ENHANCED RADIO ACCESS TECHNOLOGY SELECTION EXPLOITING PATH LOSS INFORMATION

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ABSTRACT

This paper proposes the enhancement of different Radio Access Technology (RAT) allocation strategies in a heterogeneous scenario with CDMA and TDMA access technologies by including path loss information. Results obtained from an analytical modelling reveal that, by making use of path loss information, either by allocating low path loss users in CDMA or in TDMA, depending on the specific characteristics of each technology, significant outage reductions can be achieved.

I. INTRODUCTION

The coexistence of several radio access technologies (RATs) in the current and future wireless scenarios introduce an additional dimension to achieve an efficient exploitation of the scarce available radio resources. RATs differ from each other by air interface technology, services, price, access, coverage and ownership. The complementary characteristics offered by the different radio access technologies make possible to exploit the trunking gain leading to a higher overall performance than the aggregated performances of the stand-alone networks. Clearly, this potential gain of B3G (Beyond 3G) systems can only turn into reality by means of a proper management of the available radio resources. Common Radio Resource Management (CRRM) refers to the set of functions that are devoted to ensure an efficient and coordinated use of the available radio resources in heterogeneous networks scenarios [1][2]. More specifically, CRRM strategies should ensure that the operator's goals in coverage and Quality of Service (QoS) are met while providing as high as possible overall capacity. Within CRRM, the traffic allocation in the proper RAT either at session initiation or by switching on-going connections from one RAT to another by means of a vertical handover procedure, is one of the key enablers to properly manage the heterogeneous radio access network scenario. Depending on the time scale of operation of CRRM this RAT selection procedure can be done on a long-term basis or even operating on short time-scales in joint or common scheduling algorithms.

In general, cellular wireless systems become interference-limited and, consequently, any engineering technique devoted to either reduce interference or to improve the robustness of the system to bear interference will readily increase network capacity and operator's revenue. Managing interference has been a recurrent topic of interest for many years and the problem has been dealt with from many different perspectives. Channel coding, power control or antenna beamforming are only some examples. Interference level in power-controlled systems is related on one hand to propagation losses from interference source to its target receiver and, on the other hand, on propagation losses from interference source to interfered destination. Then, considering the user's ordered path losses as a principle for radio resource management can lead to overall interference reduction and, consequently, performance and/or capacity improvement. Path loss measurements in cellular systems are typically obtained at the mobile terminal by measuring the received power from a downlink pilot channel whose transmit power is known and then reported to the network [3].

Under this framework, this paper focuses on a heterogeneous scenario where CDMA and TDMA access technologies coexist and analyses different schemes for distributing the users between the two technologies. It reveals that, by making an appropriate use of the path loss information by considering the users in an increasing order of the measured path loss towards the cell site, it is possible to improve the performance. The analysis provided here can be used as the basis for the development of new CRRM algorithms operating both in the long term (e.g. initial RAT selection or vertical handover) or in the short-term (e.g. joint scheduling algorithms where the RAT allocated to the user is changed in short periods of time).

According to the above framework, this paper is organised as follows. Section II presents the problem formulation and section III presents the statistical distribution of the path loss, which allows computing the outage probability as explained in Section IV. From the modeling in these sections, Section V presents the considered RAT selection schemes and Section VI provides some numerical results. Finally, conclusions are summarised in Section VII.

II. PROBLEM FORMULATION

Let assume a scenario with a single circular cell with radius R (km). Two base stations corresponding to the CDMA and TDMA access technologies are co-sited in the center. On the other hand, let focus on the uplink direction and assume that, for the considered service, the capacity (i.e. the maximum number of simultaneous users) of the FDMA/TDMA base station is C_T. This capacity is a hard limit posed by the amount of slots and carriers available in the cell. The bit rate of a user allocated in one slot of a given carrier is R_b. In turn, for the CDMA cell, the capacity is soft limited and therefore it depends on the maximum allowed interference. Assuming a single service and perfect power control, an upper bound for the maximum number of simultaneous users from the CDMA pole capacity can be defined according to [1]:

$$C_C = \left\lfloor 1 + \frac{W}{\left(\frac{E_b}{N_o}\right) R_b} \right\rfloor = \lfloor C^* \rfloor \quad (1)$$

where $\lfloor x \rfloor$ denotes the highest integer lower than or equal to x and C^* is the pole CDMA capacity. In turn, W is the

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transmission bandwidth after spreading, R_b the service bit rate and E_b/N_o the target quality requirement. It is worth mentioning that this capacity limit could in practice be reduced to values below the pole capacity in order to account for e.g. intercell interference or imperfections in the power control.

Then, from the point of view of a Common Radio Resource Management strategy, the total amount of resources available in the two cells is $C_T + C_C$. Let assume then that there are a total of $U \leq C_T + C_C$ simultaneous users in the scenario. According to a given RAT selection criterion, the U users will be distributed between the two technologies, so that $n_C \leq C_C$ users will be allocated to CDMA-based RAT and the remaining $n_T = U - n_C \leq C_T$ will be allocated in the TDMA-based RAT. The range of values of n_C is from $n_{C,min}$=max(0,U-C_T), accounting that if there are more users than the TDMA capacity some of them should be necessarily included in CDMA, to $n_{C,max}$=min(U,C_C), which is related with the maximum number of users or the CDMA capacity.

Under these constraints, the purpose of this paper is to show how the knowledge about the path loss of the different users can be exploited together with the different characteristics of each technology to provide a smart user distribution with better QoS performance than if path loss information was not considered at all. With respect to quality of service constraints, different parameters could be regarded. In this work the outage probability defined as the probability that the measured signal to noise and interference ratio is below the minimum requirements will be kept as a significant QoS parameter. Other parameters like e.g. error rate, delay, etc., have a strong dependency on the outage probability in the sense that a user in outage will experience a high packet error rate and also will require more packet retransmissions for non real time services thus increasing the delay.

III. Path Loss Statistical Distribution

In this section, the statistical distribution of the path loss in the cell will be computed. Without loss of generality, let assume that the frequency band is similar enough for the CDMA and TDMA technologies so that the same propagation model can be used, although no mutual interference between the two systems exists. The total propagation loss L(dB) at distance r(km) from the base station is given by:

$$L = L_o + \gamma \log(r) + S \qquad (2)$$

where L_o is a constant denoting the propagation losses at 1 Km, γ is the path loss exponent that depends on the propagation conditions (e.g. antenna heights, obstacles, etc.) and S(dB) is a Gaussian random variable with mean zero and standard deviation σ(dB) accounting for the shadowing. Then, the propagation loss in the cell L(dB) is a random variable depending on the shadowing and the distribution of the distance r (i.e. the user spatial distribution). Specifically, assuming that the users are uniformly distributed in the cell, the Appendix shows that the Cumulative Distribution Function (CDF) of the propagation loss $F_L(x)$ is given by:

$$F_L(x) = \frac{\Lambda}{2R^2}\left(e^{\frac{\sigma^2\beta^2}{2}} e^{\beta x} erfc\left(\frac{x-\xi+\sigma^2\beta}{\sqrt{2}\sigma}\right) + e^{\beta\xi} erfc\left(\frac{\xi - x}{\sqrt{2}\sigma}\right)\right) \qquad (3)$$

where:

$$\Lambda = 10^{-\frac{2L_o}{\gamma}} \quad \beta = \frac{2\ln 10}{\gamma} \quad \xi = L_o + \gamma \log_{10} R \qquad (4)$$

and erfc(z) is the complementary error function defined as:

$$erfc(z) = \frac{2}{\sqrt{\pi}} \int_z^{\infty} e^{-t^2} dt \qquad -\infty < z < \infty \qquad (5)$$

In case that the allocation strategy does not make use of path loss information, the statistical distribution of the path loss will be the same regardless of the access technology the user will be attached to. However, taking into account the different robustness of each technology with respect to interference, it can be appropriate to modify the path loss distribution so that users with low path losses are allocated in the more robust access technology. This can be achieved by ordering the users in increasing order of their path loss and allocating them to one or another RAT depending on their position in the ordered list.

For that purpose, consider U independent random variables with distribution $F_L(x)$ corresponding to the path losses of the U users in the scenario. These variables are ordered leading to the list:

$L_1 < L_2 < ... < L_i < .... < L_U$

In this list, the variable in the i-th position is called the i-th order statistic, and its cumulative distribution function is given by [4]:

$$F_{(i)}(x) = \sum_{j=i}^{U} \binom{U}{j} \left[F_L(x)\right]^j \left[1 - F_L(x)\right]^{U-j} \qquad (6)$$

which corresponds to the statistical distribution of the path loss of the user in the i-th position.

IV. Outage Probability Formulation

In this section the outage probability in the scenario will be formulated. Different possibilities will be considered depending on how path loss information is used in the user allocation to RATs. Particularly, the allocation strategies will be classified in two groups, denoted as *path-loss unaware strategies*, in case that the allocation does not consider path loss information, or *path-loss aware strategies*, in case that the allocation is done according to the ordered list of path losses. For this latter case, two possibilities will be considered, depending on whether the users with the low path loss will be allocated to CDMA or to TDMA. These two cases will be denoted in the following as *Low Path loss for CDMA* (LPC) and *Low Path loss for TDMA* (LPT), respectively.

A. Outage condition in path-loss unaware strategies

For those users allocated in TDMA, the outage condition only depends on the maximum transmit power available at the mobile $P_{max,T}$(dBm) and the sensitivity of the receiver $P_{S,T}$ (dBm), which in turn would be related to a certain background noise and signal-to-noise requirement. A TDMA user will be in outage whenever its path loss is above the following limit:

$$L_{\max,T} = P_{\max,T} - P_{S,T} \quad (7)$$

Then, the outage probability for TDMA is:

$$\theta_T = 1 - F_L\left(L_{\max,T}\right) \quad (8)$$

With respect to the CDMA RAT, assuming n_C simultaneous transmissions in CDMA, the outage condition depends on the maximum transmit power constraints, the background noise, the load factor and the path loss distribution. Particularly, a user will be in outage if its path loss is above the limit [1]:

$$L_{\max,C}\left(n_C\right) = P_{\max,C} - P_{N,C} + 10\log\left(1 + \frac{W}{\left(\frac{E_b}{N_o}\right)R_b} - n_C\right) \quad (9)$$

where $P_{N,C}$(dBm) is the background noise power at the receiver, and $P_{max,C}$ (dBm) the maximum available transmit power level.

Consequently, the outage probability for CDMA is:

$$\theta_C\left(n_C\right) = 1 - F_L\left(L_{\max,C}\left(n_C\right)\right) \quad (10)$$

Then, the total outage probability in the scenario assuming there are n_C users in CDMA and n_T=U-n_C in TDMA is:

$$\theta = \theta_C\left(n_C\right)\frac{n_C}{U} + \theta_T\frac{U-n_C}{U} \quad (11)$$

B. Outage condition in path-loss aware strategies

1) Outage condition in the LPC case

This strategy assumes that the U users are ordered according to increasing values of their path loss and the n_c users with the lowest path loss are allocated to CDMA while the rest of U-n_c users with the largest path loss are allocated to TDMA. In this case the total outage probability is given by:

$$\theta = \frac{1}{U}\left(\sum_{i=1}^{n_C}\theta_{C,i}\left(n_C\right) + \sum_{i=n_C+1}^{U}\theta_{T,i}\right) \quad (12)$$

where $\theta_{C,i}(n_C)$ and $\theta_{T,i}$ are the outage of the user in the i-th position according to the ordered path loss list when this user is allocated to CDMA or to TDMA, respectively, given by:

$$\theta_{C,i}\left(n_C\right) = 1 - F_{(i)}\left(L_{\max,C}\left(n_C\right)\right) \quad (13)$$

$$\theta_{T,i} = 1 - F_{(i)}\left(L_{\max,T}\right) \quad (14)$$

2) Outage condition in the LPT case

This strategy is similar to the previous one but in this case the n_C users with the largest path loss are allocated in CDMA while the rest of U-n_C users with lowest path loss are allocated in TDMA. Then, the total outage probability is given by:

$$\theta = \frac{1}{U}\left(\sum_{i=1}^{U-n_C}\theta_{T,i} + \sum_{i=U-n_C+1}^{U}\theta_{C,i}\left(n_C\right)\right) \quad (15)$$

where the outage probability for the user in the i-th position is given in (13) and (14) depending on whether it is allocated in CDMA or in TDMA.

V. RAT ALLOCATION STRATEGIES

The previous section has shown that by using path loss information in the RAT allocation procedure it is possible to modify the total performance in the system in terms of outage probability. However, a given RAT allocation strategy needs to define not only how the path loss information is being used but also the number of users allocated in each RAT (n_C and n_T). In this section, two possibilities are addressed for the traffic split between RATs. The first one follows a load balancing criterion whereas the second one distributes n_C and n_T in an optimized strategy according to a minimum outage probability criterion.

A. Load Balancing (LB)

The load balancing principle appears in the literature in a wide variety of contexts but profusely in the area of distributed computing where, e.g., jobs or tasks are to be assigned to a set of processors [5]. In the context of wireless access networks, load balancing may refer to the allocation of users requesting a given service to a certain cell, carrier frequency, radio access technology, etc. Load balancing algorithms have been considered to improve the performance among cells in single-RAT wireless cellular networks [6]. For multi-RAT wireless access networks load balancing has also been used in [7][8] dealing with vertical handover.

According to this principle, the distribution of users is such that the utilisation (i.e. the load) of both systems is kept as even as possible. This is achieved by keeping the equality:

$$\frac{n_T}{C_T} = \frac{n_C}{C_C} \quad (16)$$

Clearly, there are some situations in which the above equality cannot be satisfied because it would yield either to n_T>C_T or n_C>C_C. In such a situation the remaining users in one technology are moved to the other one, so that the number of users in CDMA would be:

$$n_C = \min\left(U\frac{C_C}{C_T+C_C} + \max\left(0, U\frac{C_T}{C_T+C_C} - C_T\right), C_C\right) \quad (17)$$

and the rest of the users U-n_C would be allocated in TDMA.

The load balancing principle can be combined with both the path loss aware and the path loss unaware strategies presented in section IV, thus obtaining the following RAT allocation schemes:

- Uw_LB: (path loss UnaWare Load Balancing) This corresponds to the classical load balancing without taking into account path loss information (i.e. path loss unaware strategy).

- LPC_LB: This corresponds to the combination of load balancing with the LPC case. This means that the n_C users according to (17) with the lowest path loss are allocated in CDMA.

- LPT_LB: This corresponds to the combination of load balancing with the LPT case, meaning that the n_C users according to (17) with the largest path loss will be allocated in CDMA.

B. Optimized allocation

This strategy corresponds to allocating the optimum number of users in CDMA that minimises the total outage probability in each case. Then, by considering the three possibilities identified in section IV, the following strategies are considered:

- Uw_Opt: (path loss UnaWare Optimized) In this case, the number of users allocated in CDMA, n_c, is obtained as the value that minimises the total outage probability in the scenario if no path loss information is considered. This is given by:

$$n_C^{opt} = \arg \min_{n_C \in [n_{C\min}, n_{C\max}]} \left(\theta_C(n_C) \frac{n_C}{U} + \theta_T \frac{U - n_C}{U} \right) \quad (18)$$

- LPC_Opt: Here, the number of users in CDMA is such that the outage probability assuming that the users with the lowest path loss are allocated in CDMA is minimised, that is:

$$n_C^{opt} = \arg \min_{n_C \in [n_{C\min}, n_{C\max}]} \left(\frac{1}{U} \left(\sum_{i=1}^{n_C} \theta_{C,i}(n_C) + \sum_{i=n_C+1}^{U} \theta_{T,i} \right) \right) \quad (19)$$

- LPT_Opt: In this case, the number of users in CDMA is such that the outage probability assuming the users with the lowest path loss are allocated in TDMA is minimised, that is:

$$n_C^{opt} = \arg \min_{n_C \in [n_{C\min}, n_{C\max}]} \left(\frac{1}{U} \left(\sum_{i=1}^{U-n_C} \theta_{T,i} + \sum_{i=U-n_C+1}^{U} \theta_{C,i}(n_C) \right) \right) \quad (20)$$

VI. Results and Discussion

Three different representative scenarios are considered for the evaluation of the considered RAT allocation strategies. The parameters are shown in Table 1. Scenario 1 and scenario 2 consider a typical situation with voice service with 12.2 kb/s. The difference between both is the value of the Eb/No target for the CDMA RAT, assuming that in scenario 2 a smaller value is considered thanks to e.g. the use of physical layer techniques like reception diversity, better coding schemes, etc. In turn, scenario 3 considers a data service with 64 kb/s. In this case, the cell radius is smaller and the sensitivity level is poorer. Furthermore, it is considered that the mobile terminals used for data transmission have a larger available power.

Figure 1 and Figure 2 plot the outage probability as a function of the number of users U in scenario 1 for the load balancing and the optimised strategies. It can be observed that in all the cases the use of path loss measurements by means of allocating the users with low path loss to CDMA (i.e. LPC) outperforms the path loss unaware and the LPT cases. The reason is that in this scenario the outage condition in the TDMA technology occurs for a maximum path loss of 141 dB while in CDMA in the case with minimum interference (i.e. with only a single user in CDMA) it occurs for 140 dB. As a result, it is beneficial to allocate the users with the lowest path loss in CDMA. It is worth noting that, by comparing Figure 1 and Figure 2, LPC_LB provides in this case almost the same performance as for the optimized case (LPC_Opt).

Table 1 Parameters for Each Scenario

Parameter	Scenario 1	Scenario 2	Scenario 3
Cell radius R	1154 m	1154 m	577 m
L_o	128.1 dB	128.1 dB	128.1 dB
γ	37.6	37.6	37.6
σ	10 dB	10 dB	10 dB
$P_{max,T}$	33 dBm	33 dBm	36 dBm
$P_{S,T}$	-108 dBm	-108 dBm	-82 dBm
C_T	23	23	23
W	3.84Mc/s	3.84Mc/s	3.84 Mc/s
R_b	12.2 kb/s	12.2 kb/s	64 kb/s
Eb/No target	9.5 dB	6 dB	6 dB
$P_{max,C}$	21 dBm	21 dBm	24 dBm
$P_{N,C}$	-104 dBm	-104 dBm	-104 dBm
C_C	36	80	16

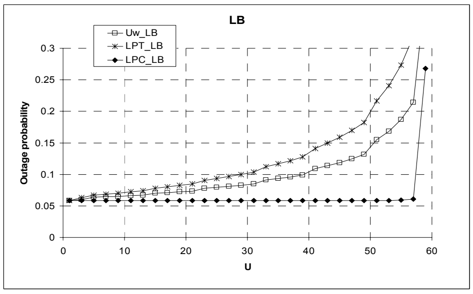

Figure 1 Outage probability for load balancing in scenario 1

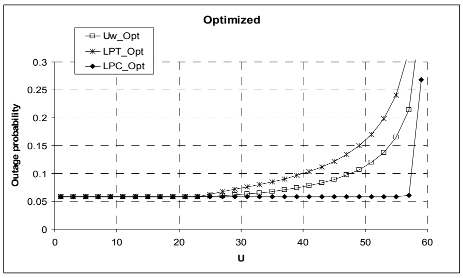

Figure 2 Outage probability for optimized allocation in scenario 1

In scenario 2 the situation differs in the fact that the outage condition in CDMA for the case with a single user occurs with a maximum path loss of 144 dB. Then, when the number of users allocated in CDMA increases, the maximum path loss decreases, and, in the specific case when there are 40 users in CDMA the maximum path loss in CDMA equals the 141 dB of TDMA. Figure 3 plots the outage probability for the load balancing case in this scenario. It can be observed that for low numbers of users, the best performance is obtained when allocating the low path loss users in TDMA by means of LPT, while for high numbers of users, the best performance is achieved when low path loss users are allocated in CDMA (i.e. LPC). The turning point of this behaviour in load balancing occurs approximately at U=51 users, corresponding to the case in which 40 users are allocated in CDMA and 11 in TDMA, corresponding to the case when the outage conditions in CDMA and TDMA are equal.

Figure 4 illustrates the effect of the path loss aware strategies with the optimized case for scenario 2. A similar trend like in Figure 3 is observed, but in this case the turning point occurs with U=63 users (again 40 users allocated to CDMA and 23 users to TDMA). Notice that, like in scenario 1, significant outage reductions are achieved by applying LFT or LPC.

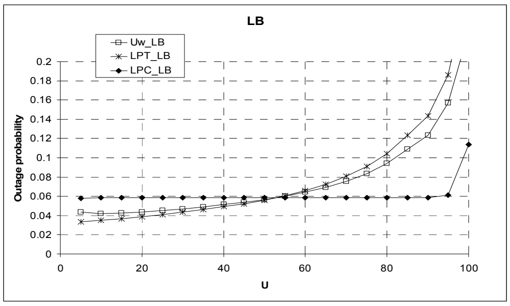

Figure 3 Outage probability for load balancing in scenario 2

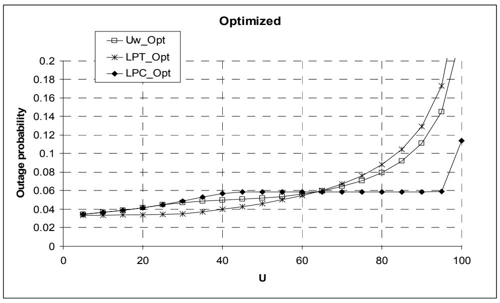

Figure 4 Outage probability for optimized allocation in scenario 2

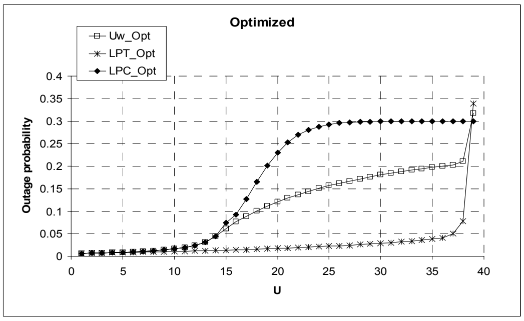

Figure 5 Outage probability for optimized allocation in scenario 3

Finally, Figure 5 plots the outage probability for the optimized case in the scenario 3 corresponding to data transmission. In this case, the outage condition in TDMA occurs for a path loss of 118 dB, which is always below the maximum path loss in CDMA (except in the case that the number of users in CDMA equals the capacity C_C=16). As a result of that, the best performance is achieved when allocating the low path loss users in TDMA by means of LPT. Again, significant outage reductions are observed thanks to the use of path loss information.

VI. CONCLUSIONS

This paper has dealt with the RAT allocation problem in a heterogeneous scenario with CDMA and FDMA/TDMA technologies. Different strategies including the use of path loss information to distribute users have been modelled from an analytical perspective providing closed expressions for the total outage probability in the uplink. Numerical evaluation in representative scenarios has been provided.

Results have shown that by making use of path loss information, either by allocating low path loss users in CDMA or in TDMA, depending on the specific characteristics of each technology, significant outage probability reductions can be achieved.

APPENDIX

In the following the CDF and the pdf of the propagation loss are computed. In particular, let start by assuming a uniform user distribution in a circular cell with radius R. Then, the probability density function (pdf) of the distance r to the base station located at the centre of the cell is given by:

$$f_r(r) = \frac{2r}{R^2} \qquad 0 < r < R \tag{21}$$

Define Y (dB) the path loss without including shadowing, given by

$$Y = L_o + \gamma \log_{10} r \tag{22}$$

The pdf of Y is given by:

$$f_Y(y) = \frac{\Lambda\beta}{R^2} e^{\beta y} \qquad -\infty < y < \xi \tag{23}$$

with Λ,β and ξ defined in (4).

The pdf of the total propagation loss L(dB)=Y(dB)+S(dB) including shadowing is obtained with the convolution of (23) with a Gaussian function of mean 0 and deviation σ, that is:

$$f_L(x) = \frac{\Lambda\beta e^{\beta x} e^{\frac{\beta^2\sigma^2}{2}}}{R^2\sqrt{2\pi}\sigma} \int_{-\infty}^{\xi} e^{-\frac{\left(t-x-\beta\sigma^2\right)^2}{2\sigma^2}} dt \tag{24}$$

By integrating (24) the final expression (3) can be obtained.

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