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Investigation of the Distributed Antenna Scheme for Multi-cell Environment in TDD-CDMA Systems

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Abstract: In this paper, both uplink (UL) and downlink (DL) performances are investigated for the TDD-CDMA system when employing the distributed antenna (DA) technology in the Macro multi-cell scenarios. In UL, both the DA and the multi-user detection (MUD) themes can suppress the interference and improve the capacity. Even the simple DA structure (called fixed DAS) can provide a high macro-diversity gain. Meanwhile, MUD technique is adopted to mitigate the intra-cell interference. In our work, the performance improvement due to DA and MUD are evaluated and compared. In order to improve the DL capacity, the advanced DL transmission mechanism, based on the virtual cell (called virtual DAS), is proposed. An advanced TDD-CDMA static system simulator for DA is built, and the simulation results show that both the capacity and coverage gain in UL are significant due to the receiving diversity gain sourced by the DA. In addition, the UL performance gain is related to the antenna element number and the MUD factor. However, in DL, due to the huge adjacent antenna's interference, the fixed DAS can't provide any capacity and coverage gain. The proposed virtual DAS provides higher capacity gain and wider coverage range than the fixed DAS does.
Keywords: Distributed Antenna; TDD-CDMA; Multi-User Detection, Capacity, Coverage

1. INTRODUCTION

3G systems, based on the code division multiplex access (CDMA), will support not only voice service, but also a wide range of broadband services such as Video and Internet traffic. Compared to FDD (Frequency Division Duplex) mode, TDD (Time Division Duplex) mode can change the uplink and downlink resources according to the traffic demands to match the asymmetric and bursty nature of data traffic. Therefore, TDD can provide higher data rate and more efficient use for asymmetric services[1].

Many advanced techniques, such as smart antenna (SA), multi-user detection (MUD) and advanced resource management schemes (RRM), are proposed to improve the system's performance and support the high speed packet transmission. Recently, distributed antenna (DA) has been one research focus because it can extend the coverage and increase the capacity together, especially the effective solution for the coverage hole, by utilizing multiple antenna elements (AE)[2]. The main advantages of DA are that the users receive multiple versions of the same signal from different directions, which provides the diversity protection against shadowing and distance-dependent propagation losses [3].

Many performance investigations about the distributed antenna system (DAS) have been presented. For example, [4] shows the performance of the generalized DAS in a multi-cell network. The performance analysis of DAS in the indoor environment for WCDMA is presented in [5]. However, the investigation based on the combing multi-user detection (MUD) scheme and DA in uplink for TDD-CDMA is still seldom. Downlink (DL) performance is still lacked in the published paper because the additional interference to the desired receiver due to the incremental AE is high. All DASs presented in the above papers are categorized as fixed DAS. However, in [2], a virtual DAS is introduced, but no any performance results are shown. Consequently, some advanced performance analysis for DAS must be proposed. The difference between fixed and virtual DAS should be evaluated.

In this paper, both UL and DL performance analysis for DAS in the multi-cell TDD-CDMA systems are presented firstly. The theoretical UL and DL performances due to DA are shown. There is some difference between UL and DL, and the fixed DAS is adopted for UL to improve the performance, while the virtual DAS is proposed for DL. The simulator building is based on the Monte Carlo mechanism for the macro environment. The simulation results demonstrated that DA can extend the coverage and improve the capacity in UL, which are related to the MUD factor and the number of antenna element in DAS. The virtual DAS configuration can mitigate the interference and enhance the interesting power level in DL.

2. Distributed Antenna Model

The distributed antenna system (DAS), also known as the “bunch” concept in FRAMES project, is an alternative to the conventional cell splitting approach for achieving increased spectral efficiency and reliable uniform coverage due to avoiding the increased handover ratio and planning complexity. Conventional cell splitting only reduces the cell radius, not the separation between co-channel cells. With the DA, a cell consists of a number of zones, each covered by an antenna element (AE) connected to the central station (CS).

In a DA system, many simple AEs are connected to the CS (similar to the based station (BS) in 3G) by the optical fiber with enough distance separation, which makes communication cheap and enables burst synchronization within all AEs in one CS. There is no specified signal processing at the AE side. In the uplink, the signal of user equipments (UEs) is received by all these AEs in one CS. The basic advantages of a DA system can be gauged as a regular sub-cell structure. In Fig. 1, the DAS with sub-cell configuration is shown. A single cell with a single omni-direction antenna is sub-divided into 7 sub-cells. It is assumed that there is no overlay between the coverage of individual sub-cells. In each sub-cell, there is one AE, and the AE is equipped with a transceiver device, which converts the radio frequency signal to and from the digital intermediate frequency signals. The intermediate frequency signal is transmitted to the CS.

The advantage of DAS can be categorized as: (1) Lower transmission power level; (2) less interference to/ from other cell or other system; (3) higher capacity and (4) larger coverage range. The TDD-CDMA system is strictly interference limited. Estimating the amount of supported traffic per CS for UL and DL is very important for allocating the

3. Capacity Model

In this paper, DAS is assumed as one that has a total N AEs spaced by large distance. Each AE has only 1 antenna. Meanwhile, no advanced multiple antenna schemes (smart antenna and multi-input and multi-output) is considered. The transmission and received signals in each AE have independent macroscopic fading as lognormal and distance dependant path-loss.

3.1. UL Capacity Model

On UL, many UEs access to one AE simultaneously, and each UE connects to several AEs in the serving CS. The theoretical spectral efficiency for the TDD-CDMA UL relates the C/I of user i to the received power of the desired signal in the AE j (P_{ij}). Additionally, it also relates to the total interference generated by those users that are connected to the same AE (I_{intra_k}) and from other AEs or other operators (I_{inter_k}), relates to the thermal background noise P_0 as well.

$$\left(\frac{C}{I}\right)_i = \sum_{k=1}^{K} \frac{P_{ik}}{(1-\beta)(I_{intra\_k} - P_{ik}) + I_{i\,inter\_k} + P_0} \tag{1}$$

In above equation, β is an interference reduction factor due to the use of interference cancellation method, for example, MUD in UL. β=1 means an ideal MUD, while β=0 means no MUD method is adopted, i.e., traditional rake receiver is used in the CS side for the signal of AE k.

Compared with the conventional omni-directional cell, the SIR in DAS can be expressed as the macro-diversity effects:

$$\left(\frac{C}{I}\right)_i = \sum_{k=1}^{K} \left(\frac{C}{I}\right)_{ik} \tag{2}$$

where K is the average number of AEs in one CS, and:

$$\left(\frac{C}{I}\right)_{ik} = \frac{P_{ik}}{(1-\beta)(I_{intra\_k} - P_{ik}) + I_{i\,inter\_k} + P_0} \tag{3}$$

If perfect power control is assumed in each AE, the target of C/I for the CS is set $(C/I)_{target}$, then the average target C/I for each AE is $\rho=(C/I)_{target}/K$. According to [6], the UL satisfied UE number N is determined by ρ, Multi-User-Detection (MUD) factorβ, background noise rising (BNR) and the ratio of other cell to own cell interference j:

$$N_{DAS} = \frac{[1+\rho(1-\beta)]*(BNR-1)}{\rho[1+j+(1+j-\beta)*(BNR-1)]} \tag{4}$$

And the UL load factor η can be expressed as:

$$\eta = \frac{(1+j-\beta)*(BNR-1)}{1+j+(1+j-\beta)*(BNR-1)}$$

(9)

Compare equation (7) with equation (9), there is no much difference between the link qualities for the two systems in DL, except that the interference comes from N BSs in the conventional system, instead of N*K in the DAS. In additional, the received interesting power is the sum of signal from the several AEs in the serving CS. Consequently, DA technique can't imply high capacity gain and even provide lower DL capacity.

In order to improve the DL capacity, some advanced interference cancellation techniques are applied, such as the directional antenna, smart antenna and Milti-Input and Milti-Output (MIMO) can be deployed in the AE side. Furthermore, advanced dynamical power allocation schemes according to the condition of AEs should be adopted in the CS side.

If the virtual DAS is adopted, the value of interference from the AEs in the adjacent virtual CS is much less than that of the non-orthogonal interference from the same CS and can be ignored. The equation (9) can be near expressed as:

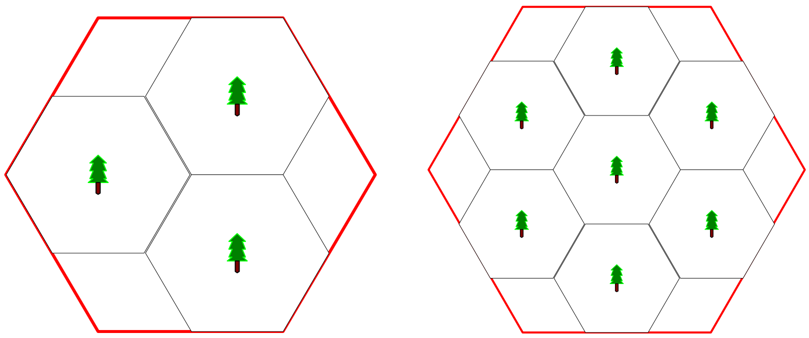
$$\rho_i = \frac{\sum_{k=1}^{K} p_{mik} / L_{mik}}{(1-\alpha)\sum_{k=1}^{K} PtxTotal_{mk} / L_{mik} + P_0} \tag{10}$$

4. System level simulator

In order to evaluate the capacity of the DAS system, an advanced static TD-SCDMA system level simulator is used to evaluate the system performance according to[8]. A simulation consists of several simulation steps (snapshot) with the purpose of covering a large amount of all possible UEs placement in the network. In each simulation step, a single placement (amongst all the possible configurations) of the UEs in the network is considered. A simulation step (snapshot) consists of mobile placement, pathloss calculations, power control and results collecting.

4.1. Deploy model

In our work, hexagonal macro scenario is considered. There are 16 cells in the environment, which is based on the Wrap-Around concept. In order to evaluate the performance of DAS, the cell splitting method is considered. Two models are focused: 3-AE and 7-AE, i.e. every cell can be divided into several sub-cell, in where there is one AE located. In Fig.3 (a), the 3-AE model is shown, while Fig.3 (b) gives the structure of 7-AE model.



(a) 3-AE in each cell (b) 7-AE in each cell

Fig. 3 DA structure

[0-1]. *j* and *k* represents that *jth* site or base station and *kth* sector.

In order to properly support radio resource management algorithm studies, the multi-path propagation environment has to be modeled and implemented in the simulator. If using the some spread spectrum techniques, the radio receiver can separate several multi-path components. Each multi-path component has its own fast fading process that may be totally uncorrelated or partly correlated to other paths. In our simulations, the number of multi-path components is 1 and Jakes model is used.

4.6. Simulation Parameters

The parameters used in hexagonal macro environment simulations are based on the TD-SCDMA system and listed in the following table. Note that only one UL slot and one DL slot is considered in this simulation. All the parameters are from the link level simulation results of [9].

TABLE I.

MACRO CELL SIMULATION PARAMETERS

Parameter	Value	Parameter	Value
Maximum total transmission power of AE (dBm)	34	Minimum transmission power of AE (dBm)	4
Maximum total transmission power of UE (dBm)	21	Minimum total transmission power of UE (dBm)	-49
BS Receiver noise floor (dBm)	-106	Number of UEs	400
Number of BSs	64	MS Receiver noise floor (dBm)	-104
MUD factor	Variable	Orthogonality factor	0.78
C/I UL Target (dB)	-3.5	C/I DL Target (dB)	-3.5

4.7. Power Control Models

Power control (PC) consists of open loop PC, inner loop PC and outer loop PC in both UL and DL. In our work, since mobility of MS is not taken into account, open loop PC is adopted for admission control, while perfect PC is used instead of inner loop and outer loop PC.

UL open loop transmission power of UE in the admission control procedure is defined as:

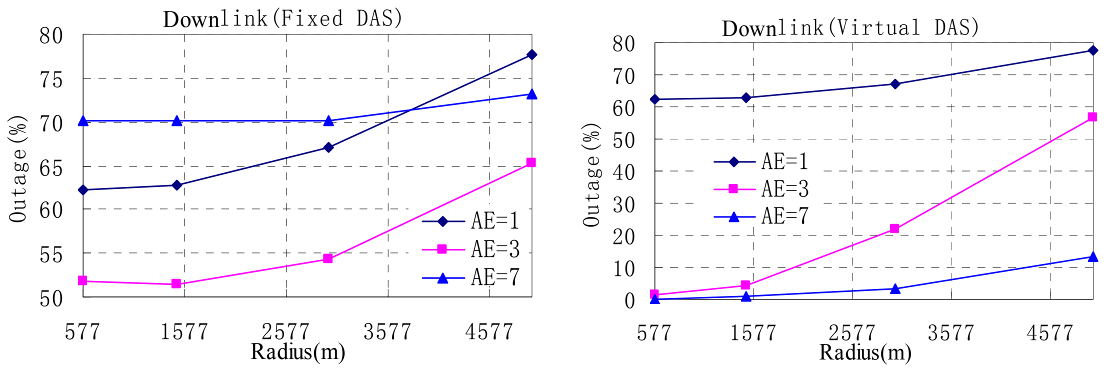
$$P_{UE} = PL + I_{total} + C/I_{tar} \tag{13}$$

where P_{UE} is the transmission power level in dBm, and *PL* is the path loss from UE to the serving base station in dB. I_{total} is the total interference of base station in dBm. $(C/I)_{tar}$ is the *C/I* UL target in dB.

In DL, open loop PC is used to set the initial power P_{new} and is calculated by the following equation:

$$P_{new} = \left(\frac{C}{I}\right)_{tar} * \left(\alpha * P_{BS_i} + \sum_{j=1, j\neq i}^{N} \frac{P_{BS_j}}{PL_j} * PL_i + P_N * PL_i\right) \tag{14}$$

where P_{BS_j} is the total transmission power level of BS *i*, and PL_i is the path loss from the serving BS *i* to MS. $(C/I)_{tar}$ is the *C/I* DL target.



(a) Based on Fixed DAS (b) Based on Virtual DAS

Fig.7 Downlink Performances VS. Radius

6. Conclusions

In order to improve the capacity and extend the coverage, the fixed DAS is proposed for UL in this paper. While in DL, the performance gain is not high when deploying the fixed DAS due to the impact of generating the additional interference sourced by the new AEs is heavier than the diversity gain sourced by the new AEs. Consequently, the virtual DAS is presented for DL to suppress the intra-cell interference and enhance the macro diversity gain. The simulation results show that the virtual DAS can provide higher performance gain than the fixed DAS in DL. Furthermore, the performance gain from both the fixed DAS in UL and the virtual DAS in DL increases with the number of AEs.

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