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Applying Genetic Algorithms to the Data Traffic Scheduling and Performance Analysis of a Long-Term Evolution System

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Abstract In this study it develops a superior transmission resource allocation method by using genetic algorithm. The convergence properties of genetic algorithm are employed to increase the transmission resource use efficiency of a base (station) to allow users to access wider bandwidth and to improve the system throughput and packet service rate. In this paper, it also studies the genetic algorithm convergent phenomena. The calculated system convergent time is significantly less than that of a long term evolution (LTE) frame duration. Finally, the system performances with and without implementing the genetic algorithm in resource allocations are simulated; their performances are compared to study the effectiveness of using the genetic algorithm in resource allocation.

Keywords Genetic algorithm · Resource allocation · Multicarrier operation

1 Introduction

With increasing demand for personal and corporate data transmission and communication quality, communications industries and researchers continue to test new communications technologies and develop mature implementation hardware to meet this demand. The International Telecommunication Union (ITU) has recently begun planning and developing fourth-generation mobile communication technology standards (IMT-Advanced) based on their previous experience in standardizing third-generation mobile communication technology. The IEEE 802.16 m physical layer transmission technology developed by the Institute of Electrical and Electronics Engineers (IEEE) contains orthogonal frequency-division multiple access (OFDMA) technology. The resource available to users in this wireless transmission technol-

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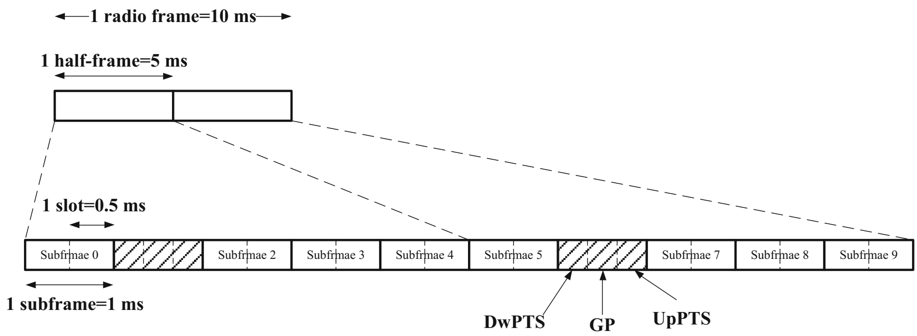


Fig. 1 the TDD radio frame of the LTE system

ogy comprises of frequency and time-dimension levels. Therefore, appropriately allocating the frequency and time of transmission resources have become a critical issue. This study proposes a highly optimized approach of using genetic algorithm to the allocation of resources. The convergent characteristics of the genetic algorithm enable a more efficient use of transmission resources. The proposed method also provides users with access to wider bandwidths under multi-carrier operations and enhances system throughput and packet service rates. The time required for the convergence of the genetic algorithm and actual operational convergence is estimated to be far shorter than a single frame duration. Finally, this study employs the convergent properties of genetic algorithm to facilitate effective resource use in base stations and to provide users in the environments of multi-carriers and multiple users with access to wider bandwidths.

The LTE system [1–8] is a set of system specifications developed by the Third-Generation Partnership Project (3GPP) in 2004. The 3GPP abandoned the code division multiple access (CDMA) technique used in third-generation mobile communication systems when developing this system standard. Instead, OFDMA was employed as the multiple access downlink technology. SC-FDMA, which has a lower peak-to-average power ratio (PAPR) compared to OFDMA, was employed for the uplink. The bands used by the LTE system range between 1.4 and 20 MHz [8]; the LTE system antenna was designed to support multi-input multi-output (MIMO); and the LTE system supports the time division duplex (TDD), frequency division duplexing (FDD), and half-duplex frequency division duplex (H-FDD) modes. The LTE TDD radio frame structure is shown in Fig. 1. The length of one radio frame was 10 ms. When one radio frame was divided into 10 subframes, the length of each subframe was 1 ms. One or two subframes can be used as special subframes, as shown in the slanted line area of Fig. 1. Each subframe of the remaining subframes can then be divided into two slots, where each slot is 0.5 ms in length.

The LTE FDD radio frame structure is shown in Fig. 2. One 10-ms radio frame was divided into ten 1-ms subframes, and each subframe was divided into two 0.5-ms slots. In the H-FDD mode, the user device cannot send and receive simultaneously. However, the FDD mode does not have this restriction. Regarding the LTE system specifications, one resource block is set to use 12 frequency subcarriers, and the allocated time equals one symbol slot. Based on various cyclic prefix (CP) settings, the length of time for the resource block is seven symbols when normal CP is used and six symbols when extended CP is used.

This paper is arranged as follows: In Sect. 2, it discusses how the genetic algorithm resource allocation method [9–21] is employed in this study, and the application of genetic

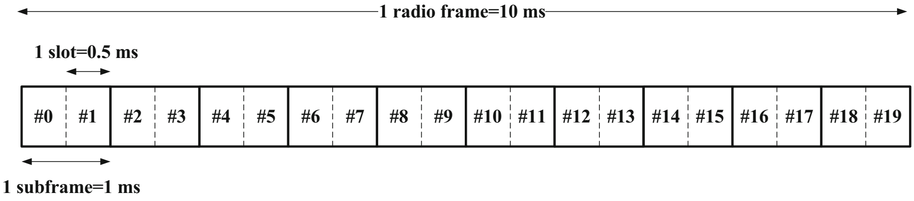


Fig. 2 LTE FDD radio frame structure

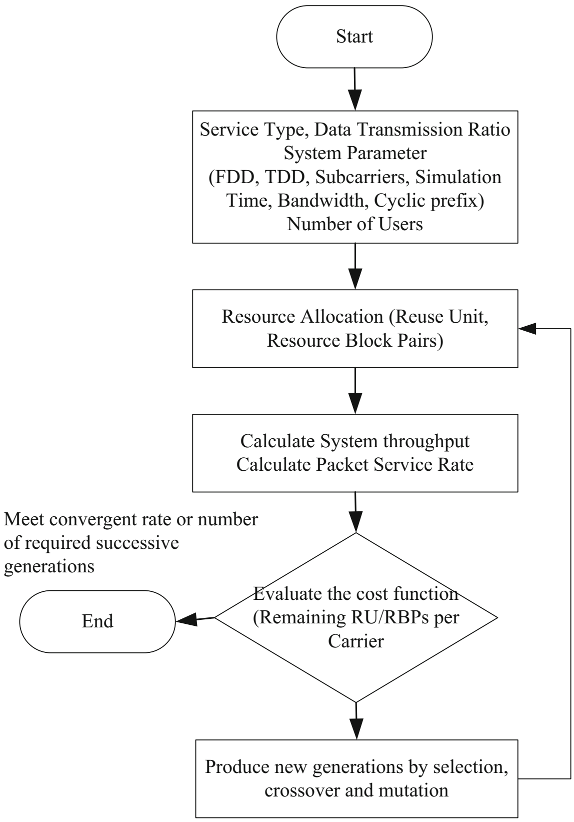


Fig. 3 Flow chart for resource allocation by using genetic algorithm

algorithm resource allocation using the multicarrier method are explained. In Sect. 3 the system resource allocation simulation results are analyzed, and the conclusion is presented in Sect. 4.

2 Resource Allocation in Multicarrier System Using Genetic Algorithm

In this paper we consider in using genetic algorithm to manipulate resource allocation problem especially for multicarrier LTE communication system that has the flow chart as shown in Fig. 3. Basically it has the following steps:

Fig. 4 Single-point mutation of binary chromosomes

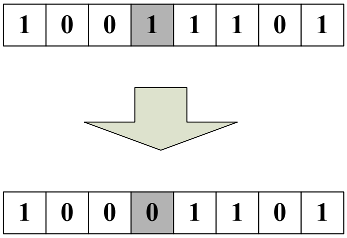
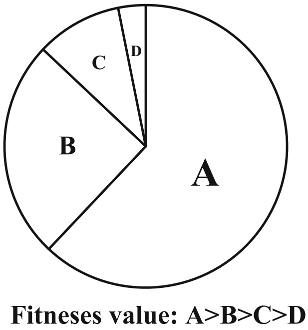


Fig. 5 Roulette selection method



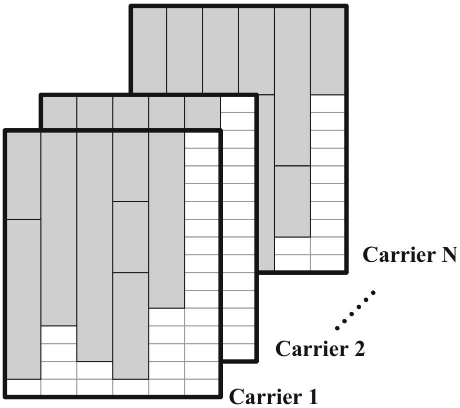
Step1: Find the interested service types and the ratio/percentage of each service type. Obtain system parameters such as the communication type (FDD/TDD), number of subcarriers, system bandwidth and number of users etc.
Step 2: Generate the initialized resource units and resource block pairs
Step 3: Calculate/evaluate System throughput, system packet service rate
Step 4: Evaluate the cost function/fit function based on the remaining resource unit/resource block pairs
Step 5: Perform genetic algorithm by processes such as selection, crossover, mutation etc.
Step:6: Repeat above steps from step 2
Step 7: The algorithm stops when the convergent rate or the number of successive generations reaches Preset number

In the preset following we briefly discuss the operations of selection, crossover and mutation processes.

The mutation is achieved by manipulating single chromosomes. This prevents the genetic algorithm from falling into optimal solution regions during computation. Figure 4 shows a type of binary bit chromosome mutation operation. Selections are made based on each individual's fitness value in the fitness value calculation group. Chromosomes with high fitness values are more likely to be selected as parents of the next generation. The following two methods are generally employed for the selection process: roulette wheel selection and tournament selection. The roulette wheel selection method is similar to Russian roulette, as shown in Fig. 5. Chromosomes with greater fitness values occupy a larger block and, thus, have a greater probability of being selected for replication. Under the tournament selection method, mating for the mutant offspring is conducted randomly (by one or more pairs), with the best offspring selected and copied into the new parent.

Under multicarrier operation, data in the LTE system is allocated from the upper layer to the physical layers with various numbers of carriers. User data is assigned to an appropriate carrier before the data allocation step is conducted. The dimensions of the chromosomes are

Fig. 6 Multicarrier chromosome form



increased from two dimensions (time and frequency) to three dimensions (time, frequency, and carrier), as shown in Fig. 6. The mating and mutation of the multicarrier chromosome are shown in Figs. 7 and 8, respectively. Subsequently, the location of the user data exchange is no longer limited to a single carrier. A genetic algorithm [22] is used to determine and allocate suitable times, frequencies, and carrier locations for user data. The fitness value of the multicarrier chromosome is the total Remaining resource unit/resource block pairs (RU/RBPs) for each carrier, as shown in Fig. 9.

3 System Performance Simulation Results and Analysis

In this section we explore how the use of genetic algorithm in the allocation of transmission resource units or resource blocks for users affecting the system performance. The system performance including the system throughput and the convergent rate of the genetic algorithm using various number of carriers are simulated and analyzed.

3.1 System Performance Simulation for LTE System

The system throughput and packet service rate, under single-carrier resource allocation, with and without exploiting the genetic algorithm are simulated and compared in the sequel. Only downlink resource allocation is examined in the simulation. Table 1 lists the fundamental users data transmission characteristics such as the service type, data rate, and service probability values used in the simulation. Tables 2 and 3 are the system parameters adopted for LTE in TDD and FDD transmission modes respectively. According to 3GPP LTE specification, in our simulation the normal CP with value 1/8 is selected [23–25]. The simulation results with and without implementing genetic algorithm are shown in Figs. 10, 11, 12 and 13 respectively. It reveals from these results that, because during resource allocation the transmission resources are more efficiently allocated by using the genetic algorithm method, its throughput and packet service rates are superior to those of the random allocation method.

Figures 14, 15, 16 and 17 show the simulation results for the LTE TDD and LTE FDD modes systems when the genetic algorithm is used for resource allocation and the number of carriers considered are 1, 2, and 4. The higher the number of usable carriers, the better the performances of throughput and packet service rate.

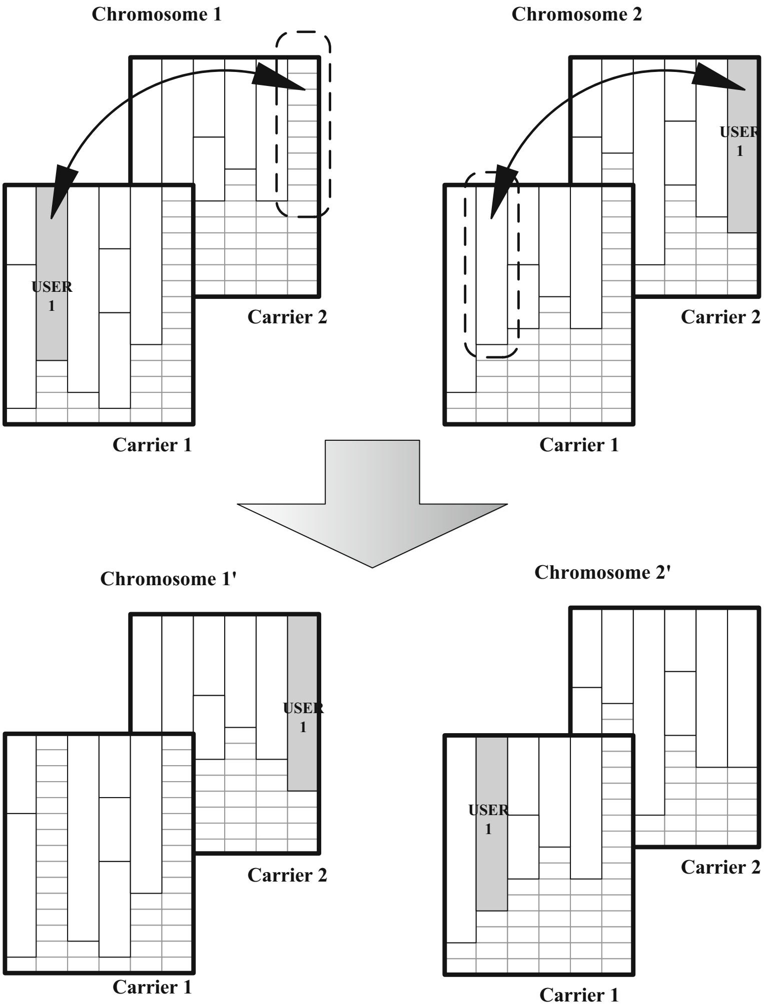


Fig. 7 Multicarrier chromosome mating

3.2 Convergent Rate Analysis when Genetic Algorithm is used in Resource Allocation

The convergent rates when various numbers of carriers are used in the resource allocation with genetic algorithm are compared in term of the average Remaining RU/RBPs per carrier as defined in the following

$$fit_{avg} = fit/N_c \tag{1}$$

where

fit is the total Remaining RU/RBPs from all carriers and N_c is the number of carriers used.

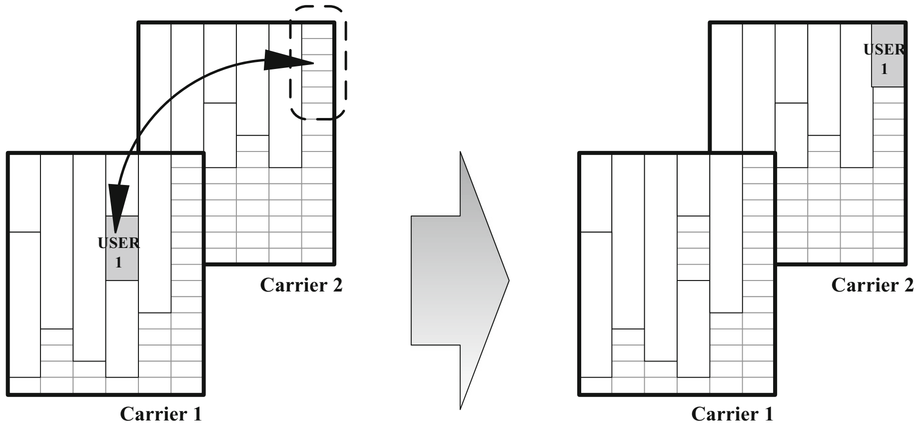


Fig. 8 Multicarrier chromosome mutation

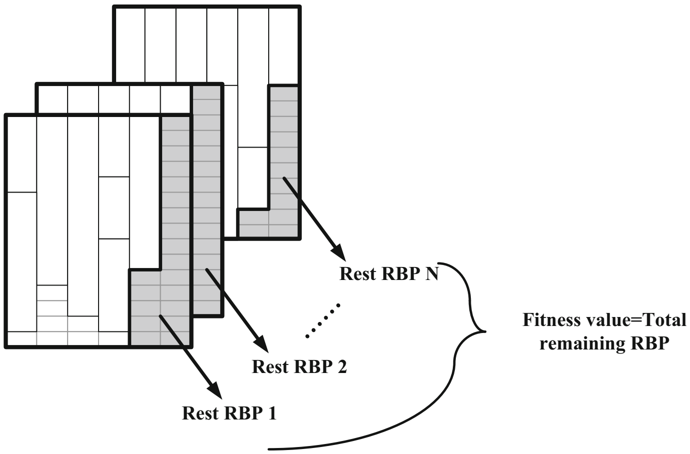


Fig. 9 Fitness value of the multicarrier chromosome

Table 1 Service type and data transmission ratio [6]

Service	VOIP	Video stream	FTP(DL)	HTTP
Data rate (kbps)	64	256	2,000	128
Ratio (%)	50	20	10	20

Then, fit_{avg} is used to normalize the average Remaining RUs per carrier, as shown below.

$$fit_{normal} = 100\% \times (fit_{avg}/convg(fit_{avg})) \tag{2}$$

where $convg(fit_{avg})$ is the fit_{avg} after the system converges.

Figures 18 and 19 are the convergent rate comparison charts when 50 users are considered with various numbers of carriers from 1 to 5 are used for LTE TDD and FDD systems respectively. In these figures the parameter designated in the horizontal axis is the number of

Table 2 LTE and TDD simulation parameters [6]

LTE TDD simulation parameters	
Simulation time	20 ms
Bandwidth	10 MHz
Used subcarriers	600
Subcarrier spacing	15 kHz
Duplex	TDD
Number of DL subframes	6
Modulation	QPSK
Coding rate	1/3
Pilot pattern	2 Antenna port
Cyclic prefix	Normal

Table 3 LTE and FDD simulation parameters [6]

LTE FDD simulation parameters	
Simulation time	20 ms
Bandwidth	10 MHz for DL
Used subcarriers	600
Subcarrier spacing	15 kHz
Duplex	FDD
Number of DL subframe	10
Modulation	QPSK
Coding rate	1/3
Pilot pattern	2 Antenna port
Cyclic prefix	Normal

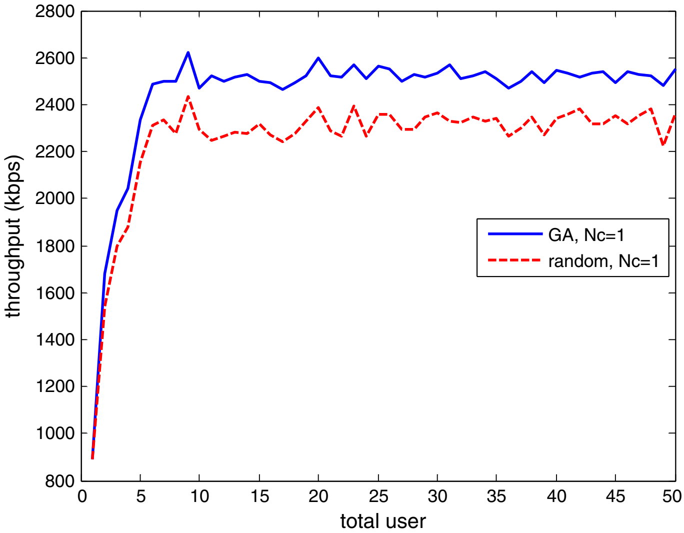


Fig. 10 LTE TDD single-carrier (Nc = 1) throughput

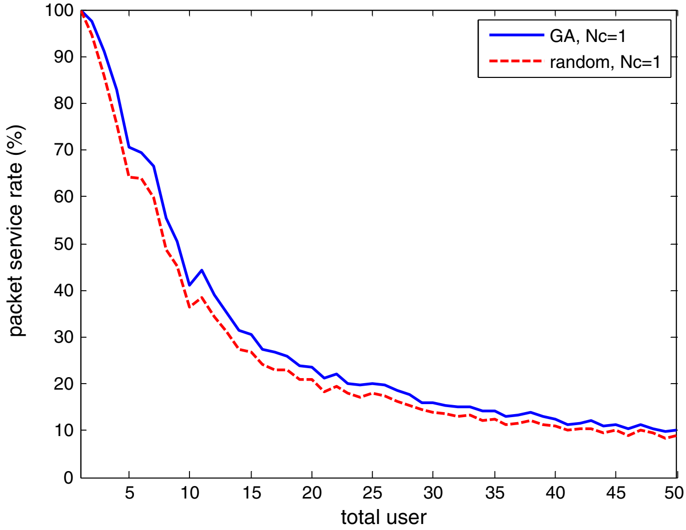


Fig. 11 LTE TDD single-carrier (Nc = 1) packet service rate

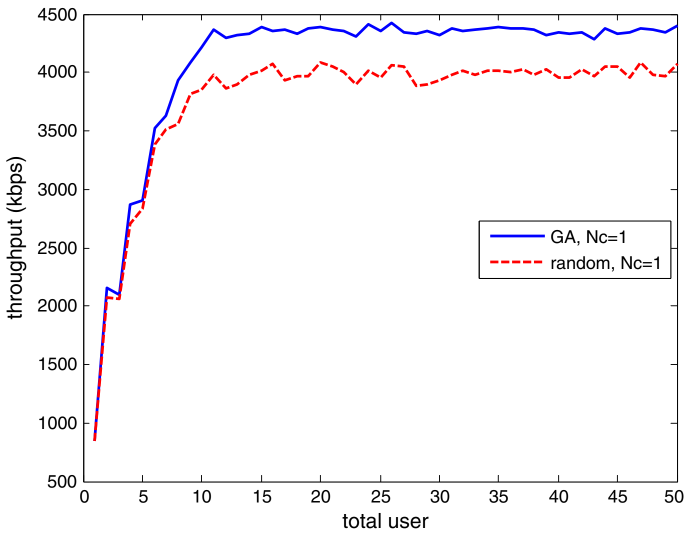


Fig. 12 LTE FDD single-carrier (Nc = 1) throughput

generations executed in the genetic algorithm while the vertical axis is the fit_{normal}. According to literature references [15], the average time required for the facilitation of hardware test in genetic algorithm after 20 generations is 22.4 ms that is equivalent to an average of 1.12 ms per generation. This value is then used as the baseline for estimating the hardware implementation time of the genetic algorithm resource allocation method proposed in this paper. Tables 4 and 5 list the average convergent rate and the hardware implementation time for the TDD and FDD modes respectively, when the radio frame length is selected as 10 ms, with various number of carriers used for 50 users. The convergent rate is defined as the minimum

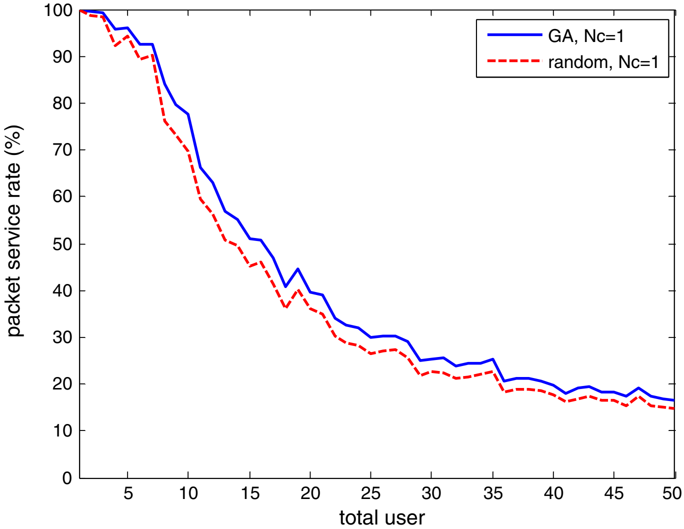


Fig. 13 LTE FDD single-carrier (Nc = 1) packet service rate

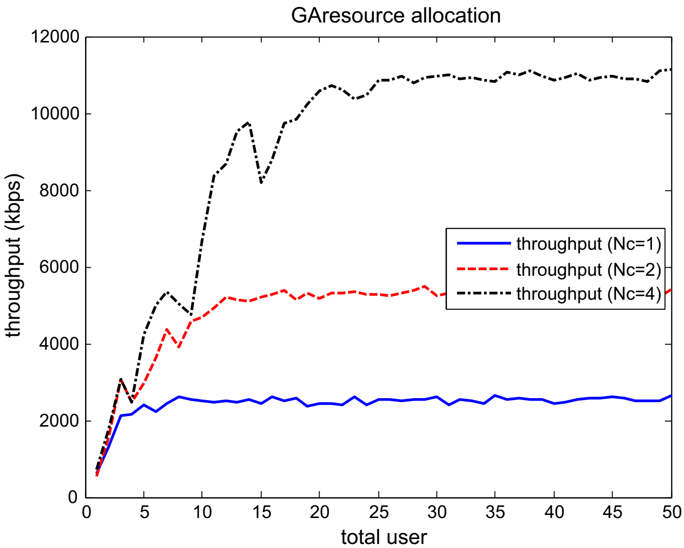


Fig. 14 LTE TDD throughput with 1, 2, and 4 carriers

nominal fit that is greater than 90% of the average fit, i.e., $fit_{normal} \geq 90\,\% \times convg(fit_{avg})$. From the results as shown in Tables 4 and 5 it reveals that the calculated hardware implementation time per generation is far less than the LTE frame length, and as the number of carriers is increased, it also increases in the hardware implementation per generation. Comparing the simulation results in using TDD or FDD operations in the same LTE system the FDD mode provides more available RU/RBPs ratio than that of TDD; and thus, FDD has a slower convergent speed than the TDD mode.

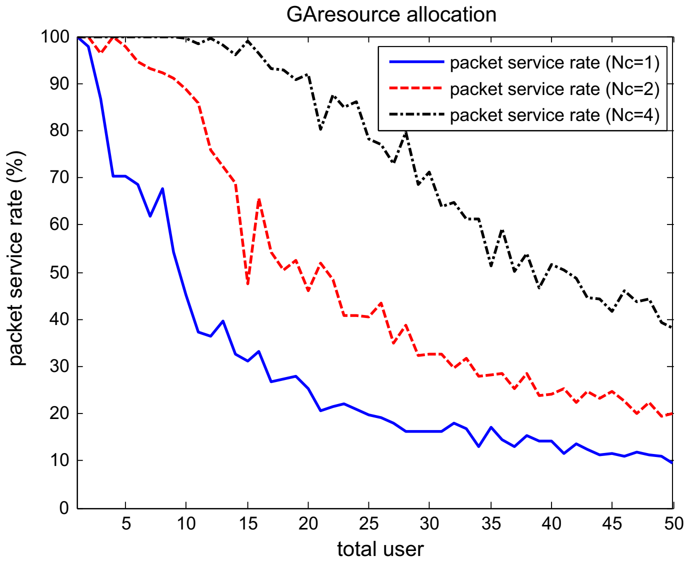


Fig. 15 LTE TDD packet service rate with 1, 2, and 4 carriers

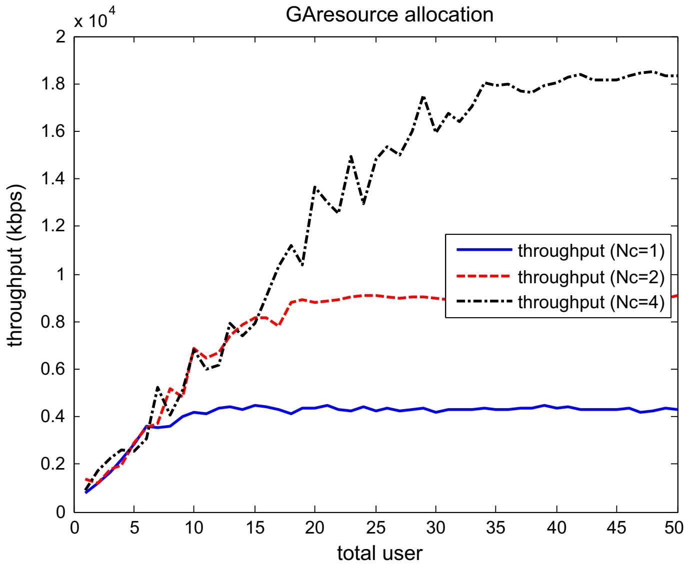


Fig. 16 LTE FDD throughput with 1, 2, and 4 carriers

In the simulation results as shown in Tables 6 and 7 they compare the performances of system throughput and packet service rate for LTE TDD and LTE FDD systems with varying number of carriers for 50 users. These tables indicated that the larger the carrier number, the better the system throughput and the packet service rates. In the TDD mode, the four-carrier packet service rate is 30.08 %, that is higher than the one-carrier case that having packet service rate of 9.423 %. In the FDD mode, the four-carrier packet service rate is 69.07 %, that

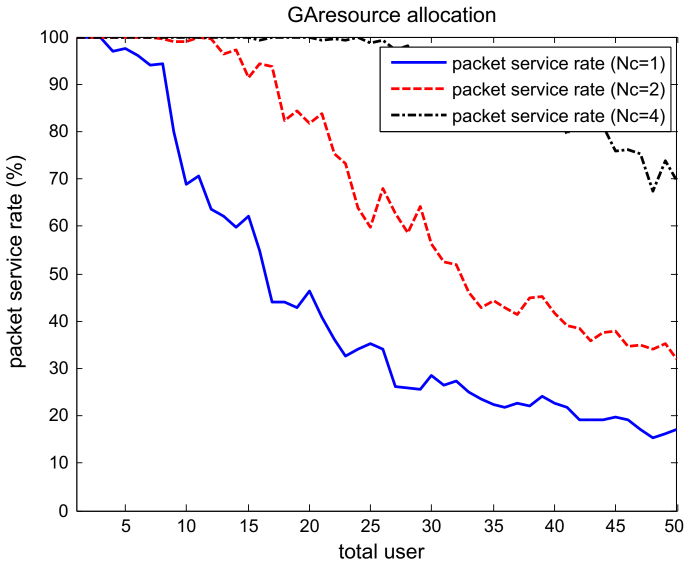


Fig. 17 LTE FDD packet service rate with 1, 2, and 4 carriers

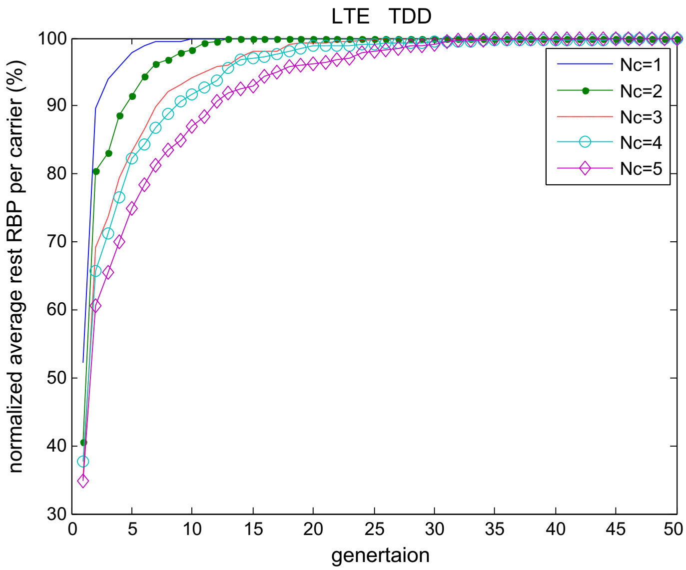


Fig. 18 Comparison of LTE TDD multicarrier convergent rates

is higher than the one-carrier case that having packet service rate of 17.15 %. Considering that the downlink bandwidth is the same in the TDD and FDD modes in the same LTE system, the performance of TDD mode is slightly worse than that of FDD mode, although its packet service rate is significantly higher than that of TDD mode.

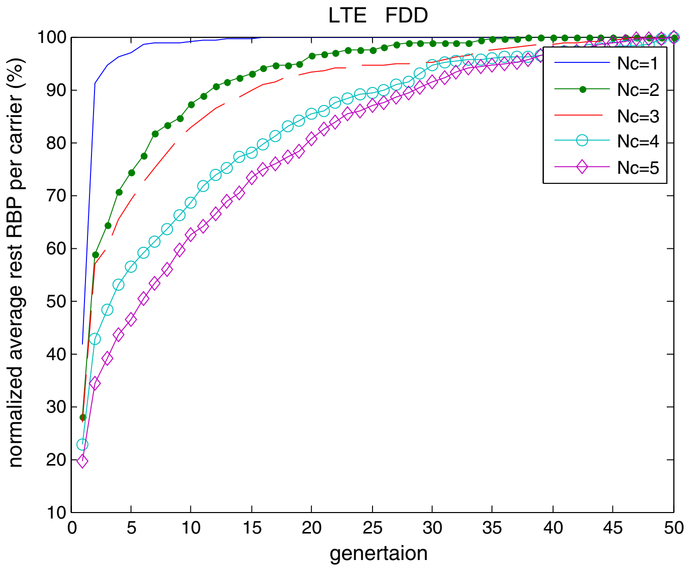


Fig. 19 Comparison of LTE FDD multicarrier convergent rates

Table 4 LTE TDD multicarrier average number of generations in convergence and the hardware implementation time per generation

Radio frame length (ms)		$N_c = 1$	$N_c = 2$	$N_c = 3$	$N_c = 4$	$N_c = 5$
10	Average number of generations in convergence (Ng)	2.9	4.55	7	8.45	11.4
	Estimated hardware implementation time per genertion (Ng*1.12us)	3.248	5.096	7.84	9.464	12.768

Table 5 LTE FDD multicarrier average number of generations in convergence and the hardware implementation time per generation

Radio frame length (ms)		Nc = 1	Nc = 2	Nc = 3	Nc = 4	Nc = 5
10	Average number of generations in convergence (Ng)	2.7	11.3	14.9	25.05	26.05
	Estimated hardware implementation time per genertion (Ng*1.12 us) = (Ng*1.12 us)	3.024	12.656	16.688	28.056	29.176

4 Conclusion

In this paper we applied genetic algorithm to resource allocation in LTE system and the results had shown that it had superior performance in transmission resource allocation than the case without using GA. Therefore, the proposed scheme achieved a more efficient use of

Table 6 Comparison of LTE TDD system performance with various numbers of carriers for 50 users

Number of Carriers	Throughput (kbps)	Packet service rate (%)	Average number of generations in convergence
$N_c = 1$	2,645	9.423	2.9
$N_c = 2$	5,423	20.09	4.55
$N_c = 4$	11,160	38.08	8.45

Table 7 Comparison of LTE FDD system performance with various numbers of carriers for 50 users

Number of carriers	Throughput (kbps)	Packet service rate (%)	Average number of generations in convergence
$N_c = 1$	4,271	17.15	2.7
$N_c = 2$	9,094	32.13	11.3
$N_c = 4$	18,330	69.7	25.05

transmission resources, and consequently enhanced the system throughput and packet service rate. Besides single-carrier resource allocation, the genetic algorithm resource allocation method was also applied to multicarrier operations, enabling base stations to use transmission resources more effectively while providing larger bandwidths to users. Finally, through simulations and calculations, this study also found that the genetic algorithm in the hardware implementation is far less than one radio frame duration.

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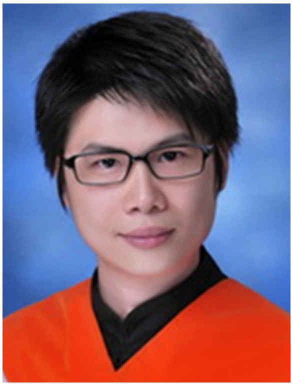

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