Throughput enhancement of Fixed Broadband Wireless Access systems through a novel Radio Resource Allocation approach

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***Abstract* - In this paper the interference management and resource assignment problem is examined for a Fixed Broadband Wireless Access (FBWA) system with full frequency reuse. The performance and coverage of FBWA systems are usually limited due to concurrent transmissions of intracell and intercell interferers. The primarily goal of Radio Resource Allocation (RRA) techniques is to find an appropriate scheduling of these transmissions so as to minimize the interference and to enhance the service quality. An improved RRA scheme based on the avoidance of major intracell interferers is proposed and analyzed for the downlink of such a system. The scheme is compared with Enhanced Staggered Resource Allocation (ESRA) method and an increase of the throughput per sector is presented.**

1. Introduction

The deployment of fixed broadband wireless access (FBWA) as an alternative technology for broadband access is an open issue for telecom operators and new entrants aiming to provide fast internet and broadband services. A typical FBWA system uses time division multiple access/time division duplexing (TDMA/TDD) techniques at user data rates above 10Mbps and operating frequency in the 2 – 11GHz band, for Non Line of Sight (NLOS) operation, or in the 11 – 60GHz band, for Line of Sight (LOS) operation [1-2].

Several methods have been proposed for the RRA of the downlink transmissions of such FBWA systems [3–6]. In this paper, an ESRA based [5] RRA method is introduced, exhibiting an improved per sector throughput for increased traffic load conditions. The method is based on an effective algorithm aiming to avoid major intracell interferers, by using a different assignment order between odd and even sectors. The rest of the paper is organized as follows. In section II, an introduction of the ESRA method is given whereas details of the proposed RRA algorithm and downlink performance are described in section III. Section IV illustrates and discusses simulation results and concluding remarks are given in Section V.

2. Background and motivation

The service area as defined by the ESRA method is divided in hexagonal cells and sectors, equipped with Base Station (BS) antennas and labelled from 1 to 6 counter-clockwise, in such a way that there are no adjacent sectors bearing the same label (Figure 1). For a multi-cell system, the labels among three adjacent cells are rotated by 120° comprising thus a hypercell and this pattern is repeated across the entire service area. User terminals employ rooftop directional antennas pointing to their respective BS antenna.

The propagation model, due to the fixed positions of BS and terminal antennas, includes only the distance-dependent path loss and lognormal shadowing. At this point, it is important to distinguish the impact of intracell and intercell interference. The interference power received at user terminal j of sector l from the BS of sector k is given by [7]:

$$I_{jk} = \frac{C \cdot P_t \cdot G_{jk} \cdot s_{jk}}{d_{jk}{}^{\gamma}} \tag{1}$$

where, P_t is the fixed BS transmitted power, G_{jk} is the composite transmit – receive antenna gain, s_{jk} the lognormal shadowing with σ dB standard deviation and zero mean, d_{jk} the distance from the interfering BS, γ the path loss exponent and C a factor including the operating frequency. The signal strength received at terminal j from serving BS l is given by (1) for $k{=}l$. Since the BS antennas are co-located, the signal to intracell interference ratio, SIR_{intra}, is given by [7]:

$$SIR_{\text{intra}} = \frac{G_{jl}}{\sum_{k,\,k\neq l} G_{jk}} \tag{2}$$

It is clear from (2) that the two adjacent sectors are the major intracell interferers due the overlapping BS antenna patterns, and thus they degrade most significantly the received SIR. As a consequence, an effective RRA method has to be developed for scheduling the concurrent transmissions from major intracell interferers efficiently in order to maximize the service quality. However, any RRA method should not presume a certain antenna radiation pattern so as to mitigate the intracell interference, but a variety of antenna types and characteristics [8].

On the other hand, the signal to intercell interference ratio, SIR_{inter}, is given by

$$SIR_{\text{inter}} = \frac{G_{jl} \cdot s_{jl} \cdot d_{jl}^{-\gamma}}{\sum_{n}\sum_{m} G_{jnm} \cdot s_{jn} \cdot d_{jn}^{-\gamma}} \tag{3}$$

where n is the number of neighbouring cells, m is the number of sectors per cell, G_{jnm} is the composite transmit – receive antenna gain from sector m of cell n and d_{jn} is the distance from BSs of cell n.

Without loss of generality, the intercell interference is examined for the tagged sector of the central cell as presented in Fig. 1. It can be shown from (3) that the most significant amount of intercell interference comes from shadowed intercell sector 3 (because of the front lobe of sector antenna 3 that point directly to the terminals of the tagged sector) and the opposite shadowed sector 2. It is important to note that the intercell interference is low compared to intracell interference due to the distance dependent path loss as well as the high Front-to-Back (FTB) ratio of BS antennas.

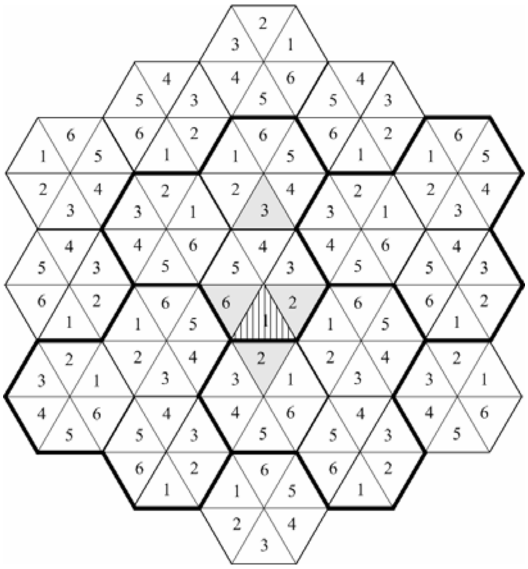

Figure 1: Hexagonal cell splitting and layout (Shadowed sectors are the major interferers for the tagged sector 1)

Following the ESRA method, the TDMA frame is divided into six subframes, which are further divided into mini-frames labelled from 1 to 6. Each sector schedules packets for transmissions following the staggered order labelled a, b, c, d, e and f (Figure 2) with a and f representing the first and last subframe to be used, respectively. The same notation in capital letters, serves the proposed method (Figures 2 and 3)

Sector \ Subframes	1	2	3	4	5	6
1	a **A**	e **F**	d **D**	b **B**	c **C**	f **E**
2	f **F**	a **A**	e **E**	d **C**	b **B**	c **D**
3	c **C**	f **E**	a **A**	e **F**	d **D**	b **B**
4	b **B**	c **D**	f **F**	a **A**	e **E**	d **C**
5	d **D**	b **B**	c **C**	f **E**	a **A**	e **F**
6	e **E**	d **C**	b **B**	c **D**	f **F**	a **A**

Figure 2: ESRA (lowercase) and proposed (uppercase) staggered order

Since in each subframe, six sectors at most may transmit concurrently, terminals are classified into six classes according to the number of maximum tolerable concurrent transmissions following the staggered order of Figure 2. More precisely, each terminal is classified through an iterative procedure, which tests the maximum number of concurrent transmissions. The criterion is the terminals' reception quality, which depends on antenna characteristics (i.e. 3dB beamwidth and FTB ratio), shadowing and distance from the serving BS.

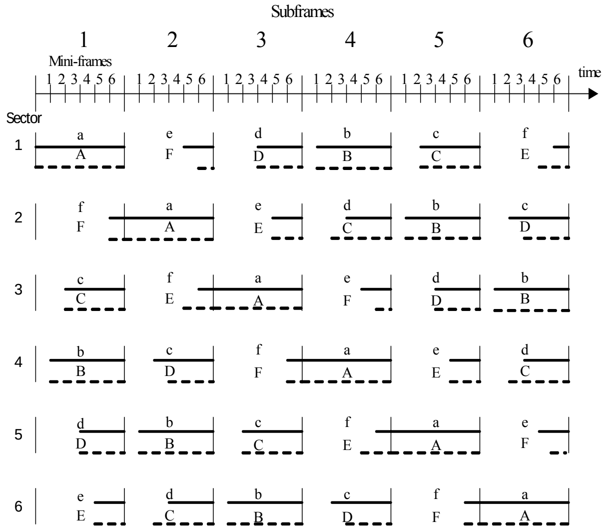

Figure 3: ESRA (continuous lines) and proposed (dashed line) available mini-frames

The procedure begins from six concurrent transmissions in the six predefined subframes following the staggered order of Figure 2. Terminals that tolerate these transmissions are classified as class-6. Then, the procedure activates five concurrent transmissions in the five predefined subframes, following the staggered order of Figure 2, for the terminals that cannot tolerate six transmissions. Terminals that tolerate five concurrent transmissions are classified as class-5 and so on.

Following this terminal classification, each sector schedules packets for transmissions only in the marked mini-frames in each subframe (Figure 3). The number of concurrent transmissions of each mini-frame is defined on its label. In other words, only class-*i* terminals are served in mini-frame *i*. The number of timeslots n_i of mini-frame *i*, i=1,2,...,6, is fixed from subframe to subframe and is appropriately chosen to match the expected traffic load from the respective class-*i*. It is obvious that the overall throughput per sector can be enhanced, when the number of timeslots n_i of higher classes is increased.

The maximum downlink throughput per sector γ, for the system under examination, is given by [5]:

$$\gamma = \sum_i \frac{i n_i}{KN} \tag{4}$$

where K is the number of sectors in each cell and n_i the number of timeslots per mini-frame i:

$$n_i = \left[\frac{N_t a_i / i}{\sum_j a_j / j} \right] \tag{5}$$

where α_i is the percentage of class i terminals, $N_t \approx N$ the total number of timeslots in each subframe and [x] the closest integer to x. So, it is clear from (4), (5) that the maximum throughput is relevant to the percentage of terminals in the defined classes and an improvement is achieved by "migrating" a portion of terminals from a lower class to an upper one.

3. The proposed RRA scheme - based on the avoidance of major interferers

Taking into account the previous description, intracell interference management is a key component for the enhancement of system performance, without neglecting the impact of intercell interference. Throughput enhancement may be achieved by upgrading the number of concurrent transmissions, which is the equivalent of increasing the number of higher order terminal classes, through advanced methods of avoiding major intercell and intracell interferers.

Following the ESRA staggered order for higher terminal classes (i.e. classes 4, 5 and 6) the major intracell interferers are appearing not only separately but also all together. So, the motivation for this work is to further examine the throughput enhancement possibilities by upgrading lower class terminals. The proposed method is based on a "mirrored" allocation scheme for odd and even sectors, which is as follows.

Each sector m (m=1,..,6) schedules packets for transmission in subframe m as shown in Figure 2. If there are more packets for transmission, it uses the first subframe of the opposite sector, in order to exploit the BS directional antennas and the low level of interference. All sectors follow this procedure for the first two subframes.

But, for the odd labeled sectors, the next two options, according to the "mirrored" method, will be the first subframes of the other two opposite sectors clockwise and the last two options will be the first subframes of the two adjacent intracell sectors counter-clockwise.

On the contrary, for the even labelled sectors, the next two options will be the first subframes of the other two opposite sectors counter-clockwise while the last two resorts will be the first subframes of the two adjacent intracell sectors clockwise.

According to this allocation scheme terminal classification is differentiated resulting in different mini-frame availability as shown in Figure 3. In addition, it may be shown from (5) that the portion n_i (i=1,..,6) is changed resulting in throughput enhancement. This is a consequence of the proposed order, where the number of class 3 terminals is increased due to the fact that each sector avoids one major intracell interferer. More explicitly, class 3 terminals for sector 1 are examined. Following the ESRA staggered order, sector 1 is interfered in subframe 4 by sector 6 (one dominant intracell interferer) and in subframe 5 by both sectors 2 (the other dominant intracell interferer and the major intercell interferer from the adjacent cell). On the contrary, following the proposed staggered order, sector 1 is interfered in subframes 4 and 5 by both sectors 2, but avoids interference from sector 6. As a result, the fraction of terminals that tolerate more concurrent transmissions is increasing as well as the maximum throughput per sector. It must also be pointed out that the coverage remains the same for both methods since it is determined by intercell interference, which can be avoided in the same manner in both methods.

4. Simulations, results and discussion

Simulation results have been obtained in order to study the terminal classification and the maximum throughput (packets/slot/sector) of ESRA and the proposed method. A three-tier cell layout consisting of 19 hexagonal cells with six sectors each has been considered. Without loss of generality, only the results for the central cell are presented here, in which 1500 terminals have been uniformly placed. Typical radiation patterns are used for BS and terminal antennas. The FTB ratios as well as the 3dB beamwidths of the BS antennas vary according to different standardised categories [8]. For the terminal antenna, a 3dB beamwidth of 30 degrees has been modelled. A simple path loss model, with an exponent of 4 and lognormal shadowing with zero mean and standard deviation equal to 8, is adopted. The reference SIR threshold for success packet transmission is taken to be equal to 15dB.

In Figures 4 and 5 the impact of BS antenna beamwidth and FTB on maximum throughput per sector is shown, following the ESRA and the proposed method.

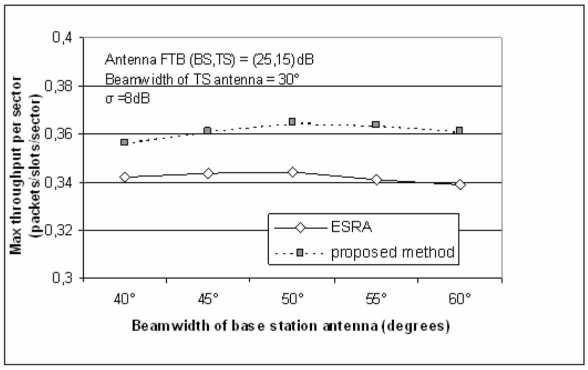

Figure 4: Impact of BS antenna beamwidth on maximum throughput per sector

As the BS antenna beamwidth decreases, the amount of intracell and intercell interference is also decreased (Figure 4) and a 50° 3dB beamwidth is the optimum value in order to serve the entire sector at the maximum throughput. Since the management of intracell interference is more efficient, following the proposed method, the difference between two methods is increased as the BS antenna beamwidth increases. On the other hand, as the FTB BS antenna ratio is increasing, the SIR is drastically increased (Figure 5), which in turn allows the upgrading of higher classes improving thus the performance.

In Figure 6 there is a presentation of how the terminal antenna FTB ratio impacts the maximum throughput per sector following both methods. As the terminal antenna FTB ratio is increased, the received signal strength is better for each terminal, more terminals meet the SIR threshold and the performance is improved. Bearing in mind that the intracell to intercell interference balance is increased, as the terminal antenna FTB ratio increases, and that the proposed method handles in the same way the intercell interference though more efficiently the intracell interference comparing to ESRA, it is understood why the difference between the two methods is also increasing, as shown in.

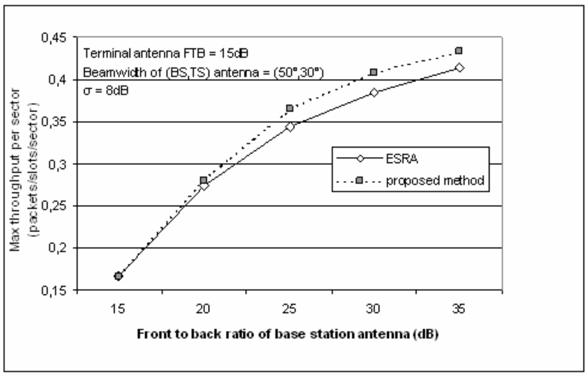

Figure 5: Impact of BS antenna FTB ratio on maximum throughput per sector

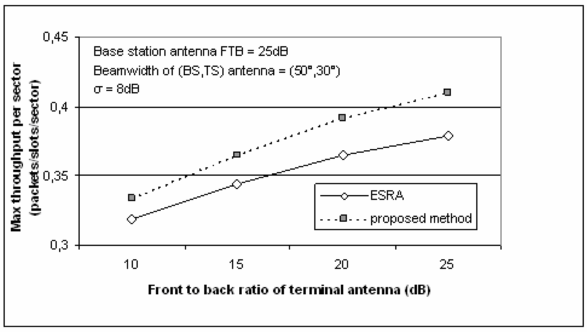

Figure 6: Impact of terminal antenna FTB ratio on maximum throughput per sector

The drastic effect of lognormal shadowing standard deviation on the maximum throughput per sector is portrayed in Figure 7 following both methods. As the lognormal shadowing standard deviation is increased, fewer terminals meet the SIR threshold resulting in performance degradation. Since the lognormal shadowing is affecting only the SIR_{inter} and not the SIR_{intra}, as is can be proven from (2) and (3), the proposed method performs better than ESRA as it manages the intracell interference more efficiently. Therefore, in realistic conditions with an increased shadowing distribution, the proposed method presents a significant throughput improvement.

5. Conclusion

A radio resource allocation method for the downlink transmission of a fixed broadband wireless access system is proposed and analyzed. The scheme improves the ESRA method in terms of throughput per sector by increasing the number of terminals that tolerate more concurrent transmissions. For a typical radio environment, a maximum throughput per sector close to 36,5% and an upgrading with respect to ESRA method of 6 percentage units are achieved. It's worth mentioning that the proposed RRA scheme performs better under realistic transmission conditions and with various types of antennas as standardised in [8] and exploits better low performance antennas, which present large beamwidths and FTB ratios. Evaluation of the scheme under reflecting conditions as well as guidelines for optimum BS and terminal positions is under preparation.

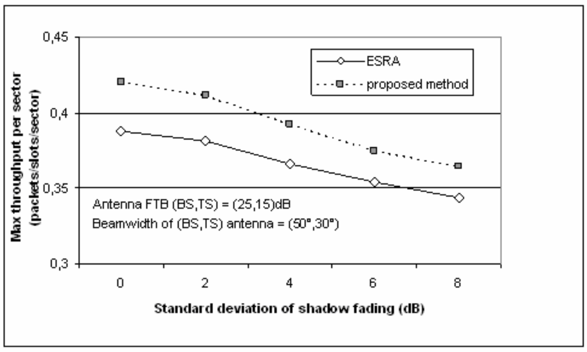

Figure 7: Impact of standard deviation of shadowing on maximum throughput per sector

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