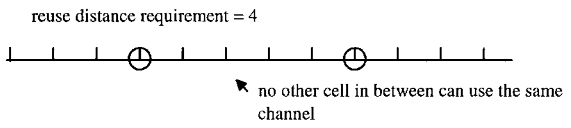

Fig. 9. Due to the nature of imperfect packing in DCA, a channel can travel a distance longer than a cell without violating the channel reuse constraint.

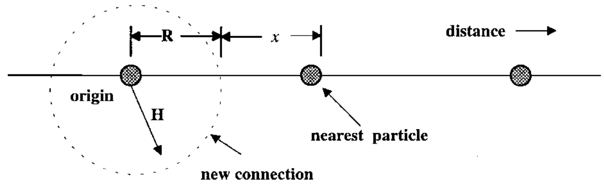

Fig. 11. Assume the new connection moving along one direction.

2. Macrodiversity increases the system's capacity. This capacity gain can be converted into handoff reduction, as shown below.

In the following we offer a simplified analysis to show the tradeoff between capacity gain and handoff reduction.

3.2.1. A Renewal Model

In MAWCC, connections using the same channel can be likened to particles moving in a chamber. Handoffs are needed when particles collide (Fig. 10). An exact analysis of this model may not be possible. In the following we study a simplified one-dimensional case shown in Fig. 11, where all users move along a line. Assume the system uses a timid DCA policy where a reuse distance limit R is imposed when a call is newly set up. Let H denote the *handoff distance* (the *minimum* reuse distance), meaning a handoff is required when the distance between any two users (particles) is less than H. Obviously the condition $R \geq H$ must hold. For example, in a conventional 7-cluster cellular system $R = 4.5$. If we assume a user needs a handoff when he/she gets to the cell boundary, then $H = 3.5$.

Perfect channel allocation in a DCA network, such as MAWCC, is usually unachievable. Because of imperfect channel packing, the distance—denoted by d—between a new connection and the nearest particle will always be $\geq R$. Let x be the random variable representing the extra distance, i.e., $d = R + x$ (Fig. 11). The average value of x is determined by the efficiency of the DCA

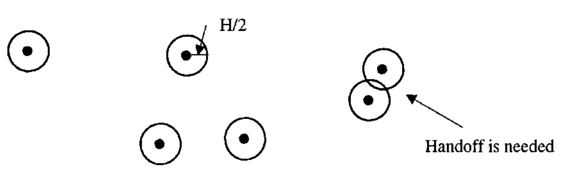

Fig. 10. Each active instance of a channel is likened to a particle. A handoff is needed only when the distance between two particles is less than H; H is called the handoff distance in this paper.

channel assignment algorithm (for random assignment, the efficiency is about 80% of the maximum packing efficiency [12]). Although x can have a general distribution, we assume d has a negative exponential density function to reduce the computation complexity. That is,

$$f(d) = 0 \quad \text{if} \quad d < R$$
$$= \mu e^{-\mu(d-R)} \quad \text{if} \quad d \geq R \tag{17}$$

We intend to get an estimation for the average number of collisions of a connection during its lifetime. In Fig. 11, the collision rate is determined by the relative movements among particles. We simplify the analysis by assuming that only the new connection is moving and the rest are idle. This will remove the dynamics and turn the model into a static one. In this static model we can treat the new connection as a particle with a radius H and the other, old connections using the same channel only as a point. After the new connection collides with its neighbor (same channel), a new channel will be used (i.e., a handoff) and the whole process will repeat. Thus the model renews itself upon collision times, and the average number of handoffs follows the *renewal* formula.

Let C_y be the random number of collisions of the new connection after it travels a distance y. Let s be the location of the *nearest* mobile unit using the same channel. Given s, we can write C_y as

$$C_y = 0 \quad \text{if} \quad s > y$$
$$= 1 + C_{y-s} \quad \text{if} \quad s \leq y \tag{18}$$

Taking the expectation of C_y, we find that (18) results in

$$E[C_y | s, s < y] = 1 + E[C_{y-s} | s, s < y] \tag{19}$$

Let $\overline{C}(y)$ be the average value of C_y, i.e., $\overline{C}(y) = E[E[C_y | s]]$. Then, taking another expectation of both sides of Eq. (19) with respect to s leads to

$$\overline{C}(y) = F(y) + \int_0^y \overline{C}(y-s)f(s)\,ds \qquad (20)$$

where $f(\cdot)$, given in Eq. (17), is the density function of the distance d of the nearest neighbor and $F(\cdot)$ is the distribution function. The above integral equation can be solved numerically.

Let z be the total distance traveled by the new particle (connection) during its lifetime. Suppose that z also has a negative exponential distribution with mean $1/\lambda$. Since the moving particle has a radius H, then the total number of collisions is $\overline{C}(z+H)$ for a given z. Averaging this number with respect to z, we get the average number of handoffs, denoted by C_{ave}, during the lifetime of the new connection in Fig. 11:

$$C_{\text{ave}} = \int_0^\infty \overline{C}(z+H) \times \lambda e^{-\lambda z}\,dz \qquad (21)$$

Figure 12 plots C_{ave} against R. In the figure, we assume packing efficiency = 80% [12] [meaning $R/(R+1/\mu) = 0.8$]. We can compute μ for different R. We also assume the average traveling distance $1/\lambda = 1$. The range for R is chosen as follows. We begin with $R = 4.5$, the same value used in a 7-cluster cellular system [13]. In a FCA network, a handoff occurs when the mobile unit is on the boundary. That means the handoff distance $H = 3.5$. If we assume the macrodiversity gain = 5 dB (Section 3.1), we can get a rough estimation for the new handoff distance H' using the deterministic path loss model: $10\log(H/H')^4 = 5$ and this leads to $H' = 2.62$. will not be worse than that in an FCA network. Figure 12 shows the conversion Thus, within this range $R \geq 2.62$, the CCI performance between capacity and handoff reduction. At $R = 2.6$, the network has the highest capacity. At $R = 4.5$, the entire capacity gain is traded for handoff reduction.

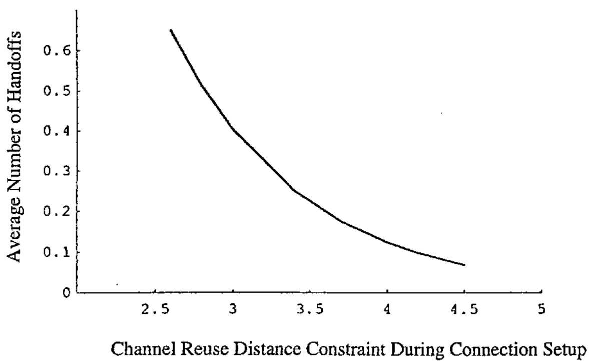

Fig. 12. Tradeoff between capacity gain and handoff reduction.

4. CONCLUDING REMARKS

The trend toward smaller cells and multirate has pushed handoff and call-dropping to the forefront of mobility management issues in wireless communications. The frequent handoffs existing in the current cellular architectures could render them incapable of supporting high-speed multirate services. In the paper we argued for a new network architecture for wireless communications. We also showed how its capacity gain from macrodiversity can be converted into a reduction in handoffs.

The convertibility between the two offers a new direction for designing a wireless network. Consider the issue of macrocells versus microcells. Smaller cells, while offering more capacity, are unable to handle high-mobility users. To deal with this problem, a common approach is to design a network with macrocells overlaying on microcells, one for high- and the other for low-mobility users. But the unpredictability in traffic estimation and user mobility profiles will reduce the efficiency of the partitioning scheme.

MAWCC offers more efficient options. We can design the network with the same cell size (the small one) to support both high- and low-mobility users. If a user's mobility is high, the same channel will be reallocated at a greater distance away; if low, then at a shorter distance. When a high-mobility user stops and turns into a low-mobility user, the reuse distance of the same channel can be shortened. The reduced mobility is then converted back into network capacity. Priority can also be included to manage mobility. For instance, if a user deems his/her call important, he/she can require the call be given high priority (of course, the user will pay more). When a high-priority user collides with a low-priority user, the latter is forced to do the handoff and the former is allowed to continue with the same channel and thus experiences a lower call-dropping probability.

These new options are only part of the features provided by MAWCC. Many other features in MAWCC, like location identification through macrodiversity, are also important. We will report our findings on them in a future paper.

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