Performance analyses of in building distributed antenna (DA) systems for W-CDMA are presented in this paper. Uplink and downlink outage probabilities are related to the loading factor and it is observed that by deploying DA’s in a multi-floor environment the advantages in terms of both coverage and capacity are significant. Investigation of DA has been performed for a specific building scenario. However, similar performance is expected in environments characterised by high attenuations, which cannot be covered by single antenna cells.

INTRODUCTION

Distributed antennas (DA) have been proposed for providing coverage and increasing the capacity of indoor wireless communication systems by using multiple antenna elements (access points) [1]-[4]. The main advantages are that the mobiles receive multiple versions of the same signal from different directions, providing diversity protection against shadowing and distance-dependent propagation losses [1]. Simulcasting of the signals is performed by all the radio ports, so no handover operation is performed when a user is in the overlapping area of two antenna elements (AE). Low transmitted power levels, less interference to other systems and uniform coverage of the service area are also some of the characteristics of DA.

The performance of DA systems in both coverage and capacity in a multi-storey environment and with W-CDMA system parameters is presented in this paper. Outage probabilities are related to the transmitted power, the statistics of final component and the loading of the cell and the effects on coverage and capacity are discussed. In addition, the impact of DA on the transmitted power of the mobile appears to be significant and is also addressed. Lognormal shadowing is considered, and the final statistics of the signal received by the DA system are approximated as another lognormal and could be calculated by either the Wilkinson’s approximation [5] or the Extended SY method [6].

W–CDMA ANALYSIS WITH DA

In a WCDMA system, signals from other users, in home and adjacent cells, act as thermal noise-like interference, which raises the noise floor of the receiver. This depends on the power control errors and on the loading of the cell. Power control is a necessity in the CDMA system as many users simultaneously transmit to a base station with the same frequency spectral allocation. The purpose of the power control is to guarantee a particular level of performance, which is a function of the required bit-energy-to-interference density, \( Eb/No \).

Fig. 1: Concept of in-building DA for W-CDMA (i) Uplink, and (ii) Downlink
Uplink

Depending on the service (e.g., voice, video) and on the required Eb/No to maintain the quality of the link at acceptable levels, the required received power (receiver sensitivity, $P_{SENS}$) can be calculated as:

$$P_{SENS}[dBm] = N_f[dB] + \frac{E_{b}}{N_0}[dB] + R[dB] + 10 \log(kT) + F[dB] + R_{IM}[dB]$$

(1)

where $R$ is the data rate of the service, $F$ is the noise figure of the receiver and $R_{IM}$ is the interference margin due to home cell power controlled interferers, which gives rise over the thermal noise, $N_f$ [7][8]. A lognormal approximation of the received power with mean equal to the noise rise and variance equal to the power control error has been assumed. Given the fact that the speed of the MS indoors is small, and since the delay spread of the signal is less compared to macro-cell environments, the PCE standard deviation should be very small (<1 dB).

The power required by the MS should be such that the path losses are overcome and still greater signal than the noise power is obtained:

$$P_{TX,REQ} = L_{EFF} + G(0, \sigma_{EFF}) - Gain_{BS,MS} + Loss_{BS,MS} + P_{SENS}$$

(2)

Where, $Gain_{BS,MS}$ represents the antenna gains of the base and the mobile stations, $Loss_{BS,MS}$ is the effective attenuation due to receiver cable and connector losses and also due to body loss. $L_{EFF}$ and $G(0, \sigma_{EFF})$ represent the effective path loss and log-normal shadowing of the environment, which is a superposition of multiple components due to DA, each with variance $\sigma$. Final statistics calculations can be implemented by either the Wilkinson’s Approximation (WA) method for variances up to 4-5 dB [5], whereas the Extended SY method should be deployed for higher variances [6]. Outage is considered to occur when the power, required to maintain the quality of the link, is greater than the maximum power of the mobile and is given by:

$$P_{OUT} = \Pr\{P_{TX,REQ} \geq P_{TX,MAX}\} = Q\left(\frac{P_{MAX} - L_{EFF} + Gain_{BS,MS} - Loss_{BS,MS} - P_{SENS}}{\sqrt{\sigma_{EFF}^2 + \sigma_{PCE}^2}}\right)$$

(3)

where $Q(.)$ is the complementary cumulative normal distribution.

Downlink

A similar approach has been followed for the outage probability calculations in the downlink. The power received by the mobile station is given by:

$$P_{MS} = P_{RX} - \sum_{i=1}^{M-1} \left\{ P_{SENS} + [L_{EFF,i}, G(0, \sigma_{EFF,i})]\right\} - L_{MS} + G(0, \sigma_{EFF})$$

$$- Loss_{BS,MS} + Gain_{BS,MS} - R_{IM} - G(0, \sigma_{PCE})$$

(4)

The BS has to transmit power to $M-1$ home cell power-controlled interferers, as well as to the required user. Effective path losses and variances due to DA have to be considered, as is the case in the uplink. The downlink orthogonality factor and the other-cell-to-home-cell interference factor are accounted for by the interference margin [7][8].

Outage occurs when the received power at each location is less than the required power ($P_{SENS}$) of the service that is investigated. By deploying the $Q$-function we finally get:

$$P_{OUT} = \Pr\{P_{SENS} \geq P_{MS}\} = Q\left(\frac{P_{MAX} - (P_{SENS} + L_{EFF}) - M_{SUM} + Gain_{BS,MS} - Loss_{BS,MS} - R_{IM}}{\sqrt{\sigma_{EFF}^2 + \sigma_{SUM}^2 + \sigma_{PCE}^2}}\right)$$

(5)

where $M_{SUM}$, and $\sigma_{SUM}$ are the final mean and variance of the sum term in (4).
Outage Results

The environment that has been deployed for the analysis is a 10-floor 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. 2. The average floor distances are assumed to be 4 metres, whereas attenuations of 4dB/wall and 15dB/floor are considered [9][10]. The propagation model proposed by [9] is used for this analysis. The antennas are located on the ceiling of the floors in a non-aligned configuration to provide better coverage throughout the building [11]. The radiation patterns are typical indoor omni-directional antennas, which provide coverage downwards. A simulation tool, developed within CCSR, for calculation of the signal strength in indoor environments has been deployed for path loss calculations [12]. The analysis presented here is based on active DA systems, since cable losses of passive DA may degrade the performance. With active DA an increase of the noise levels by an amount equal to 10log(N), where N is the number of AE, occurs in the uplink.

![Fig. 2: Floor layout of the CCSR building](image)

The parameters that have been used follow the 3GPP guidelines for micro-cell environments [13]. Video service is investigated (144 Kbps), whereas inter-cell interference factor of 0.2 and downlink orthogonality factor of 0.9 are assumed [7][8]. Lognormal shadowing with variance of 5 dB, cable losses of the BS of 2 dB and antenna gains of 2 dBi for BS and 0 dBd for the MS are considered.

Fig. 3 displays the impact of the DA system on the outage probabilities for both the uplink and the downlink. In the uplink more than 4 AE are required for this scenario to meet the targets of e.g. 95% availability and 0.8 loading of the cell. Higher values of loading will result in instabilities of the system and therefore should be avoided. Additional elements do not provide significant improvements in terms of capacity as this is limited by the pole capacity of the system. However, by adding more elements in the cell the required levels of MS transmitted power would be decreased dramatically, as can be seen in Fig. 4. In the uplink, even with 5 DA elements, the above targets are met and addition of more elements could lead to power gains up to 16 dB with 10 DAE. With 4 AE it is not possible to obtain 95% availability for cell loading 0.8 and more power needs to be transmitted by the MS to achieve this target. In addition, as the W-CDMA system is interference limited, it should be noted that the far-field interference, produced by the in-building cell to the outdoor environment, will be also greatly reduced, enhancing the capacity of the whole network.

![Fig. 3: Outage probabilities versus the cell loading of the investigated scenario (i) Uplink and (ii) Downlink](image)
Downlink comparisons are presented in Fig.3(ii). The theoretical capacity in the downlink is much higher than that of the uplink, since the orthogonality factor is maintained at high levels. With 8 AE it is observed that the pole capacity is reached, whereas coverage is maintained at more than 95%. Power gains with higher numbers of antenna elements would also be possible. Finally, it should be noticed that although for small number of AE, both uplink and downlink appear to provide similar system capacity, while as the number of the AE increases the limiting factor is the uplink since the maximum number of users that could be supported in the downlink is much higher than in the uplink. The power gain improvements, however, are still valid.

**Fig. 4:** Power gain of MS for a load-limited system with load threshold of 0.8

**CONCLUSIONS**

Coverage and capacity analyses in a multi-floor environment with distributed antennas and with W-CDMA system parameters are presented in this paper. Uplink comparisons are presented first and it is seen that DA offer great advantages in terms of coverage and capacity even with small numbers of antenna elements, whereas big power gain improvements are obtained with additional elements. In the downlink, the capacity improvements are also very significant since with additional AE’s it is possible to reach the pole capacity of the system, which is much increased due to high values of orthogonality, compared to the uplink.

**REFERENCES**


