A New Cell Structure For Distributed Wireless Communication System Without Inter-cell Interference

Jianjun Li*, Sungjin Kim*, Hojin Kim†, Zhengzi Li†, Kwang Bok Lee*

† Samsung Advanced Institute of Technology
* School of Electrical Engineering, Seoul National University

Abstract—Distributed wireless communication system (DWCS) is one of the candidate architectures for future mobile communication system. In this paper, based on the TDD DWCS, a new cell structure is proposed with universal frequency reuse. In the proposed structure, the cells are divided into 2 groups, and when one group is in the uplink period, the other transmits the downlink data. All the basestations share the whole frequency spectrum. By use of the advantage of the distributed processors, the inter-cell interference in the uplink of a cell can be perfectly removed. As to the downlink, the inter-cell interference can also be avoided by proper resource allocation among mobile users. With universal frequency reuse and without the inter-cell interference, simulation results show that DWCS with the proposed structure has an extremely high capacity.

I. INTRODUCTION

With the rapid progress in telecommunications, more and more services are provided on the basis of broadband communications, such as video services and high-speed Internet. With worldwide fundamental construction based on optical fiber, the backbone network can provide almost unlimited communications capability. However, for mobile access, the throughput is much lower. The basic problem of wireless access is that the available spectrum is too limited compared to the almost unlimited service requirement, just like cars jammed in crowded narrow paths. Another basic problem is that there is great attenuation of energy.

Distributed wireless communication system (DWCS) proposed in [1-2] is one of the candidate architectures to fulfill these requirements and solve the problems. DWCS is a new architecture for a wireless access system with distributed antennas, distributed processors, and distributed controlling. With distributed antennas, system capacity can be expanded through dense frequency reuse, and transmission power can be greatly decreased. With distributed processors controlling, the system capacity can be increased by coprocessing of signals to and from multiple antennas. In fact, DWCS can be seen as the extension of the distributed antenna system (DAS), which has received a great deal of attention recently [3-5]. DAS was considered to be applied inside a cell or to the indoor environment, while DWCS extends this concept to large area network.

DWCS increases the system capacity through dense frequency reuse. However, the spectrum efficiency of frequency reuse is much lower than that of the CDMA system such as IS-95 [6], where all the cellular share the same spectrum. Moreover, for conventional CDMA system, there exists inter-cell interference, which decreases the system capacity greatly.

In this paper, based on the TDD DWCS, a new cell structure is proposed. In the proposed cell structure, the cells are divided into 2 groups. When one group is in the uplink period, the other transmits the downlink data, and vice versa. All the basestations share the whole frequency spectrum, that is, the frequency reuse is 1. By use of the advantage of the distributed processors and the cell architecture, the inter-cell interference canceling for both the uplink and the downlink are investigated. Performance analysis and simulation results on the system capacity are also given.

The rest of this paper is organized as follows: In Section II, the basic concept of DWCS is introduced, and the new cell structure for the DWCS system without inter-cell interference is proposed in Section III; Performance analysis and simulation results on the system capacity are given in Section IV; Finally we give our conclusions in Section V.

II. THE CONCEPT OF DWCS

In this Section, the basic concept of DWCS scheme is introduced. In DWCS, the traditional basestation is reduced to an antenna connected with processing center through optical fiber. The processing center is realized by many workstations in parallel, which are distributed in different places and exchange data among them through a high speed network. This extremely powerful processor is actually a software radio equipment.

The logical architecture of DWCS is shown in Fig. 1, which is composed of three layers: distributed antennas, distributed signal processing, and distributed high layer control. 1) Distributed Antennas: The new structure has distributed antennas. Each antenna is equipped with a transceiving device, which converts the RF to and from digital IF signal. The received IF signal is transmitted to processing center through optical fiber. The IF signal for transmission and system timing is also provided by processing center through optical fiber. 2) Distributed Signal Processor: This is the essential part of the architecture. All signal processing concerning wireless access are involved in
Distributed Signal Processor

Distributed high layer control

Fig.1 The logical architecture of DWCS

this layer including modulation/demodulation, channel coding/decoding, joint detection, channel measurements, and MAC, LLC, RLC, RNC, etc. Logically, this layer can be regarded as an extremely powerful processor, which connects all the RF modules of distributed antennas. 3) Distributed High Layer Control (DHLC): This layer may be performed on the same platform of signal processing. This layer performs all the high layer protocol control, including all signaling, switching and mobility management gateway to core network, etc.

From the above, we know that in DWCS, the distributed Signal Processor knows all signals received from all antennas, and can control the transmission of all the antennas. So there is more system information can be utilized in the baseband signal processing. Based on this advantage, a new cell structure for DWCS system and an inter-cell interference canceling scheme are well designed, which will be described in the following section.

III. THE NEW CELL STRUCTURE FOR TDD DWCS

In this section, a TDD-mode DWCS system will be investigated with new cell structure, new transmit scheme and new receive scheme in both uplink and downlink.

A. System Cell Architecture

In the TDD-mode DWCS system considered in this paper, we use universal frequency reuse scheme to obtain higher spectrum efficiency, that is, every basestation uses the whole frequency spectrum. The proposed cell architecture is show in Fig.2. The cells are designed as square with inner radius \( r \) and with a base station (BS) situated in the center. All the cells are divided into 2 groups. In the communication, when one group is in the uplink period, the other transmits the downlink data and vice versa. Thus, the inter-cell interference to the uplink of a cell of the group 1 only comes from the downlinks of its adjacent cells of the group 2, and the inter-cell interference to the downlink comes from the mobile users’ uplink signal of the group 2, which is quite different from the conventional cellular system. For the TDD DWCS system with proposed cell structure, this kind of inter-cell interference can be removed or avoided easily by proper processing.

From Fig.2, we can see that for any cell of group 1, there are 4 adjacent cells of group 2 side-by-side and 4 adjacent cells of the same group by point of intersection. The distance between a cell and its adjacent cells of different group is \( 2r \), and the distance between a cell and its adjacent cells of the same group is \( 2\sqrt{2}r \). In order to obtain the spatial gain by MIMO technique, the mobile user connects with all the basestations in its neighbor cells of the same group to transmit and receive signals, which can improve the system capacity and the performance. Thus, the basestation transmit signal to not only the mobile users in its own cell, but also the users in its adjacent cells of the same group. In the case of the system architecture in Fig.2, 5-order spatial diversity gain can be achieved with proper space diversity technique [7], which can be seen as a kind of macro diversity.

B. The Uplink

Here, without loss of generality, we select the uplink and downlink of the cell of group 1 to analysis. If we just take the interference from the neighbor cells into account and ignore the interference of the cells far away, the system model of the uplink can be simplified as shown in Fig.4. In the uplink, \( m \) mobile users send signals \( s_i^{u}(t) \) \( (i=1,2,\ldots,m) \) to the basestation of the cell that we consider. At the same time, the
downlink signals of the adjacent cells of the group 2, \( S_{0}^{(i)}(t) \) \((i=1,2,3,4)\), are also very strong at this basestation, which act as inter-cell interference. So the received uplink signal at the basestation can be expressed as:

\[
R_{up}(t) = \sum_{i=1}^{m} h_{u}^{(i)} s_{u}^{(i)}(t) + \sum_{i=1}^{4} H_{B}^{(i)} S_{B}^{(i)}(t) + N(t) \quad (1)
\]

where \( h_{u}^{(i)} \) denotes the channel from the \( i \)th mobile user to the basestation of the selected cell, and \( H_{B}^{(i)} \) denotes the channel from the \( i \)th basestation of the cell of group 2. In (1), \( N(t) \) is AWGN.

In DWCS, the distributed signal processor collect all uplink signals received from the antennas of all the basestations to process. At the same time, it is also the distributed signal processor that generates the downlink signals of all the basestations. In the uplink of the proposed system, the inter-cell interference comes from the downlink signals transmitted by the basestations of the different group. So if the distributed signal processor estimates the channel accurately, the inter-cell interference can be completely removed, as shown in Fig. 6. After the interference canceling, the uplink signal can be expressed as:

\[
\tilde{R}_{up}(t) = R_{up}(t) - \sum_{i=1}^{4} H_{B}^{(i)} S_{B}^{(i)}(t) = \sum_{i=1}^{m} h_{u}^{(i)} s_{u}^{(i)}(t) + N(t) \quad (2)
\]

Since the channels \( H_{B}^{(i)} \) \((i=1,2,3,4)\) are from basestation to basestation, they change very slowly. As to the nearly fix channels, the distributed signal processor can easily estimate their value in very high accuracy. So the proposed scheme for the inter-cell interference canceling is very feasible.

In the downlink, the mobile user receives signals \( S_{B}^{(i)}(t) \) \((i=0,1,2,3,4)\) from 5 nearby basestations of the cell of the group 1 to obtain diversity or multiplexing. Simultaneously, these exist interference signals \( s_{I}^{(i)}(t) \) \((i=1,2,\ldots,n)\) from the \( n \) mobile users of the adjacent cells of the group 2, which is in the uplink period. The corresponding system model is shown in Fig. 5. Thus, the received downlink signal at the mobile user can be written as:

\[
R_{down}(t) = \sum_{i=0}^{4} H_{u}^{(i)} S_{B}^{(i)}(t) + \sum_{i=1}^{n} h_{I}^{(i)} s_{I}^{(i)}(t) + N(t) \quad (3)
\]

Correspondingly, \( H_{u}^{(i)} \) denotes the channel from the \( i \)th nearby basestation of the cell of group 1 to the mobile user that we investigated, and \( h_{I}^{(i)} \) denotes the channel from the \( i \)th mobile user of the cells of group 2.

In the TDD DWCS system with proposed cell structure, all the basestations use the whole frequency spectrum. During the communication, the basestation keeps connection with not only the mobile users in its own cell, but also the users in its adjacent cells of the same group. Thus, for the mobile users of the cell, they have to share the spectrum with the users in the adjacent cells of the same group. Since the
diversity order is 5, we divide the whole frequency spectrum into 5 parts, **F1-F5**. If we allocate **F1-F5** to mobile users of different cells as Fig. 5, there will be no user occupy the same spectrum in the neighbor cells. In addition, because the signal power of the basestation is much higher than that of a mobile user, the effect of the inter-cell interference in the downlink can be ignored. So the inter-cell interference of the downlink is avoided. Thus the capacity of the downlink is also extremely high just like the case of the uplink. Thus, the received downlink signal at the mobile user can be written as:

\[
R_{down}(t) = \sum_{i=0}^{4} H_u^{(i)} S_B^{(i)}(t) + N(t) \quad (4)
\]

C. The Handover

In the new cell structure, there are two kinds of handover depend on the movement of the mobile users. If a mobile user moves from a cell to another cell of the same group, he just needs to update 3 connections of the 5, that is, remove 3 connections with the cells far away and replace them with 3 new connections with the cells of the same group adjacent to the cell that he moves in. This can be regarded as one kind of soft handover. However, in the case of a mobile user moving from a cell to its adjacent cell of the different group, he will have to give up all the current radio links and set up 5 new connections with the cells of the new group. This is traditional hard handover. For DWCS, since all the control is implement together in the DHLC, the reliability of the hard handover is nearly the same as that of the soft handover.

### IV. PERFORMANCE ANALYSIS AND SIMULATION RESULTS

Now, we investigate the system capacity of the TDD-mode DWCS with the new cell structure, and the simulation results are also given to support our analysis.

From the cell architecture, we know that the proposed system can achieve universal frequency reuse without inter-cell interference. Considering the 5-order macro diversity, if the total spectrum bandwidth is \( B \), the capacity of the uplink can be expressed as:

\[
C_{up} = \frac{B}{5} \log_2(1 + \rho HH^*) \quad (5)
\]

where \( \rho \) is SNR and \( H = [h_u^{(0)}, h_u^{(1)}, h_u^{(2)}, h_u^{(3)}, h_u^{(4)}] \) is the channel matrix from the mobile user to the basestations. Similarly, the capacity of the downlink can be written as:

\[
C_{down} = \frac{B}{5} \log_2(1 + \frac{P}{5} HH^*) \quad (6)
\]

where \( I \) is 5 order identity matrix and \( H \) is the channel matrix from the basestations to the mobile user.

For conventional cellular system, the frequency reuse is 7. So its system capacity is:

\[
C_{freq} = \frac{B}{7} \log_2(1 + \rho |h|^2) \quad (7)
\]

where \( h \) is the channel matrix between the basestation and the mobile user. As to CDMA system, the frequency reuse is 1. But there exists inter-cell interference, and the factor of the inter-cell interference on the capacity is typically set to 0.55. Thus, the system capacity of the CDMA system can be approximately given by:

\[
C_{cdma} = \frac{1}{1 + 0.55} B \log_2(1 + \rho |h|^2) \quad (8)
\]

Based on the above analysis, we will compare the capacity of the three systems by simulation. In the simulation, the composite fading channel model is employed to describe not only small scale fading but also large scale fading and path loss. Considering path loss, the small scale fading model is Rayleigh channel, which is independent, complex, zero mean with none unit variance \( v \), that is,
Normal\left( {0, \frac{\sqrt{v}}{2}} \right) + j \cdot \text{Normal}\left( {0, \frac{\sqrt{v}}{2}} \right) \tag{9}
\]

where \( v \) represents shadowing of the channel, which is modeled as lognormal. The different channels are independent but not identical due to different path loss. The path loss, \( \mu = E[10 \log_{10} v] \), is set to 0dB for the channel between the basestation and the mobile users in the same cell, and –3dB for the channel between the basestation and the mobile users of the neighbor cell. The shadowing of the channel, \( \sigma \) is the standard deviation of \( 10 \log_{10} v \). Here we select \( \sigma = 8 \) in the simulation.

Fig. 8 displays the 10% outage capacity \( (P(\frac{C}{B} < C_{outage}) = 0.1) \) of the different systems. We can observe that the uplink of the proposed TDD DWCS system has the highest capacity so that the mobile users can save their power. The capacity of the downlink of the proposed TDD DWCS system is lower than that of the uplink, but still higher than that of the CDMA system. The capacity of the frequency reuse is the lowest. So we can say, the proposed cell structure can extremely improve the system capacity.

V. CONCLUSION

In this paper, based on the TDD DWCS, a new cell structure is proposed. In the proposed structure, all the cells share the same frequency spectrum, and those cells are divided into 2 groups, and when one group is in the uplink period, the other transmits the downlink data. By use of the advantage of the distributed processors, the inter-cell interference in the uplink of a cell can be perfectly removed. As to the downlink, the inter-cell interference can also be avoided by proper resource allocation among the cells. With universal frequency reuse and without the inter-cell interference, simulation results show that the TDD DWCS system with the proposed cell structure has an extremely high capacity.

REFERENCES

Fig. 6 Outage Capacity of different systems