UMTS Receive Diversity and Intra-cell Mitigation with Multiple Antenna Terminal

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Abstract: Emerging of multimedia service with the new wireless communication standards at high data rate imposes the need to use new systems with a very high efficiency. The antenna diversity often used at the base station but never at the handheld would seem an ideal candidate. The topic of this article is to investigate the suitability and to show the feasibility of exploiting the antenna diversity in a mobile receiver.

1. Introduction.

At the present time voice services represent the main revenue for the operators. However the runaway success of SMS in Europe and of i-mode in Japan with its internet service (bank account access, hotel and travel booking) which runs on an older network indicate that the voice service will become secondary in the next generation.

Across Europe, data revenues today account for around 10 per cent of average revenues per user although most of operators hope to increase this to 25 per cent by 2004. Multimedia Messaging (MMS), which will allow users to send pictures and eventually moving video clips between phones, is expected to account for much of this growth. However to facilitate the proliferation of multimedia services for both professional and mass consumer markets at an affordable and to avoid a repetition of the fiasco of the WAP, mainly due to limited content and slow access speeds the cost of radio transmission should be reduced significantly. SIMO (Single input Multiple Output) systems are potentially very interesting to mobile operators and the users, with the possibilities of increasing the capacity, the data rates or to enhance the QoS (Quality of Service) and hence the possibility to diminish the cost of air time.

The goal of this article is to investigate the behaviour of multi-dimensional RAKE receivers in SIMO systems for future generation of wireless systems. In the first part the space diversity to mitigate the unfriendly effects of multipath fading at a W-CDMA terminal is briefly recalled. The analytical expressions for bit error rate (BER) are derived in order to determine the maximum diversity gain expected for a $[1\times2]$ and $[1\times3]$ SIMO system. The main objective of this part is to establish the best trade off between complexity/cost and diversity gain. Given the cost of a handset and the competition in the mobile telecommunication sector, it is essential to have an appropriate design of mobile receivers. Through the simulation results, we will try to understand the influence of complex environments on diversity receiver. A good understanding of the interference mechanism will help us to design the best receiver for UMTS downlink, which is often considered as the bottleneck for multimedia applications.

2. Multi-antenna terminal

UMTS employs RAKE reception, which offers multipath diversity. It is a low complexity structure matched for fast time to market. Nevertheless, in environments with low time dispersion the RAKE receiver performance does not allow the possibility of having the required QoS. One way to avoid this problem is to introduce more diversity, one of the most promising solution is to use space diversity. The basic principle of diversity is to exploit the information receive on different branches (antennas) available to the receiver in order to increase the signal to noise ratio (SNR). In multipath environments, when all multipath components add destructively, the receiver can be in a deep fade deteriorating the communication link. When the different antennas are in an independent environment this situation rarely occurs. This notion of independence is linked to the spatial correlation. The degree of correlation as a function of antenna separation has been investigated both theoretically [1], [2] and experimentally [3]. It can be seen that the spatial correlation is a decaying function of the antenna separation. The experimental curve is very close to the theoretical curve, which describes the behaviour of the spatial correlation as a function of a wavelength) is needed to have a decorrelation in the received signals. Moreover it has been shown in [4] that the mutual coupling can reduce the correlation coefficient so good diversity gain can be obtained for antenna spacing as small as one tenth of a wavelength.

figure 1 shows an example of received envelopes simulated by a dual antenna receiver. Both antennas are identical. The distribution of multipath components is uniform. The envelope correlation between the two branches is r = 0.7. The solid black curve represents the combined signal of the two branches and it appears that the combined signal is less fade than the signal in the two antennas.

Without restriction to the number of antennas in the user terminal, a basic approach is a system equipped with a number of RF modules equivalent to the number of antennas. The main advantage of this architecture is that all received signals are coherently processed, allowing the application of an optimal combining method. Nevertheless, the using of multiple and independent RF and baseband modules has a harmful influence on the overall cost and figure 1: Envelopes received by a dual antenna receiver complexity.



and combined envelope of the two branches

3. Analytical diversity gain

First, we present the analytical expression of the BER for a multi-dimensional RAKE receiver formed by P antennas each followed by a L finger RAKE receiver without transmit diversity, i.e. (1,P) systems. We will use the well-known method [5] for coherent modulation scheme and BPSK modulation to determine the conditional error probability. At first we find the characteristic function of the SNR g_{s} , y_{s} and then we perform the inverse Laplace transform to obtain the marginal probability density function. The average error probability in the presence of fading is obtained by averaging the conditional error probability over the values of the SNR.

$$P_{b} = E_{g} \left\{ \frac{1}{2} \cdot \operatorname{erfc}(\sqrt{g}) \right\} = \frac{1}{2} \int_{0}^{\pi} f_{g}(g) \cdot \operatorname{erfc}(\sqrt{g}) \cdot dg$$

$$\tag{1}$$

For the RAKE receiver, from the signal to noise ratio the Bit Error Rate (BER) may be deduced. We present the average error probability for a multi-dimensional RAKE receiver with an arbitrary number of antennas, we denote g_{i} the instantaneous SNR (signal noise ratio) of the l^{th} path on the i^{th} antenna and P is the number of antennas. For equally likely transmitted symbols, the total SNR by symbol g is given by:

$$g = \sum_{i=1}^{p} g_{i} = \sum_{i=1}^{p} \sum_{l=1}^{L} g_{l}$$
(2)

For identical channel (i.e. $\bar{g}_i = \bar{g} \forall i$), the characteristic function is:

$$\mathbf{y}_{g} = \prod_{i=1}^{L} \left\{ \frac{1}{1 - s \bar{\mathbf{g}}_{i}} \right\}^{p}$$
(3)

We derive an analytical expression for P = 2, 3. Substituting, the Laplace inverse transform of (3) in (1), gives the bit error rate for respectively two and three antennas:

$$P_{\scriptscriptstyle b} = \sum_{l=1}^{L} \left| \prod_{\substack{k=1\\k\neq l}}^{L} \left\{ \frac{\overline{g}_{\scriptscriptstyle l}}{\overline{g}_{\scriptscriptstyle l} - \overline{g}_{\scriptscriptstyle k}} \right\}^2 \cdot \sum_{\substack{k=1\\k\neq l}} \frac{\overline{g}_{\scriptscriptstyle k}}{\overline{g}_{\scriptscriptstyle k} - \overline{g}_{\scriptscriptstyle l}} \left\{ 1 - \sqrt{\frac{\overline{g}_{\scriptscriptstyle l}}{1 + \overline{g}_{\scriptscriptstyle l}}} \right\} + \frac{1}{4} \prod_{\substack{k=1\\k\neq l}}^{L} \left\{ \frac{\overline{g}_{\scriptscriptstyle l}}{\overline{g}_{\scriptscriptstyle l} - \overline{g}_{\scriptscriptstyle k}} \right\}^2 \left\{ 2 + \sqrt{\frac{\overline{g}_{\scriptscriptstyle l}}{1 + \overline{g}_{\scriptscriptstyle l}}} \right\} \right) \right|$$
(4)

$$P_{b} = \sum_{l=1}^{L} \frac{9}{4} \left\{ \prod_{\substack{i=1\\i\neq l}}^{L} \frac{\overline{g}_{l}}{\overline{g}_{l} - \overline{g}_{i}} \right\} \left\{ \left[\sum_{\substack{i=1\\i\neq l}}^{L} \frac{\overline{g}_{i}}{\overline{g}_{i} - \overline{g}_{l}} \right]^{2} + \frac{1}{3} \sum_{\substack{i=1\\i\neq l}}^{L} \left[\frac{\overline{g}_{i}}{\overline{g}_{i} - \overline{g}_{l}} \right]^{2} \right\} \left\{ 1 - \sqrt{\frac{\overline{g}_{l}}{1 + \overline{g}_{l}}} \right\} + \frac{3}{4} \left\{ \prod_{\substack{i=1\\i\neq l}}^{L} \frac{\overline{g}_{l}}{\overline{g}_{l} - \overline{g}_{i}} \right\} \left\{ \left\{ 1 - \sqrt{\frac{\overline{g}_{l}}{1 + \overline{g}_{l}}} \right\} \right\} \right\} \left\{ 1 - \sqrt{\frac{\overline{g}_{l}}{1 + \overline{g}_{l}}} \right\} + \frac{1}{8} \left\{ \prod_{\substack{i=1\\i\neq l}}^{L} \frac{\overline{g}_{l}}{\overline{g}_{l} - \overline{g}_{i}} \right\} \left\{ 1 + \sqrt{\frac{\overline{g}_{l}}{1 + \overline{g}_{l}}} \right\}^{3} \left[4 + \frac{9}{2} \sqrt{\frac{\overline{g}_{l}}{1 + \overline{g}_{l}}} + \frac{3}{2} \left(\sqrt{\frac{\overline{g}_{l}}{1 + \overline{g}_{l}}} \right)^{2} \right] \right\}$$

$$(5)$$

However, in the expression (4) and (5) it is assumed that the combined signals are independent of one another, this assumption is not valid for a small handset equipped with space diversity. In [6] the authors present a generalised expression of the BER including the antenna correlation. Nevertheless, the antenna separation and the spatial distribution of scatters have a significant impact on the correlation and for the mobile short antenna separations are sufficient to have a decorrelation of received signals.

Figure 2 represents the uncoded BER using [1,1], [1,2] and [1,3] systems using Rayleigh fading with six resolvable paths (Vehicular A). Time delay dispersion, a result of multipath scattering, is an inherent aspect of reception in most wireless system. The temporal dispersion has a great affect on system performance and determine the effectiveness of RAKE receiver in CDMA system (i.e. determine the amount of frequency diversity attainable). The temporal dispersion of the channel is

completely characterised by the power delay profiles also called multipath intensity profiles [7].

The reference profile for most environments is specified in [7]:

$$P(t) = \frac{1}{t_m} e^{-\frac{t}{t_m}}$$
(6)

To determine the theoretical performance of multidimensional RAKE receiver, we have used an exponential profile define by (6). We have determined the delay spread (t_{m}) for a channel whose power delay profile is specified by vehicular A, using the following expression [8]:



figure 2: Performance comparison for Multidimensional RAKE receiver

$$\boldsymbol{t}_{m} = \sqrt{\frac{1}{P_{T}} \sum_{i=1}^{n} P_{i} \boldsymbol{t}_{i}^{2} - \boldsymbol{t}_{0}}$$
(7)

The performance improvement is shown to be very impressive between the systems [1x1] and [1x2]. From figure 2 we can observe gains up to 6.7dB between RAKE receiver and dual RAKE receiver. However for the systems [1x2] and [1x3] the gain is much more moderate (3.7dB). Hence the cost, hardware an power consumption must be considered along with the gain that diversity brings. It appears that using more than twoantenna element and so increasing the hardware cost and the power consumption is not fully justified. For high data rate and reliable communication the best solution is to use a dual antenna receiver.

3. Simulation

Simulation were done to evaluate the performance and limitation of the chosen solutions, the downlink has been modelled in using SPW (with perfect channel estimation). These simulations will be completed by statistic measures on received signals, which we will allow to evaluate the performance of multi-antenna receivers in the case of no homogeneous received power on each antenna. These simulations result for mono and multidimensional RAKE receivers are plotted in figures 3,4,5 for downlink scenarios.



intracell users

The performance is computed for a constant spatial correlation equal to 0.7 and an environment close to the 3GPP standard. Each simulation was realised for 1, 4 or 10 users. The intercell sources are modelled as a white gaussian noise whereas the intracell sources are considered as single communication with the same spreading factors as the wanted user.

For figure 3, the ratio between the number of intracell users and the spreading factor is too low and we can not see the effect of intracell interference. In all results presented we can observe the benefit introduced by space diversity. At 10^{-1} the gains are between 2 and 3dB in a mono user situation. In multi-user configuration, firstly we can observe that the mono-sensor receiver performance is poor. Figure 4 and 5 show us that the BER stay at about 10⁻¹ even for moderate E_{h}/N_{a} . Indeed, several publications show that there is an irreducible threshold due to ISI (Inter-Symbol Interference) and mainly to MAI (Multiple Access Interference). When a multi-antenna receiver is used in multi-user configuration, we notice that the performance is much more promising. Indeed, figure 4 shows us that without interference rejection, the BER tends towards a threshold at a lower level because the



figure 5: Simulation result for SF=8 and several intracell users

spatial diversity does not decrease the MAI but allow it to drop the saturation threshold. The influence of multiple access interference can be investigated in an analytical way in assuming the MAI as a white noise. The analytical expression of the BER is obtained by modifying the SNR g_i in (4) and (5) by g_i^{MU} , define by the following expression:

$$\boldsymbol{g}_{x}^{MN} = \frac{1}{(\boldsymbol{g}_{x})^{-1} + \frac{\boldsymbol{a}}{SF}(N_{u} - 1) + \frac{\boldsymbol{b}}{SF}N_{u}}$$
(8)

Where **a** and **b** are two parameters that model the rejection techniques used (without interference rejection a = 1 and b = 0), N_u is the number of users and SF the spreading factor.

4. Conclusions

The behaviour of multi-dimensional RAKE receiver has been studied via an analytical approach and simulations. It has been observed that the saturation threshold due to intra-cell interference is always present with space diversity but at a much more low level. We have shown that the efficiency of multi-dimensional RAKE in multi-user scenario is a promising solution that gives good performance.

5. References.

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