DESELECTION OF ANTENNA ELEMENTS FOR AVOIDING BLOCKING EFFECTS

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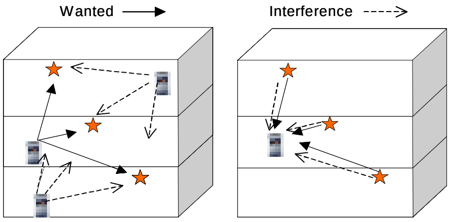
ABSTRACT

A new technique for improving the performance of indoor distributed antenna systems (DAS) operating in W-CDMA systems is proposed and analysed. This is based on the deselection of an antenna element (or elements), which receives excessively strong signal strength from a nearby user having reached its smallest power control step. This would otherwise result in a potential masking of other users lying at the edge of the cell with the potential of reducing the coverage and capacity of a W-CDMA system. It is found that the proposed scheme significantly reduces the resultant coverage and capacity degradation.

INTRODUCTION

Distributed Antenna Systems (DAS) have been proposed for providing coverage and increasing the capacity of indoor wireless communication systems by using multiple antenna elements (access points) as described in e.g. [1] and illustrated in Fig. 1. The main advantages are that the users receive multiple versions of the same signal from different directions, providing diversity protection against shadowing and distance-dependent propagation losses. Simulcasting of the signals is performed by all the radio ports, so no handover operation occurs when a user is in the overlap area between two antenna elements (AE's). Low transmitted power levels, less interference to other systems and near-uniform coverage of the service area are also characteristics of DAS.

In a W-CDMA system, the power levels transmitted by the mobile users are under continual power control (PC) by their closest base station (Node B). However, the PC dynamic range limits the minimum power that the mobile user can transmit. If a user has reached the lowest PC step and is close to the Node B, the received signal will be very strong and much higher than the thermal noise levels of the receiver. If another user is lying close to the boundary of the cell then, even at the highest power, the difference between the received signals of both users at the base station may exceed the base station's linear dynamic range. This results in either distortion of the stronger signal, which may degrade the performance for all users in the cell, or the dynamic range has to be adjusted to provide linear operation for the stronger user. The noise floor of the receiver is then increased and the weaker users at the cell edge will be lost from coverage. Consequently this results in cell shrinkage with potential system capacity degradation. The same issue can also occur from users operating in adjacent channels. Although these users are somewhat protected by the receiver's adjacent channel rejection ratio, they will not be power controlled with respect to the receiving system so the blocking levels produced may be correspondingly larger. The likelihood of both co- and adjacent-channel effects is highest for in-building scenarios, since there may be users that lie very close to an indoor DAS antenna element (AE) and their signal masks distant users. In order to numerically illustrate these effects, the following example is presented.



(i) **(ii)**

Fig. 1: Concept of the DAS architecture (i) Uplink and (ii) Downlink

Under normal conditions the noise floor, N_T of the receiver is calculated in dBW by:

$$N_T = 10 \cdot \log(k \cdot T \cdot W) + F \qquad (1)$$

where k is Boltzmann's constant (1.379x10^{-23} W/Hz/K), T is the absolute temperature of the input noise source in K, W is the effective noise bandwidth of the W-CDMA system (3.84 Mcps), and F is the noise figure of the receiver in dB. Different values of F for the user equipment (UE) and the Node B are proposed in the literature, with 5 dB being a commonly used value in the uplink. However, due to the use of active DAS it is expected that F will further increase by 10log(N), where N is the number of AE's used in the DA system. Therefore, for a 6 element DAS the noise floor of the receiver is approximately –95.3 dBm.

In a W-CDMA system with a maximum UE transmit power of 21 dBm and power control dynamic range of 65 dB, the minimum transmit power of the UE is –44 dBm (i.e. 21 dBm – 65 dB). Considering the free space path loss, L [dB], at distance of 4 metres from the closest AE, and at 2 GHz we get:

$$L = 32.4 + 20 \cdot \log(d_m) + 20 \cdot \log(F_{GHz}) \cong 50.5 \text{ dB} \qquad (2)$$

where d_m is the distance in metres, and F_{GHz} is the frequency in GHz.

Assuming an indoor AE effective gain of 2 dBi, effective UE gain of 0 dBd (=2.15 dBi), and also that the cable losses, connecting the AE with the central location, are overcome by a low noise amplifier (LNA) of an active DAS, the received signal strength at the Node B, $P_{RX,NB}$ [dBm], becomes:

$$P_{RX,NB} = P_{TX,UE} - L + G_{UE,NB} \cong -90.3\,\text{dBm} \qquad (3)$$

where $P_{TX,UE}$ [dBm] is the minimum transmit power of the UE (i.e. –44 dBm), L [dB] is the path loss as calculated by (2), and $G_{UE,NB}$ [dB] replaces the gains of the UE and the AE (i.e. 4.15 dBi).

Decreasing the gain of the amplifier of the Node B to operate in the linear region, the maximum level of the Rx has now to be adjusted to –90.3 dBm instead of the normal conditions receiver noise levels of –95.3 dBm. Therefore, shrinkage of the coverage area occurs, similar to that presented in high load factor situations, with the potential of losing the users lying at the edge of the cell even when they operate at their maximum available transmit power.

DESELECTION OF ANTENNA ELEMENTS

When a DAS architecture is deployed to provide coverage in an indoor environment, the signal of each user is received by many AE's, which are distributed around the building. It is proposed by the authors in [2] that the use of DAS can provide an effective means of avoiding blocking effects, by deselecting any antenna that encounters a signal, which is too strong to provide the required dynamic range. Although this reduces the overall effectiveness of the distributed antenna system when operating in normal conditions, it avoids the catastrophic impact of receiver blocking and only compromises coverage in the local region around the antenna.

The system operation would differ for active and passive DA systems, thus for active systems a receiver (or at least a low noise amplifier) exists at each AE. The system would monitor this level at each DA element and would deselect those which exceed a preset threshold.

For a passive system the Node B only has access to the combined signal from all elements. If the resultant signal exceeds a preset threshold level the Node B would deselect antenna elements sequentially, one-by-one, until the resultant signal is sufficiently small. This can be accomplished faster by subdividing the elements into two groups, examining the combined signal in one group, then subdividing the group with the higher combined signal and repeating the process until a single element is obtained. This reduces the number of steps from N, where N is the number of elements, to less than or equal to:

$$1 + ceil\left[\log_2(N)\right] \qquad (4)$$

where $ceil[.]$ represents the next highest integer.

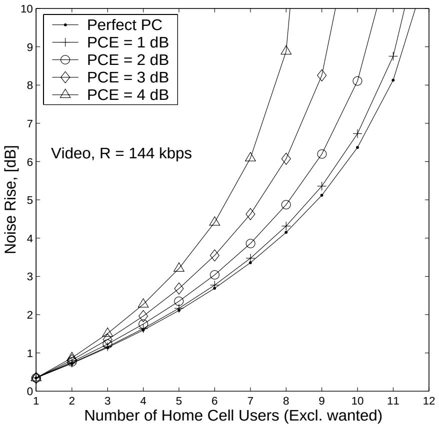


Fig. 2: Impact of power control errors on the noise rise of a W-CDMA system

DISTRIBUTED ANTENNA MODELLING

In a W-CDMA system the total interference received by the Node B results in a noise rise over thermal noise. Therefore, an interference margin, R_{IM}, is commonly used to account for the total noise-plus-interference, which, following the analysis of [3] and [4] and for a single service, is given by:

$$R_{IM} = 10 \cdot \log(I + N_T) = 10 \cdot \log\left(\frac{N_T}{1 - n_{UL}}\right) \qquad (5)$$

where I [W] is the total received interference, N_T [W] is the thermal noise of the receiver, and n_{UL} is the uplink load factor, which is a ratio of the active-user power over the power from the maximum number of users that can be supported by the W-CDMA system, M_{MAX}, given by:

$$M_{MAX} = \frac{W / R}{v \cdot (1 + f) \cdot [E_b / N_o]_{MIN}} + 1 \qquad (6)$$

where v is the voice activity factor (e.g. 1 for video), f is the inter-cell interference factor (e.g. 0.2 indoors [5]), W is the chip rate of the W-CDMA system, R is the bit rate of the investigated service (144 kbps) and E_b/N_0 is the bit-energy-to-noise-plus-interference density, equal to 2.4 dB in the UL, as proposed by 3GPP, [6].

For users with power control errors (PCE) this can be calculated as a power sum of multiple Gaussian RVs, L_i [dB], each modelled as a zero mean and standard deviation equal to the PCE [dB], as given by:

$$n_{UL} = \left(\sum_{i=1}^{M} 10^{L_i/10}\right) / M_{MAX} \qquad (7)$$

The sum term can be solved by the Wilkinson Approximation (WA) as presented in [7], whereas for zero PCE (i.e. perfect PC) it results in the same noise rise as when dividing the active user power by the power from the maximum number of users, as explained in [3].

Fig. 2 displays the effect of the PCE on the capacity of the system and it is seen that the capacity reductions with PCE are significant. The same assumptions should also hold when DAS are deployed, since the same medium is used to deliver the signals to and from the central location. Therefore, no capacity increase is expected with DAS beyond the pole capacity. The outage probabilities for the single and the DA system can be calculated by the complementary cumulative normal distribution (*Q*-function) as:

$$P_{OUT} = 1 - Q\left(\frac{CINR_{THR} - C + R_{IM}}{\sqrt{\sigma_C^2 + \sigma_{PCE,EFF}^2}}\right) \qquad (8)$$

where C [dBW] and σ_C [dB] are the overall mean carrier signal strength and standard deviation of a superposition of multiple log-normally distributed random variables (RV's), each corresponding to an AE. Calculations of these overall statistics can be performed either by the WA for shadowing standard deviation values of up to 4-5 dB, or the Extended Schwartz and Yeh (Extended SY) method for higher standard deviations, as described in [7]. $\sigma_{PCE,EFF}$ [dB] is the final standard deviation of the PCE as calculated by (7). $CINR_{THR}$ [dB] is the required carrier-to-interference-plus-noise requirements of the W-CDMA system given by:

$$CINR_{THR} = 10 \cdot \log\left(\frac{E_b / N_o}{W / R}\right) \qquad (9)$$

SCENARIOS AND PERFORMANCE RESULTS

The environment that was deployed for the analysis was a 13-storey office building, with the layout of each floor considered to be the same as that of the CCSR floor at the University of Surrey, Fig. 3(i). Two distributed antenna configurations with 8 and 6 antenna elements were deployed, and a multi-wall model, as presented by [8], was used for path loss calculations. Average floor heights of 4 metres and attenuations of 3.4 dB/wall and 15 dB/floor were considered. Location variability of 5 dB was assumed, whereas the effects of shadowing correlation on the outage probabilities have been seen to be insignificant and, therefore, were neglected, [7].

Location of the antenna elements is of importance, since a non-aligned configuration in the vertical direction may be proved more efficient. However, this depends on the building under investigation and the number of the antennas deployed to cover the cell. It was seen that, for the investigated building scenario, and with a small number of AE's, the outage obtained with an aligned element configuration outperformed that with the antennas located in a non-aligned pattern.

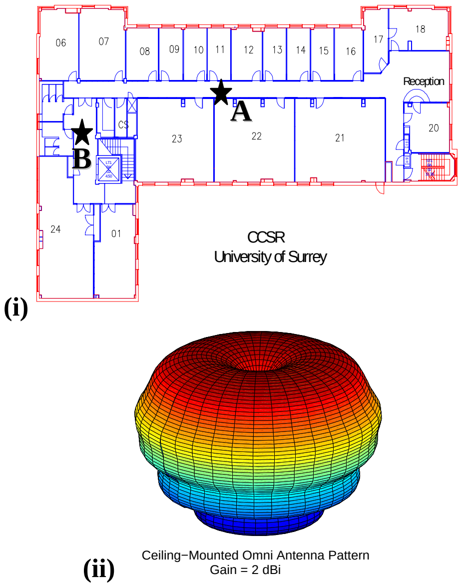


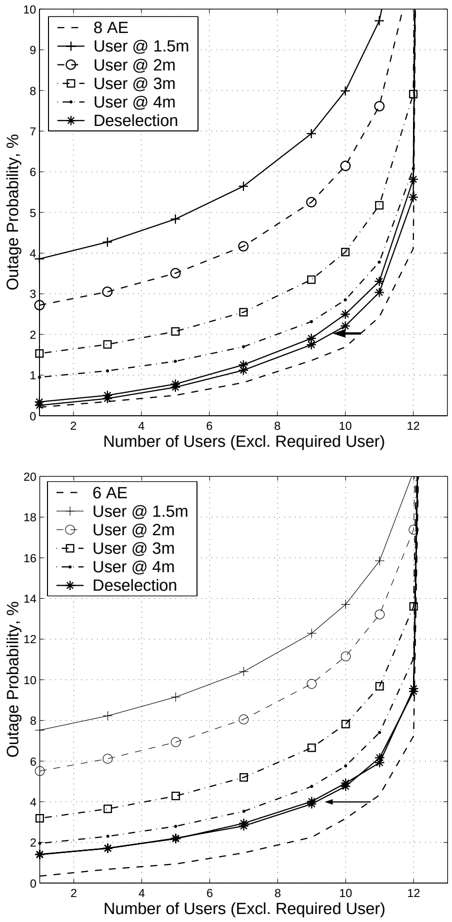
Fig. 3: (i) Floor layout together with the antenna element location, (ii) Typical ceiling-mounted omni antenna pattern

This was due to the fact that the wall attenuations were not high enough to justify the location of the antenna elements in a non-aligned form. The main cause of shadowing in the specific environment was the floor attenuations, and therefore, the antennas had to be deployed in a way to provide coverage on the floor they were located and also to maximise coverage on adjacent floors.

Therefore, with less than 6 AE's only point A was used for the location of the antennas. However, when more than 6 AE's were deployed, it was possible to locate the additional elements at point B, on different floors of the building to obtain better coverage, Fig. 3(i).

The radiation pattern of the antennas was typical of ceiling-mounted omni-directional antennas, providing coverage mainly downwards but with significant upward pointing lobes as well, Fig. 3(ii). Antenna gains of the AE's were 2 dBi, whereas the antenna gain of the UE was 0 dBd with maximum transmitted power of 21 dBm.

The outage probabilities of the deployed DAS configuration with the 8 AE's under normal conditions are shown in Fig. 4(i) with a dashed line. It is seen that, for a coverage requirement of 95% of floor area (i.e. 5% outage), the maximum number of users, as given by (6), has been reached (pole capacity). The blocking effects of a nearby user are also shown at distances of 1.5, 2, 3 and 4 metres away from the closest AE. It is observed that the capacity reductions are significant for distances up to 4 metres away from the AE. With a user standing at 1.5 metres away from the AE, the capacity has more than halved (6 users instead of 13) compared to when no blocking effects are present, whereas the capacity increases as the user moves away from the affected AE.



(i)

(ii)

Fig. 4: Performance of the deselection in two DAS arrangements with (i) 8 AE's and (ii) 6 AE's

The performance of deselection of the AE that receives the strongest signal can be seen with the solid starred lines. Each line corresponds to a different deselected AE. Based on a uniform user distribution it is seen that the differences regarding which antenna element is deselected are not significant, provided that the deselected AE is the one that receives the strongest signal. The degradation in terms of coverage and capacity is small, since it is still possible to accommodate 12 users instead of a maximum number of 13 when no blocking effects are present.

The performance of the deselection is also presented for the case where 6 antenna elements are deployed to provide coverage in the same environment, Fig. 4(ii). The effect of a user being very close to one AE can be very detrimental, since at distances of less than 2 metres it is not possible to provide coverage to any user at 95% of the locations. By deselecting the AE that receives a very strong signal the detrimental effects are avoided, since the number of users is maintained at high levels (i.e. 11 users at 5% outage).

Therefore, it can be concluded that the number of AE's deployed, determines the degree of coverage and capacity degradation of the DAS architecture in a blocking situation. The greater the number of AE's the higher the resilience of the system when no deselection is performed, because a more uniform coverage of the cell area is obtained due to the macro-diversity effects of the DA system. The use of deselection will, however, avoid the detrimental effects in all cases.

CONCLUSIONS

A scheme based on deselection of distributed antenna elements has been proposed and investigated. In all cases it was seen that when a user is very close to an AE the coverage and capacity degradation are significant, since the interference levels of the nearby user are high and it is not always possible for the distant users to overcome these resulting in shrinkage of the cell similar to that observed when the loading of the cell is very high. By performing deselection, the detrimental effects on availability are avoided, and only a small degradation in terms of outage is observed affecting mainly the area around the deselected AE. The overall capacity of the system, however, is maintained at very high levels.

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