**Downlink Transmission of Distributed Antenna Systems in High Building Environments**

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**ABSTRACT**

Over the last few years high data rate wireless transmission has gained considerable attention in hot spot areas, including high buildings. It has been demonstrated that distributed antenna systems (DASs) improve the performance of the indoor environment by covering dead spots. In this paper, a DAS architecture for high buildings is investigated, proposed and analyzed. The goal is to provide high data rate for indoor mobile users by exploiting spatial diversity and reducing the distance of radio transmission. In this system, the frequency is reused among floors. The radio signals in high buildings can propagate vertically and reach the neighbouring floors. Therefore, the performance of the system is limited by co-channel interference. Direct propagation inside the building and reflection from nearby buildings have been considered in the channel model. Based on the theoretical analysis, the impact of the position of the user on the performance is discussed in terms of the bit error rate (BER). It is also demonstrated how the attenuation caused by the floor separation in high buildings should be taken into consideration during the planning of the frequency reuse factor.

**Index Terms** – Indoor wireless communication, DAS, co-channel interference, frequency reuse factor.

**I. Introduction**

Future wireless communication systems are expected to provide high data rate transmission in indoor environments such as office buildings, warehouses and factories. Recently, the transmission of wireless data has been growing fast and the mobile communications industry expect that wireless high data rate services will form the foundation for future services. Although voice and low data rate services were the first applications for mobile users, the focus in recent years has shifted. Advancement in technologies and the need for wireless communications services offered by the service providers have led to an increased level of high data transmission in mobile applications.

Delivering a high speed wireless transmission for indoor environments is becoming a challenge in recent years. The indoor channel suffers from severe multipath fading, which seriously degrades the performance of the communication systems [1]. The modern high buildings can represent a harsh propagation environment because, the metallic structure of the building, metallic window shield and furniture can prove to be real reflectors and blockers of the signals. The penetration and propagation loss among floors is also present. However, for existing wireless communication it is a challenge to deliver high data rates transmission for indoor users because the distance between the outdoor base station and the user is too far. Therefore to cope with the future wireless transmission demand, the distance between the base station and indoor user should be shortened. An effective and feasible solution for this problem is the indoor distributed antenna systems (DASs) [2].

Indoor DASs have gained considerable attention, due to its capability to improve the coverage in indoor communications, and it also helps to increase the data rate transmission, spectral efficiency, and the diversity offered by the DAS can combat shadowing and fast fading. The DAS not only reduces transmit power, cover dead spots and provide macrodiversity of the large scale fading, but also have the capability to enhance signal quality, increase system capacity and reduce transmission distance [3, 4]. The DAS comprises a number of antennas that are spaced apart from one another. These antennas, called remote antenna units (RAUs) are separated and connected to a central unit (CU) via optical fibres or coaxial cables. In the proposed DAS in a high building environment, a number of neighboring floors are grouped together and are controlled by one CU. In this system, downlink transmission is considered where a CU transmits information to the user in the reference floor, the RAUs in the floor first receive the signal from the CU via optical fibres, and then forward it to the user via radio channels. Thus, multiple RAUs on the floor provide spatial diversity by sending the same data to the user.

Due to limited available spectrum, the same spectrum can be vertically reused among floors controlled by different CUs. However, co-channel interference will exist among the floors using the same spectrum.

In high buildings, it has been demonstrated that the radio signal propagates among the floors and can reach the other floors. According to measurements results [5, 6], the radio signal reaching the other floors can be strong in some circumstances.

Indoor DAS has not been investigated yet in high buildings, although some propagation measurements have been presented for the indoor environments. A vertical spectrum reuse among floors in a building was presented in [7] by evaluating the outage probability. However, only one BS with one antenna unit was considered for each floor and the bit error rate (BER) performance was not evaluated. In the work presented in [8], the spectrum efficiency in high buildings based on the position of the base station has been presented. However, the vertical frequency reuse of DAS in a high building has not yet been studied. In this paper, mathematical channel model based on measurements results has been proposed for high building environments, the indoor DAS has been investigated in terms of BER performance.

The influence of the position of the user in the reference floor
on system performance is theoretically analysed. For a given BER performance like in [9]-[22], since floor attenuation varies for different buildings, conclusions are drawn for various values of the attenuation factor introduced by the floor separation.

II. SYSTEM MODEL

The downlink transmission of the DAS is shown in Fig. 1, where there are $L$ floors in the building. Each floor has $N$ RAUs and every $L'$ floors are controlled by one CU. $F$ is the frequency reuse factor and is equal to $1/L'$. The entire building is served by $U$ CUs and $L = L' \cdot U$ and there are $N \cdot L'$ RAUs within the coverage of each CU. Since the interference can be ignored after five floor separation between the transmitter and the receiver in high buildings [6], the total number of floors in the building does not affect the analysis results. In this analysis the case of a general building has been considered and the number of floors in the building is not fixed.

Considering a reference user located within the coverage of the $u$th CU in the building, the complex representation of the binary phase shift keying (BPSK) signal from the RAU $u,n$ before weighting is expressed as

$$x_{u,n}(t) = \sqrt{P_s} e^{j2\pi f_c t} \sum_{j=-\infty}^{\infty} h_{u,n}(j) P(t - jT_S)$$

where $P_s$ is the transmit power, $f_c$ is the carrier frequency, $h_{u,n}(j)$ is the data of the $n$th RAU in the $u$th CU taking $\pm 1$ with equal probability, and $P(t)$ is pulse function defined as $P(t) = 1$ for $0 < t < T_S$ and $P(t) = 0$ otherwise.

The reference building is assumed to be surrounded by one building as indicated in Fig. 2, $d_j$ is the distance between the surrounding building and the reference building. The shape of the floor of the reference building is rectangular, where $a$ and $b$ are respectively the length and the width. For simple analysis, the RAUs are deployed along the length in the middle of the ceiling equidistant between each other. However, the RAUs can be deployed in different ways. In the reference floor, the vertical distance between the user and the floor is given by $d_z$. In high buildings when the transmitter and receiver are in two different floors, the signal generated by the transmitter can reach the receiver in other floors through internal direct path and external reflected path by the nearby building as shown in Fig. 2.

The radio propagation channel from RAU $u,n$ to the reference user in the $u$th CU can be described mathematically by its low pass equivalent impulse response, $h_{u,n,u'}(t)$ as

$$h_{u,n,u'}(t) = h_{u,n,u'}^d(t) + h_{u,n,u'}^r(t)$$

where $h_{u,n,u'}^d(t)$ and $h_{u,n,u'}^r(t)$ are respectively the direct and reflected components. These two components are uncorrelated [6].

![Fig. 1. Indoor downlink transmission in the DAS](image)
at the transmitter side by the following weighting factor
\[ \frac{\alpha_{u,n,R}}{\sqrt{\sum_{m=0}^{N-1} \alpha_{u,n,R,m}^2}} e^{-j\Theta_{u,n,R}}. \]

III. PERFORMANCE ANALYSIS

It is assumed that the reference user is located in the middle of the building that is served by the \( U_R \) CU. In this case the user suffers from strong interference from the floors above and below.

The complex representation of the received signal \( R(t) \) at the reference user can be expressed as
\[ R(t) = \sum_{u=0}^{U-1} \sum_{n=0}^{N-1} X_{u,n}(t) \frac{\alpha_{u,n,R}}{\sqrt{\sum_{m=0}^{N-1} \alpha_{u,n,R,m}^2}} e^{-j\Theta_{u,n,R}} \otimes h_{u,n}(t) + \eta_r(t) \]

where \( \otimes \) stands for convolution operation and \( \eta_r(t) \) is the additive white Gaussian noise (AWGN).

The complex representation of the demodulated signal is given by
\[ Y = \frac{1}{T_S} \int R(t)e^{-j2\pi f_c s} dt = S + I + \eta \]

where \( \eta \) is the noise term and \( S \) is the desired signal component from the reference floor, given by
\[ S = \sum_{n=0}^{N-1} S_n \]

where \( S_n \) is the desired signal received from the \( n \)th RAU in the same floor.

By substituting \( S_n \) in (7) with (8), the total desired received signal \( S \) from the RAUs in the same floor can be written as
\[ S = \sqrt{P_S b_{1,0}^{(0)}} \frac{\left( \alpha_{u,n,R} \right)^2}{\sqrt{\sum_{m=0}^{N-1} \left( \alpha_{u,n,R,m}^2 \right)^2}} \left( d_{u,n,R}^2 \right)^{1/2} \]

where \( b_{1,0}^{(0)} = b_{0,0}^{(0)} = b_{1,0}^{(0)} \), the data transmitted by the RAUs to the user in the same floor are the same.

By substituting \( S_n \) in (7) with (8), the total desired received signal \( S \) from the RAUs in the same floor can be written as
\[ S = \sqrt{P_S b_{1,0}^{(0)}} \frac{\left( \sum_{m=0}^{N-1} \left( \alpha_{u,n,R,m}^2 \right)^2 \right)^{1/2}}{\left( \sum_{m=0}^{N-1} \left( \alpha_{u,n,R,m}^2 \right)^2 \right)^{1/2}} \]

In (6) \( I \) is the complex representation of co-channel interference from the other floors, given by
\[ I = \sum_{u=0}^{U-1} \sum_{n=0}^{N-1} I_{u,n} \]

where \( I_{u,n} \) is the interference from the RAU \( u,n \) in the \( n \)th floor. When there is a large number of RAUs in each CU and there are many interfering floors, the number of \( I_{u,n} \) terms becomes large, according to the central limit theorem (CLT) the total interference \( I \) can be approximated as a Gaussian RV.

The received signal to interference plus noise ratio (SINR) at the reference CU can be derived as follows,
\[ \gamma(S) = \frac{S^2}{\sigma_i^2 + \sigma^2} \]

where \( \sigma^2 \) is the variance of the noise.

Since channel fading factor \( \alpha_{u,n,R} \) is Rayleigh distributed, \( (\alpha_{u,n,R})^2 \) is chi-square distributed with two degrees of freedom (i.e., exponentially distributed). The instantaneous SINR is a sum of exponentially distributed RVs. The probability density function (PDF) of \( \gamma \) is given by equation (14.5-26) in [9], which can be expressed
\[ f_\gamma(\gamma) = \sum_{n=0}^{N-1} \pi_n e^{-\gamma/\beta_n} \]

where \( \beta_n \) is average of \( \gamma \) given by
\[ \beta_n = \frac{p_S \left( d_{u,n,R}^2 \right)^2}{\sigma_i^2 + \sigma^2} \]

and
\[ \pi_n = \frac{1}{\beta_n - \beta_{n-1}} \]

For a given \( S \), the conditional error probability of BPSK symbol can be expressed as follows
\[ P_e(S) = Q(\sqrt{2\gamma(S)}) \]

where \( Q(\cdot) \) is the Q(.) function.

The conditional error probability is given by
\[ P_e = \int_{0}^{\infty} P_e(S)f_\gamma(\gamma)d\gamma. \]
\[
\sum \int \sum = \int_0^{\infty} O(2^{27}) \sum_{n=0}^{\infty} \frac{\pi}{\beta_n} e^{-\gamma/\beta_n} d\gamma = \frac{1}{2} \sum_{n=0}^{\infty} \frac{\pi}{\beta_n} \left( 1 - \sqrt{\frac{1}{1 + \beta_n}} \right)
\]

(17)

IV. NUMERICAL RESULTS

In this section, the effect of the position of the user in the reference floor and the attenuation introduced by the floor separation on the BER performance are presented. The values of these parameters are shown in table 1 unless noted otherwise.

Table 1 – The values of the parameters used in the DAS

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(d_0)</td>
<td>2.5m</td>
<td>(\phi_{soft})</td>
<td>-8dB</td>
</tr>
<tr>
<td>(d_1)</td>
<td>20m</td>
<td>(\phi_{glass})</td>
<td>-0.26dB</td>
</tr>
<tr>
<td>(d_2)</td>
<td>0.8m</td>
<td>(\phi_{floor})</td>
<td>-10dB</td>
</tr>
<tr>
<td>(a)</td>
<td>20m</td>
<td>(N)</td>
<td>3 RAUs</td>
</tr>
<tr>
<td>(b)</td>
<td>15m</td>
<td>(L')</td>
<td>2 floors</td>
</tr>
<tr>
<td>(U)</td>
<td>7 CUs</td>
<td>(\lambda)</td>
<td>2.7</td>
</tr>
</tbody>
</table>

In Fig. 3, the effect of the position of the reference user on the floor is evaluated. The BER is plotted for three positions of the user on the floor. The shape of the floor is assumed to be rectangular and the user can move around the floor. The first position is the middle of the floor which means that the user is at the diagonal cross point of the rectangle. In this case, the distances between the desired RAUs and the user in the reference floor are relatively short, therefore the received SNR is high and the performance is good as Fig. 3 indicates. Furthermore, the signal received from the reflected path of the co-channel interference is significantly attenuated due to the path loss introduced between the outer edge and the middle of the floor. However, when the user is at the inner or outer edge of the floor, most distances between the RAUs and the user are relatively large compared to the previous case. As shown in the figure, the performance degrades. When the user is at the outer edge, the reflected path of the co-channel interference is strong due to the shorter distance between the user and the nearby building, this position has the worst performance compared to the other positions.

The attenuation introduced by the floor separation can vary between buildings, this attenuation depends on the building materials of the floor separation. If the floor separation is made of reinforced concrete or precast slab floors the attenuation introduced by the floor separation is 10 to 13dB. However, if the floor separation is made by concrete over corrugated steel the attenuation can be 25 dB per floor. From Fig. 4, the effect of the attenuation introduced by the floor separation on the BER performance is presented for a received SNR equal to 15dB. For a given performance such as BER < 10^{-3}, the frequency reuse factor can be one if the attenuation introduced by the floor separation is high such as 19dB. However, frequency reuse factor of 1/3 or 1/4 suffices for acceptable BER performance in any buildings.

![Fig. 3. The effect of the position of the user in the reference floor](image)

![Fig. 4. Effect of the attenuation introduced by the floor separation](image)

V. CONCLUSION

In this paper, DAS system is studied in high buildings. Several floors are covered by one CU. The frequency can be reused between the CUs. According to numerical results, the following has been concluded,

1) The position of the user on the floor has a significant effect on the BER. The distances between the user and the RAUs in the same floor has a significant effect on
the performance and the interference can be strong when the user is close to the outer edge position.

2) Significant effect of the building characteristics on the BER performance is illustrated. Different building materials of the floor separation attenuate the radio signal differently. The building materials have a significant effect on the propagation characteristic among floors. This has a direct effect on the planning of the number of floors in each CU. It is illustrated that to have an acceptable performance, e.g. BER<10^3 in a building, the number of floors should be at least three in each CU.

REFERENCES


