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Enhancing Cell Edge Performance in Cellular Mobile System

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Abstract

Cell edge effect has been recently paid much attention in the development of new mobile communication systems because it can cause serious performance degradation in the cell edge. The cell edge problem is essentially due to non-uniform distribution of the radio power of cellular systems. It can be softened to a certain extent by using new radio architecture called distributed antenna system (DAS). In traditional collocated antenna system (CAS), multiple antennas are centrally located at the BSs, while in the DAS, multiple antennas of BS called remote antenna unit (RAUs) are separately and remotely located in a cell and connected to a baseband processing unit (BPU) via high speed backbone links. Since the distance between the mobile terminals (MTs) and the antenna of the BS is greatly reduced by introducing RAUs, the large path loss of the radio signals can be avoided. The objective is to tackle the shortcomings due to the cell edge effects in a cellular system by suitably changing the existing collocated antenna system (CAS) to a distributed antenna system (DAS) and to compare its performance. The performance analysis namely bit error rate (BER) and capacity were performed and the results are shown. It is inferred from the results that the proposed DAS scheme outperforms the existing CAS scheme.

Keywords: *Collocated antenna system, Distributed antenna system, MIMO*

1. Introduction

Next-generation mobile communication systems will provide very high data rates and mass wireless access service for broad area coverage. The data rate of mobile communication services has increased by about 100 times every six to seven years [11]. Correspondingly, with the development of advanced mobile communication techniques, the spectral efficiency of commercial mobile communications must be increased by about 10 times in 6 to 7 years, from the current 0.5–2.5 b/Hz to 5–20 b/Hz. The increase of spectral efficiency using current technologies cannot satisfy the increasing requirements in high data rates.

With increasing demands for various data and multimedia services [12], future mobile communication systems should be able to provide very high data rates and mass wireless access services over a limited spectrum bandwidth. Some advanced radio transmission techniques, including multiple-input-multiple-output (MIMO) and orthogonal frequency division multiplex (OFDM) have been proposed to improve the spectrum efficiency of mobile cellular systems. However, spectrum efficiency at the cell edge is usually very poor.

The cell edge problem is essentially due to the non-uniform distribution of the radio power of cellular systems. For the traditional cellular architecture, a single or multiple antennas of a base station (BS) are collocated at the center of a cell. Since the received power of a radio signal decays exponentially with the propagation distance, the mobile terminals (MTs) at the cell edge experience large path loss. The spectrum efficiency at the cell edge is usually much less than unities, even if some advanced transmission

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techniques like MIMO-OFDM is applied. The cell edge problem will be very serious in future mobile communications, because radio frequency higher than 2 GHz will be exploited.

When applying MIMO techniques to the traditional mobile network, the multiple antennas of a radio base station (BS) are geometrically collocated. Since the power of a radio signal exponentially decreases with increasing distance between a BS and its mobile terminals (MTs), a serious cell edge problem is caused. The MTs near the BS can achieve higher data rates, whereas the MTs on the cell edge can only get a lower data rate service, which significantly deteriorates the user's satisfaction with mobile communication services. Therefore, efficient allocation of the transmit power over the coverage area is necessary by introducing the MIMO technologies into new radio network architectures, especially for future mobile communication systems working at frequencies higher than 2 GHz where the cell edge effect becomes more serious due to the larger attenuation of the radio signal.

The cell edge problem can be softened to a certain extent by using some new radio network architectures. The distributed antenna system (DAS) has emerged as a promising architecture for future mobile communications, due to its advantages in improving system coverage and mitigating the cell edge problem. In the DAS, multiple antennas of a BS, called remote antenna units (RAUs), are separately and remotely located in a cell and connected to a baseband processing unit (BPU) via high-speed backbone links, e.g. radio over fiber or microwave repeater. Since the distance between the MTs and the antennas of the BS is greatly reduced by introducing the RAUs, the large path loss of the radio signals can be avoided.

2. Overview of Distributed Antenna System

At the beginning, distributed antenna system (DAS) was simply introduced to improve the coverage for indoor radio. In the indoor environment, distributed antenna can cover the dead region easily. The antenna deployment cost is cheap, because the length of the wire connecting the distributed antennas is short and the size of antenna module is little. In the outdoor environment, the antenna deployment cost is expensive at that time, due to the materials science limit.

In recent years, the technology improvement is fast. The high cost problem of antenna deployment is basically solved by cheaper, faster wire such as optical fiber. For this reason, the concept of distributed antenna is introduced in the recent researches for the outdoor environment. The definition of distributed antenna system is as follows: The antenna modules are distributed in the cell, and are connected to the base station or central unit via dedicated wires, optical fibers, or radio frequency link. An antenna module consists of power amplifier, transceiver.In practice, the antenna module should be a low cost equipment. The distributed antenna system can improve the coverage, increase system capacity, improve trunking efficiency, reduce the maintenance difficulty and have lower power consumption.

In traditional collocated antenna system (CAS) also known as collocated MIMO, a single or multiple antennas of a base station (BS) are collocated at the center of a cell. Single antenna system or Single-input single-output (SISO) require both the transmitter and receiver of communication link to be equipped with single antenna. Multiple antenna system or MIMO, require both the transmitter and receiver of communication link to be equipped with multiple antennas. Some of the advantages of DAS include ease of planning, maximum coverage, and minimum radiated power, enhanced outage capacity, reduced interference and increased capacity.

The deployment of DAS can be done in two ways.

1. Random antenna location
2. Fixed antenna location

2.1. DAS with Random Antenna Locations

The original form of DAS has a bus-type antenna configuration (BDAS) and consists of omni-directional transmit/receive antennas of street lamp height with minimum complexity that are scattered around the region of interest.

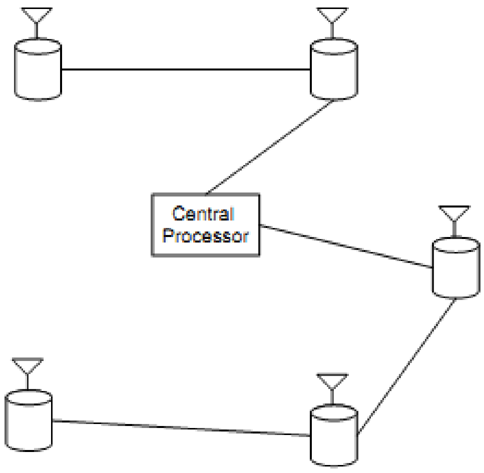

Figure 1. Bus Type DAS (BDAS)

Many commercial products are of this type, whose main purpose is to cover dead spots within the cell. Bus-type of topology is not suitable for high speed transmission due to many antenna elements sharing the same wire will consume huge bandwidth and more delay.

In order to overcome this shortcoming with the common feeder, sectorized DAS (SDAS) is proposed, where each distributed antenna module has a separate feeder to and from the control unit so that coherent diversity and interference reduction techniques can be implemented. Generalized DAS (GDAS) is based on SDAS. The most difference between SDAS and GDAS is that each antenna element of SDAS is equipped with only one antenna whereas the antenna element of GDAS can be equipped with more than one antenna. This multiple antennas in an antenna element property have the potential for supporting MIMO technique much more efficiently than SDAS or BDAS. GDAS have better outage performance than BDAS or SDAS.

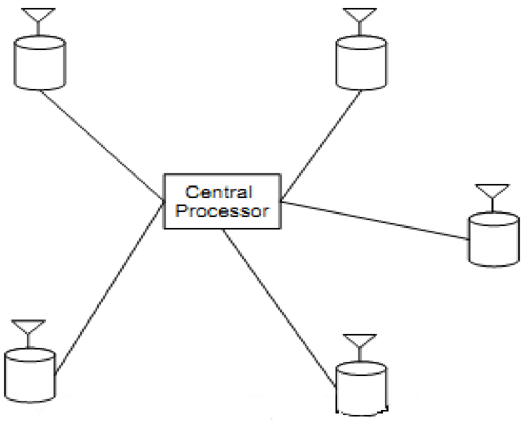

Figure 2. Sectorized Das (Sdas)

2.2. DAS with Fixed Antenna Locations

In practice, randomly located distributed system might not achieve the optimal system performance. To solve this problem, the position of antenna should be optimally fixed. Figure 3 illustrate fixed antenna deployment. Deploying antennas with this pattern can enhance the coverage of system, line of sight (LOS) transmission and shorter transmission distance. This antenna deployment can reduce transmission power efficiently. In the other words, the inter-cell interference is mitigated, if the system parameters are coordinated properly, the system has the potential of higher throughput.

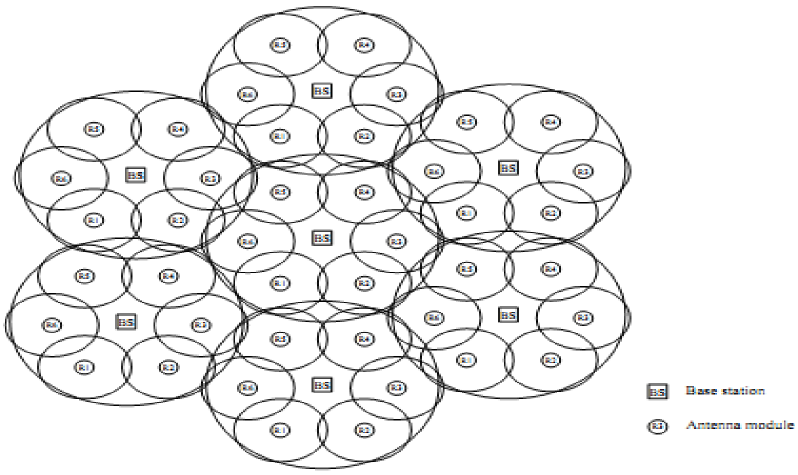

Figure 3. Deployment of Fixed Antenna Location

2.3. DAS System Configuration

The system configuration of DAS is illustrated in figure 4.It consist of

i. Baseband processing unit(BPU)
ii. Remote antenna unit(RAU)
iii. High speed backbone link

The baseband processing unit (BPU) is also known as central unit (CU) and remote antenna unit (RAU) is also known as distributed antenna module. In DAS, distributed antenna modules are geographically distributed to reduce access distance instead of centralizing at a location. Each distributed antenna module is connected to a baseband processing unit (or central unit) via dedicated wires, fiber optics, or an exclusive RF link. DAS is rather similar to repeater systems from the fact that the distributed antenna modules and the home base station are physically connected. However, DAS is distinguished from conventional repeater system by the fact that each distributed antenna module is able to transmit different data in the downlink whereas repeaters just repeat signals from the home base station. Therefore, DAS is a generalization of conventional repeater systems. From an architectural point-of-view, DAS has manifest advantages over conventional communication systems. DAS can reduce the cost of installing system and simplify maintenance because DAS can reduce the required number of base stations within a target service area. Furthermore, blocking probability can be improved owing to the principle of trunking efficiency because resources for signal processing such as channel cards/elements are centralized and shared at the home base station (or central unit). In addition to these architectural advantages, DAS also have advantages in terms of power, signal-to-interference-plus-noise ratio (SINR), and capacity owing to macro diversity and the reduced access distance. Based on these advantages, many cellular service providers or system manufacturers are seriously considering replacing legacy cellular systems with distributed antenna systems or adopting the distributed antenna architecture.

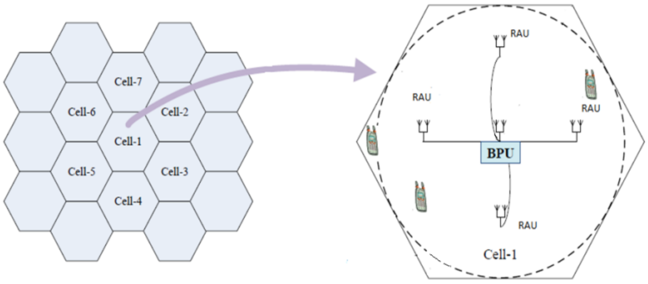

Figure 4. Das System Configuration

Because of the scarcity of frequency resource and the increasing demand for data rate, next generation cellular systems will adopt a very low frequency reuse factor. For these systems, interference is an important issue since the same frequency is used everywhere. Joint processing is one of the most efficient methods to combat interference. However this technique requires a large number of spatial degrees of freedom (or observations). For that reason distributed antenna systems provide a competitive solution to mitigate interference in single frequency reuse deployments. Two main architectures are being proposed for DAS: distributed and centralized. The distributed topology relies on the legacy cellular architecture where standalone base-stations communicate together in order to mitigate interference. This approach requires a very high speed digital backhaul. On the countrary, centralized topology relies on a central unit (CU) which is connected to a large number of non-collocated remote antenna units. The connection between the CU and the RAUs can be of different types: outband radio link, dedicated cables, digital optical network or radio-over fiber. In uplink context, interference can be mitigated using joint processing in the central unit. However in the downlink, different methods are possible. The interference can be pre-cancelled by the central unit using linear or non-linear precoding. This approach requires channel feedback from the MT to the CU. In practice, residual interference occurs because of the channel estimation errors and the limited rate on the feedback link. In another approach the interference can be cancelled by the user equipment using additional information provided by the central unit.

3. Related Work

Effects of fading correlations in multi element antenna (MEA) communication systems are investigated by Da-Shan Shiu, Gerard J. Foschini, Michael J. Gans and Joseph M. Kahn [1]. The investigated results showed that the transmit and receive antenna elements are independently, identically distributed. MEA’s offer a large increase in capacity compared to single-antenna systems.

Roh and Arogyaswami Paulraj [20] investigate the performance of distributed antenna systems (DAS) consisting of multiple ports and multiple antennas employing various combining schemes in a flat composite fading channel. Sectorised DAS and generalized DAS are discussed.

W. Roh and A. Paulraj [3] have investigated the channel capacity of MIMO generalized distributed antenna system (GDAS). In GDAS, multiple ports are essential to achieve high channel capacity in a composite fading channel both for the uplink and the downlink. Specifically, for the same number of total antennas involved, multiple ports always yield more capacity than multiple co-located antennas, especially in the outage region.

A. J. Paulraj, D.A. Gore, R.U. Nabar, and H.B olcskei [4] have provided an overview and the fundamentals of MIMO wireless technology covering channel models of MIMO, performance limits, coding, and transceiver design. The importance of MIMO for future mobile communication system is also discussed.

Zhengdao Wang, and Georgios B. Giannakis [5] derived an analytical expressions for the probability density function (pdf) of the random mutual information between transmitted and received vector signals of a random space-time independent and identically distributed multiple-input multiple-output (MIMO) channel, assuming that the transmitted signals from the multiple antennas are Gaussian.

N. Ngajikin N. N. Nik Abdul Malik, Mona Riza M. Esa,Sevia M. Idrus and Noorliza Ramli, [6] have presented the drawbacks in CDMA system, analyzed the performance of MIMO-CDMA and its performance is compared with conventional Code Division Multiple Access (CDMA) system. The performance metrics namely BER and channel capacity are analyzed and compared for both the system. The obtained result shows that MIMO -CDMA gives the best performance compared to conventional CDMA.

Wan Choi, and Jeffrey G. Andrews [7] analytically quantifies downlink capacity of multicell DAS for two different transmission strategies: selection diversity (where just one or two of the distributed antennas are used) and blanket transmission (where all antennas in the cell broadcast data). The selection diversity is preferable to blanket transmission in terms of achievable ergodic capacity.

Jun Zhang, and Jeffrey G. Andrews [8] proposed distributed antenna system with randomness. Previous analyses have neglected the key sources of randomness in such systems, notably (i) random channel effects (fading and shadowing) and (ii) the random quantity and locations of both the mobile users and the AEs(antenna elements). AEs will be placed irregularly in practice.

Wonil Roh and Arogyaswami Paulraj [9] Traditionally combining techniques have been applied to the base station where the multiple receive antennas are placed within tens of wavelength to get uncorrelated multipath fading at each antenna. The problem with this conventional compact array is that all the participating antennas experience the same shadowing, a slow variation of the mean signal envelope (or power) due to terrain change, which necessitates the use of complex power control schemes. To overcome this, generalized distributed antenna system (GDAS) has been proposed and its performance in a multi cell environment is investigated.

X.-H. You, D. M. Wang, B. Sheng, X. Q. Gao, X. S. Zhao, and M. Chen [11] the basic conceptual description of cooperative DAS or distributed MIMO is presented and compared with the conventional cellular architecture. By reducing the transmission distance of radio signals over the coverage area, improved spectral efficiency and power efficiency can be achieved. It was shown that the distributed MIMO formed by the cooperative DAS can utilize the channel independence of both microscopic and macroscopic fading factors in a better way than the centralized MIMO.

Xiaohu You, Dongming Wang, Pengcheng Zhu, and Bin Sheng [12] The major limitation in collocated antenna system (CAS) and the solution to overcome that limitation is presented. The limitation in collocated antenna system is that the users in the cell edge have poor performance and the solution to this problem is to use new radio architecture namely distributed antenna system (DAS).The performance of collocated antenna system (CAS) and distributed antenna system (DAS) are analysed and they are compared. The system configurations of DAS have been clearly explained with diagram and both the systems are simulated using Monte carlo simulation.

4. Simulation Results and Discussion

4.1. Numerical Results

The simulation is performed using MATLAB R2009b software. The path loss model is simulated to show that the cell edge users are affected by more path loss. Performance metrics namely ergodic channel capacity and bit error rate (BER) are simulated and the BER performance of both the systems are compared. The BER for proposed scheme is less compared to existing scheme and the capacity is high in DAS than CAS system.

4.1.1. Comparison of Path Loss for Cell Interior and Cell Edge User

The path loss for cell interior user and cell edge user is simulated and compared. Hata model for urban area is considered. The distance between MT and BS for cell interior user is assumed to be 0.5km and the distance between MT and BS for cell edge user is assumed to be 2km. The path loss comparison of cell interior user and cell edge user is given below.

Table 1. Path Loss Comparison

Height Of Receiving Antenna in meter	Path Loss For Cell Interior User(dB)	Path Loss For Cell Edge User(dB)
1	76.2947	78.3084
2	75.8623	77.8759
3	75.6003	77.6140
4	75.4103	77.4239
5	75.2603	77.2739

In case of CAS, the distance between BS and MT for cell edge user will be very high. As a result, path loss increases. The path loss is simulated for different receiving antenna height. For receiving antenna height of 1m, there is 2dB increase in path loss from cell interior user to cell edge user.

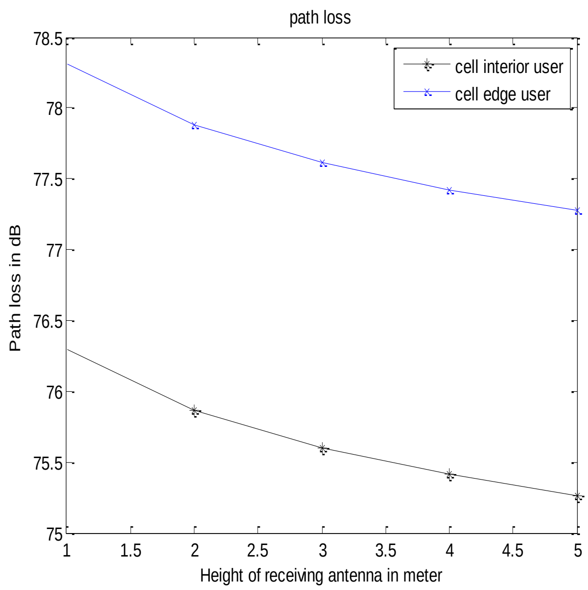

Figure 5. Influence of Path Loss on Cell Coverage

4.1.2. BER Comparison of CAS and DAS

The simulated result for BER comparison is shown in Figure 4.4 for the existing and the proposed system. It is assumed that the MT is present in the cell edge for both existing and proposed system. It is inferred from the graph that the bit error rate (BER) is more in the existing collocated antenna system (CAS) than the proposed distributed antenna system (DAS).To achieve BER of 10^{-4} , SNR of 14dB is required in DAS whereas in CAS, to achieve the same BER of 10^{-4} , SNR of 18dB is required. As the BER is less in DAS, the received signal quality will be high.

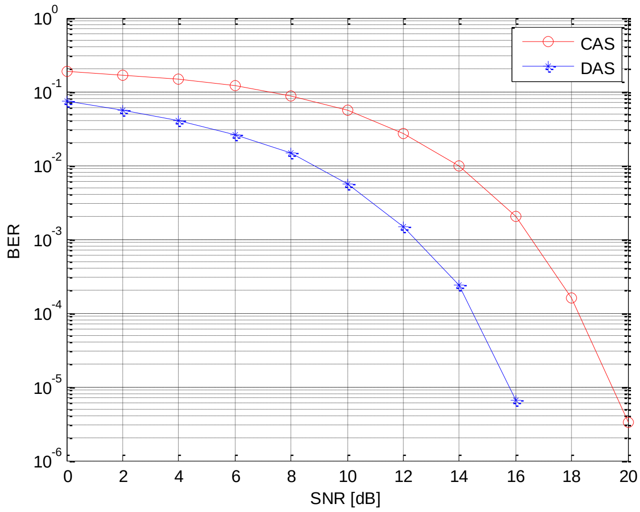

Figure 6. BER Comparison of CAS and DAS

4.1.3. Capacity Comparison of CAS and DAS

The simulated result for capacity comparison is shown in Figure 4.5 for the existing and the proposed system. It is assumed that the MT is present in the cell edge for both existing and proposed system. It is inferred from the graph that the capacity is high in DAS antenna system (DAS) compared to collocated antenna system (CAS).For SNR of 5dB, 2.9bps/Hz is achieved in CAS whereas 6bps/Hz can be achieved in DAS.

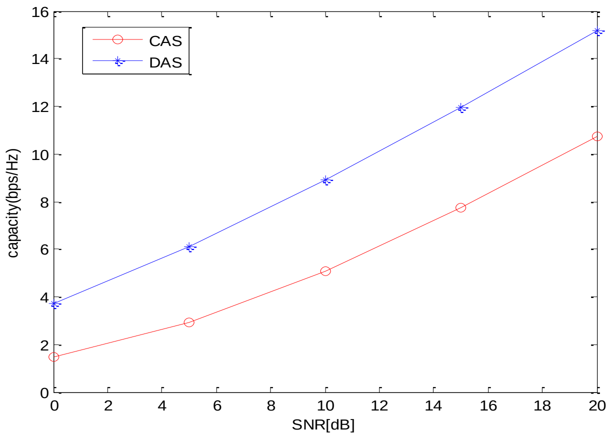

Figure 7. Comparison of Capacity

5. Conclusion

The performance analysis of existing collocated antenna system (CAS) and proposed distributed antenna system (DAS) were performed. The performance analysis namely bit error rate (BER) and capacity were performed and the results are shown. The simulation results show that the DAS achieves large performance gain over the conventional CAS for the cell edge users because the DAS efficiently improves the signal quality by reducing the path loss. The distributed antenna systems effectively reduce other cell interference (OCI) and improve SINR especially for users near cell boundaries that normally are performance limiting users, compared to conventional cellular systems in an interference limited multicell environment. As a result, distributed antenna systems achieve lower bit error probability and higher capacity than conventional collocated antenna system.

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