Dynamic Resource Allocation Protocols for 4G Mobile Networks

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Abstract – **In this paper we propose a system that controls mutual interfering distance d, between the users belonging to two different cells, in order to reduce the intercell interference in cellular wireless networks. Within this concept we present a protocol with constant distance between the receiving cochannel users from different cells that will keep the downlink intercell interference under a pre-specified threshold. This protocol is based on user position awareness (cognition) and coordination (cooperation) of the resource allocation protocols in adjacent cells. The protocol will keep the interference level low, independent on the position of the mobile in the cell and can provide in the cell border area a signal to interference ratio improvement in the order of (10 - 30) dB compared to the system with arbitrary distance between the cochannel interfering users.**

Keywords – **Cognitive networks, Dynamic resource allocation, Cooperative protocols, Intercell interference avoidance**

I. INTRODUCTION

The fourth generation (4G) mobile communication systems air interface coding and modulation are more or less defined, but the work on a new, more efficient, multiple access schemes still remains to be done. This paper suggests a new multiple access scheme for 4G mobile communication systems based on *intercell interference coordination (IIC) in MAC layer (IIC MAC).* This requires a certain level of cognition and cooperation designed to reduce the intercell interference on the downlink.

In space division multiple access (SDMA), within each channel, multiple beams are formed by a smart antenna array at the base station. The radiation pattern of each beam is adjusted, so that the main lobe is steered to the direction of the desired user and nulls are placed in the directions of interfering users. Down-link beamforming for power minimization in a single-cell system is studied in [1-5]. None of these contributions take into account multicellular scenarios. The main problem which arises in distributed resource allocation in such systems is the management of the intercell interference. In systems with connection oriented services, it can be handled by adaptive channel reallocation and distributed power control [6-8].

The Power Shaping technique [9] was proposed as an efficient resource (slot and power) allocation in a multicell packet environment with sectorized base station antennas and either TDMA or TD/CDMA radio interface. Unlike in traditional approaches, where time slots are allocated first, and then power control is performed, power shaping first assigns in advance (static allocation) a maximum power level to each slot by means of the so called power profiles, and then dynamically performs slot allocation (optionally fine power control as well).

Having in mind all above results we further elaborate multiple access protocol by introducing more detail in intercell interference coordination and cancellation. We combine the concept of SDMA and transmit power control into the concept of (θ, d, c) user spatial separation. By proper scheduling, the cochannel (c) users that can not be separated in angular domain (θ), are kept on such mutual distance d, that guarantees required SIR. Depending on user location this can provide a SIR improvement in the order of (10 – 30) dB compared with system without IIC. The algorithm provides a constant distance between the interfering user (CD IIC). The algorithm is systematic and scalable to enable interference coordination in a network with arbitrary number of interfering cells. It can be adaptive and easily reconfigurable to be implemented in ad hoc networks where instead of fixed cells a time varying clusters of terminals are coordinating the mutual level of interference. This becomes of interest in anticipating the trend in the evolution of cellular networks to include multihop transmission where the elements of ad hoc networks will be incorporated within the cells.

II. SYSTEM MODEL

It should be intuitively clear that if the two users, due to their position in the network, are not *θ-separable,* then we have to use additional steps to reduce the intercell interference. For example, in Fig. 1, transmission to user b will be also received by user a. On the other hand, transmission to user a, will not be received by user b because that direction can be spatially notched out while still transmitting successfully to user a.

In our model we assume that the beam forming has generated M spatial channels which are reused across each cell. Within each spatial channel, N additional channels are generated by using either time slot (TDMA), frequency bean (subcarrier in OFDM) or code (CDMA).

In order to minimize the intercell cochannel interference a special, intercell coordinated, channel allocation patterns are used. For a simple model with two cells, the channel allocation scheme will assign the channel index (1, 2,…, n,…N) depending on the user distance from the BS differently

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in a reference cell and its neighboring cell. We will use notation

$$a\left[(\text{start}, \text{direction})n,\ (\text{start}, \text{direction})r\ \right] \tag{1}$$

to denote the channel allocation pattern. As an example,

$$a[(1,\text{up})n,\ (0,\text{up})r] \tag{2}$$

means that channels (n) are allocated in increasing order (up) of indices starting from index 1 to the users on increasing (up) distances (r) from the BS, starting with distance 0. In other words the channel with lowest index is allocated to the user on shortest distance from the BS. In order to avoid the situation were two users from the different cells positioned close to each other at the borders of their cells, receive at the same channel, the assignment in the neighboring cell should use the pattern

$$a[(1,\text{up})n,\ (R,\text{down})r], \tag{3}$$

which means that the channels (n) are allocated in increasing order (up) of indices starting from index 1 to the users on decreasing (down) distances (r) starting with the maximum distance R. This suggests an alternative notation for IIC MAC as SDMA(θ, r, c) where c stands for channel.

III. SIGNAL TO INTERFERENCE RATIO ANALYSIS

For the analysis of signal to interference ratio we will suppose that the mobile stations a and b are located in two adjacent cells as shown in Fig. 1. In a conventional system these two mutually interfering stations may be at arbitrary distance. Formally we will refer to this as arbitrary distance (AD) protocol.

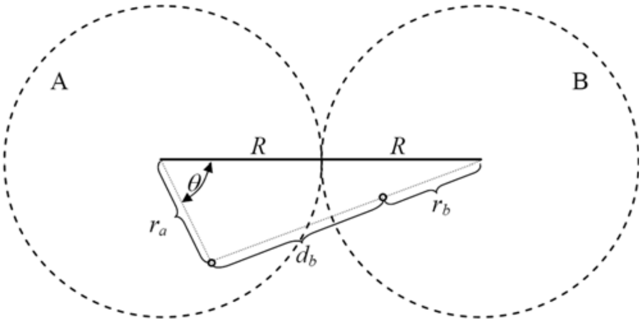

Fig. 1. Two cells scenario.

A. AD Protocol with no power control

With the transmit power P, the signal power transmitted by base station A, at the location of station a is

$$p_a = \frac{P}{r_a^{\alpha}} \tag{4}$$

where α is the propagation constant, r_a is the distance of station a from the base station A. The effect of fading and shadowing is neglected for the analysis, and it is left for the future work. Simillary, the signal power transmitted by base station B, at the location of station b is

$$p_b = \frac{P}{r_b^{\alpha}} \tag{5}$$

Therefore, the interference power at the location of station a is

$$p_{b\to a} = \frac{P}{(r_b + d)^{\alpha}} \tag{6}$$

where d is the distance between stations a and b. Signal to interference ratio is

$$SIR_1 = \frac{p_a}{p_{b\to a}} = \frac{P(r_b + d)^{\alpha}}{r_a^{\alpha} P} = \left(\frac{r_b + d}{r_a}\right)^{\alpha} \tag{7}$$

Having in mind Fig. 1, and by using cosine theorem, we get

$$(d + r_b)^2 = (2R)^2 + r_a^2 - 4Rr_a\cos\theta \tag{8}$$

$$\left(\frac{d + r_b}{r_a}\right)^2 = \left(\frac{2R}{r_a}\right)^2 + 1 - 4\frac{R}{r_a}\cos\theta \tag{9}$$

$$\frac{d + r_b}{r_a} = \sqrt{4/g^2 + 1 - 4/g\cos\theta} \tag{10}$$

where $g = r_a / R$.

Now we have

$$SIR_1 = \left(4/g^2 + 1 - 4/g\cos\theta\right)^{\alpha/2} \tag{11}$$

B. AD Protocol with power control

In case of power control, the received signal power at the location of stations a and b, transmitted by their base stations, is the same, and is defined by

$$p = \frac{P_a}{r_a^{\alpha}} = \frac{P_b}{r_b^{\alpha}} \tag{12}$$

where P_a and P_b are the transmit powers of base stations A and B, respectively. The interference power at the location of station a is

$$p_{b\to a} = \frac{P_b}{(r_b + d)^{\alpha}} \tag{13}$$

The signal to interference ratio is

$$SIR_2 = \frac{p}{p_{b\to a}} = \left(1 + \frac{d}{r_b}\right)^{\alpha}. \tag{14}$$

By dividing (10) with r_b we get

$$1 + \frac{d}{r_b} = \frac{1}{h}\sqrt{4 + g^2 - 4g\cos\theta}. \tag{15}$$

Signal to interference ratio is

$$SIR_2 = \left(\frac{1}{h}\sqrt{4+g^2-4g\cos\theta}\right)^{\alpha}, \qquad (16)$$

where $h = r_b / R$.

C. Constant Distance CD Protocol

As already mentioned, in order to avoid the situation were two users from the different cells positioned close to each other at the borders of their cells, receive at the same channel, and therefore to keep a low interference level, the assignment of channels in the two neighboring cells should use the pattern

$$a\big[(1,up)n,\ (0,up)r\ \big] \qquad (17)$$

$$b\big[(1,up)n,\ (R,down)r\ \big] \qquad (18)$$

In this case the following condition is always satisfied: $r_b = R - r_a$. The set of equations derived in *A* and *B* can be applied in this case if we set $h = 1 - g$. Therefore, we have

$$SIR_3 = SIR_1 = \left(4/g^2+1-4/g\cos\theta\right)^{\alpha/2}, \qquad (19)$$

$$SIR_4 = SIR_2\big|_{h=1-g} = \left(\frac{1}{1-g}\sqrt{4+g^2-4g\cos\theta}\right)^{\alpha}. \qquad (20)$$

IV. NUMERICAL RESULTS

In this section we present some results to illustrate performance of the protocols. Signal to interference ratio, for the IIC CD protocol (SIR_{CD} in the following text), and the same parameter for NIIC AD protocol (SIR_{AD} in the following text), for two isolated cells, are presented in Fig. 2.

In Fig. 2, one can see that $h = 0.9$ in the most of the terminal positions $SIR_{CD} > SIR_{AD}$. Also, $SIR_{CD} - SIR_{AD}$ is of the order of (10 – 30) dB, for $g > 0.5$. Of course, if the user is close to base station ($h = 0.2$) SIR_{AD} is significantly larger than SIR_{CD}.

Fig. 2 also shows the significance of power control .

The advantage of IIC protocol is that independent on user location, including the cell border area, SIR remains acceptable (larger than 15 dB).

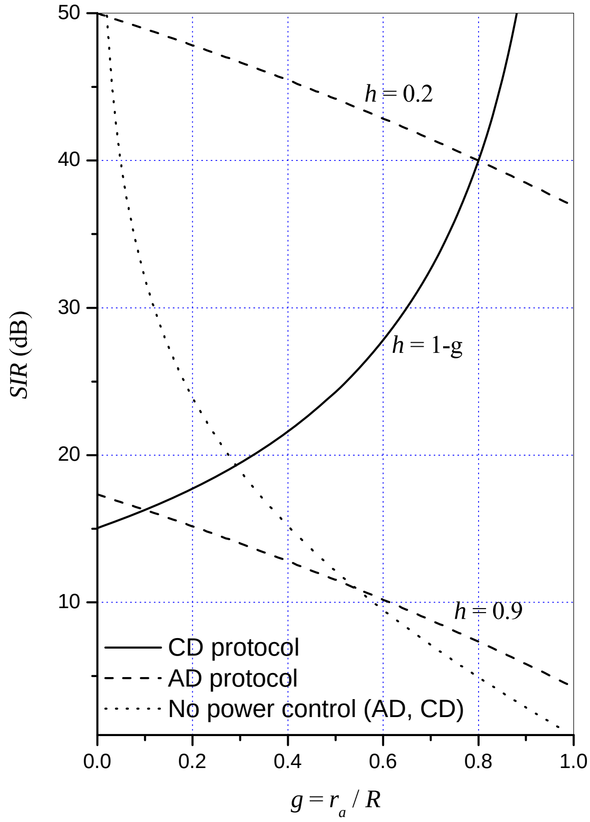

Fig. 2. Signal to interference ratio as a function of normalized distance *g*

V. CONCLUSION

In order to reduce the intercell interference for 4G systems, in this paper the concept of angular or θ–separability is extended by introducing a mutual interfering distance *d*, or *d*–separability, between the users belonging to two different cells. The MAC scheduling with constant distance between the receiving cochannel users from different cells will keep the downlink intercell interference under a pre-specified threshold. It was shown that the constant distance protocol can provide in the cell border area a SIR improvement in the order of (10 – 30) dB compared with system with arbitrary distance between the cochannel interfering users. The main advantage of the proposed protocol is that independent on user location, including the cell border area, SIR remains acceptable (larger than 15dB), which insures the complete cell coverage.

ACKNOWLEDGEMENT

This work was supported in part by the Ministry of Science of Serbia within the Project "Development and realization of new generation software, hardware and services based on software radio for specific purpose applications" (TR-11030).

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