Access Control for Coordinated Multi-antenna Cellular Architecture with Scheduling

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Abstract—**While current research focuses on Enhanced 3rd Generation and IMT-Advanced mobile systems, many advanced techniques are investigated by world-wide research institutes and standard organization, such as Multi-Input Multi-Output, Coordinated Multi-Point and coordinated multi-antenna cellular network architecture. Based on these novel techniques, the access control strategies also need to be developed. Based on Maximum Utility Principle Access Control method, improved access control algorithm with combination of scheduling for coordinated multi-antenna cellular architectures is proposed in this paper. Two algorithms are brought out with the Proportional Fairness and Maximum C/I utility function respectively. By application in Coordinated Multi-Point based Group Cell architecture, performance evaluation and analyses verify the merits of two proposed algorithms in improving system throughput, user fairness and efficiency of system resources usage.**

Keywords-Access Control; coordinated multi-antenna; scheduling; Maximum Utility Principle Access Control; Group Cell

I. INTRODUCTION

The objective of the Enhanced 3rd Generation (E3G), 4G has been anticipated to provide users after the year 2010 with the data rate up to 100Mbps or 1Gbps in mobility environments [1-2]. Numerous research plans and projects towards E3G and 4G have been initiated in Europe, East Asia and North America, etc. Many international standardization organizations, such as 3GPP Long Term Evolution (LTE) [1] and LTE-Advanced [3], have initialized the research and standardization of E3G systems. Moreover, International Telecommunication Union (ITU) has also launched 4G standardization work, named IMT-Advanced [4].

With the research and development for E3G and 4G systems, a lot of advanced physical layer technologies show their merits to be applied in next generation mobile telecommunication systems. Among these techniques, the multi-antenna techniques and multi-carrier techniques, such as Multi-Input Multi-Output (MIMO) and Orthogonal Frequency Division Multiplex (OFDM), show their merits in improving system capacity and coverage. MIMO and OFDM techniques have been standardized in 3GPP LTE system as key techniques of E3G physical layer. Moreover, Coordinated Multi-Point joint transmission was proposed in 3GPP LTE-Advanced standard work as a key technique to mitigate Inter Cell Interference and further improve the cell-edge performance [5-6]. In this approach, if both data and channel of all users could be shared in real time, adjacent base stations could act as a single and distributed antenna array and hence, data to a user is simultaneously transmitted from multiple base stations to improve the received signal quality. Notice that Coordinated Multi-Point (CoMP) techniques have been already implemented in Group Cell architecture [7-8] with coordinated multi-antennas as early as 2001, which has been implemented in China Beyond 3G (B3G) Future Technologies for Universal Radio Environment (FuTURE) TDD systems in B3G trial network with OFDM, and MIMO techniques, etc.

Accordingly with the evolution of physical layer techniques, the Media Access Control (MAC) and Radio Resource Management (RRM) techniques are all facing the requirements for evolution. Furthermore, in order to apply CoMP joint transmission effectively, traditional RRM strategies for cooperation among coordinated cells also need to be evolved either.

The access control methods used in 2G/3G systems [9-10] cannot accommodate the features of coordinated multi-antenna cellular architecture, especially for users served by coordinated multiple antennas. There are a lot of challenges for coordinated multi-antenna access control strategy, such as the optimization of choosing multi-antennas to form the coordinated transmission set for access users, the definition of admission threshold for access users and the principal of admission and rejection etc.

In [11], Maximum Utility Principle Access Control (MUPAC) method for coordinated multi-antenna cellular architecture with application in Group Cell architecture was brought out as an example. MUPAC method can maximum the usage of limited system resources with guaranteeing access users' QoS requirements based on defined utility functions [11]. Furthermore, through MUPAC method, the interference increasing caused by access users can also be mitigated maximally and the accessing success probability, accessed user number can also be improved.

With MUPAC method, when the system is under heavy-load situation, MUPAC can fully show its merits in improve resource usage efficiency. However if the system is relatively light loaded and the capacity is enough for more users, MUPAC method may not fully use system capability to serve users with its best, because MUPAC cares more on the minimum QoS requirements for resource utility rather not on users better performance. So, scheduling can be used in combination with MUPAC method to solve this problem and improve user service experience after access success ratio improvement.

This paper presents two improvement algorithms based on MUPAC with scheduling utility function. One is Throughput Targeted MUPAC (TT-MUPAC) and another is Throughput and Fairness Targeted MUPAC (TFT-MUPAC) algorithm.

In Section II, MUPAC method is briefly introduced with an application example in coordinated multi-antenna Group Cell architecture. In Section III, TT-MUPAC and TFT-MUPAC are described in details combining with scheduling in access control. The performance evaluation and simulation results are stated in Section IV. Finally, there comes the conclusion.

II. Maximum Utility Principle Access Control Strategy in Group Cell Architecture

In order to further improve performance for the cell edge users, CoMP will be applied in LTE-Advanced. CoMP implies dynamic coordination among multiple geographically separated transmission points, which involves two schemes with coordinated scheduling and joint processing/transmission. By aggregating the joint processing of multiple cells, CoMP technology can increase the throughputs on the cell-edge. A typical system model for coordinated multi-antenna cellular architecture is Group Cell, which is described in Figure 1.

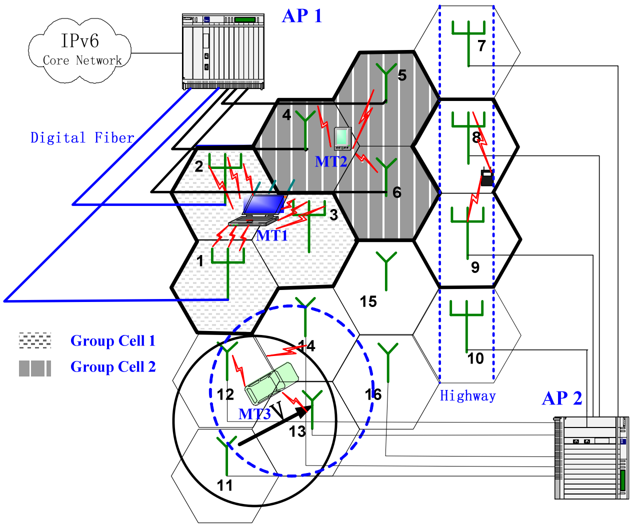

Figure 1. Group Cell Architecture with CoMP

In Group Cell architecture, users in the system are served by more than one antenna (Group Cell) included in Access Points (AP). The access control method in the Group Cell needs to solve the problem of how to choose multiple antennas to form the serving Group Cell and allocate appropriate resources to users. The size of Group Cell can be adjustable for users by their QoS requirements. Therefore, by adding antenna with maximum utility to user's current serving Group Cell step by step to fulfill the users' QoS requirements can solve this problem. This solution can maximize the usage of limited system resources with guaranteeing access users' QoS requirements. Furthermore, the interference caused by new users can also be mitigated maximally and the accessing success probability can also be improved.

The steps of adding antennas with maximum utility can be accomplished based on Dijkstra's Shortest Path Algorithm [12] in Graph Theory. Based on Dijkstra's Shortest Path Algorithm, when there are new users initiate their access attempts in Group Cell architecture, the shortest path in the Dijkstra's Algorithm can be replaced by the minimal cost of accessing process. The cost of accessing process includes the interference to other users and occupying system resources (antennas, channels and other resources). Furthermore, the cost can be represented by the utility functions, including the gains for the access user and deterioration to other users. Therefore, the seeking for shortest path in Dijkstra's Algorithm can be transferred to seeking the antennas or resources with maximum utility. The Maximum Utility Principle can improve the system capacity and load ability. By the Dijkstra's Shortest Path Algorithm and the Maximum Utility Principle, the user accessing in multi-antenna distributed Group Cell can be effectively accomplished.

The utility function of MUPAC has two aspects, including the gain of new antenna added in current serving Group Cell and the deterioration for other users existed in the system.

The utility function is shown as (1).

$$U(i,...,j,k) = \zeta_{Ck}[G_C(i,...,j,k) - I_C(i,...,j,k)] + \beta(1-\zeta_{Ck}) \max_{M \neq C} \{\zeta_{Mi} \cdot ... \zeta_{Mj} \cdot \zeta_{Mk}[G_M(i,...,j,k) - I_M(i,...,j,k)]\}, \quad (1)$$

where $U(i,...,j,k)$ denotes the utility of adding antenna k to current serving Group Cell formed by antennas $i,...,j$. C and M denote the resources and C is the current resource used by the serving Group Cell. ζ_{Ck} is an indicator function, which indicates the occupying information of resource C in antenna k.

$$\zeta_{Ck} = \begin{cases} 0, \text{Resource } C \text{ occupied in } AE\ k \\ 1, \text{Resource } C \text{ available in } AE\ k \end{cases}, \quad (2)$$

where $G_C(i,...,j,k)$ denotes the gain achieved by adding antenna k to current Group Cell with resource C. $I_C(i,...,j,k)$ denotes the interference to other users by adding antenna k to current serving Group Cell with C. β is a constant between 0 and 1 to introducing the penalty for replacing current resource C with different resource (resource C') for the new serving Group Cell. β can be set according to the current system load condition. The choice of C' to replace C can also be achieved by Maximum Utility Principle with the utility function, which is:

$$C' = \arg\max_{M \neq C} \{\zeta_{Mi} \cdot ... \zeta_{Mj} \cdot \zeta_{Mk}[G_M(i,...,j,k) - I_M(i,...,j,k)]\}. \quad (3)$$

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Considering the actual mobile systems, the gain and interference in utility function are usually represented by SINR. Therefore, (1) can be revised to:

$$U(i,...,j,k) = \zeta_{Ck}[\frac{\lg_{k,i}}{\sum_{n\neq i,j...,k}(1-\zeta_{Cn})\lg_{n,i}} - \sum_{n\neq i,...,j,k}(1-\zeta_{Cn})\frac{\lg_{n,n}}{\lg_{k,n}}] + \beta(1-\zeta_{Ck})\arg\max_{M\neq C}\left\{\begin{array}{l}\zeta_{Mi}\zeta_{Mj}\cdots\zeta_{Mk} \\ [\frac{\lg_{k,i}}{\sum_{n\neq i,...,j,k}(1-\zeta_{Mn})\lg_{n,i}} - \sum_{n\neq i,...,j,k}(1-\zeta_{Mn})\frac{\lg_{n,n}}{\lg_{k,n}}]\end{array}\right\} \quad (4)$$

And (4) can also be revised to:

$$U(k) = \arg\max_{C}\left\{\zeta_{Ck}[\frac{\lg_{k,k}}{\sum_{n\neq k}(1-\zeta_{Cn})\lg_{n,k}} - \sum_{n\neq k}(1-\zeta_{Cn})\frac{\lg_{n,n}}{\lg_{k,n}}]\right\}, \quad (5)$$

where $\lg_{n,k}$ denotes the path gain between antenna n to the access user who is currently served by antenna k. The power for each antenna in (4) and (5) are equally allocated.

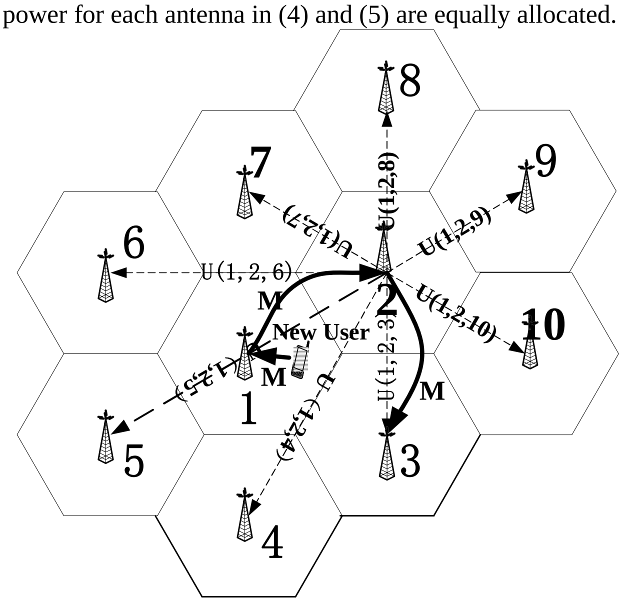

Figure 2. MUPAC process in Group Cell

The application example of MUPAC in Group Cell architecture is shown in Figure 2. The detailed implementation steps of MUPAC are shown as follows.

1) Access user initiates access attempt.

2) AP obtains the users' receiving pilot strength of each antenna.

3) Based on the information in step 2), AP calculates the utility of each antenna and available resource by utility function and chooses the first antenna and resource with the Maximum Utility Principle to form the serving Group Cell. If all the antennas detected by access user have no resource available, the access user will be transferred to the accessing waiting list. In Figure 2, the access user select antenna 1 as the first serving antenna with resource unit by Maximum Utility Principle.

4) AP obtains the users' receiving SINR of serving Group and compares it with user's QoS requirement. If current serving Group can provide adequate QoS to the user, the access process accomplishes successfully. Vice verse, the access user need more antennas added to the current serving Group. In Figure 2, the access user needs more antennas to get its desired QoS. So, antenna 2 is chosen to be added in current serving Group Cell.

5) AP obtains the users' receiving SINR of antennas excluding current serving Group and chooses the antenna with maximum utility to add it to the serving Group Cell. This step needs to guarantee the new antenna and current serving Group Cell to use the same resource. The utility function includes the penalty of resource changing. Then, goes to step 4). In Figure 2, antenna 3 is added and the serving Group Cell of 1, 2 and 3 has enough quality to serve the user with resource unit M.

III. MAXIMUM UTILITY PRINCIPLE ACCESS CONTROL WITH SCHEDULING

When we are choosing the algorithms for access control, we always care about the quality of services, as well as the efficiency of resource which is associated with the system capacity. Ensuring the QoS of access users' communications, MUPAC method gives the least sources to users to reach a minimum acceptable QoS. Considering the variable mobile communication environments and multi-user diversity, also the service experience of users, it will be helpful to implement scheduling into the process of access control for coordinated multi-antenna cellular architecture.

A. Throughput Targeted-MUPAC

In order to enable better use of the resources and reaching higher system throughput, we should consider using scheduling in access control to adapt to different environments and make full use of the resources. When the system load is light, MUPAC is not good enough, especially in the condition of dealing with data services. If we make full use of system resources and increase the system throughput, it would be beneficial to either the users or the system. TT-MUPAC brings out a good consideration on this point.

TT-MUPAC strategy gives different resources to different users in access control which depends on the system conditions. If the system is heavy-loaded with many services required, it gives the user the least resource to reach the required QoS. On the other hand, if the system is relatively light-loaded and there are many resources available, the access users will get most resource to improve system throughput.

In TT-MUPAC strategy, MAX C/I scheduling is employed. The key point of combination of MAX C/I and MUPAC is to give some users more resource to get multi-user diversity in the system. In this way, we can improve the system throughput obviously.

B. *Throughput and Fairness Targeted-MUPAC*

TT-MUPAC brings some advantages on system throughput, but when it comes to user fairness, the performance is decreased. Throughput and fairness are both important in access control strategy. So we should make some improvements on MUPAC and TT-MUPAC methods to reach a better performance on throughput and fairness. TFT-MUPAC method is proposed to achieve a balance between fairness and system throughput.

In the TFT-MUPAC strategy, the utility function of TFT-MUPAC should consider both system throughput and user fairness. In order to include the consideration of fairness into the access control strategy, we add a fairness factor into the utility function to present the improvement.

$$U'(i,...,j,k) = F \bullet G(i,...,j,k) = \left(\frac{R_{average}}{R_{generated}}\right)^{\gamma} \bullet \zeta_{Ck}[G_C(i,...,j,k) - I_C(i,...,j,k)] + \beta(1-\zeta_{Ck}) \max_{M \neq C} \left\{ \zeta_{Mi} \cdot ... \zeta_{Mj} \cdot \zeta_{Mk}[G_M(i,...,j,k) - I_M(i,...,j,k)] \right\} , \quad (6)$$

F denotes the fairness of the service quality, which is,

$$F = \left(\frac{R_{average}}{R_{generated}}\right)^{\gamma} . \quad (7)$$

$R_{generated}$ is the service quality user can get with the target antennas when he is accessed. $R_{average}$ is the average service quality of the users already in the system. γ is the factor of fairness and can be adjust with the actual situation. When γ is getting bigger, the fairness will be better. In the simulation of this paper, γ is set as 1.

The flow chart of TFT-MUPAC is show in the Figure 3.

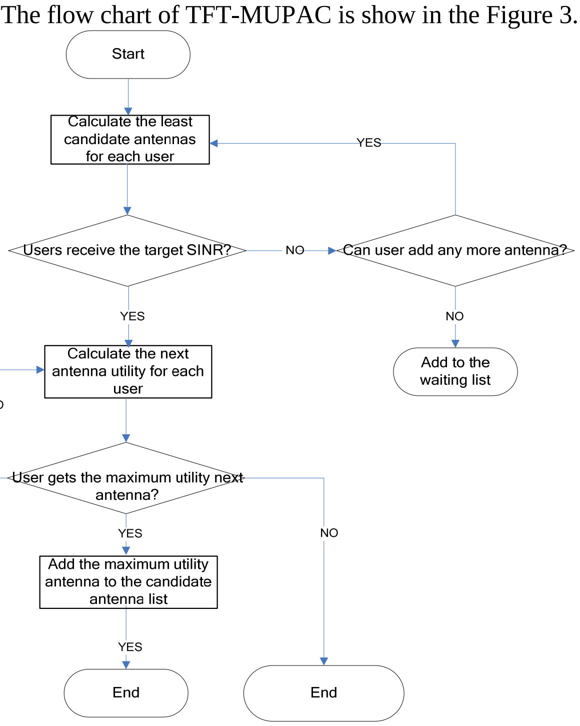

Figure 3. TFT-MUPAC method Flow Chart

In the TFT-MUPAC strategy, antennas are allocated to receive a fairer QoS. At the same time the system throughput is also considered. Proportional fairness scheduling method is employed. In this way, system carries out a good performance on both system throughput and fairness.

IV. PERFORMANCE EVALUATION

For the performance evaluation and analyses, MUPAC method is taken for performance comparing based on coordinated multi-antenna Group Cell architecture. Maximum Utility Principle Access Control chooses antennas and allocates resources according to the Maximum Utility Principle. The Group Cell size of Maximum Utility Principle Access Control method is limited up to 4. TT-MUPAC and TFT-MUPAC employs scheduling with MAX C/I and Proportional Fairness algorithms. System-level simulation is adopted to evaluate these three access control methods by comparing the successfully accessed user numbers with different system load (total access user number generated), system throughput and fairness. The power allocation for these three algorithms is the same as fixed power allocation scheme. The simulation parameters and setting are shown in Table I.

TABLE I. SIMULATION PARAMETERS AND SETTING

Parameters	Setting
Traditional inter-site distance	$500\sqrt{3}$ m
Group Cell inter-antenna distance	500m
Carrier Frequency	5.3GHz
Path gain model	25log10(d)+35.8 [13]
Shadow fading deviation	5dB
Total bandwidth	20MHz
Effective bandwidth	17.27MHz
Number of useful sub-carriers	884
Sub-carrier spacing	19.5KHz

The simulation results are shown in Figure 4 to Figure 8.

Figure 4 shows the system throughput of MUPAC and TT-MUPAC. TT-MUPAC has obvious throughput advantage over MUPAC scheme. The reason for this throughput gain mainly comes from multi-user diversity with MAX C/I scheduling. MUPAC only guarantees the minimum requirements of access users' QoS for maximum resource efficiency. By TT-MUPAC, scheduling is to improve the throughput with light load.

Figure 5 shows the access success rate of MUPAC and TT-MUPAC. TT-MUPAC is better than MUPAC, because TT-MUPAC use more resources for few users to get more throughputs. The relatively low efficiency of resource utility makes access users having less available resources and lows down the access success rate.

Figure 6 shows the fairness of access users based on MUPAC and TT-MUPAC by SINR variance. From the simulation results, TT-MUPAC has worse fairness than MUPAC. This is the nature of MAX C/I scheduling method.

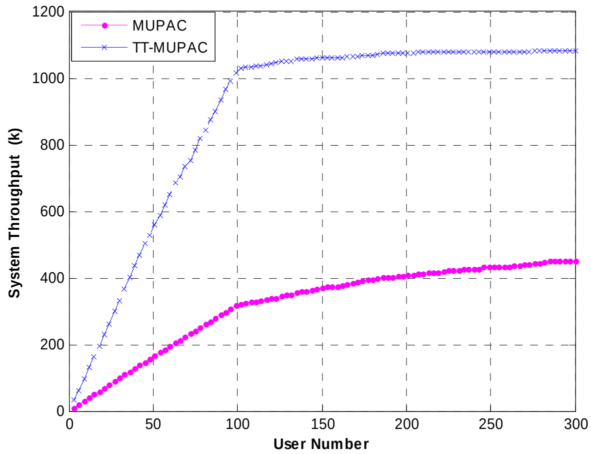

Figure 4. System Throughput of MUPAC vs. TT-MUPAC

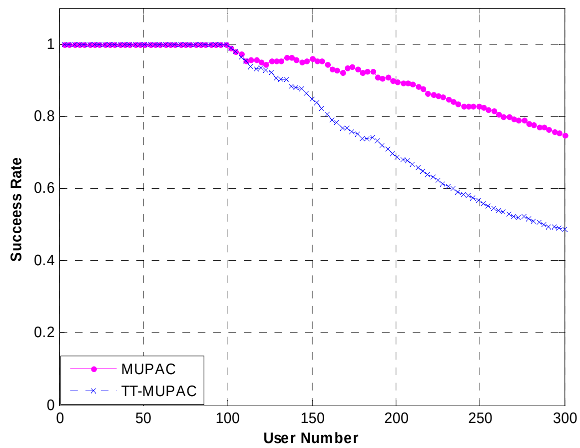

Figure 5. Access Succeed Rate of MUPAC vs. TT-MUPAC

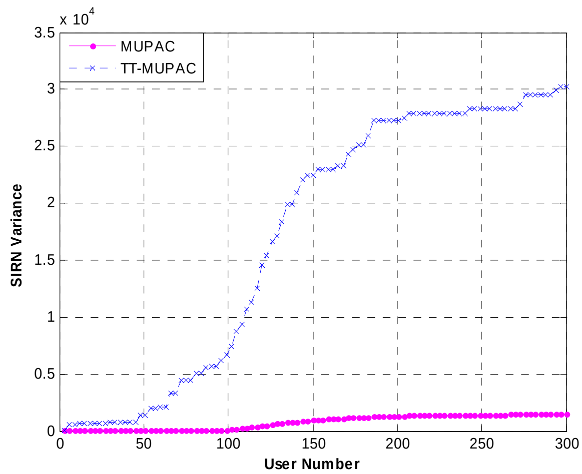

Figure 6. System Fairness of MUPAC vs. TT-MUPAC

Figure 7 and Figure 8 show the performance of MUPAC, TT-MUPAC and TFT-MUPAC, including system throughput and user fairness. Figure 7 shows the throughput performance of MUPAC, TT-MUPAC and TFT-MUPAC. TT-MUPAC has the best performance and TFT-MUPAC has the worst performance with the features of scheduling methods. Figure 8 shows the user fairness of these three methods. TFT-MUPAC has better fairness performance than MUPAC and TT-MUPAC.

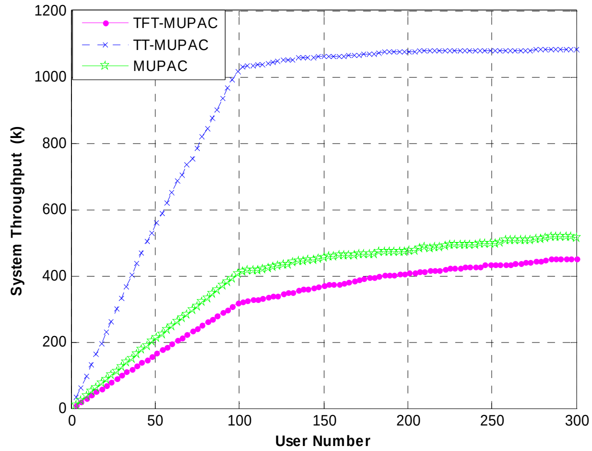

Figure 7. System Throughput of MUPAC, TT-MUPAC and TFT-MUPAC

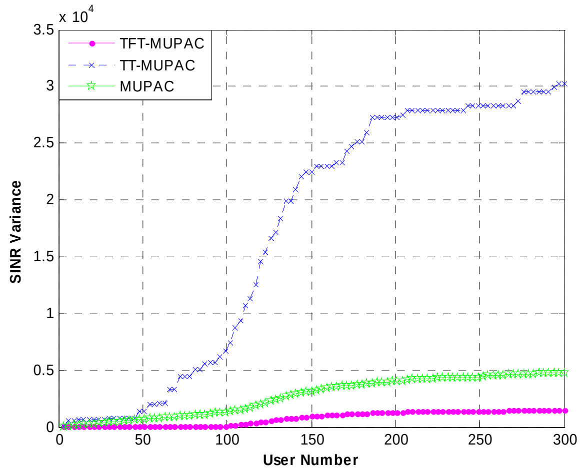

Figure 8. User Fairness of MUPAC, TT-MUPAC and TFT-MUPAC

V. CONCLUSIONS

Maximum Utility Principle Access Control method was proposed for coordinated multi-antenna cellular architecture by Dijkstra's Shortest Path Algorithm and utility function with Maximum Utility Principle for step by step multi-antenna choosing for access users.

Based on MUPAC, this paper proposed two improvements for MUPAC with scheduling algorithms. With combination of scheduling and access control strategy, Throughput Targeted-MUPAC and Throughput and Fairness

Targeted-MUPAC can get better performance of system throughput and user fairness respectively with appropriate resource utility efficiency to accommodating different situation of system load and access users. Taken coordinated multi-antenna cellular architecture - Group Cell as application, TT-MUPAC and TFT-MUPAC algorithm are described in details with the utility function, revised maximum utility principle and flow chart of accessing process. Performance evaluation and analyses verify the merits of TT-MUPAC and TFT-MUPAC algorithms in improving system throughput, accessing success rate and user fairness.

VI. ACKNOWLEDGMENT

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REFERENCES

[1] 3GPP. TR25.913, Requirements for Evolved UTRA (E-UTRA) and Evolved UTRAN (E-UTRAN), 2009.

[2] ITU-R 229-1/8, Draft text for ANNEX 4 of the Circular Letter on an invitation propose candidate radio interface tech. for IMT-Advanced.

[3] 3GPP R1-082024, A discussion on some technology components for LTE-Advanced," Ericsson, 3GPP TSGRAN WG1 #53, 2008.

[4] C. Wijting, K. Doppler, K. KallioJarvi, T. Svensson, M. Sternad, G. Auer and N. Johansson. Key technologies for IMT-advanced mobile communication systems, IEEE Wireless Communications, vol. 16, no. 3, pp. 76-85, 2009.

[5] 3GPP R1-082024, A discussion on some technology components for LTE-Advanced, Ericsson. 3GPP TSGRAN WG1 #53, Kansas City, MO, USA, 2008.

[6] 3GPP TR 36.814, Further Advancements for E-UTRA Physical Layer Aspects (Release 9), 2010

[7] P. Zhang, X. Tao, J. Zhang, Y. Wang, L. Li, and Y. Wang. The Visions from FuTURE Beyond 3G TDD, IEEE Communications Magazine, vol. 43, no.1, pp. 38-44, Jan. 2005.

[8] X. Tao, Z. Dai, and C. Tang. Generalized cellular network infrastructure and handover mode-group cell and group handover. Acta Electronic Sinica, vol. 32, no. 12A, pp. 114-117, 2004.

[9] R. M. Rao, C. Comaniciu, T. V. Lakshman, and H. V. Poor. An overview of CAC principles in DS-CDMA networks – call admission control in wireless multimedia networks, IEEE Signal Processing Magazine, vol. 21, no.5, pp. 51-58, 2004.

[10] N. Bambos, S. C. Chen, and G. J. Pottie. Channel access algorithms with active link protection for wireless communication networks with power control, IEEE/ACM Trans. Networking, vol. 8, no.5, pp. 583-597, 2000.

[11] X. Xu, C. Wu, X. Tao, Y. Wang, and P. Zhang. Maximum Utility Principle Access Control for Beyond 3G Mobile System, Wireless Communications and Mobile Computing, Journal of Wiley, vol. 7, no. 8, pp. 951-959, 2007.

[12] E. W. Dijkstra. A note on two problems in connection with graphs. Numerische Mathematik, pp:269-271, 1959.

[13] X. Zhao, J. Kivinen, P. Vainikainen, and K. Skog. Propagation characteristics for wideband outdoor mobile communications at 5.3 GHz, IEEE Journal on Selected Areas in Communications, vol. 20, no.3, pp. 507-514, 2002.