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# Optimal Size Selection for Group Cell Architecture for beyond 3G systems

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*Abstract*—**Group Cell, Generalized Distributed Cellular Architecture for China Beyond 3G (B3G) mobile communication systems, was proposed to increase coverage area, adopt new techniques and solve the frequent handover problem with increase of carrier frequency. In order to analyze the optimal size selection for Group Cell, namely the number of cell antennas in a cell group, the power cost model is firstly set up to give the criterion of selection. Then average received power and average received Signal to Interference Ratio (SIR) are respectively taken as the criteria, including Outage Probability. Further more, average channel capacity is discussed as the criterion to select the size of group. Finally, the optimal size selection for Group Cell is given due to the four pieces of criteria. Based on the simulation and analysis, the optimal size selection criteria are applicable to certain Generalized Distributed Cellular Architecture with different performance demands.**

*Keywords-Group Cell;Outage Probability; Channel Capacity*

## I. Introduction

With the rapid development of research in digital signal processing technology and RF technology, a lot of advanced physical layer technologies are predicted to be applied in the new mobile telecommunication systems. The traditional cell concept and handover strategy brought out by the Bell Lab. in 1971 could not fully use the advantages of new physical layer technology, especially the advantages of multi-antenna technologies. Furthermore, with higher carrier frequency being used in future mobile communication system, the cell radius will reduce further. The handover between cells will be more frequent than now.

Based on these requirements of physical techniques, the advantage of enlarging coverage by Distributed Antenna System (DAS) and the advantage of improving capacity by MIMO are focused and connected to a further step. Many researchers have been dedicated to novel cellular constructive methods [1] [2] [3]. Tao and Zhang brought out a new concept – Group Cell - a Generalized Distributed Cellular Architecture and its evolved version Slide Group [4-9].

Group Cell is a Generalized Distributed Cellular Architecture with multi-antenna elements. Several antenna elements constitute a Group Cell. In order to do further research in Group Cell architecture, the cell size of the Group Cell should be firstly confirmed. So selecting the size of Group Cell is an essential problem.

The size selection for Group Cell is an optimization problem. The key is the criteria of selecting optimal size. Based on users' Quality of Service (QoS), many performance parameters could be considered as the criteria, such as SIR and channel capacity [10] [11]. According to the reasons mentioned above, this paper introduces four pieces of criteria to select optimal cell size in Group Cell architecture.

This paper is organized as follows. Section II presents the Generalized Distributed Cellular Architecture - Group Cell architecture for B3G systems. Section III brings up and analyzes four pieces of criteria to select optimal size of Group Cell, the system-level simulation results are respectively shown with four pieces of criteria. In section IV, the optimal size selection for Group Cell is derived from the criteria. Finally, there comes a conclusion.

## II. Generalized Distributed Cellular Architecture-Group Cell For Beyond 3G Systems

A possible system structure for B3G TDD, including Access Points (AP) and mobile terminals (MT), is plotted in Fig. 1. In a typical Group Cell based wireless communication system, AP1 has totally N antennas (9 in this figure) and serves the same area of N traditional cells (shadowed area). If antennas in the area are indexed by 1~9 and the cell size of the Group Cell (GC in short) is 3, we can find there are 3 Group Cells connected with AP1 in this area, which are GC1 of antenna 1,2 3, GC2 of antenna 4,5,6 and GC3 of antenna 7,8,9.

The construction of Group Cell can be dynamically changed instead of fixed. In timeslot 1, antenna 11, 12, 13 are used for an MT. With the movement of the MT, in timeslot 2, antenna 12, 13, 14 will be selected in AP2. This is a slide-window Group Cell structure.

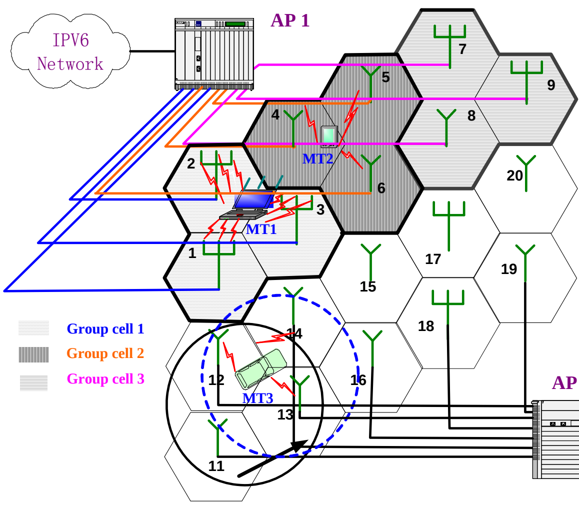


Figure 1. Group Cell Architecture

## III. Optimal Size Selection Criteria Analyses For Group Cell

On the assumption that single antenna in each cell, namely spaced MIMO structure, the size of Group Cell is discussed with equal transmitted power of each antenna. The size selection is an optimization problem with certain criteria. So the optimal result is given with different condition demands.

At first, the criteria of selecting the size of Group Cell should be confirmed, which is Quality of Service (QoS). The criteria targets include average received power, average received SIR, average channel capacity and Outage Probability, which are taken as the criteria to weight the communication quality in different size of Group Cell.

### *A. Criterion of power cost (Criterion A)*

The power cost model is abstracted from user's received power. The cost function is set up as the criterion to select optimal size of Group Cell.

#### *1) Modeling of power cost function*

It's only supposed that in the free spatial model with the criterion of power cost, because an abstract mathematic model of cost function is to be set up at first. The transmitted power is $P_0$, and the received power is $P = (\lambda/4\pi d)^2 P_0$. The smaller received power is, and the worse communication quality is. So the distance square $d^2$ is taken as the cost weight standard. $d_i$ is the distance from each cell center to Group Cell center, the greater $\sum_{i=1}^{n} d_i^2$ is, the worse the communication quality is. $n$ is the number of cells in Group Cell, namely the number of antennas in Group Cell, which can bring the diversity gain, so the cost function should be multiplied by $1/n$. The greater $\sum_{i=1}^{n} d_i^2 \Big/ n$ is, the worse the communication quality is. And the area of Group Cell including more cells is larger, in order to compare average performance, the cost should be the average cost in the area, so the total cost function should be multiplied by $1/n$ once more. Finally, the cost function is $L = \sum_{i=1}^{n} d_i^2 / n^2$. The minimum value of the cost function belongs to Group Cell with optimal size.

The model is set up as the following.

$$Min \qquad L = \sum_{i=1}^{n} d_i^2 / n^2 \qquad n \ge 2 \tag{1}$$

$$s.t. \qquad \forall n \ge 2, \ \ Min \ \sum_{i=1}^{n} d_i^2$$

#### *2) Simulation results*

The total transmitted power is fixed, and the antenna transmitted power of Group Cell is allocated equally. It's supposed that the cell radius $R = 1000$. The unit of cell radius has no effect to the results, which can be ignored.

In Fig. 2, when $n = 3$, the cost function reaches its minimum value, $L = 3.333 \times 10^5$, so the optimal size of Group Cell is 3. Fig. 2 also shows the rule of cost function: The cost of centrally symmetrical Group Cell is smaller, e.g. $n = 3$, $n = 7$ and $n = 19$. So the centrally symmetrical architecture is good for constructing the whole network.

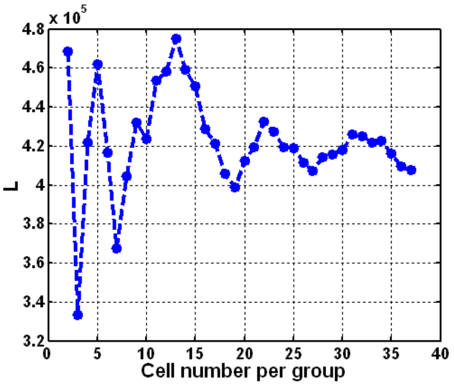


Figure 2. Cost Function Values with different Size of Group Cell.

### *B. Criterion of average received power (Criterion B)*

The average received power in Group cell is set up as the criterion to select optimal size of Group Cell.

#### *1) Modeling of Group Cell average received power*

$P_{ti}$ is the transmitted power of the antenna in cell $i$. $P_t = \sum_{i=1}^{n} P_{ti}$ is the total transmitted power of all the antennas in Group Cell, which is a fixed value. $Loss_i$ is the path loss from the antenna in cell $i$ to a user at random point in Group Cell, which is a function with variables of user's position . $P_i = P_{ti} \times Loss_i$ is the power received by a user in the Group Cell from the antenna of cell $i$. So $\sum_{i=1}^{n} P_i$ is received power of a user at random point in Group Cell. $n$ is the number of cells in one Group Cell. $S_{cell}$ is the area of cell. The user's average received power on the total area of Group Cell is $P_{avg} = \int_0^{n \times S_{cell}} \sum_{i=1}^{n} P_i ds \Big/ n \times S_{cell}$, which is the criterion of selecting optimal size. Group Cell with optimal size has greatest average received power.

$$Max \qquad P_{avg} = \int_0^{n \times S_{cell}} \sum_{i=1}^{n} P_i ds \Big/ n \times S_{cell} \tag{2}$$

$$s.t. \quad \sum_{i=1}^{n} P_{ti} = P_t$$

The outage power target is used to judge whether a user communicating normally. If received power of a user is smaller than the outage power target, the user's communication state is of outage. The average received power with outage power target is the average value without outage users'. The average received power without outage power target is the average value of all users.

*2) Simulation results*

The total transmitted power is fixed, and the antenna transmitted power of Group Cell is allocated equally. The outage target is given. The main characteristics of the simulation for the Generalized Distributed Cellular Architecture are summarized as follows:

TABLE I
PARAMETERS OF SIMULATION

| Parameters | Setting |
|---|---|
| Total power | 20W |
| Carrier frequency | 5.3GHz |
| Cell radius | 1000 m |
| Channel model | COST231 |
| AP antenna Height | 30.0m |
| MT antenna Height | 1.5m |
| Thermal noise | -146dBW |
| Outage power target | -139dBW |
| Outage SIR target | 3dB |

Fig. 3 compares average received power with and without outage target of Group Cell for different size, which shows that the average received power becomes smaller and smaller with the increase of the size of Group Cell. In Fig. 4, it is shown that Outage Probability is bigger and bigger with increase of the size of Group Cell. On the assumption that average received power without outage $P_{avg} \geq -119dBW$ in the demands of systems, the size of Group Cell $n \leq 4$.

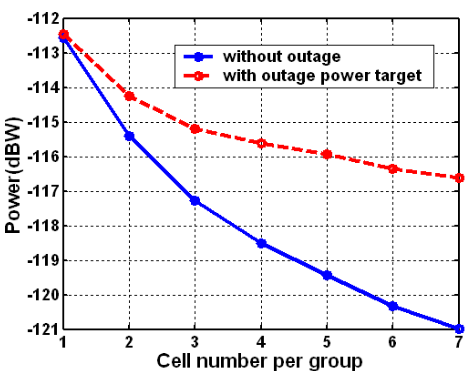


Figure 3. Average Received Power with different Size of Group Cell.

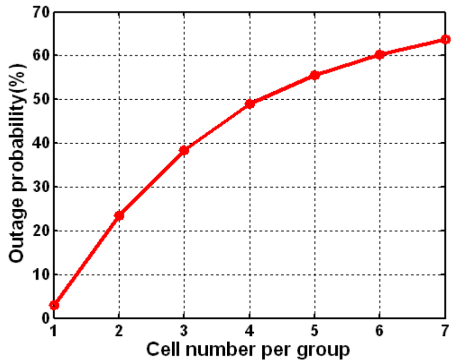


Figure 4. Outage Probability with Target of Average Received Power.

## C. *Criterion of average received SIR (Criterion C)*

The average received SIR in Group cell is set up as the criterion to select optimal size of Group Cell.

*1) Modeling of Group Cell average received SIR*

On the assumption that there are $m$ cell interfering to a random user in the Group Cell, $I_j$ is the interference power received by the user from the antenna of interference cell $j$. $SIR = \sum_{i=1}^{n} P_i / \sum_{j=1}^{m} I_j$ is the SIR received by the user. The user's average received SIR on the total area of Group Cell is $SIR_{avg} = \int_0^{n \times S_{cell}} SIRds \Big/ n \times S_{cell}$, which is taken as the criterion of selecting optimal size of Group Cell. Group Cell with optimal size has greatest average received SIR.

$$Max \quad SIR_{avg} = \int_0^{n \times S_{cell}} \left( \sum_{i=1}^{n} P_i \Big/ \sum_{j=1}^{m} I_j \right) ds \Big/ n \times S_{cell} \qquad (3)$$

$$s.t. \quad \sum_{i=1}^{n} P_{ti} = P_t$$

The outage SIR target is used similarly with the outage power target in Criterion B. The Outage Probability, average received SIR with outage SIR target and without outage SIR target are the criteria.

*2) Simulation results*

The simulation conditions are the same as Criterion B. We only calculate interference from two loops of closest cells out of the current Group Cell, since the interference from the third loop of cells is very small, which can be ignored.

It shows in Fig.5 and Fig.6 that whether with or without outage SIR target, the bigger the size of Group Cell is, the smaller average received interference is, the greater average received SIR is, the smaller Outage Probability is. On the assumption that average received SIR without outage $SIR_{avg} \geq 26.5dB$, the size of Group Cell $n \geq 2$.

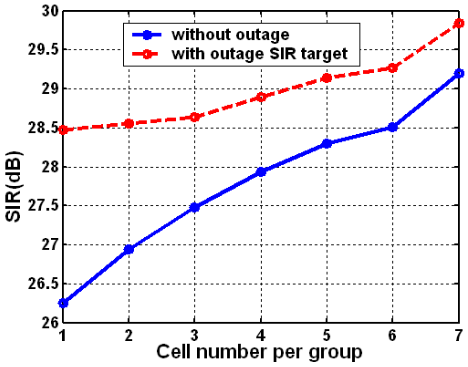


Figure 5. Average Received SIR with different Size of Group Cell.

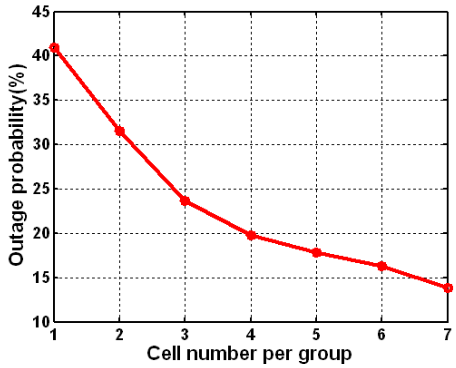


Figure 6. Outage Probability with Target of Average Received SIR.

### D. *Criterion of average channel capacity (Criterion D)*

The channel capacity analysis of Group Cell is based on MIMO channel model.

#### *1) Signal and channel model in the Group Cell architecture*

In the multi-antenna systems with $M$ transmitted antennas and $K$ users at the same time, channel is supposed as flat Raleigh fading channel, the received signal is shown as

$$y = \sqrt{P_r} Hx + z \tag{4}$$

Where $y = \left[ y_1 \cdots y_K \right]^T$ is the user's received signal vector, $x = \left[ x_1 \cdots x_M \right]^T$ is the multi-antenna transmitted signal vector, and $xx^H = I_M$, $H = \left[ h_{k,m} \right]_{K \times M}$ is complex Gauss channel matrix, and mean $E\left\{ h_{k,m} \right\} = 0$. On the assumption that the sum of received power from all the antennas to either user is a constant $P_r$, $z = \left[ z_1 \cdots z_K \right]^T$ is the complex Gauss noise, and $E\{z\} = 0$, variance $\mathrm{var}\{z\} = E\left\{ zz^H \right\} = \sigma^2 I_k$. $\rho$ is average received Signal to Noise Ratio (SNR).

Group cell is set up on the basis of cellular architecture and channel gains $h_{k,m}$, $m = 1,\cdots,M$, $k = 1,\cdots,K$, obey the same probability distribution. It is supposed that the probability distribution is the following.

$$h_{k,m} \sim N\left( 0, 1/\sqrt{2M} \right) + jN\left( 0, 1/\sqrt{2M} \right)$$

Where $N(0,1)$ shows Gauss distribution, whose mean value is zero and variance is one.

#### *2) Group Cell average channel capacity*

A universal MIMO channel model, such as (4), is supposed that all of the channel information is known. According to [11], channel capacity in (4) is

$$C = \frac{1}{K} \log_2 \det\left[ I_K + \rho HH^H \right] \tag{5}$$

Where det [A] is the determination of matrix A, the unit of channel capacity is bit/s/Hz/Dim, an antenna denotes a dimension. $H$ is a random variable matrix, so the average channel capacity $\overline{C} = E_H(C)$ is statistical average with $H$. According to the above and [15], multi-antenna channel capacity of Group Cell is

$$\overline{C} = \frac{1}{K} E_H \log_2 \det\left[ I_K + \rho HH^H \right] \tag{6}$$

In order to discuss the comparison of average channel capacity with different value of $M$, we suppose $K = 1$, the short formula of average channel capacity is

$$\overline{C} = E_h \log_2 \left[ 1 + \rho \sum_{m=1}^{M} \left| h_m \right|^2 \right] \tag{7}$$

#### *3) Simulation results*

The simulation conditions are same as Criterion B.

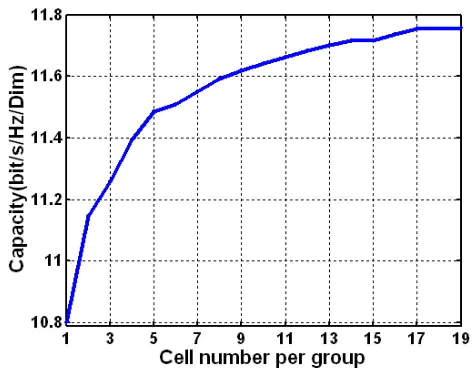


Figure 7. Average Channel Capacity with different Size of Group Cell.

Fig. 7 shows that the average channel capacity is bigger and bigger, which tends to limit with the increase of the size of

Group Cell. When the size of Group Cell is smaller than 5, the increase of average channel capacity is basically linear. On the assumption that average channel capacity $\overline{C} \geq 11 bit/s/Hz/Dim$, the size of Group Cell $n \geq 2$.

## IV. Optimal Size Selection Results Analyses For Group Cell

In this section, we analyze the simulation results, compare the performance parameters taken as criteria in the different size of Group Cell, and deduce optimal cell size of Group Cell

Firstly, the power cost model is set up. The cost function is taken as a criterion for selecting optimal size of Group Cell, which is abstracted from received power and includes the considerations of diversity gain and the average of area. The minimum value of the cost function belongs to Group Cell with optimal size. The optimal size of Group Cell is 3, as shown in Fig. 2.

Secondly, Group Cell with optimal size has greatest average received power. The outage power target is used to judge whether a user communicating normally. Outage Probability, average received power with outage power target and without outage power target are the criteria. Fig.3 and Fig.4 show that the average received power becomes smaller and smaller with the increase of Group Cell size, but Outage Probability is bigger and bigger. So the size of Group Cell cannot be big, $n \leq 4$ is better.

Then interference is considered, which is only calculated from two loops of closest cells out of the current Group Cell. Combining received power, user's average received SIR on the total area of Group Cell is taken as the criterion. Group Cell with optimal size has greatest average received SIR. Outage Probability is also used as the criterion to judge percentage of users communicating abnormally. It shows in Fig.5 and Fig.6 that the bigger the size of Group Cell is, the greater average received SIR is, the smaller Outage Probability is. So the size of Group Cell cannot be small, $n \geq 2$ is better.

Finally, based on MIMO channel model, average channel capacity in Group Cell architecture is deduced, which is taken as the criterion to select optimal size of Group Cell. Fig. 7 shows that the average channel capacity is bigger and bigger, which tends to limit with the increase of the size of Group Cell. When the size of Group Cell is smaller than 5, the increase of average channel capacity is basically linear.

To sum up the above, with the size increase of Group Cell, average received SIR and average channel capacity are bigger and bigger, but the average received power is smaller and smaller. So the better size of Group Cell is 2-4.

In highway environment, the architecture of Group Cell should be linear, so the optimal size of Group Cell is 2. In the urban circumstance, centrally symmetrical architecture is better for constructing the whole network, so the optimal size of Group Cell is 3. Aiming at the special standard demands of the communication systems, we can select out the optimal group size by the above criteria.

## V. Conclusions

The Group Cell Architecture is a Generalized Distributed Cellular Architecture, which combines the merits of DAS and MIMO techniques to provide high data rate and large coverage area. The further study of Group Cell Architecture is useful for China B3G mobile communication systems. Optimal size selection of Group Cell, namely the optimal number of antenna elements for Group Cell, is the key in Group Cell architecture.

In this paper, this problem is analyzed and evaluated under criteria of four performance parameters. The average received SIR and average channel capacity are bigger and bigger with the size increase of Group Cell, and average channel capacity tends to limit asymptotically. But the bigger size of Group Cell is, the smaller average received power is. So the better size of Group Cell is 2-4. In highway environment, the architecture of Group Cell should be linear, so the optimal size of Group Cell is 2. In the urban circumstance, centrally symmetrical architecture is better for constructing the whole network, so the optimal size of Group Cell is 3. Aiming at the special standard demands of the communication systems, the optimal size selection for Group Cell can be given by the four pieces of criteria.

Based on the analysis and simulation, the optimal size selection criteria in this paper can also be applicable to other multi-antenna cellular architecture with different performance demands.

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