Introducing power-shaped advanced resource assignment (PSARA) in fixed broadband wireless access systems [*]

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ABSTRACT

In this paper we propose a new technique for assigning radio channels in TDMA-based fixed broadband wireless access systems (FBWA) with full frequency reuse. The proposed technique, named Power-Shaped Advanced Resource Assignement (PSARA), has the aim of partially organizing the intercell and intersector interference in a cellular system where base stations assign radio resources in an uncoordinated fashion. This is done by using an appropriate set of power profiles that limit (or shape) the power transmitted in each slot of the frame. The allocation algorithm assigns time slots to users on the basis of the power required to fulfill a predefined carrier-to-interference ratio, which is suitably estimated. Simulation results for a typical cellular FBWA system show that this technique significantly improves the capacity with respect to a system that assigns resources without power shaping, even with power control.

1 INTRODUCTION

Fixed Broadband Wireless Access (FBWA) systems, including broadband wireless local loops and LMDS, have been recently introduced to provide integrated interactive multimedia broadband services, such as video conference, video on-demand, high-speed access to the Internet, to residential and business users. They should be able to provide a large amount of on-demand bandwidth in a very flexible manner to fixed terminals without the need for laying cables. In a typical FBWA scenario the coverage area is divided into cells having a base station equipped with sectored antennas posed on a suitable site overlooking the service area; subscriber terminals are usually equipped with directional antennas [1, 2].

For these applications resource management techniques play a key role to ensure an efficient use of the radio spectrum and to increase system capacity. To support data and multimedia traffic, data units from different users at the radio interface have to be suitably scheduled in order to share the available radio channels according to the needs of upper layer protocols and applications. In order to achieve efficient use of the radio resources, it is required that scheduling algorithms be channel aware or channel dependent [3].

Different choices are possible when designing resource allocation and scheduling. A centralized algorithm (running on a network unit controlling a set of cells) would be the optimal choice since it has complete information and therefore can perform optimal decisions. However, it may be complicated and require a large signaling burden, which requires large computing power and/or may result in excessive latency in the decisions. A distributed algorithm may be simpler, but it requires a smart management of radio power and bandwidth with incomplete information to achieve a large system capacity. This potential inefficiency due to lack of full information is the price to pay for keeping the algorithms simple and avoiding single points of failure in the network. A related issue, which also affects how users can simultaneously transmit, is the frequency reuse plan. A system with full reuse greatly simplifies planning needs and allows for easy introduction of additional base stations. The resulting interference, often intolerable in classic narrowband cellular systems, is mitigated in FWBA systems by using highly directional antennas (especially at the user terminal) which greatly reduce the amount of power which interferes with other users.

Having this view in mind, we propose a resource assignment method, which can be advantageously applied in distributed channel dependent scheduling algorithms. The proposed technique, named Power-Shaped Advanced Resource Assignment (PSARA), has the aim of partially organizing the intercell and intersector interference in a cellular system where base stations assign radio resources in an uncoordinated fashion (with the only requirement of frame synchronization). This is done by using an appropriate set of power profiles that limit (or shape) the maximum power transmitted in each slot of the frame. The allocation algorithm assigns time slots to users on the basis of the power required to fulfill a predefined carrier-to-interference ratio, which is suitably estimated.

In the literature, several works have appeared which deal with resource management in fixed wireless access systems (i.e., [4, 5, 6, 7]). [4] deals with resource allocation in a micro cellular LMDS with OFDM, whereas [5, 6, 7] propose time division schemes for generic fixed wireless. The allocation algorithms in [6, 7] are distributed and take advantage of cell sectorization, taking into account two key points:

- resource assignment can take advantage of the small number of interferers in the system thanks to the use of directional antennas, thereby avoiding "unfavorable" time slots (i.e., slots with significant interfer-

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ence) or using them only as a last resort;

- in a fixed environment, it is very useful to utilize interference measurements obtained from wireless terminals to perform the assignment.

The first scheme manages intercell interference, is fully measurement based and does not require any planning [6]. The second scheme handles both intracell and intercell interference and requires some form of preplanning [7]. In our proposal we try to consider the two points outlined above in a flexible scheme, which is useful for both intercell and intracell interference management and results in simplified planning needs.

The paper is organized as follows. In Section 2 we introduce the system model for the cellular environment considered, Section 3 describes the resource allocation strategies considered, including the proposed PSARA algorithm. Section 4 reports some numerical results showing the benefits of the new scheme, and Section 5 concludes the paper.

2 WIRELESS SYSTEM MODEL

We consider the downlink of a fixed wireless cellular system with square cells. Each cell has four sectors, obtained with four 90 degree beamwidth base station antennas. Each sector is assigned a label (A or B) which is suitably reused according to a given reuse plan. The meaning of this label and its use will be made clear in the next section. The simulated scenario includes C cells on a wrapped toroidal structure. U user terminals are randomly placed in the service area with uniform spatial distribution, and each terminal is equipped with a directional antenna pointed towards the direction of the base station with the smallest channel loss. The propagation model includes path loss and lognormal shadowing. The latter is assumed to be constant in time due to the fixed positions of the users. Once all user antennas are oriented, the relationship between the power $P_t(s,b)$ transmitted by sector antenna s $(s \in [0..3])$ of base b $(b \in [0..C-1])$ and the corresponding power $P_r(u)$ received at terminal u, is given by

$$P_r\left(u\right) = g\left(s,b,u\right) P_t\left(s,b\right) \tag{1}$$

with

$$g\left(s,b,u\right) = kd^{-\beta} Log[1,\sigma] f_t(\varphi_t) f_r(\varphi_r) \tag{2}$$

where k is a constant which accounts for the effects of carrier frequency and antenna gains, d is the link length between the transmitting antenna of sector s of base b and user u, β is the propagation coefficient, $Log[1,\sigma]$ is a lognormal random variable with unit median value and dB spread σ. $f_t(\varphi_t)$ and $f_r(\varphi_r)$ take into account the effect of the directivity of transmitter and receiver antennas at an angle φ between the direction of maximum gain and the direction of an ideal line joining transmitter and receiver antennas; more specifically, we have $0 \leq f(\varphi) \leq 1$ and $f(\varphi) = 1$ for $\varphi = 0$, which is assumed to be the direction between a user and its serving sector. Angles are considered only on the horizontal plane, hence not taking into account antenna heights and tilting. Each user is served by the sector and the cell for which the received power is maximum.

The delivery of the packets to users is performed on a TDM frame composed of N slots, numbered from 0 to $N-1$. All base stations are assumed to be perfectly synchronized on each slot (i.e., appropriate guard times are assumed). As a first step in determining the throughput efficiency, we do not consider any arrival distribution but rather assume that each user always has packets to transmit, and that the base station tries to schedule one packet per user per frame. A packet does not reach successfully the user either if there are no available time slots in the frame or if the packet is transmitted but at the terminal side the signal to interference plus noise ratio (SINR) is below a reference threshold SINR$_{thr}$. The SINR for user u served by sector s_o of the base b_o is defined as

$$SINR = \frac{g(s_o,b_o,u)P_t(s_o,b_o)}{\sum_{(s,b)\neq(s_o,b_o)} g(s,b,u)P_t(s,b)} \tag{3}$$

Future studies will address the effect of the traffic distribution and of more advanced scheduling policies as well as the relevant queueing behavior and performance.

3 RESOURCE ASSIGNMENT METHODS

Consider a full reuse cellular system in which packet traffic is to be transmitted from the base station to fixed users. Only downlink traffic (expected to be the dominant flow in typical fixed broadband applications) is considered in this paper. The base stations, placed on a regular square grid and sectorized into four beams, are assumed to be slot-synchronous while being uncoordinated for any other function. On the other hand, since the four sectors of a given cell are managed by a single controller, we assume that operation in the four sectors of any given base station can be fully coordinated.

Since in this paper we focus our attention on the efficiency of resource assignment methods for intercell interference management, we consider here a system with cells having ideal non overlapping sectors, i.e. $f_t(\varphi_t) = 1$ for $\varphi_t \in [-45°, 45°]$ and 0 outside. This makes the coordination among the sectors of a cell in this case not necessary. Therefore, this aspect of the resource assignment methods is not addressed here, but it has to be suitably considered in the general case with overlapping sectors.

When used, power control is assumed to work as follows. Based on channel measurements, a user terminal is able to estimate the worst-case interference coming from base stations other than its own. In order to do so, it is assumed that a transmission is performed in all cells at the maximum possible power. This correepónds to the worst possible case, and makes it easy to handle intercell interference which is estimated through a simple constant. On the other hand, the actual intracell interference can be considered when deciding which power to transmit. In the ideal case in which intersector interference is zero (via ideal nonoverlapping antenna patterns) the power assignment is trivial, whereas if intersector interference is to be considered the power assignment is to be done jointly in a cell by solving a linear system.

For the sake of comparison, and in order to highlight the benefits of the scheme proposed, we consider here the following resource allocation strategies.

1) *Random resource assigment (RRA) without power control*

In this case, the assignment of packets to slots is done randomly, i.e., no channel information is taken into account. The multiple access strategy across different cells is essentially slotted ALOHA. The power used in each slot to transmit a packet is constant and equal to P_{max}. This scheme, similar to [8], is very simple and will be considered here as the baseline case.

2) *RRA with power control (RRA-PC)*

A slightly improved version of the previous scheme uses some channel information in order to decide how much power to use based on channel attenuation measurements. In this case, the power control strategies described above is implemented.

3) *PSARA*

The aim of this method is to partially organize the interference power affecting each slot of the frame in order to determine different levels of interference in the slots. Within this framework the allocation algorithm can assign slots according to different levels of protection against interference required by each user. The allocation algorithm also assigns the power level needed to ensure the predefined $SINR_{thr}$.

To achieve the outlined tasks, each sector of each base is assigned a power curve, called power profile, that is a function of the label of the sector. It determines the maximum transmission power that a sector antenna that uses such profile is allowed to radiate in time slot i. In this study two different power profiles are considered, $P(i, A)$ and $P(i, B)$, with $P(i, A) = P(N-1-i, B)$ (symmetric profiles). Two simple choices for the power profiles are the straight line (linear shaping)

$$P(i, A) = P_{max} - i\frac{P_{max} - P_{min}}{N-1} \qquad (4)$$

and the step (step shaping)

$$P(i, A) = \begin{cases} P_{max} & \text{if } i \leq N/2 \\ P_{min} & otherwise \end{cases} \qquad (5)$$

P_{max} and P_{min} are parameters that should be suitably set. In the case depicted in Fig. 1 the two profiles, A and B, are suitably reused in the cellular scenario according to the geometrical constraints of a square cells scenario. Specifically, the labeling is done in such a way that for a user in a sector labeled with A (B), the largest interference comes from sectors labeled with B (A). In this way, slots that allow a large (small) transmission power, are mainly interfered with a small (large) power leading to slots with different levels of protection.

P_{max} is taken as the maximum power at the transmitter. The P_{max}/P_{min} ratio has been set by considering the interference condition experienced by a set of uniformly distributed users placed on a test sector with label A. Powering on all A sectors to P_{max}, and all B sectors to P_{min}, some users are below the SIR target for any value of P_{max}/P_{min}, whereas other users reach the SIR target by raising P_{max}/P_{min}. P_{max}/P_{min} is set to the value for which the most critical users in the test area can be served at the target $SINR$.

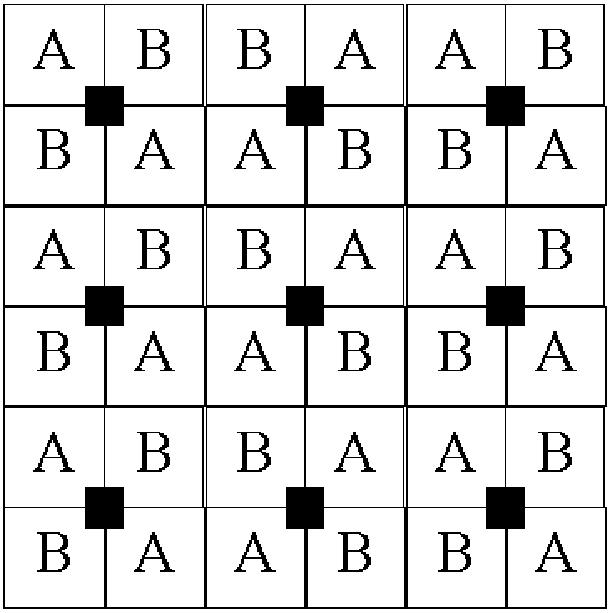

Figure 1: Sector pattern

The allocation algorithm is performed independently base by base and it is composed by the slot allocation procedure (that assigns users to time slots) and the power allocation procedure (that decides the serving powers). Each sector of each base knows the users to serve and their link gains g.

The user allocation procedure is repeated for each sector s_0 of each base b_0 and acts as follows:

1. For each user u in the sector s_0 of base b_0,
    (a) Compute the maximum value of intercell and intracell interference for each user u in each slot i, $i = 0..N-1$.

$$I_{\max}(i, u) = I_{\max(in)}(i, u) + I_{\max(out)}(i, u) \qquad (6)$$

$$I_{\max(out)}(i, u) = \sum_{b \neq b_0} \sum_{s=0}^{3} g(b, s, u) P(i, l_{b,s}) \qquad (7)$$

$$I_{\max(in)}(i, u) = \sum_{s \neq s_0} g(b_0, s, u) P(i, l_{b_0,s}) \qquad (8)$$

where $l_{b,s}$ is the label of sector s of base b.

    (b) Compute the power that the sector antenna should radiate to counteract $I_{\max}$, in slot i, with $i = 0..N-1$

$$P_c(i, u) = \frac{SINR_{thr}\left(I_{\max}(i, u) + V\right)}{g\left(b_0, s_0, u\right)} \qquad (9)$$

where V is the noise power, that in our simulations has been considered as negligible.

Based on $P_c(i,u)$, we have slots (*insecure slots*) where $P_c(i,u)$ exceeds the power profile and other slots (*secure slots*) where $P_c(i,u)$ is lower than the power profile. In a *secure slot* a packet will be received by user u with a SINR$\geq$SINR$_{thr}$, whereas in an *insecure slot,* this is not known a priori, since a base station is not allowed to radiate a power that exceeds the power profile. On the other hand, since the interference evaluation is performed by considering a wirst case scenario, transmission in an insecure slot doe not necessarily lead to a failure. Some users have no *secure slots:* such users are called *bad users*. Users that have at least one secure slot are called *good users.*

2. Sort *good users* by increasing number of their *secure slots*. Therefore the priority is given to users that have fewer secure slots.

3. Allocate *good users* in the order given at the previous point and between free slots choose the slot i that corresponds to the minimum value of $P_c(i,u)$. It is worth noting that when almost all slots are allocated, it may occur that a *good user* is allocated in a *insecure slot*: this is the reason for the order established at the previous point. Finally, it is possible that a user finds all slots busy: in this case it is not allocated.

4. Allocate *bad users* with the same criterion adopted at the previous point. Bad users are allocated after good users since all slots are insecure for the former and so they might uselessly subtract secure slots to the latter.

The user allocation procedure presented here can be further improved by taking into account the actual value of the intracell interference, which is controlled by the same base station. This is, however, not considered in this paper. Note that, in the absence of intracell interference, the allocation procedure also includes power allocation.

4 NUMERICAL RESULTS

Numerical results were obtained by simulation of a cellular environment of 36 square cells with 4 sectors each. Antenna patterns were chosen with $f(\varphi) = 1$ for $-\varphi_0/2 \leq \varphi \leq \varphi_0/2$ and $f(\varphi) = 1/ftb$ otherwise, where φ_0 and ftb are the antenna beamwidth and front to back ratio. Sectored antennas at the base station have φ_0 set to 90 degrees and ftb to infinity. Each sector is assigned a label as shown in Figure 1. In all figures except Figure 5, lognormal shadowing was not considered (dB spread set to 0 dB) and all figures except figure 6 refer to step shaping curves. An ideal antenna pattern for base station sectored antennas results in zero intracell interference and permits to study only the effect of intercell interference. In fact, PSARA was specifically proposed for the management of intercell interference.

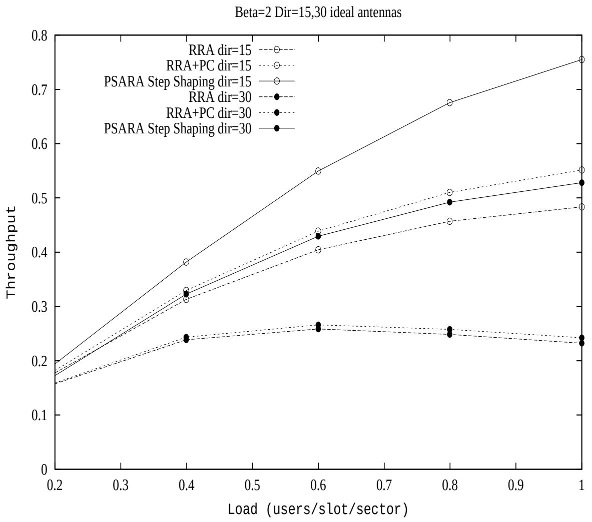

Figure 2: Throughput vs load: effect of user antenna directivity

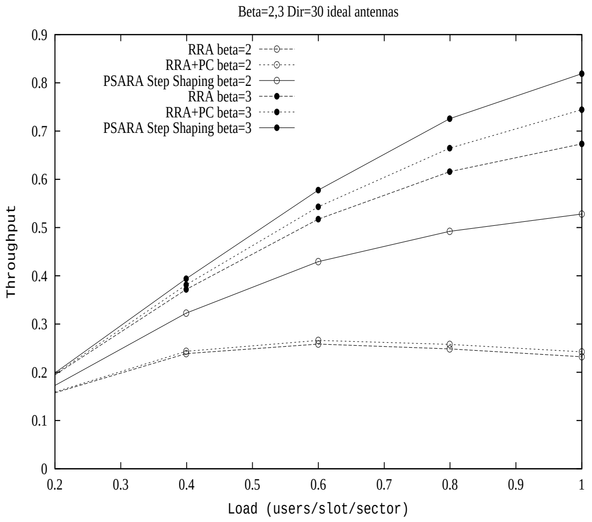

Figure 3: Throughput vs load: effect of propagation exponent

Figure 2 shows the results obtained with a propagation exponent $\beta = 2$ and user antenna beamwidth of 15 and 30 degrees. We note the great improvement in performance of PSARA over both RRA and RRA+PC, in a propagation scenario in which intercell interference effect is very important ($\beta = 2$ and beamwidth of 30 degrees). It is worth noting that the improvement introduced by PSARA is much more significant than that of power control. Moreover, the reduction of antenna directivity appears to have a remarkable impact, as was to be expected.

In Figure 3 the effect of the propagation exponent is shown: β is set to 2 and 3 and, as expected, the reduction of the interference by spatial filtering improves throughput. The smaller gain introduced by PSARA with respect to RRA and RRA+PC with $\beta = 3$ confirms that this technique is most effective in scenarios with significant intercell interference. In Figure 4 the effect of a finite front to back ratio of 30 dB is considered. It can be noted that PSARA continues to mantain a considerable gain over random allocation: in fact, PSARA estimates of the worst case interference, and this calculation ac-

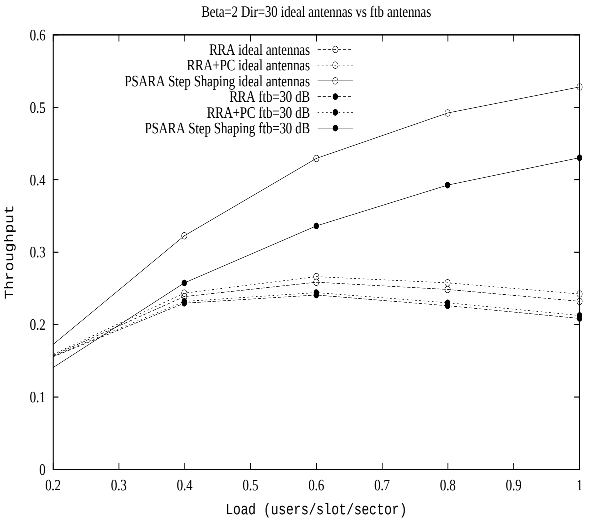

Figure 4: Throughput vs load: effect of front to back ratio

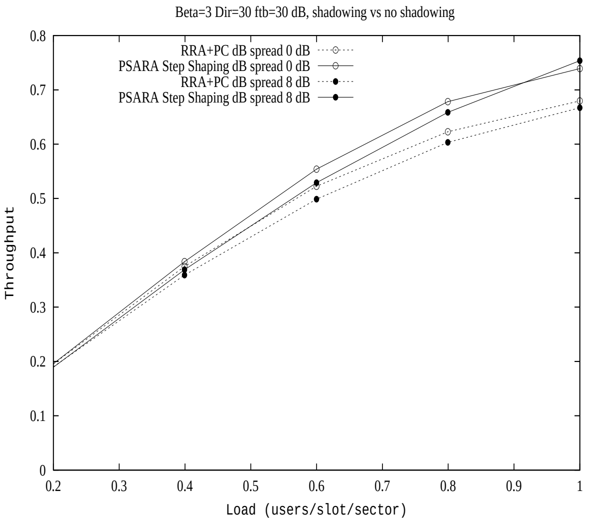

Figure 5: Throughput vs load: effect of lognormal shadowing

counts for the effect of non ideal antennas as well.

The effect of lognormal shadowing with spread $\sigma = 8$ dB is shown in Figure 5, relative to a propagation exponent $\beta = 3$, 30 degree user antenna beamwidth and front to back ratio set to 30 dB: the curves show that PSARA is effective also in presence of shadowing.

Finally, Figure 6 reports a comparison between step and linear power shaping (with $\beta = 2$): in the first two curves, (front to back ratio 30 dB, terminal antenna beamwidth 15 degrees) linear shaping performs better than step shaping. The other two curves are relative to ideal antennas and terminal antenna beamwidth of 30 degrees: in this case step shaping outperforms linear shaping. The aim of this figure consists of showing that there are cases in which one profile performs better than one another and vice versa. Also other types of power shapes were studied, but the effectiveness of each one in different propagation conditions and a choice criterion are currently under investigation.

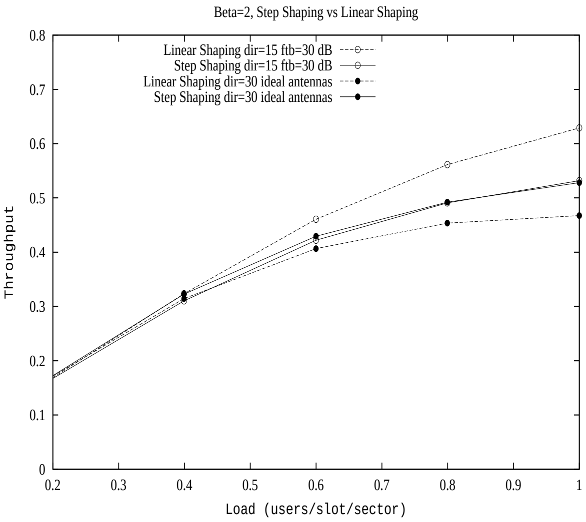

Figure 6: Throughput vs load: comparison between step shaping and linear shaping

5 CONCLUSIONS

In this paper, a new resource allocation strategy based on transmit power shaping has been described and compared with a basic random resource allocation scheme with and without power control. It has been shown via simulation that the new strategy outperforms more classic scheme and is therefore promising for application to fixed broadband wireless access systems. Sensitivity to some system parameters has also been performed.

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