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Distributed Antenna Systems Aspects and Deployment

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Abstract— **A lot of schemes are proposed to exploit the transmit diversity. Distributed antenna systems (DAS) constitute one of the most attractive schemes to efficiently achieve the stringent quality of service demands of next generation wireless networks. In this paper, we investigated MISO assisted different transmission techniques used in DAS and the performance of downlink multi-cell DAS in terms of capacity improvement using SINR for different transmission scheme. A system level simulation tool is used to analyze the performance.**

Keywords-DAS, MIMO, MISO, Simulation

I. INTRODUCTION

Future wireless systems will need to provide high data rates to a large number of users. Experience shows that these networks will be interference-limited, since the interference from either in-cell users or from other-cell users will determine how heavily the system can be loaded. Among the most relevant signal processing schemes that will help wireless networks achieve future data rate requirements we find those based on multiple antenna transceivers, which are commonly known as MIMO (multiple-input multiple - output) systems [1]. The basic idea behind MIMO systems is to exploit the diversity provided by their spaced antenna elements in order to improve either the decoding or the multiplexing gain [1].

MIMO systems, however, may face limited success in current mobile networks due to terminal size constraints, particularly in the downlink. As an answer to this, the area of distributed antennas systems (DAS) ([2][3][4]) has recently received special attention since the spatial diversity gain is achieved by geographically distributed nodes interconnected by highly reliable links such as optical fiber, thus acting as a macroscopic multi-antenna system. DAS systems have been conventionally studied as coverage improvement schemes (e.g. in [2]), or as a means to improve the capacity of both the downlink and uplink of CDMA (Code Division Multiple Access) single-cell systems (e.g. [3]), and for the analysis of downlink single-user multi-cell systems (e.g. [4]).

In a radio communication system, MISO refers to links for which the transmitting end with multiple Antennas and the receiving end is equipped with single antenna elements. The idea behind MISO is that the signals on the transmit antennas at one end and the receive antennas at the other end are “combined” in such a way that the quality (bit-error rate or block error rate BER/BLER) or the data rate (bits/sec) of the communication for each MISO user will be improved. In this study we integrated the MISO principles into the distributed antenna cellular systems.

Multiuser receivers are one potential way to reduce interference in cellular systems [5]. This requires a more complicated receiver. An alternative strategy is to try to reduce the overall transmit power (and hence other-cell interference) using distributed antennas, which has the additional merit of providing better coverage and increasing battery life [6]. Although distributed antennas systems (DAS) were originally introduced to simply cover the dead spots in indoor wireless communications[7], recent studies have identified other potential advantages such as power and system capacity, and expanded its applications([8][9][10][11][12]) .

The objective of this paper is to use system level simulation tools in the performance analysis and optimization of the downlink of DAS systems in multi-cell environments. The performance analysis is first carried out using a simplified system level simulation tool that allows the understanding of the basic relationships that rule a distributed antenna system. The results and the learning experiences from these preliminary simulation results are then employed in the setup of a complete system level simulator called MOTION, which has been especially designed for the validation of third generation and beyond 3G radio access technologies. A brief overview of the simulation tool, the modeling methodology and the network configuration used for distributed antenna systems is also presented.

This paper is organized as follows. Section II describes the Distributed Antenna System architecture. Section III describes the transmission strategy. After this Section IV presents the channel model for DAS, and section V describes the performance analysis. Section VI describes the complete system level simulation tool and its configuration for the analysis of DAS, while Section VII shows results for the

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chosen configuration. Finally, Section VIII draws concluding remarks.

II. DAS ARCHITECTURE

In DAS, the main processing modules such as channel cards are centralized at a location (central unit) and are connected with distributed antenna modules. Each distributed antenna module is physically connected with a home base station via dedicated wires, fiber optics, or an exclusive RF link. A general architecture of DAS in a one-cell environment is given in Figure 1, where a cell is covered by a small base station and six distributed antenna modules. In contrast, the same area is covered by only a single high-power base station in traditional cellular systems.

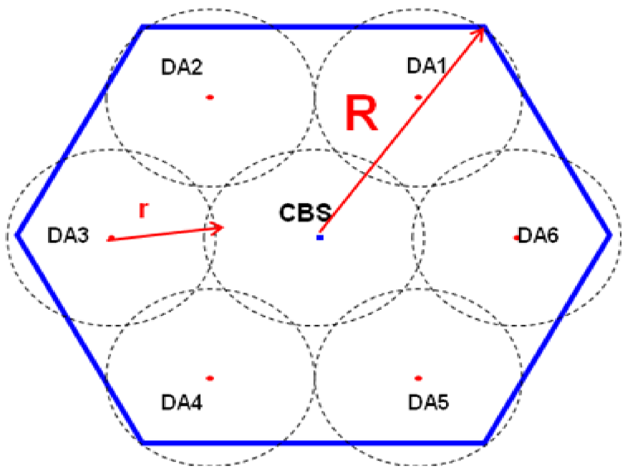

Figure 1: Structure of DAS in one CELL

Figure 2 shows the architecture of 1-tier cellular structure with universal frequency reuse, where a given cell is surrounded by one continuous tier of six cells.

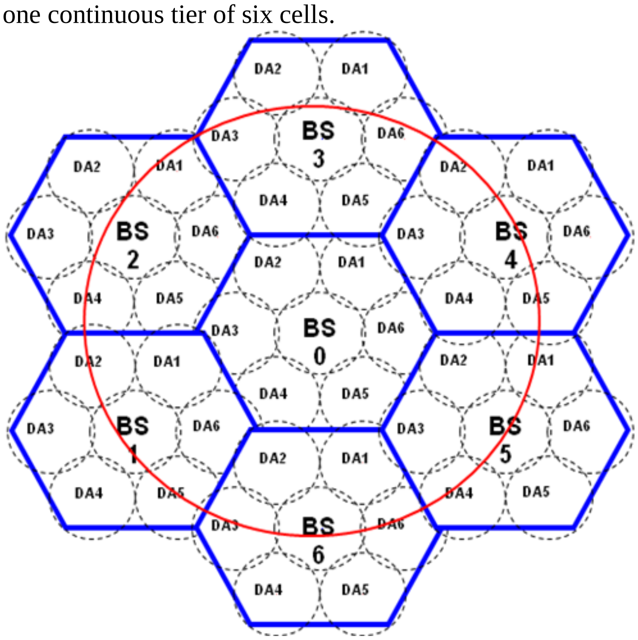

Figure 2: Structure of a DAS in 1-tier

Alternatively, the Central base station and 6 distributed antenna modules can be viewed as an alternative to 7 small traditional base stations (pico/micro cells). The actual number of distributed antenna modules would be determined by coverage, user densities, and other environmental factors but we only consider 6 distributed antenna modules as a reasonable example. The total transmit power of the ith distributed antenna module of the jth cell is P_i^j, where the small base station of each cell and and the distributed antennas are indexed by i=0 and j = 0, respectively.

Throughout this paper, we assume that $\sum_{i=0}^{6}\sum_{j=0}^{6} P_i^j = P$, where P is the total transmit power of the conventional base station for a fair comparison. In Figure 1, polar (r, θ) coordinates are employed and the location of the base station 0 corresponds to the origin of the coordinates. The radius of a cell is R and the radius of coverage of a distributed antenna module is r.

Although this assumption of only 1-tier of interfering cells is optimistic, a pessimistic assumption that all the distributed antenna modules and the base stations are transmitting full power all the time easily compensates.

III. TRANSMISSION STRATEGY

In cellular DAS, there are several possible transmission strategies using multiple distributed antenna modules. Either all or some of the antenna modules can be used in transmission. Although many methods of using the distributed antenna modules are possible, we consider three likely transmission strategies: the blanket transmission scheme, single transmit selection scheme, and dual transmit selection scheme [4].

A. Single Transmission Scheme

In the single transmit selection scheme, the mobile terminal connected to the single remote antenna unit whose channel (between the mobile and remote antenna) has the least pathloss. In conventional scenario we have no option to select more than one base station.

B. Dual Transmission Scheme

In the dual transmit site selection, the mobile terminal connected to the two remote antenna units whose channels (between the mobile and remote antenna) with the minimum propagation pathloss.

C. Blanket Transmission Scheme

The mobile terminal connected to all remote antenna units where they transmit the same signal to the terminal inside the cell. Therefore, the distributed antenna modules construct a macroscopic multiple antenna system.

The assumption of the above transmission schemes holds for most practical multiuser systems. Because time division multiple access (TDMA), frequency division multiple access (FDMA), orthogonal code division multiple access (CDMA), and orthogonal frequency division multiple access (OFDMA) systems basically correspond to these transmission strategies [4].

IV. CHANNEL MODEL AND POWER FORMULATION

We consider MISO (Multiple Input Single Output) channel model for Blanket transmission implementation. MISO is used here because of mobile can receive more than one signal from different DAS, but it transmits only one. When the blanket transmission scheme is used, the multiple distributed antenna modules and the home base station together construct a macroscopic MISO vector channel.

Let the transmitted signal vector be $x=\left[x_0 x_1 \dots x_6\right]^T$,where x_i is the transmitted signal from the *i*th distributed antenna module. we calculated received signal y (t) using multipath

$$y(t) = \sum_{i=0}^{6} \sqrt{L_i} \sum_{k=0}^{2} h_i^k x(t)$$, where

i = number of Distributed Antenna

k = number of path

L_i = Propagation pathloss and shadowing from the distributed antenna.

h_i^k = fastfading from the ith distributed antenna through kth path.

Therefore, the received power of the central cell (cell ID 0)

$$P_y = \left(\sum_{i=0}^{6} \sqrt{L_i} \sum_{k=0}^{2} h_i^k x(t) \right)^2 = \sum_{i=0}^{6} L_i \left(\sum_{k=0}^{2} h_i^k \right)^2 P_X$$

Since $\left(\sum x(t)\right)^2 = P_X$ i.e., transmitted power.

After generalizing $\sum_{k=0}^{2} \left| h_i^k \right| = \left| h_{eq_i} \right|$ the received power is

$$P_y = \sum_{i=0}^{6} L_i \left| h_{eq_i} \right|^2 P_x .$$

Finally, we get total Received Power with considering Interference plus noise for 1-tier:

$$P_{Total} = \sum_{i=0}^{6} L_i \left| h_{eq_i} \right|^2 P_X + \sum_{j=1}^{6} \sum_{i=0}^{6} L_i^j \left| h_i^j \right|^2 P_{X_i}^j + n$$

, where n is the additive Gaussian noise with variance $\mathrm{E}\left[nn^H\right] = \sigma_n^2$

i = number of Distributed Antenna and

j = number of Cell (1…6 i.e. 6 adjacent cells in first tier)

For simplicity of analysis, we assume that the transmit power of each distributed antenna module and the home base station in DAS is P/7 whereas the transmit power of the base station in the traditional cellular system is P

V. PERFORMANCE ANALYSIS

At first we deal with the performance of power and then SINR experienced by the users under the transmission schemes to be studied.

A. *Power Efficiency*

Power efficiency is computed by comparing the required power for supporting the coverage area of a single cell, and is calculated based on propagation pathloss. In the distributed antenna architecture given in Figure 2, the area covered by a small base station and 6 distributed antenna modules is $(3\pi+6\sqrt{3})r^2 (= 7\pi r^2 - 24(\sqrt{(12\sqrt{3}/\pi} - 1))$ **[4].** Then, the radius of a circle with the same area becomes $r\sqrt{(12\sqrt{3}/\pi} - 1)$ For a fair comparison, we regard this circle as the effective coverage of a high-power base station in a traditional cellular system instead of the bold dotted circle in Figure 2.

Let the required transmit power for each distributed antenna module and the small base station to support the circular area with radius r be P. Then, the total required power to support the effective coverage area is $7P$ in the distributed antenna structure, whereas that for the big base station with the same effective coverage area in the traditional cellular structure becomes $(12\sqrt{3}/\pi - 1)^{\alpha/2}P$ if the propagation pathloss is assumed to be $L = d^\alpha$ where α is the pathloss exponent.

Then, the power efficiency of the distributed antenna structure is given by

$$\eta = \frac{(12\sqrt{3}/\pi - 1)^{\alpha/2} P}{7P} = \frac{(12\sqrt{3}/\pi - 1)^{\alpha/2}}{7}$$

For the case that the path loss exponent α is 4, the power efficiency gain η is about 4.51(= 6.54dB). This result shows that a distributed antenna structure requires much less power to support the same coverage area.

B. *Signal-to-interference-plus-noise ratio (SINR)*

The distributed antenna structure can reduce OCI and improve SINR in downlink by increasing the received strength of the desired signal and reducing the power of the received interference. Since the outage-limiting scenario in cellular networks is usually a mobile station at the cell boundary, maintaining the SINR of the users near cell boundaries above a given level is particularly important [13].

The same uncoded data is transmitted through multiple antenna modules. For a fair comparison with the traditional cellular structure, we also assume that the transmit power of each distributed antenna module and the central base station is equivalent to *P*, for a total transmit power of *P* in both the distributed antenna structure and the traditional cell structure.
For a given location of the target mobile station, the expected SINR over fastfading for blanket transmission scheme is given by

$$SINR = \frac{\sum_{i=0}^{6} L_i \left| h_{eqi} \right|^2 P_x}{\sum_{j=1}^{6} \sum_{i-0}^{6} L_i^j \left| h_i^j \right|^2 P_{x_i}^j + n}$$

VI. THE SYSTEM LEVEL SIMULATION TOOL

A system level simulation tool is a piece of software which aims to recreate as accurately as possible all the stochastic processes, management algorithms and/or dynamic control mechanisms that are relevant for an appropriate analysis and performance measurement of predefined metrics of any type of system or network. This tool gives the researcher a proven, cost-effective research capability of a system.

A. MOTION: An Overviewof the system level tool

MOTION is a system level simulation tool which has been initially designed for the simulation of beyond 3G (third generation) mobile communication systems. However, the design has evolved to include the possibility of simulating any type of wireless communication network. This has been achieved by using the modular approach of object programming oriented design and analysis. Hence, every object contains all information and functions that correspond to its functionality, and which also maps to real-life objects found in wireless systems. The MOTION tool has been designed, updated and refined under several European projects.

The main advantage of the MOTION tool architecture is that it differentiates between functionalities related to the particular radio access technology such as look up tables of the physical layer schemes, channel models, interference models, resource allocation and packet scheduling algorithms, and those functionalities non-related to a particular radio access technology such as services and traffic models (www-wireless world web-, ftp -file transfer protocol- and NRTV -non-real time video-), base station deployments (cellular hexagonal, Manhattan, etc), mobility models and the assumptions about the user distributions. This flexibility allows the deployment of the characteristics of several radio access technologies by reusing RAT-independent features. The current radio access technologies supported are HSDPA (High Speed Downlink Packet Access), WiMAX and MC-CDMA (multicarrier code division multiple access) all using hexagonal cell deployments.

VII. SIMULATION RESULTS

This section represents the results for the simulation of a WiMAX network with distributed antenna systems .The antenna radiation pattern has been considered using the data from [14] and the user deployment model has been considered to be random and uniformly distributed. The channel model, pathloss and interference models have been set up according to the guidelines of the WINNER project, while the traffic used is an on-off non-real time video model for 64 Kbps services.

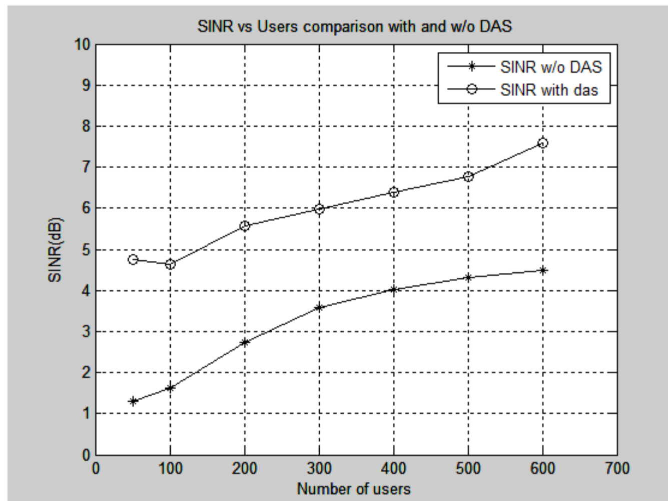

Figure 3: Improvement of SINR using DAS

Simulation scenarios have been given in Table1

TABLE I. SIMULATION SCENARAIO

Parameter	**Input**
Cellular Layout	Omni-directional
Simulation Type	Combined Snapshot Mode
Tier	One
Number of Simulation Run	10
Mobile Users	50……500
Cell radius	933 meters
DAS Radius	311 meters
System used	WiMAX-OFDM
Environment	Urban
Channel	MISO
Fading	Fast fading (Jakes Power Model
Cell Type	Omni
No. of Cell in One Super Cell	7
Traffic Model	Non-real time video

Packet Scheduling	Maximum throughput C/I

The first metric used for the performance analysis is called over-the air throughput(OTA) that accounts for the number of bits transmitted over the network divided by the time required to be transmitted. Blanket and single transmission schemes have been tested and their results are shown in Fig. 4. Note that, the results agree with those the SINR formula obtained in previous sections of this paper thus confirming the advantages of distributed antenna systems in the achievement of the stringent quality of service requirements of next generation networks.

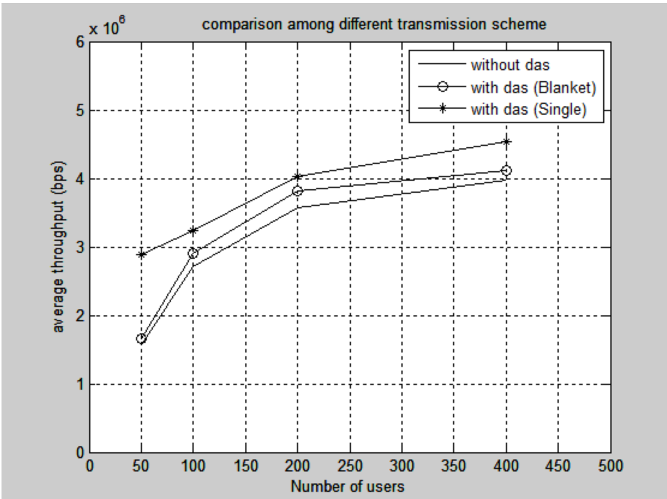

Figure 4: OTA throughput for a WiMAX system using DAS scenario using different MISO transmission strategies

Fig.3 shows the performance improvement of cellular network using DAS. We have acquired a pragmatic result from the simulation in terms of throughput.

The second metric used for the performance analysis is called Service throughput that accounts for the number correct of bits transmitted over the network divided by the time required to be transmitted. Blanket transmission scheme has been tested and their results are shown in Fig. 5. Note that the results agree with those obtained in previous sections of this paper thus confirming the advantages of distributed antenna systems in the achievement of the stringent quality of service requirements of next generation networks.

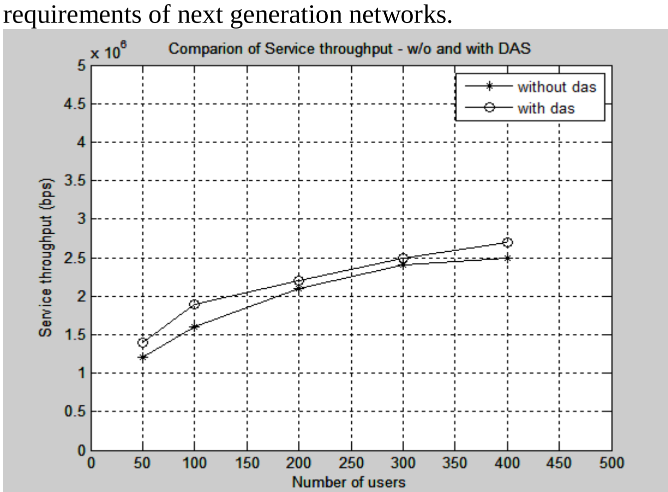

Figure 5: Average Service throughput vs. Number of Mobiles

Fig.4 shows the performance improvement of cellular network using DAS. We have acquired a pragmatic result from the simulation in terms of throughput.

Last but not least we use the metric called spectral efficiency. The spectral efficiency of the system is the ratio of the system capacity, (nominal total information rate supported by the hosting network) to the total amount of spectrum used by the system, i.e., system capacity per unit bandwidth. Blanket transmission scheme has been tested and their results are shown in Fig.6. Figure 5 shows us the improvement of the system using DAS.

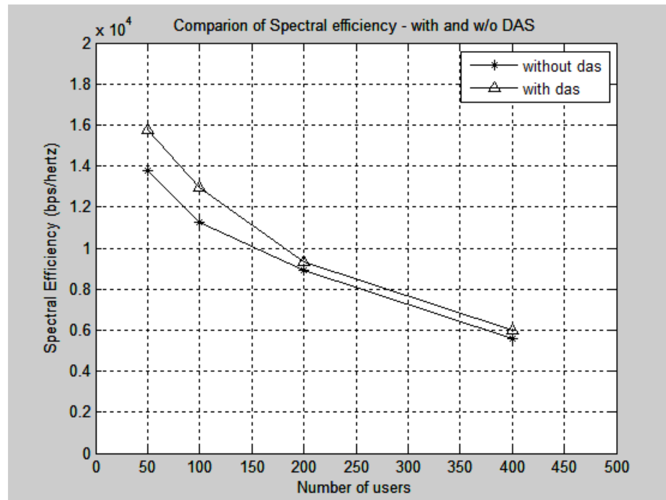

Figure 6: Spectral Efficiency under DAS Scenario

VIII. CONCLUDING REMARKS

In this paper, the architectural advantages of downlink DAS in a multicell environment have been investigated in terms of power efficiency, capacity improvement using SINR formulation in terms of mobile user. We have also analyzed transmit diversity performance and achievable gain of different transmission schemes. The results of this paper suggest that distributed antenna systems effectively reduce OCI and improve SINR compared to conventional cellular systems in an interference-limited multicell environment. The distributed antenna environment might be an effective solution to reduce OCI in an interference-limited cellular environment.

This paper has also presented a study by means of simulations of the downlink performance of distributed antenna systems under the assumptions of multicell and multiuser environments with different buffer occupancy .The results confirm that DAS significantly improve the performance of conventional cellular network architectures and that in combination with appropriate radio resource management schemes that consider adaptation of physical and link layer parameters then further improvement can be achieved. The results were validated in a system level simulator especially designed for the proof of concept of 3G and B3G radio access technologies.

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