Smart Channel Assignment Algorithm for SDMA Systems

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Abstract

In order to exploit the potentialities of Space Division Multiple Access (SDMA) in mobile cellular systems the conventional radio resource management functions must be revised, especially the channel assignment algorithms. In the paper an algorithm designed to this purpose is presented and analysed in reference scenarios and under various traffic load conditions.

Key words: SDMA, channel assignment algorithm, intra-cell handover

1. Introduction

Mobile cellular systems are characterised by an impressive subscriber increase. In order to satisfy such a large demand, operators have to cope with the scarceness of the limited frequency spectrum. One approach which looks very appealing is the use of adaptive antennas at Base Station site, combined with Space Division Multiple Access (SDMA) technique [1]. SDMA allows the simultaneous use of any conventional channel (frequency, time slot or code) by multiple users of the same cell by exploiting the angular separation among them. This is achieved by taking advantage of the ability of the adaptive antenna technology to distinguish between desired and interfering signals as well as to calculate their direction of arrival. Following the changes in users' locations, the antenna system continuously adapts its radiation pattern, so that the target user is tracked with the main lobe, while nulls of the antenna gain diagram are set in the direction of the interferers. As result the spectral efficiency and hence the capacity of the system increases [2]. On the other hand, SDMA may introduce some critical aspects in the radio resource management. Particularly, the conventional channel assignment algorithms, both in case of call set-up and handover, must be harmonised with the characteristic of the SDMA approach [3,4].

The paper presents a channel assignment algorithm for a generic frequency/time division multiple access (FDMA/TDMA) system applying SDMA and evaluates its performance in reference scenarios and under various traffic load conditions.

2. Channel assignment algorithm

In order to exploit the potentialities of SDMA, the Base Station (BS) must keep track of the position and mobility behaviour of all mobile users (MSs) within the cell. When a user requires a channel, the channel assignment algorithm should select it so that the probability of two co-channel users coming close to each other (and then asking for intracell handover) is minimised. A number of factors can affect the optimal choice; amongst them, the most significant are:

- Cell topography;
- MSs positions;
- MSs mobility characteristics (speed and direction).

The proposed algorithm takes into account these parameters, leading to an optimised allocation of the radio resources. The basic principles the algorithm relies on are described in the sequel.

2.1. Basic principles

First, the area of the cell is subdivided into N sectors (see Figure 1). A regular, rectangular grid is adopted here, nevertheless other partitioning schemes (e.g. specifically tailored on the cell topography) could be used. MSs position within the cell is identified by means of the correspondent sector. Then, for each pair of sectors S_i and S_j belonging to the cell a coefficient is defined as:

$C_{i,j} = f(P(S_i, S_j), T(S_i, S_j))$

where:

$P(S_i, S_j)$: is the estimated probability that a mobile entering sector S_i will come to collide with a mobile that at the same instant is located in sector S_j (i.e. the probability that the main antenna beams formed towards the two mobiles will overlap, thus causing an intracell handover);

$T(S_i, S_j)$: is the estimated elapse of time before the collision between a mobile entering sector S_i and a mobile that at the same instant is located in S_j occurs.

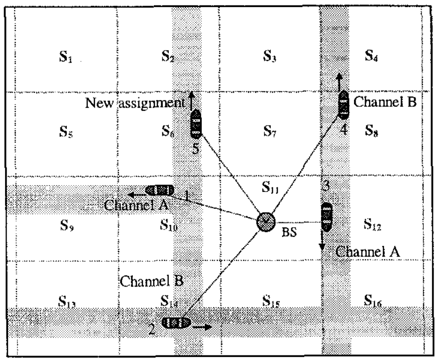

Figure 1: Channel assignment

The coefficients $C_{i,j}$ are used as a metric to sort the candidate channels for channel assignment purpose. Let consider the case when a channel assignment request is submitted by a user located in a generic sector S_h of the cell. If no free channel is available, the spatial reuse technique has to be applied.

According to the proposed algorithm, for each candidate channel z a cost figure $\boldsymbol{W}_z$ is evaluated, based on the coefficients $C_{h,k}$ referring to all the sectors k where the candidate channel is currently in use:

$$\boldsymbol{W}_z = w(C_{h,k} \mid \text{channel z is in use in sector k})_{k\in\{1,..,N\}}$$

Finally, candidate channels are sorted according to their cost, and the one corresponding to the minimum cost value is selected and assigned to the mobile. In order to clarify how the algorithm works, an example is given with reference to the scenario depicted in Figure 1. Mobile 1 and 3 are sharing channel A, while mobile 2 and 4 are sharing channel B. No other channel is available in the cell. If mobile 5, located in S_6, performs a channel request, then the following cost coefficients are evaluated for channels A and B respectively:

$$\boldsymbol{W}_A = w(C_{6,10}, C_{6,12})$$

$$\boldsymbol{W}_B = w(C_{6,8}, C_{6,14})$$

If $\boldsymbol{W}_A < \boldsymbol{W}_B$ channel A is assigned to mobile 5, otherwise channel B will be chosen.

2.2. Further enhancements

The procedure described so far takes into account only the cell topography and the mobiles positions. To enhance the performance of the algorithm by making the estimation of the handover probability more accurate, the mobility trends (speed and direction) of the mobile users have to be considered. Hereafter it is explained how to include them in the algorithm.

2.2.1. Influence of movements direction

The direction of the MSs can be taken into account by introducing the direction of arrival into a sector as an additional parameter in the evaluation of coefficients $C_{i,j}$. This means that for each couple of sectors S_i and S_j, there will be a number of coefficients:

$$C_{i,j}^{m,n} = f(P(S_i^{m}, S_j^{n}), T(S_i^{m}, S_j^{n}))$$

where m and n indicate respectively the direction of arrival in sector S_i and sector S_j.

As our partitioning scheme is a regular rectangular grid, for each sector the direction of arrival can be identified with the four sides of the sector. Thus, for a given couple (i,j), the number of coefficients $C_{i,j}^{m,n}$ will be 16 and m, n can assume the values N (north), S (south), E (east) and W (west).

Applying the proposed enhancement to the example of Figure 1, the following coefficients are computed:

$$\boldsymbol{W}_A = w(C_{6,10}^{S,N}, C_{6,12}^{S,N})$$

$$\boldsymbol{W}_B = w(C_{6,8}^{S,S}, C_{6,14}^{S,W})$$

2.2.2. Influence of speed

The MSs speeds can be taken into account by defining different speed classes and by determining one coefficient for each speed class. This means that, assuming that the speed classes are M, for each couple of sectors S_i and S_j, there will be M^2 coefficients:

$$C^{p,q}_{i,j} = f(P(S^{p}_{i}, S^{q}_{j}), T(S^{p}_{i}, S^{q}_{j}))$$

where p and q indicate respectively the speed class of the MS in sector S_i and of the MS in sector S_j.

2.3. Matrix coefficients computing

The coefficients $C_{i,j}$ are computed during the system initialisation phase. During this phase, the BS monitors the behaviour of each active user served by the cell, keeps track of the ordered list of sectors that any user comes through following its own path within the cell and of the entering times into those sectors. It records the user collisions with other users, the positions (in terms of sectors), where each collision takes place, as well as the time instants when these events occur.

From these samples the values of $P(S_i, S_j)$ and $T(S_i, S_j)$ are derived, and, finally, the coefficients $C_{i,j}$ are drawn. An example of how the procedure works is given in the sequel, with reference to the case depicted in Figure 2.

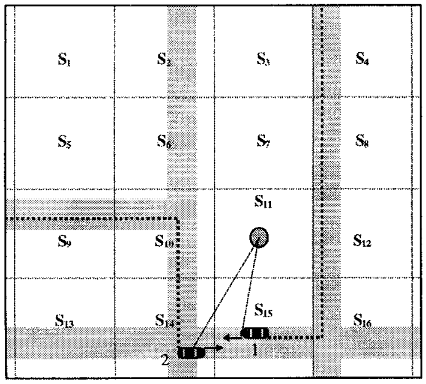

Figure 2: Matrix coefficients computing (1)

Two users, namely user 1 and user 2, are moving through the area of the cell. The path followed by each of them is stored in a dedicated record, which is updated each time the user enters into a new sector. At the time depicted in Figure 2, when the two users come to collide (i.e. their angular separation with respect to the BS goes below a pre-set threshold), the records stored so far for them are the following:

Sector	S_4	S_8	S_{12}	S_{16}	S_{15}	**User**
Entering time	t_4	t_8	t_{12}	t_{16}	t_{15}	**1**

Sector	S_9	S_{10}	S_{14}	**User**
Entering time	t_9	t_{10}	t_{14}	**2**

Starting from them, a new sample of $T(S_i, S_j)$ is evaluated, for each couple of sector S_i and S_j which has been visited by one of the two user respectively. With reference to Figure 3, the coefficients $T_{14,15}^{N,E}$, $T_{15,10}^{E,W}$, $T_{16,10}^{N,W}$, $T_{10,12}^{W,N}$, $T_{12,9}^{N,W}$ and $T_{9,8}^{W,N}$ are computed.

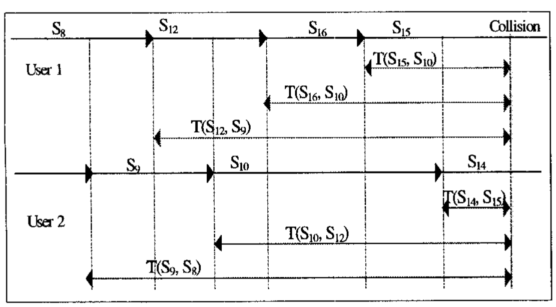

Figure 3: Matrix coefficients computing (2)

At the end of the initialisation phase, the final values of $T^{m,n}(S_i^m, S_j^n)$ are obtained by averaging the values collected for each instance of the random process. The values of $P^{m,n}(S_i^m, S_j^n)$ are determined by averaging the number of collisions of the users entering in S_i with the users that are in S_j respect to the total number of users entering in S_i.
Finally, the coefficients $C_{i,j}^{m,n}(S_i^m, S_j^n)$ are computed.

3. Simulation tool

A software simulation tool has been developed to evaluate the performance of the channel assignment algorithm. The basic features are described in [3] and summarised hereafter. A single rectangular shaped cell with the Base Station positioned in its centre is considered. Inside the area, streets are traced according to a rectangular grid; a generic settlement can be considered, provided that the roads can run either parallel or perpendicular to each other. The mobile terminals are generated and move onto this grid according to the implemented call and mobility models. The number of ongoing calls inside the area is an input parameter and is kept constant along the whole simulation time. The number of physical traffic channels assigned to the cell is also fixed as an input parameter (15 channels for the simulations). The tool allows to compare the performance of the algorithm under study with respect to a reference one, since initial channel assignment, handover triggering and execution can be performed in parallel according to the two criteria, one independently from the other. The reference algorithm (hereafter indicated as A1) chooses the channel randomly among those (if any) satisfying the basic requirement about the minimum angular separation among co-channel users. The handover is initiated when the angular separation between any co-channel users goes under a value related to the minimum beamwidth of the antenna radiative pattern. In the simulation a fixed value equal to 15° is assumed. When a handover is required, the channel assignment algorithm is applied. If no useful channel is available, the call is dropped and a handover failure is recorded.

The outputs of the simulation are expressed in terms of Intra-cell Handover rate per call and Assignment Failure rate per cell. With reference to the proposed channel assignment algorithm (hereafter referred as A2), the coefficients and cost parameters are evaluated according to the following functions:

$$f(P(S_i, S_j), T(S_i, S_j)) = 1 / P(S_i, S_j) * T(S_i, S_j)$$

$$w(C_{h,k}) = 1 / \text{sum}(1/C_{h,k})$$

Furthermore no speed class subdivision has been adopted.

4. Simulation scenarios and results

Three scenarios have been selected in order to analyse the performance of the algorithm with respect to area topography and mobility features. *Scenario A* (see Figure 4) represents a rural area crossed by highways where only high speed mobiles exist. *Scenario B* (see Figure 5) represents a urban area with low speed mobiles. *Scenario C* (see Figure 6) represents a residential area, where only very low speed mobiles are supposed to be present. The performance of the channel assignment algorithm has been analysed in each reference scenario for different values of the mean spatial reuse factor RF, defined as the ratio between the number of ongoing calls and the number of available traffic channels in the cell (R_{HO}).

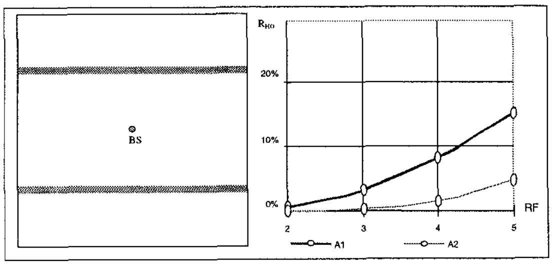

Figure 4: Scenario A

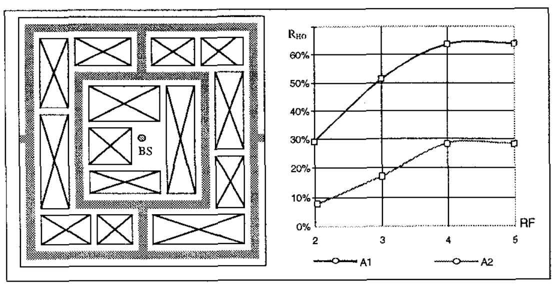

Figure 5: Scenario B

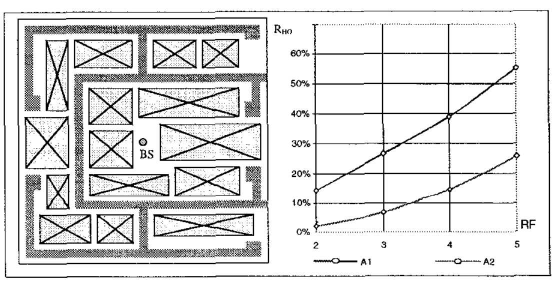

Figure 6: Scenario C

The results (see Figure 4-5-6) show that, by exploiting information about the mobiles spatial distribution in the channel assignment process, the proposed algorithm provides a substantial improvement in SDMA performance. Note that the characteristics of the environment can heavily influence the performance of each channel assignment algorithm. For instance, in a scenario where the roads disposal is such that the users can move along a low number of well predictable paths, the algorithm is likely to perform well. On the contrary, in a scenario characterised by many alternative ways, the performance of the algorithm worsen. For example, for RF=3, the ratio between $(R_{HO})_{A1}$ and $(R_{HO})_{A2}$, is 12,5 in scenario A, while it is reduced to 3.9 in scenario B and C. Concerning the impact of traffic load on the algorithm performance, it results that as the traffic load, and then the reuse factor, increases, the relative gain of algorithms A2 with respect to A1 becomes lower. This can be justified by the fact that, when the users density inside the area served by the cell is very high, it is likely that the interference spatial distribution becomes, on average, similar on different traffic channels, thus making the performance less sensitive to the channel assignment policy.

5. Conclusion

A channel assignment algorithm for SDMA mobile systems has been described and analysed in reference deployment scenarios and under various traffic load conditions by means of software simulation. The results obtained show that the algorithm performance, evaluated in terms of average number of intra-cell handovers per call, are considerably better respect to other algorithms that do not take into account the users spatial distribution and their mobility features.

6. References

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