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Adaptive Resource Balanced Allocation Algorithm for Inter-Cell Interference

Jung-Shyr Wu[1], Yu-Shun Liu[12], Zhi-Kai Zhan[1]

[1]Dept. of Communication Engineering, National Central University
No. 300, Zhongda Rd., Zhongli District, Taoyuan City 32001, Taiwan (R.O.C.)

[2]Dept. of Computer Science and Information Engineering, Vanung University
No.1, Wanneng Rd., Zhongli Dist., Taoyuan City 32061, Taiwan (R.O.C.)

Abstract

To resolve issue of poor mobile communication signaltransmission, one of the solutions is to deploy small base stations. However, overly dense deployment results in interference between adjacent frequency bands, which subsequently causes Inter-Cell interference. Furthermore, users in the base station coverage edge can be interfered by other base stations more easily. The traditional Inter-Cell Interference Coordination (ICIC) mechanism lets adjacent base stations use different frequency bands. It reduces interference among small base stations in densely deployed areas efficiently, and is simple to implement, yet not flexible enough. This paper proposes Adaptive Resource Balanced Allocation Algorithm (ARBA), which takes into account the Quality of Service (QoS) and Channel Quality Indicator (CQI) and calculates the weight of allocating RB according to how many users each base station serves and the current Guaranteed Bit Rate (GBR) to Non-GBR ratio of the base stations. The algorithm allocates Resource Blocks (RBs) dynamically to raise system throughput and user's satisfaction level. Base stations which is short of resource can hence obtain minimum resource. The use of resource becomes optimized and fairer.

Keywords:ICIC, Resource Allocation, QoS, CQI

1. INTRODUCTION

User client hardware has become much more powerful. Data transmission throughput is getting larger. The initiation of Long Term Evolution (LTE) [1] wireless network access technology aims at providing higher data transmission rate and improving spectrum usage to satisfy user's transmission demand. According to 4G mobile communication technology standard set by International Telecommunication Union (ITU), the transmission rate and system data of LTE are below standard, and therefore is not real 4G. LTE-Advanced (LTE-A) [2] is a new standard set by ITU. In normal Carrier Aggregation (CA) [3] specification, only a single Component Carrier (CC) is used for transmission. However, to satisfy high transmission requirement, LTE-A allows 2 or multiple CC to be employed. UE can use different CC simultaneously; bandwidth of a single CC can be 1.4, 3, 5, 10, 15, or 20MHz. LTE-A allows continuousor non-continuous CA.

It also allows inside or outside-spectrum CA, as well as Intra-Band Continuous, Intra-Band Non-Continuous, and Inter-Band Non-Continuous CA mode.

Coordinate Multipoint (CoMP) [4] has two major modes: Joint Processing (JP) and Coordinated Scheduling/Beaforming (CS/CB). Joint Processing is divided into Joint Transmission (JT) and Dynamic Cell Selection (DCS). Joint Transmission is a simultaneous transmission mode. It enables multiple base stations or Remote Radio Heads (RHHs) to serve one user together at the same time, which makes the user feel good about the transmission quality. Dynamic Cell Selection is distributed on every transmitter over CoMP. It controls base station to determine which transmitter is best for the user and enables the transmitter to be responsible for transmitting data to the user. In this way, the user receives signals from only one transmitter. Coordinated Beamforming aggregates energy into a small area in order to transmit data to users in distance, and thus, it is less easy to be interfered or interfere other base stations.With regard to Enhanced MIMO specification, [5] LTE MIMO specification allows 4 x 4 antennas maximally downlink. LTE-A MIMO specification allows maximally 8 x 8 antennas downlink and 4 x 4 antennas uplink. In addition, Multi-User MIMO (MU-MIMO) is also provided. In Single-User MIMO specification, multiple antennas are used simultaneously to transmit data to a single user, whereas in MU-MIMO specification, multiple antennas are allowed to transfer data to multiple users at the same time. The transmission performance is evidently improved.

LTE uses Orthogonal Frequency Division Multiple Access (OFDMA) modulation technique downlink to divide resource by frequency and time. It is capable of high speed data transmission. In Each time slot, twelve 15 kHz continuous sub-carriers are formed a downlink Resource Block (RB) to serve as the basic unit in LTE's resource allocation. Each RB is composed by 7symbols and 12 sub-carriers. The smallest block composed by each symbol and sub-carrier forms the minimum Resource Elementunit of spectral resource. There are 84 REs in each RB. Each RE has its own modulation mode depending on the CQI. Each RB's data transmission amount also varies. With respect to time domain, each frame is divided by a 10ms period. The latter is further divided into 10 sub-frames of 1ms. Each sub-frame is made up of two 0.5ms time slots. Each time slot has 6 to 7 symbols. There are a few methods to improve the transmission rate of wireless communication system, e.g., spectral usage rate, frequency allocation, modification of base station deployment density, and etc. Among them, raising base station deployment density is a better solution. Therefore, developing high density small base station related technique becomes crucial for moving forward to 5G.Small base station provides better signal quality because it is closer to users. It is usually installed in the coverage edge of macro base station. It not only enhances the signal quality in the edge, but also extends service range. Additionally, it can also be constructed in densely populated areas to share the load of macro base station, or to solve poor signal problems in large buildings or basements. When small base stations have been densely deployed, interference among them becomes obvious. Although small base station has a variety of advantages, user who is in the overlapping area of two small base stations may receive signals from both of them. If they are of the same frequency, the user client can be severely interfered, even suffer from reception break up.

This paper is organized as follows: 1. Introduction. 2. Related works. 3.Problem formulation. 4. Proposed algorithm. 5. Performance validation and results. 6. Conclusions. 7. References.

2. RELATED WORKS

Inter-Cell interference often happens in cell edge. In homogeneous network architecture, UE receives several small cell signals of the same frequency, and thus has a high opportunity to be interfered by other small cell signals. The solution 3GPP release 8 proposestoresolve inter-cell interference is Inter-Cell Interference Coordination (ICIC) [6]. Its major technique is Frequency Reuse, which reduces inter-smallcell interference by reallocating frequency. Soft Frequency Reuse (SFR) is the most typical method of ICIC. The spectrum is divided into two groups: major sub-carrier group and minor sub-carrier group. The UE in service is categorized into two kinds: UE of relay node (at cell edge) and UE of central node (at cell center).Related study is as presented in [7]. The study was based on cognitive sensing technique and proposed a multilayer solution, containing channel assignment, power allocation, and macrocell to femtocell scheduling, to decrease interference. The adjacent small cells were grouped as a physical cluster (PC) to reduce interference. Virtual Cluster (VC) mechanism was then employed to reallocate power so as to decrease inter-layer interference. The result performance was acceptable.[8] adopted traditional ICIC method. In sector regional networks, partial resource preserved for UEs in the small cell center and that in the small cell edge were allocated by orthogonal adjacent small cells. eNBcould allocate users using sub-carriers and was capable of carrying communication information such as ICIC. The relay nodes could self-adaptively reused boundary spectrum in the adjacent small regions (center of orthogonal small region and edge of adjacent small region) to serve UEs. The gains were thereby reused to reduce interference and increase average SINR and user throughput. [9] equaled the distance between a smallcell and a macrocell to the priority of sub-carrierallocation. The smallcell closest to the macrocell was given the priority to allocate sub-carriers. As a result, SINR became the foundation of allocation (the one with the best SINR had the priority to allocate sub-carriers). The priority was determined according to the user's interference level, QoS, and Head of Line (HOL). The priority of scheduling sub-carriers could be found, throughput and performance be boost as well. Nevertheless, the default setting of small cells was similar. Therefore, the distance between smallcell and macrocell became the deciding factor of priority and QoS. Authors of [10]investigated the factors of frequencyreuse. [11] proposed a channel signal quality based technique, which divided users into cell edge group and cell center group, instead of grouping them according to their distance to the cell. Its interference coordination method was SFR. This coordination mechanism was based on a diagram of interference, which showed the interference relationship among mobile network users.In work [12], a SFR-based multi-cell system mode resource allocation mechanism simplified and established an optimal solution within the restriction of SFR's spectrum and power to obtain an optimized local allocation rule.Many studies focused on how to improve FFR technique so as to become methods of ICIC. This paper proposes dynamic Resource Blocks (RBs) allocation mechanism, which takes into account the Quality of Service (QoS) and Channel Quality Indicator (CQI) and calculates base station weight to allocate RBsbasing on how many users each base station serves and the current Guaranteed Bit Rate (GBR) and Non-GBR ratio of the base stations. Bases stations short of resource can hence obtain minimum resource. The use of resource becomes optimized and fairer.

3. PROBLEM FORMULATION

3.1 Quality indicators

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Channel Quality Indicator (CQI) [13] is a parameter designin cellphone to regularly report backconnection condition ofto base station or to respond to inquiries from base station. Each UE may have specific CQI for each RB. The CQI of LTE is shown in Figure 1. The higher the value of CQI, the better the channel quality, the better the modulation coding mechanism, and the higher the throughput. CQI allows base stations to know the current channel quality. Higher CQI value indicates better channel quality. Base station thus chooses the modulation technique which has higher transmission rate. However, more data are transferred at oncein this way, and the ability to protect signals might be sacrificed. When transmission quality degrades, lower CQI value is reported back by the cellphone. Knowing that the channel quality is bad, base station chooses the modulation technique with lower transmission quality and thereby has stronger ability to protect the transmission data. As a result, less interference, but worse transmission efficiency.

CQI index	modulation	code rate x 1024	efficiency
0	out of range		
1	QPSK	78	0.1523
2	QPSK	120	0.2344
3	QPSK	193	0.3770
4	QPSK	308	0.6016
5	QPSK	449	0.8770
6	QPSK	602	1.1758
7	16QAM	378	1.4766
8	16QAM	490	1.9141
9	16QAM	616	2.4063
10	64QAM	466	2.7305
11	64QAM	567	3.3223
12	64QAM	666	3.9023
13	64QAM	772	4.5234
14	64QAM	873	5.1152
15	64QAM	948	5.5547

Figure 1 Channel Quality Indicator (CQI) [Source of information: 3GPP]

Quality of Service (QoS) [14] is a traffic prioritization control mechanism in packet-switched networks. It provides different priority to different UEs or to different types of data in order to raise or ensure the service quality of certain data, especially time-sensitive voice data or multimedia application. For example, Voice over IP (VoIP) and almost real-time data transmission need stable transmission time and rate, and therefore they should be given higher service priority. 3GPP release 8 defines nine service levels (QoS Class Identifier, QCI). Important QoS parameters of EPS loading contains QCI, the classification of which is shown in Figure 2, containing parameters such as priority of service, packet delay budget, etc. This QCI table categorizes resource into two types, Guarantee Bit Rate (GBR) and Non-Guarantee Bit Rate (Non-GBR). GBR allows required data to keep being transferred and guarantees service quality even in high loading condition. In contrast, Non-GBR intends to lower transmission rate in high loading condition. Non-GBR tolerates packet loss and thus is more possible to establish connection all the time. Yet, GBR often sets up connection when it is necessary.

QCI	Resource Type	Priority	Packet Delay Budget	Packet Error Loss	Example Services
1	GBR	2	100ms	10^{-2}	Conversational Voice
2		4	150ms	10^{-3}	Conversational Video (Live Streaming)
3		3	50ms	10^{-3}	Real Time Gaming
4		5	300ms	10^{-6}	Non-Conversational Video (Buffered Streaming)
5	Non-GBR	1	100ms	10^{-6}	IMS Signalling
6		6	300ms	10^{-6}	Video (Buffered Streaming) TCP-based (e.g., www, e-mail, chat, ftp, p2p file sharing, progressive video, etc.)
7		7	100ms	10^{-3}	Voice, Video (Live Streaming), Interactive Gaming
8		8	300ms	10^{-6}	Video (Buffered Streaming) TCP-based (e.g., www, e-mail, chat, ftp, p2p file sharing, progressive video, etc.)
9		9			

Figure 2 QoS Class Identifier (QCI) (Source of information: 3GPP)

3.2 Scheduling algorithms

Packet Scheduling Algorithm is a treatmentby base station to allocate resource to UE. RB is the unit of resource allocation. It is allocated to UE according to the computational result of an algorithm. UE then uses these RBs to transmit data. If a base station receives many requirements, good scheduling mechanism will be necessary in order to complete the work of allocation. For instance, a LTE base station which has 20MHz bandwidth only has 100 RBs to assign per 0.5ms. How to make optimal allocation withinresourcelimit depends on a variety of scheduling algorithmdesigns. When there are different data flows entering the scheduler at the same time, the scheduler collocates the RBs in the scheduling matrix in terms of the scheduling algorithm, e.g., the i^{th} data flow is marked flow(i) and the j^{th}RB is marked RB(j). Each data flow and its corresponding RB have a weight value $m(i,j)$. The corresponding RB will be allocated to the data flow.

The well-known Proportional Fair (PF) [15] algorithm considers both throughput and fairness. Many algorithms base on PF. PF gives priority of resource usage to UE with better channel quality. Thus, a less considerate algorithm could let UE with better channel quality occupy valuable resource and pretend UE with poor channel quality to have enough resource, even starve to death. The feature of PF algorithm is that it can lower the weight of the UE which has higher resource usage rate for a longtime at any time.PF is able to allow disadvantage UE to be allocated with proper resources fairly. To take into account of channel quality and throughput boost, the algorithm is demonstrated by the following equation.

$$m(i,j) = \frac{r_i(t)}{\overline{r_i}(t-1)} i \in NRT, RT \text{ ....}(1)$$

$$\overline{r_i}(t) = \beta \cdot \overline{r_i}(t-1) + (1-\beta) \cdot r_i(t) \quad 0 \le \beta \le 1 \text{ ....}(2)$$

In Equation (1):

1. $r_i(t)$denotes the transmission rate of the data flow in time point t. Channel quality and throughput are both considered. The bigger the value of $r_i(t)$, the higher the priority of the data flow. For fairness of resource allocation, $\overline{r_i}(t-1)$ is used for modification.
2. $\overline{r_i}(t-1)$is regarded as the average transmission rate from the i^{th}data flow to $t-1$. The larger the value of$\overline{r_i}(t)$, the lower the priority. If average rate increases, the weight decreases. Equation (2) figures out $\overline{r_i}(t)$. βvalue is designed as a parameter to make minor modification in order to control the ratio of average rate to attainable rate.

Modified Largest Weighted Delay First (MLWDF) [16] has a largest weighted delay control mechanism. It possesses the advantage which PF does and considers service quality. It guarantees real-time data transmission rate. To take into account head-of-line packet latency and packet loss rate, the algorithm is demonstrated with the equation as follows.

$$m(i,j) = \begin{cases} \frac{r_i(t)}{\overline{r_i}(t-1)} i \in NRT \\ -\log \delta_i \cdot \frac{D_{HOL_i}}{\tau_i} \cdot \frac{r_i(t)}{\overline{r_i}(t-1)} i \in RT \end{cases} \text{ ....}(3)$$

MLWDF processes Real Time (RT) data and Non-Real-Time (NRT) data separately. NRT data is processed usingPF's method. Yet, with regard to RT data, packet latency and loss rate must be taken into consideration. Therefore, in Equation (3), denotes acceptable loss rate. $\boldsymbol{D_{Hi}}$ is the latency of data flow . is the upper limit of the latency of data flow . Compared to the equation of NRT data, RT data transmission contains an additional parameter of weight, $-\log \delta_i \cdot \frac{D_{HOL_i}}{\tau_i}$, for increasing the algorithm's stability.

4. PROPOSED ALGORITHM

Macro base station has bigger power and larger coverage. It demands simulation of many conditions and scenarios before deployment in order to be established. Nevertheless, small base station has the advantages of low power, cost, small coverage, and low tendency to be affected by geographic environment. The factors for consideration concerning establishing small base station are less than those for macro base station. If small base stations are deployed by forming a cluster, the signals from one another will certainly overlap. UE which is in the overlapping area cannot avoid being interfered by signals from other base stations. If the interference must be eliminated, spectrum allocation coordination among base stations should be done. Methods of eliminating interference include frequency division, time division, and space division.

Frequencydivision allows adjacent base stations to use different frequency bands to avoid interference, e.g., ICIC. Time division staggers the time when adjacent base stations use the same frequency band, e.g., eICIC. Space division coordinates the power of the base stations that interfere one another and reduces signal overlapping areas. Static way of space division adjusts the power of the newly added base station with signal factors of other base stations in mind. Dynamic way of space division allows base stations to dynamically detect the environment and automatically adjust power and other parameters. Traditional ICIC is simple and easy to implement. It is suitable for frequency domain resource allocation that is dynamic user priority based. However, this method is not flexible enough regarding the use of spectrum. To cope with this, this paper proposes Adaptive Resource Balanced Allocation algorithm (ARBA) to solve the interference problem that happens in small base station clusters, Different from normal ICIC that is inflexible as to the allocation of spectrum, our algorithm is able to choose the most suitable UE to be assigned with proper resources. This algorithm allocates resources effectively according to the number of UEs which the base station serves and the ratio of GBR to Non-GBR flows. This algorithm is capable of improving system performance and user satisfaction.

Figure 3 illustrates the workflow of ARBA algorithm. The steps are described as follows.

1. by the UEs.
2. Sum all CQI values reported back by all UEs according to the RB's serial number. Categorize the RBs into five groups according to the sum. Give each group a serial number (from 1 to 5). The smaller the number the higher the priority.
3. Figure out ratio, R, of GBR to Non-GBR flows. Mark Hold to the RB which is not yet allocated and has the smallest serial number.
   3-a If no other base station competes for it, the base station will hold the RB.
   3-b If other base stations also mark Hold to RB No.1, then a conflict occurs. The holder of the RB is decided by comparing base stationweight. Weight W_i is calculated by Equation (4). The one with the highest W_i holds the conflicting RB. The other base stations give up this RB.
4. When the competition for RB finishes, each base station calculatesweightratio. Weight ratio, n_i^{demand} , is figured out by Equation (5). Base station that is

lower than the weight ratio should select n_i^{demand} RBs randomlyand be compelled to hold them; the base station should notify adjacent base stations about the situation.

5. Repeat Step 3 to Step 4 until all RBs with a serial number are allocated.

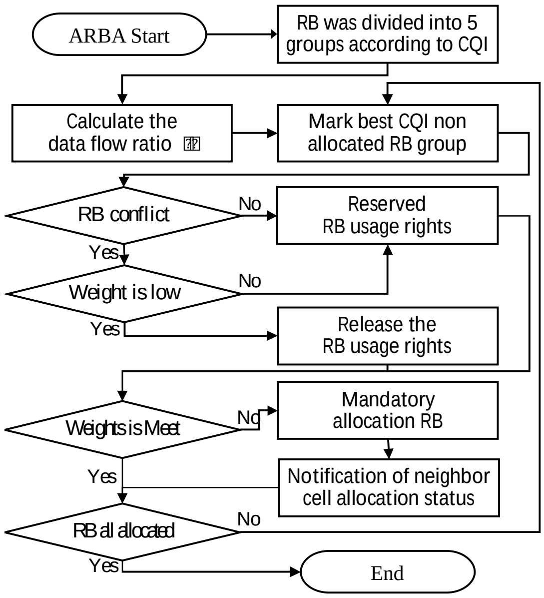

Figure 3 Flowchart of ARBA algorithm

UE1		UE2		UE3		eNB		RB*i* Group	
RB1	5	RB1	7	RB1	10	RB1	22	RB1	3
RB2	10	RB2	4	RB2	5	RB2	19	RB2	4
RB3	2	RB3	11	RB3	1	RB3	14	RB3	5
RB4	6	RB4	8	RB4	6	RB4	20	RB4	4
RB5	8	RB5	5	RB5	8	RB5	21	RB5	3
RB6	4	RB6	10	RB6	15	RB6	29	RB6	1
RB7	16	RB7	5	RB7	13	RB7	34	RB7	1
RB8	13	RB8	9	RB8	6	RB8	28	RB8	2
RB9	1	RB9	15	RB9	2	RB9	18	RB9	5
RB10	9	RB10	13	RB10	4	RB10	26	RB10	2

Figure 4 Base station categorizes RBs into groups according to channel quality indicator (CQI).

Base station weight is calculated as follows.

$$W_i = (\alpha \times R_i \times N_i + (1-\alpha)(1-R_i)) \times N_i \quad \text{.....................(4)}$$

In Equation (4), *i* represents the ***ith*** base station. W^i is the weight of the i^{th} base station. The higher the weight, the higher the priority to possess RB. α is weight coefficient, and it is set between 0.5 to 1. R_i stands for the current ratio of GBR flow to total data flow of the i^{th} base station. N_i is the current amount of people served by the i^{th} base station.

The weight ratio for determining the amount of RBs that the base station requires is calculated as follows.

$$n_i^{demand} = \frac{W_i}{W_{total}} * n^{temp} - n_i^{hold} \quad \text{..............................(5)}$$

In Equation (5), the extra amount of RBs that the base station needs is n_i^{demand}. The weight of the i^{th} base station is W_i. The sum of all base station weight is W_{total}. The total number of currently held RBs is n^{temp}. The i^{th} RB that is temporarily held by the base station is n_i^{hold}. If the computational result by the base station is $n_i^{demand} \geq 1$, then the base station should hold additionally an integer number of $\lfloor n_i^{demand} \rfloor$ RBs; if $n_i^{demand} < 1$, then the base station does not have to hold any more RBs.

For instance, if there are three base stations, $\alpha = 0.55$, each base station serves 20 people, ratio, R, of GBR data flow to total data flow is $R_1 = 0.20$, $R_2 = 0.43$, $R_3 = 0.65$, respectively, W_i is close to $W_1 = 52$, $W_2 = 100$, $W_3 = 148$, respectively after calculation, 10 RBs should be allocated to three base stations (in the simulation, 20MHz and 100 RBs), how much the base station favors the RBs is put into three levels (in the simulation, five groups), according to Equation (5), the extra amount of necessary RBs are:

Presume that base station 1 calculates

$$n_i^{demand} = \frac{52}{300} \cdot 6 - 0 = 1.04 \geq 1.$$

Base station 1 will hold an extra RB from the same group serial number and notify the adjacent base stations that it has held an extra RB.

Presume that base station 2 calculates

$$n_i^{demand} = \frac{100}{300} \cdot 6 - 2 = 0 < 1.$$

Base station 2 does not need to hold more RBs. Ratio balance has been reached.

Presume that base station 3 calculates

$$n_i^{demand} = \frac{148}{300} \cdot 6 - 3 = -0.04 < 1.$$

Base station 3 does not need to hold more RBs. Ratio balance has been reached.

In the aforementioned example, when each base station reaches ratio balance, RB which has group serial number and is already allocated will stay unmoved. The system then starts allocating RBs of the next group.

Supposethat all base stations serve the same amount of people, the larger the GBR data flow of the base station, the more RBs the base station will be allocated. UEs that transfer GBR data flow should also obtain more resources. Yet, in order to pretend base station with small weight from being allocated with no RB, the weight ratio balance here is brought into effect to allow more reasonable resource allocation.

5. PERFORMANCE VALIDATION AND RESULTS

5.1 Simulation architecture and parameter settings

Figure 5 shows a flowchart of the simulation. The system first detects the nearby base stations to know which spectrum resources are conflicting and then proposes a simulation to solve the interference among base stations. Next, the system performs the ARBA mechanism we propose in this paper and the ICIC mechanism. After initial allocation of RBs has finished, base station then uses PF and MLWDF packet scheduling algorithms respectively to assign RBs to UEs.

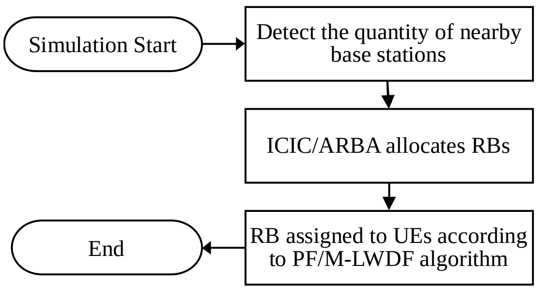

Figure 5 Flowchart of the simulation architecture

Table 1 shows the parameters of the simulation, which are number of base station, base station power, coverage, path loss, shadow fading, system bandwidth, number of RB, length of frame, number of symbol, and modulation and code scheme.

Table 1:PHY layer parameters (Source of information: 3GPP)

Parameter	Value
Number of small-cell in a cluster	3, 5, 7
Marco-Cell transmission	46dBm
Marco-Cell coverage	1000m radius
Small-Cell transmission	30dBm
Small-Cell coverage	100m
Path Loss	128.1+37.6log10(R),R:km
Fast Fading	log-normal shadow fading(8dB)
System Bandwidth	20MHz
Number of Resource Block	100
Length of Frame	10ms
Number of symbol per slot	7
MCS(Modulation and Codec Scheme)	Modulation: BPSK, QPSK, 16QAM, 64QAM Code Rate: 1/2, 2/3, 3/4, 5/6

A single image in a video stream is termed a Frame. Video stream transmission of QCI=2, as shown in Figure 2, requires Frame per Second (FPS) to be more than 25 so as to provide consistency of the video. If clearer image quality is desired, then FPS should be even higher. Table 2 shows the parameters of video stream transmission of the simulation. When FPS is 25, the video plays 25 images per second. The interval between images is 40ms. Each image needs 8 packets to be transmitted.

Table 2: Video stream model parameters

Component	Parameters
Inter-arrival time between frames	40ms
FPS(Frame Per Second)	25
Number of Packets in a Frame	8
AVG Bit Rate	2.3Mbps
Packet Size	Mean:1250Byte
Inter-arrival time between packets	Mean:5ms

5.2 Simulation data and discussion

In this paper, we presume that there is no latency of X2 interface transmission between base stations and the buffer size of base station is not considered. The system is written in C/C++ to simulate ICIC and ARBA algorithms. The number of adjacent base stations is 3 to 7. The validation indicators are throughput, fairness, and satisfaction for evaluating and comparing the advantages and disadvantages of the algorithms.

5.2.1 Throughput

Table 3 shows the parameter value with respect to three base stationswhile GBR rate stays fixed and the number of UE differs.

Figure 6 shows the throughput results of MLWDF downlink scheduling mechanism in combination with ARBA algorithm and ICIC algorithm, respectively. Base stations adopting ARBA algorithm are allocated with more resource and generate higher throughput as UE number increases. Base stations adopting ICIC algorithm are relatively worse in resource and throughput. Figure 7 shows the throughput results of PF downlink mechanism in combination with ARBA algorithm and ICIC algorithm, respectively. The result coincides with which shown in Figure 7. The higher the UE number, the higher the base station throughput.

Table 3:Parameter valueof each base station; GBR rate is fixed.

Serial number of base station	Number of UE	GBR rate
1	70	0.8
2	60	0.8
3	50	0.8

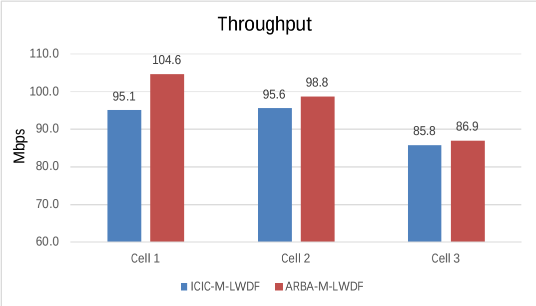

Figure 6 Downlink throughput while GBR rate is fixed.

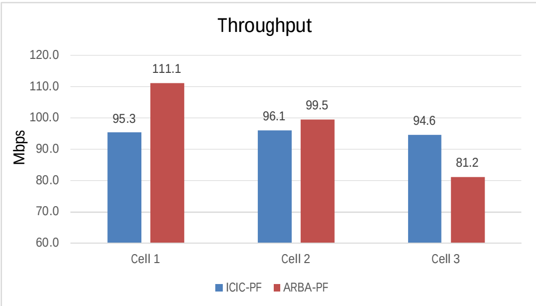

Figure 7 Downlink throughput while GBR rate is fixed.

Figure 8 shows the system allocation rate generated by MLWDF and PF downlink algorithms while GBR is fixed but UE varies. MLWDF generates higher system allocation rate, up to 86.7%, no matter ARBA or ICIC is adopted by UEs of GBR flow. In this case, GBR service quality is guaranteed. However, as to total system throughput, the ARBA-PF algorithm proposed in this paper produces the highest throughput. The transmission quality of GBR flow is better guaranteed. Figure 9 shows the comparison of throughput among different algorithms while GBR rate is fixed.

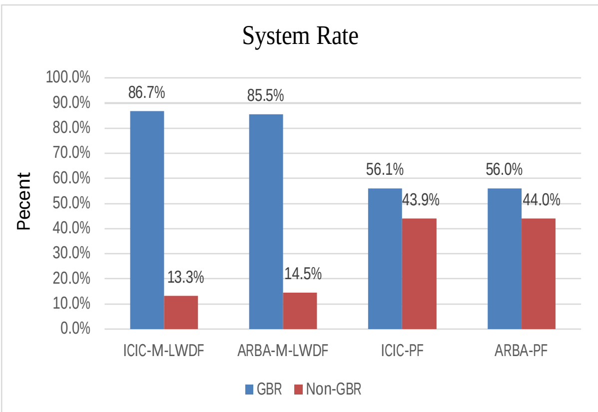

Figure 8 System throughput rate of the algorithms while GBR rate is fixed.

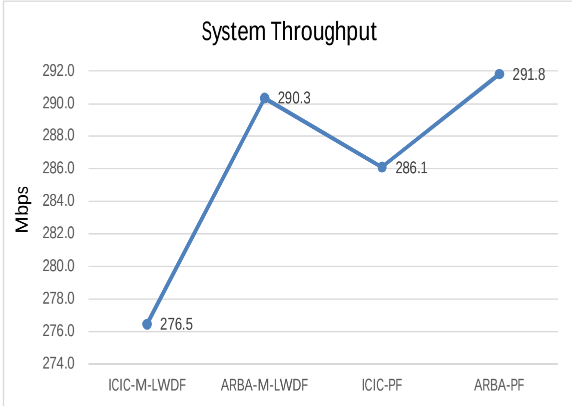

Figure 9 Comparison of system throughput among the algorithms while GBT rate is fixed.

Figure 4 shows the parameter value of the simulation with respect to three base stations while GBR rate varies and UE number is fixed.

Figure 10 shows the simulation results using MLWDF mechanism in combination with ARBA algorithm and ICIC algorithm, respectively. Base station that has higher GBR rate generates better throughput when combining ARBA algorithm. The throughput generated by the three base stations which have adoptedICIC algorithm don'thave much difference among one another. This figure again gives clear evidence that ARBA algorithm is able to guarantee GBR packet transmission, which is more time sensitive.

Table 4: Parameter value of the simulation while UE number is fixed.

Serial number of base station	Number of UE	GBR rate
1	70	0.9
2	70	0.6
3	70	0.3

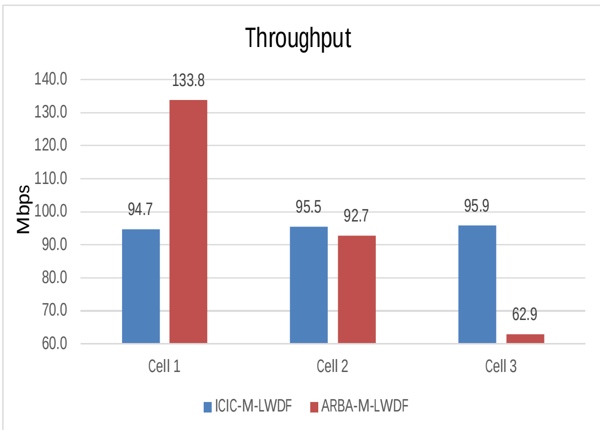

Figure 10 Throughput of the scheduling algorithms while UE number is fixed.

Figure 11 shows the throughput results of the simulation using PF downlink scheduling mechanism with the combination of ARBA algorithm and ICIC algorithm, respectively. With ARBA algorithm, base stations which have higher GBR rate still generate better throughput. However, the difference in throughput among the three base stations is smaller than the result of employing MLWDF downlink scheduling mechanism. The throughput is less influenced by GBR rate. The throughput generated by the three base stations using ICIC algorithms don't have much difference among one another, either. In conclusion, ARBA algorithm certainly has the ability to guarantee GBR packet transmission, which is more time sensitive.

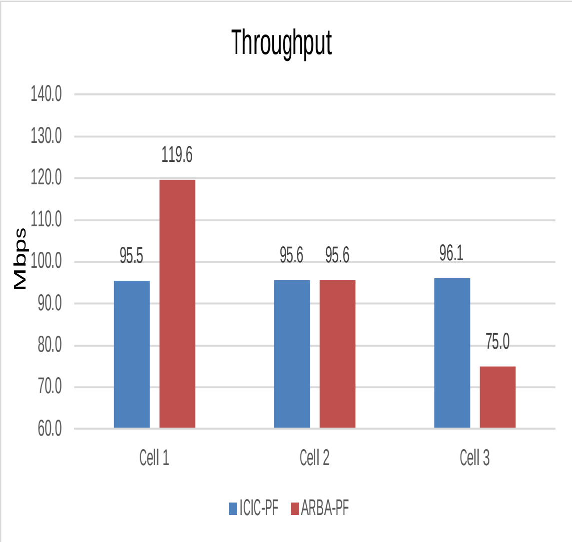

Figure 11 Throughput of the scheduling algorithms while UE number is fixed.

Figure 12 shows system throughput generated by MCWDF and PF downlink scheduling algorithms while GBR rate varies but UE number is fixed. UEs of GBR flow transferred with MLWDF obtain more system rate, both in ARBA and ICIC mechanisms, up to 92.9% maximum. The service quality of GBR is guaranteed. Total system rate is less affected by GBR rate; its slope is close to the number of UEs. The system rate generated by different algorithms and scheduling mechanisms have even fewer differences among one another. Nevertheless, with regard to overall system throughput, the proposed ARBA algorithm still outperforms ICIC. Under such circumstances, we can see that MLWDF can better guarantee the service quality of GBR flow; ARBA algorithm can produce the best overall system throughput. Figure 13 is a comparison of system throughput among different scheduling algorithms while UE number is fixed.

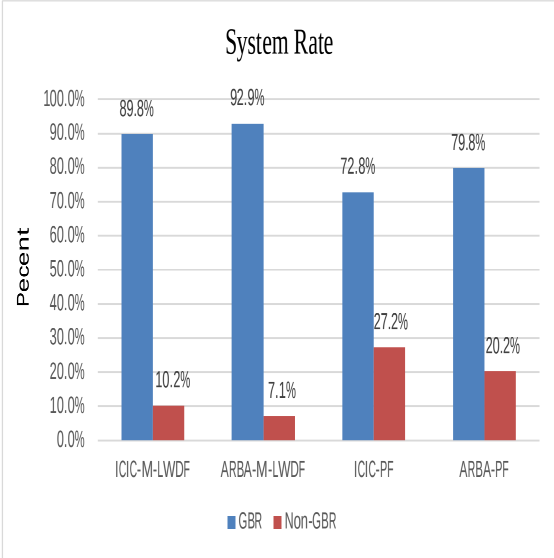

Figure 12 System throughput rate of the scheduling algorithms while UE number is fixed.

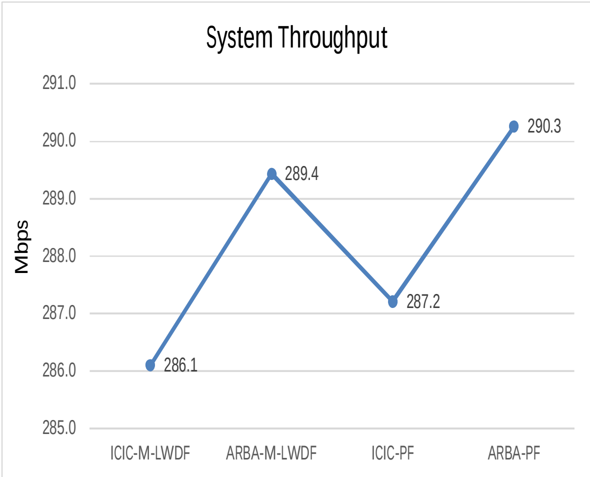

Figure 13 Comparison of throughputamong different scheduling algorithms while UE number is fixed.

Table 5 shows the parameter valuewith respect to three types of base station quantity while the number of UE is fixed and GBR rate varies.

Figure 14 shows throughput change using MLWDF mechanism in combination with ABRA and ICIC algorithm, respectively, while the number of base stations is 3, 5, and 7, respectively, the number of UEs is 70, and GBR rate varies. When the number of base stations is 3, there is not much difference in throughput between ARBA and ICIC algorithms. When the number of base stations is increased to 5, the throughput generated by ARBA algorithm remains the highest. When the number of base stations is increased to 7, the throughput generated by ARBA algorithm surpasses others significantly. Hence, it is proved that ARBA algorithm is capable of raising base station overall throughput.

Table 5:Parameter value of each base station while UE number is fixed.

Serial number of base station	Number of UE	GBR rate
1	70	0.9
2	70	0.8
3	70	0.7
4	70	0.6
5	70	0.5
6	70	0.4
7	70	0.3

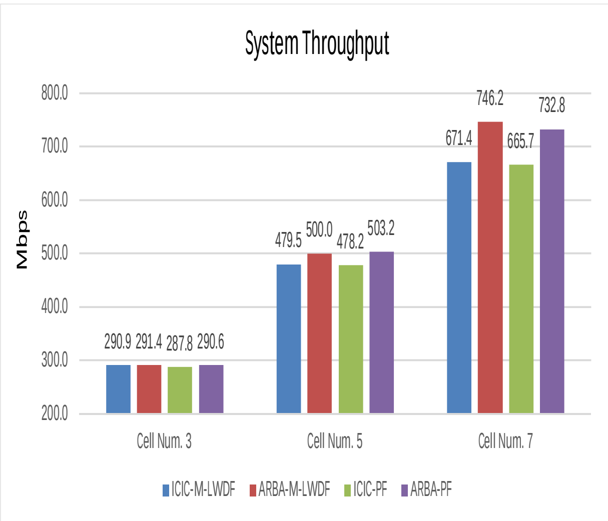

Figure 14 Throughput change of various scheduling algorithms with respect to different base station numbers while UE number is fixed.

Table 6 shows parameter value with respect to three types of base station quantity while the number of UE varies, and GBR rate staysfixed.

Fig 15 shows the throughput generatedby MLWDF downlink scheduling mechanism combining ARBA algorithm and ICIC algorithm, respectively while base station number is 3, 5, and, 7, respectively, the GBR rate of each base station is identical and the number of UE varies. When the number of base station is 3, the throughput generated by different algorithms does not show much difference among one another. When the number of base station is increased to 5 and 7, it is proved as shown that ARBA algorithm can produce better throughput

Table 6:Parameter value of each base station while GBR rate is fixed.

Serial number of base station	Number of UE	GBR rate
1	70	0.8
2	60	0.8
3	50	0.8
4	40	0.8
5	30	0.8
6	20	0.8
7	10	0.8

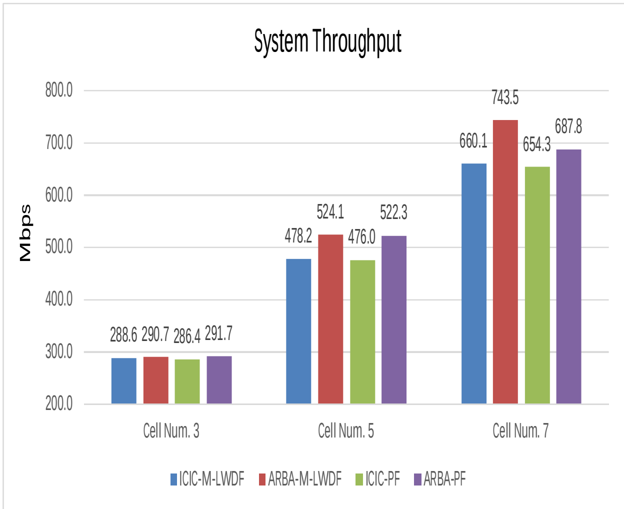

Figure 15 Throughput change of various scheduling algorithms with respect to different base station numbers while GBR rate is fixed.

5.2.2 User fairness

Resource allocation fairness of the simulation system is calculated according to Jain Index [17] algorithm, as follows.

$$User\ Fairness\ Index = \frac{(\sum_{j=1}^{n} User\_throughput_j)^2}{n * \sum_{j=1}^{n} User_{throughput_j}{}^2} \ldots\ldots(6)$$

In Equation (6), n refers toUE number. $User\_throughput_j$ refers to each UE's throughput, the value of whichis between 0 to 1. The closer it is to 1, the fairer the allocation.

Table 7 shows parameter valuewith respect to three types of base station amount while UE number varies and GBR rate is fixed.

Figure 16 shows fairness change of GBR flow produced by ARBA algorithm and ICIC algorithm in combination with MLWDF mechanism and PF mechanism, respectively, while the number of base stations is 3, 5, and 7, respectively. Employing ABRA algorithm in combination with either MLWDF or PF algorithm can both remain higher degree of fairness as the number of base stations increases. On the other hand, by comparing the simulation results in accordance with the serial number of the base station, it is even more evident that the results of ARBA-based simulation show higher degree of fairness. Among them, ARBA-PF scheduling mechanism is especially satisfactory on fairness. Figure 17 shows fairness change of various cell number with respect to different scheduling mechanisms. In multi-cell environment, ARBA mechanism remains better on fairness

.**Table 7:** Parametervalue of each base station in fairness simulation while GBR rate is fixed.

Serial number of base station	Number of UE	GBR rate
1	70	0.8
2	60	0.8
3	50	0.8
4	40	0.8
5	30	0.8
6	20	0.8
7	10	0.8

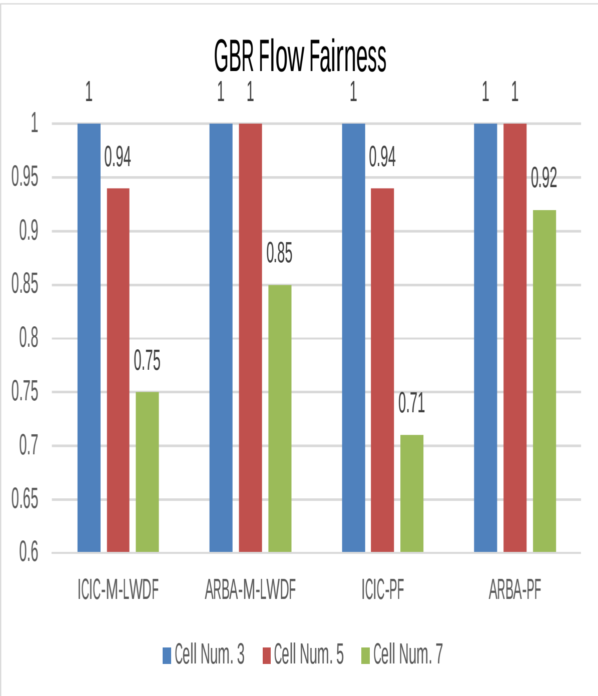

Figure 16 Fairness change of GBR flow of various scheduling mechanisms with respect to different cell numbers.

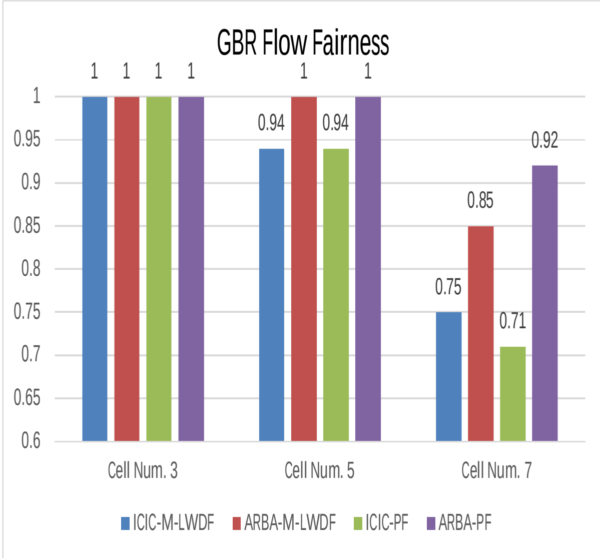

Figure 17 Fairness change of GBR flow of various cell numbers with respect to different scheduling mechanisms.

Figure 18 shows parameter value with respect to three types of base station quantity while UE number varies but GBR rate remains the same.

Inspection on the fairness change of Non-GBR flow produced by MLWDF mechanism and PF mechanism with respect to 3, 5, and 7 base stations shows that ARBA generates better in fairness than ICIC. On the other hand, inspection by comparing the simulation results in accordance with the serial number of base station indicates again that ARBA-based algorithms perform better in fairness. Among them, ARBA-PF scheduling mechanism is the fairest. Figure 19 shows fairness change of Non-GBR flow of various cell numbers with respect to different scheduling algorithms. In multi-cell environment, ARBA mechanism provides better fairness.

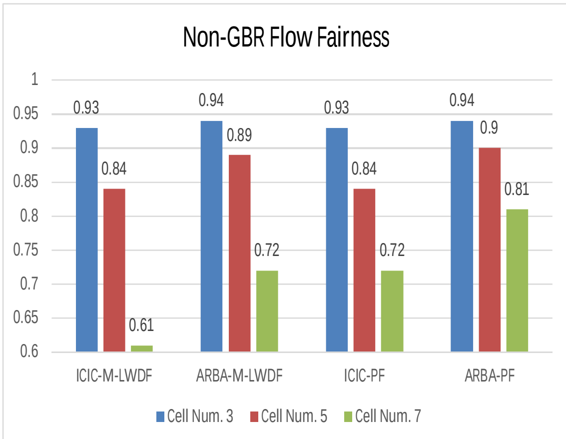

Figure 18 Fairness change of Non-GBR flow of various algorithms with respect to different cell numbers.

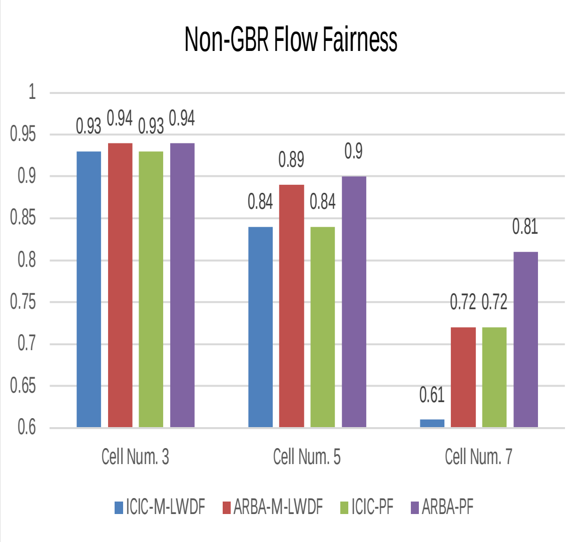

Figure 19 Fairness change of Non-GBR flow of various cell numbers with respect to different scheduling algorithms.

5.2.3 Satisfaction

Satisfaction is a quantized indicator. From an individual user's point of view, if an user needs 5Mbps and the system provides 5Mbps, the satisfaction is 100% because the supply equals the demand. If the user needs 5Mbps but the system provides only 4Mbps of transmission rate, the satisfaction is only 80% because the supply is below the demand. The satisfaction is low. Quantized calculation of satisfaction can be figured out by dividing demand by supply (most algorithms set the upper limit of the value to 1.) [18] therefore, the calculation of GBR user satisfaction in the simulation cen be written as follows.

$$Sat_{GBR} = \frac{RB_{GBR\_use}}{RB_{GBR}} \qquad (7)$$

In Equation (7), RB_{GBR_use} is the amount of transmission data of GRB user, RB_{GBR} denotes the minimum amount of data guaranteedby GBR. The average RB_{GBR} of video in the simulation is set to 2.3 Mbps.

Table 8 shows parameter value of each base station in satisfaction simulation while UE number is different but GBR rate is the same.

Figure 20 shows the satisfaction results generated by ARBA algorithm and ICIC algorithm in combination with MLWDF and PF downlink scheduling mechanisms, respectively while base station number is 3, 5, and 7, respectively, UE number varies but GBR rate remains fixed. ARBA algorithm evidently performs better in satisfaction. Since ARBA algorithm contains GBR rate indicator, base station can obtain more GBR flow data, resulting in better satisfaction from GBR UE. In Figure 21, it is even clearer. Because of ARBA algorithm, base station is able to have more GBR flow resource. Satisfaction provided by ARBA-based algorithms surpass those by ICIC-based algorithms, especially in multiple base station environment.

Table 8: Parameter value of each user in the satisfaction simulation while GBR rate is fixed.

Serial number of base station	UE number	GBR rate
1	70	0.8
2	60	0.8
3	50	0.8
4	40	0.8
5	30	0.8
6	20	0.8
7	10	0.8

Figure 20 Satisfaction change of various scheduling algorithms with respect to different cell numbers while GBR rate is fixed.

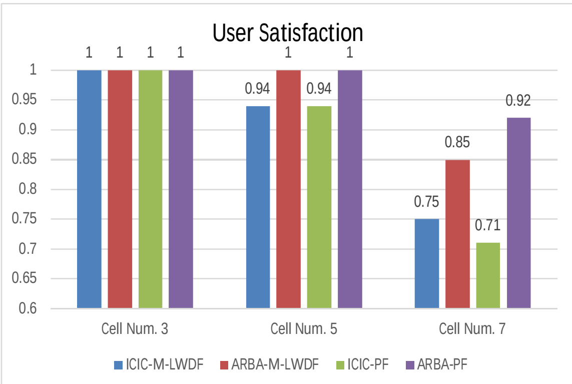

Figure 21 Satisfaction change of different cell numbers with respect to various scheduling algorithms while GBR rate is fixed.

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Table 9 shows parameter value of each base station while UE number is the same but GBR rate varies.
Figure 22 shows the simulation results of ARBA algorithm and ICIC algorithm in combination with MLWDF and PF downlink scheduling mechanisms, respectively with respect to 3, 5, and 7 base stations. ARBA algorithm combining MLWDF scheduling mechanism generates better performance. Also because of GBR rate in weight, base station can obtain more GBR flow resource when UE number remains the same. MLWDF scheduling mechanism provides better satisfaction when combining ARBA than ICIC. In Figure 23, it is also found that ARBA algorithm combining PF mechanism does not present better performance than ICIC algorithm as it does in other indicator simulations in this paper.

Table 9: Parameter value of each base station in the satisfaction simulation while UE number is fixed.

Serial number of base station	UE number	GBR rate
1	70	0.9
2	70	0.8
3	70	0.7
4	70	0.6
5	70	0.5
6	70	0.4
7	70	0.3

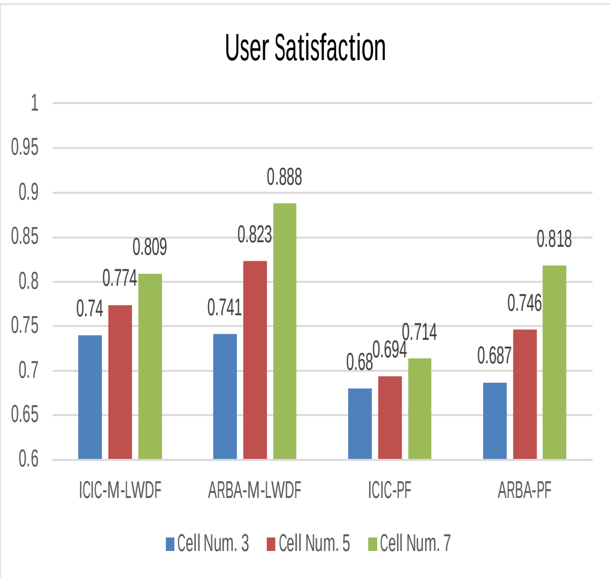

Figure 22 Satisfaction change of various algorithms with respect to different cell numbers while UE number is fixed.

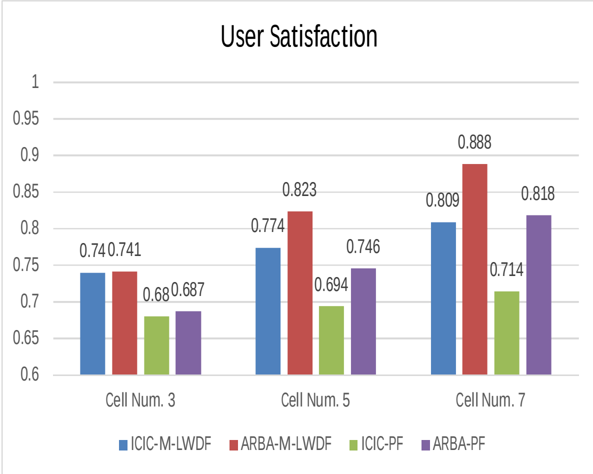

Figure 23 Satisfaction change of various algorithms with respect to different cell numbers while UE number is fixed.

Performance analysis basing on satisfaction indicator shows that when UE number is different but GBR rate is the same, all ARBA-based scheduling algorithms outperform ICIC-based algorithms. The performance of ARBA algorithm is less affected by UE number when GBR rate is high. It can perform better especially in multi base station interference environment. On the contrary, ARBA algorithm combining PF scheduling mechanism is unable to show its performance potential when UE number is the same but GBR rate is different. It is because the amount of base station is small and the interference is not serious. However, this mechanism performs well in environment where the amount of base station is large and the interference is serious.

6. CONCLUSIONS

To deal with environment facing poor signal transmission, overall throughput boost and satisfaction improvement have been common research topics. ARBA algorithm proposed in this paper is more advantageous and able to obtain better achievementsin poor single environment. However, to satisfy large demand for internet connection from users nowadays, and to respond to the development of mobile communication networks, massive deployment of small base stations will be a possibility in the future. Interference among small base stations in a cluster will be an important issue subsequently. This paper proposes Adaptive Resource Balanced Allocation (ARBA) algorithm to cope with inter-cell interference in a cluster. The algorithm has been proved to improve the inflexibility of spectrum usage of ICIC, allocate resource to the most favorable base station, and significantly boost the overall system performance. Additionally, this algorithm joins weight ratio balance mechanism, with which the system is able to reserve some resource for disadvantaged base stations and keep resource allocation fair. Satisfaction is thereby improved. ARBA algorithm outperforms ICIC no matter which packet scheduling algorithm is adopted, as we can see from the results of the simulations. In the future, user quantity will rocket, and killer application is going to appear in our communication environment. Various types of data flow and massive UEs which cluster rapidly will be a big challenge to work of resource allocation and anti-interference.

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AUTHORS

Jung-ShyrWu received the Ph.D. in electrical engineeringfrom the University of Calgary, Calgary, AB,Canada, in 1989.
He is a Full Professor with the Graduate Instituteof Communication Engineering, National CentralUniversity, Chung-Li, Taiwan. His research interestsinclude computer networks, wireless networks, mobilecommunication, and queueing theory.

Yu-ShunLiuwas born in Taiwan in 1972. Hereceived the M.S. degrees in Computer Science & Engineering from Yan Ze University, Chung-Li,Taiwan, in 1999 and 2002. He is currentlyworking toward the Ph.D. degree with the Departmentof Communication Engineering, National CentralUniversity, Chung-Li.
Since 2002, he has been with the Departmentof Computer Science and Information Engineering,Vanung University, Chung-Li, as a Lecturer. His currentresearch interests include computer networks, wireless networksand mobilecommunication.

Zhi-Kai Zhanwas born in Taiwan, in 1992.He received the B.S. degree in Electronic Engineering from National Changhua University of Education, Changhua, Taiwan, in 2014 and the M.S. degree in Communication Engineering from National Central University, Chung-Li, Taiwan, in 2016. Since 2016, he is with private companies in Taiwan and focused on the LTE wireless router development.