Optimization Of Spectrum Auction in 5th Generation Mobile Networks By The Optimization Algorithm

The Simulated Annealing Algorithm And Genetic Algorithm For The Spectrum Below 6 GHz

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***Abstract*—It is now important to prepare spectrum auction for the 5th Generation Mobile Networks that will start operation in 2020. This paper proposes a novel approach for the optimization for the 5G spectrum. Our ultimate target is to determine the various variables of 5G to optimize the revenue of the spectrum auction by the optimization algorithms. For the optimization, we develop advanced Simulated Annealing Algorithm and Genetic Algorithm. We use the costs and benefits of telecommunication companies as a constraint to achieve the goal of revenue maximization. Finally, this paper shows the optimal results by chart. This study is the first of its kind thus far.**

Keywords-5th Generation Mobile Networks; IMT-2020; Optimization Algorithm; Simulated Annealing Algorithm; Genetic Algorithm

I. Introduction

A. Background Information

Releasing spectrum will allow mobile companies to increase data capacity and enable their customers to benefit from more reliable network applications. The new generation (5th Generation, abbreviated 5G) mobile communication technology is anticipated to realize enhanced device and network level capabilities with higher throughput, higher spectrum efficiency and lower latency. Telecom operators are competing to provide better services and innovative applications such as self-driving cars, telemedicine and internet of things by 5G technologies and benefits of spectrum.

In Taiwan, National Communications Commission (NCC) holds spectrum auction to protect competition in the market and improve the efficiency of spectrum. Companies would have better quality of network when they get more blocks, but the construction costs are also higher. As spectrum is a vital resource, government always likes to ensure optimal spectrum efficiency, achieve economic and social development goals, and recover spectrum management costs in principle. Auction is the usual way for regulators to enforce the fair and transparent spectrum allocation. Hence, companies need a good measurement to win the bids.

Numerous factors in spectrum auction have to be considered to achieve the goals aforementioned. This study is to obtain the optimal solution by Simulated Annealing (SA) Algorithm, Genetic Algorithm (GA), and Random Optimization (RO) Algorithm. The proposed mechanism \could be a good reference for the optimal revenue solution of 5G spectrum auction.

B. Research Purposes

The main purpose of this paper is building the analysis model for spectrum auction of 5G which enables government to obtain the best auction solution.

First, we use the spectrums from Ministry of Transportation and Communications (MOTC) to get the spectrum value ($/MHz-Population) in New Taiwan Dollar (NTD). The price in 2020 is also calculated considering inflation. Second, there are about 30 million mobile communication users in Taiwan. Last, the block size of minimum auction unit based on frequency-division duplexing (FDD) is 5 MHz, i.e. 5 MHz for uplink and downlink respectively, total bandwidth is 10 MHz. Therefore, the price is spectrum value×10 MHz×30 million.

The price of the best base station of 4G is about 1.8 million (NTD). However, the number of base stations required for different bands is different. The higher the band frequency, the shorter the transmission distance will be and equipment cost is higher. The revenue is calculated by the market share of telecom companies and weighted average cost of capital (WACC) as a discount rate in net present value (NPV) over next 15 years (lifetime of mobile communication licenses).

II. Literature Review

A. 5G: IMT-2020

5G Mobile Networks was named International Mobile Telecommunication-2020 (IMT-2020) in Radiocommunication Assembly 2015 by International Telecommunication Union (ITU). According to the timeline from ITU, 5G standard and related system will be produced in 2020 [17].

B. Spectrum Value

Spectrum is a scarce resource. On the financial side, spectrum value represents how many people are willing to pay for spectrum use. Besides the aforementioned values, spectrum market is highly influenced by government policies and social-economic effects. There are many factors that affect it, such as population, geography, competition, technology, quality of services requirements, and market scenario, etc. Therefore, spectrum value has considerable variability in different situation [1].

C. Weighted Average Cost of Capital (WACC)

The capital cost of a company is an important part of investors. On the economic side, it depends on expected market risk for a company. When risk is higher, the expected return on investment and company capital cost are higher. Therefore, the capital cost can be defined as the minimum rate of return required by investors.

WACC is used to assess the total cost of capital level of the company and measure the overall cost of financing. It is the discount rate when assessing the cash flow from the expansion of a company's existing operations. It also means the return on investment by investors [15].

Since 6 March 2018, the paper recorded WACC of each telecom company in Taiwan for five days [9-12] as in Table I.

TABLE I. ESTIMATED DISCOUNT RATE IN 2018

Date	Telecom	Post-Tax WACC (%)	Effective Tax Rate (%)	Pre-Tax WACC (%)
3/6	CHT	4.89	16.64	5.87
	TWM	4.27	16.11	5.09
	FET	2.67	17.25	3.23
	APTG	9.22	13.54	10.66
	Average			6.21
3/7	CHT	4.91	16.64	5.89
	TWM	4.29	16.11	5.11
	FET	2.69	17.25	3.25
	APTG	9.24	13.54	10.69
	Average			6.24
3/8	CHT	4.61	16.64	5.53
	TWM	4.34	16.11	5.17
	FET	2.85	17.25	3.44
	APTG	9.30	13.54	10.76
	Average			6.23
3/9	CHT	4.62	16.64	5.54
	TWM	4.35	16.11	5.19
	FET	2.86	17.25	3.46
	APTG	9.31	13.54	10.77
	Average			6.24
3/10	CHT	4.59	16.64	5.51
	TWM	4.32	16.11	5.15
	FET	2.83	17.25	3.42
	APTG	9.28	13.54	10.73
	Average			6.20
Average				6.22

WACC of four companies are recoded as the reference of discount rate in Table I, as no actual record is available for Taiwan Star Telecom Company.

D. Net Present Value (NPV)

NPV is a method to evaluate an investment project. It converts the future cash flow into the value of initial day of investment. Since NPV considers all cash flows during the investment, it is the basis for many companies when they make investment assessments.

$$NPV = \Sigma [C_t / (1 + r)^t] - C_0. \quad (1)$$

In eq. (1), C_t is net cash inflow during time interval t. C_0 means the total initial investment costs. r means the discount rate; t means the number of time periods [18].

E. Spectrum Value—600 MHz

In 2017, the United States holds the Incentive Auctions for 600 MHz. It means that government allows broadcasters to voluntarily surrender spectrum license and get a part of strike price from auction. It consists of two parts: Reverse Auction and Forward Auction. In reverse auction, broadcasters announce the spectrum they surrender and price. Generally, the size and price will gradually decrease as auction proceeds. On the contrary, contents of forward auction are provided by telecom companies. They will express price and size they are willing to pay. The auction price and size will gradually increase as auction proceeds[5]. Final strike price is US$ 19.6 billion, 70 MHz spectrum in total, with average cost US$ 0.88 per MHz-pop:

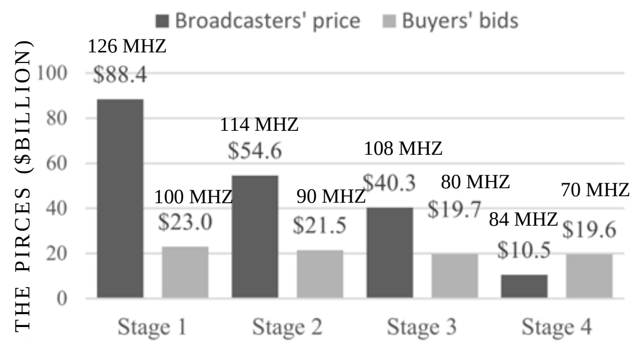


Figure 1. 600 MHz Incentive Auction in the United States [7].

F. Spectrum Value—800 MHz

According to the European Commission Decision in 2010, its purpose is to 'Transforming the digital dividend into social benefits and economic growth'. It emphasizes the importance of 800 MHz of part of the spectrum in the digital dividend [14].

European Union (EU) has launched auctions for 800 MHz as summarized in Table II [4].

TABLE II. EU 800 MHZ AUCTION AND RESULTS [4].

Country	Auction Date	$/10MHz	$/MHz-Pop
Italy	2011.09	€493,750,000	€0.810
Germany	2010.05	€596,079,167	€0.729
France	2011.12	€439,847,834	€0.697
Spain	2011.07	€217,554,765	€0.473
Sweden	2011.03	€36,725,520	€0.393

G. Spectrum Value—L-Band

In 2015, ITU proposed new bands allocated to mobile services: L-Band (1427—1518 MHz) and C-Band [6].

Because it was the first L-Band auction, spectrum value should be obtained by estimation. The propagation characteristic of 1.4 GHz is between 800/900 MHz and 2.1 GHz. But the coverage area from 1.4 GHz offer significant advantages over 2.1 GHz. This situation shows that the use of 1.4 GHz is more similar to 800/900 MHz than 2.1 GHz. Therefore, L-Band is expected to have similar but not equal characteristics to sub 1 GHz spectrum. This means that the spectrum value of 1 GHz is the upper bound of 1.4 GHz.

Accordingly, Plum proposed the 1.4 GHz spectrum value as outlined in Table III [13].

TABLE III. THE SPECTRUM VALUE OF 1.4 GHZ

spectrum value	Description	1.4 GHz value (€/MHz-pop)
Low	1.4 GHz value << sub 1 GHz value	0.25
Medium	Value of 1 GHz is the lower bound of sub 1 GHz spectrum.	0.40
High	Value of 1 GHz is about the middle of the upper bound of sub 1 GHz.	0.60

H. Spectrum value—C-Band

C-Band is the range of spectrum in 3400–3600 MHz. The harmonized technical conditions and frequency arrangements for 3.6 GHz have been defined in EC Decision 2014/276/EU on 2 May 2014.

The estimated spectrum value can be obtained by referring to the economic indicators which is calculated by auction results, Purchasing Power Parity (PPP) provided by the world bank, Consumer Price Index (CPI), and national population. It shows that global average price (€/MHz-pop) is about 0.0152. European average price is 0.0084. However, from the data of auctions after 2010, global average price is about 0.0116, and European average price is 0.0380 [2].

I. Spectrum Auction Process

For the bidding process, MOTC publishes the spectrum which will be released. Next, NCC will announce which spectrum band and how many blocks will be released. According to this information, telecom companies can decide which band they should bid.

For the bidding method, Simultaneous Multi-Round Auction (SMRA) model is used. In this method, bidders can "Switching". That is to say, bidders could change bid targets among all the different spectrum blocks. And all bid targets end at the same time. Additionally, this study adapts the Two-Phase Auction method used by NCC for 4G Mobile Broadband in 1800 MHz and 2100 MHz. In the first phase, bidders get the generic spectrum blocks. Namely, each telecom company only bids for the virtual block rather than the physical block of spectrum. That is, the reverse price of all blocks in the same band is the same. In second phase, one round auction for location of blocks is holding [20]. The range of the price of quotations is between NT$ 0 and 1 million [23].

III. RESEARCH DESIGN

A. Cost Function

Cost function of this study is the possible costs and revenues of telecom companies from auction. Costs can be divided into two parts: spectrum purchase cost and equipment construction cost. The spectrum purchase cost is the value of a block, which is calculated by spectrum value, the 30 million mobile communication users in Taiwan, and 10 MHz per blocks. The equipment construction cost is calculated by a base station price multiplied by number of base stations in each band. In addition, the revenue is obtained by NPV from 30 million mobile communication users multiplies the market shares of each telecom company muliplies ARPU. Finally, cost function is use of estimate the cash flow in the future by revenue minus costs.

B. The Spectrum Value of 600 MHz

The United States started the Incentive Auction of 600 MHz in 2017. In conclusion, the spectrum value is US$ 0.88/MHz-Pop. The NT$ 26.62/MHz-Pop is calculated by the exchange rate 1:30.25 at the end of the auction. The Consumer Price Index (CPI) in February 2017 was 99.96 and the CPI in February 2018 was 102.15. Therefore, the inflation rate can be calculated as:

$$\begin{aligned}\text{Inflation Rate} &= (CPI_{2018}-CPI_{2017})/CPI_{2017}\\ &= (102.15-99.96)/99.96 = 2.19\%.\end{aligned} \quad (2)$$

Moreover, the spectrum value of 600 MHz in 2020 can be predicted with inflation rate as Eq. (3)

$$\begin{aligned}\text{After Inflation} &= \text{Cost}\times(1+\text{Inflation Rate})^{year}\\ &= \$26.62\times(1+2.19\%)^3 = \$28.41.\end{aligned} \quad (3)$$

As a result, the cost that a company spend for a unit is NT$ 28.41×10 MHz×30 million users = NT$ 8.523 billion.

C. The Spectrum Value of 800 MHz

The possible value of 800 MHz in 2020 is calculated by the result from auctions in EU. We convert EUR into NTD by the exchange rate at the end of the auction. Then use average inflation rate by CPI from the end of the month of auction to the same month in 2017 to predict the possible spectrum value in 2020. Finally, the average price is the predicted spectrum value of 800 MHz in the future. In consequence, the average price is NT$ 27.534/MHz-Pop as summarized in Table IV, so the price is NT$ 8.2602 billion per block.

TABLE IV. THE PREDICT SPECTRUM VALUE OF 800 MHZ

Country	Spectrum Value	Exchange Rate	NTD price	Inflation Rate	After Inflation
	€/MHz-Pop	***EUR: NTD***	***NT$***	***%***	***NT$***
Germany	0.729	1：40.1	29.245	0.978%	32.234
Sweden	0.393	1：41.2	16.193	0.962%	17.650
Spain	0.473	1：41.6	19.675	0.937%	21.398
Italy	0.810	1：41.3	33.489	0.934%	36.412
France	0.697	1：39.6	27.579	0.931%	29.978
Average					27.534

D. The Spectrum Value of L-Band

Plum gave three different spectrum values of L-Band, namely low, medium, and high prices. The low price is €0.25/MHz-Pop which ensures that the value of L-Band is significant lower than the value of sub 1 GHz spectrum. The medium price is €0.40/MHz-Pop which comes from the lower bound of the value of sub 1 GHz. The high price is €0.60/MHz-Pop which is the median price of upper bound of spectrum value of sub 1 GHz. To protect strong competitions between telecom companies in Taiwan, this study will be based on the high price.

According to the publication date of the Plum report, the exchange rate of the EUR: NTD is 1: 42.078. The spectrum value is NT$ 25.247/MHz-Pop. Moreover, the average inflation rate is 0.888% from June 2011 to June 2017. Thus, we get the possible spectrum value NT$ 27.338/MHz-Pop in 2020. And the cost of a block is about NT$ 8.2014 billion.

E. The Spectrum Value of C-Band

The values from Commission for Communications Regulation (ComReg) is €0.0152/MHz-Pop from global data, €0.0084/MHz-Pop from European data, and €0.0116/MHz-Pop from global data after 2010, as well as the price of €0.0380/MHz-Pop from Europe after 2010. We consider that C-Band was applied to satellite service rather than IMT in the past. Therefore, this study uses the price estimated from global data after 2010.

The exchange rate of EUR: NTD is 1: 35.783 on the report publication date. The spectrum value is NT$ 0.415/MHz-Pop. The inflation rate from August 2016 to August 2017 is 0.96%. Thus, the spectrum value in 2020 is NT$ 0.431/MHz-Pop. Consequently, the cost for a block is about NT$ 129.3 million.

F. Other Affecting Factor

This study is based on SMRA auction method that NCC used for the 4G auction. Due to the generic block auction at the first phase, we could assume that the auction price should be the same for different blocks under the same band. Moreover, according to the information provided by the Chunghwa Telecom, the capacity will increase by one-third when a company has adjacent blocks in the same band. We could assume that telecom companies are willing to pay more to obtain adjacent blocks. Hence, if a company has more than one block in a band, the cost will increase by one-third. This one-third increase includes the highest NT$ 1 million price in the second phase of SMRA.

G. Equipment Construction Cost

Since the equipment of the base station for 5G mobile communication are still developing, the price has not yet been set exactly. The basic price of a 5G base station is calculated by estimated price in 2020 of the highest price NT$ 1.8 million of base station for 4G mobile communication.

The average inflation rate from the end of first auction of 4G in October 2013 to October 2017 is 0.679%. Thus, the price of the base station is NT$ 1,887,317 in 2020.

Furthermore, we will calculate the minimum number of base stations for operational mobile communication in Taiwan. First, the coverage of a base station at 600 MHz is approximately 1.25 times of the coverage of a base station at 700 MHz. Therefore, the number of base stations at 600 MHz is 0.8 times of the base stations at 700 MHz [8]. Then, we will use the same value of the number of base stations since the propagation characteristics at 800 MHz and 900 MHz are almost the same [3]. Next, the propagation characteristic of L-Band is the intermediate value between 900 MHz and 2.1 GHz. The coverage of L-Band is 1.5 times of 2.1 GHz and is 0.75 times of 900 MHz. Therefore, the number of base stations of L-Band is the 1.33 times of 900 MHz [13]. Finally, the coverage of C-Band is 1.87 times smaller than 2.3 GHz. And the coverage of 2.3 GHz is 1.8 times smaller than 900 MHz. Therefore, the number of base stations of C-Band is 3.366 times of 900 MHz [16].

TABLE V. THE MINIMUM OF BASE STATIONS IN TAIWAN [19].

	700 MHz	**900 MHz**	**1800 MHz**
Minimum number of base stations (per 10 MHz)	1400	1900	3000

According to the above information, the number of base stations at 600 MHz is 1400×0.8 = 1120. Due to the propagation characteristics of 800 MHz and 900 MHz are almost the same, the number of base stations at 800 MHz equals to 1900 base stations at 900 MHz. Next, the number of base stations at L-Band is 1900×1.33 = 2527. Finally, the number of base stations at C-Band is 1900×3.366 = 6395.

In conclusion, the cost of the equipment per block is the number of base stations multiplies NT$ 1,887,317 per base station.

H. Telecommunication Company Revenue

The number of mobile communication consumers/ Subscriber Identity Module (SIM) cards is about 30 million in Taiwan. According to the market share data in the third quarter 2017 provided by NCC, we calculate the number of users that each telecom company should serve.

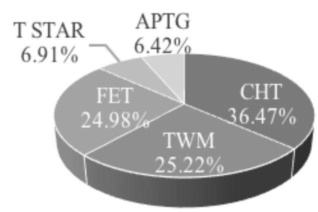


Figure 2. Market Share of telecom companies [22].

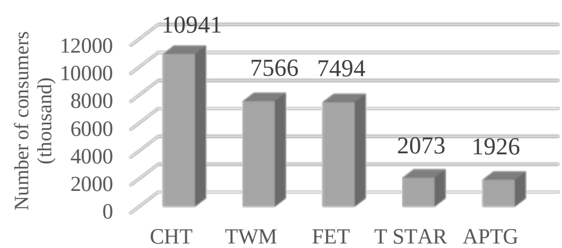
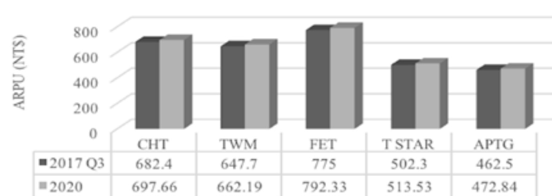


Figure 3. The number of customers in each telecom company.

After getting the market share and the possible number of consumers of each telecom company, we obtained the ARPU price for each telecom company and converted it to the predicted price in 2020. Then the revenue for each telecom company is obtained by market share, number of customers,



and ARPU price. Using average inflation rate of 0.74% in the third quarter 2017 to calculate possible ARPU price in 2020:

Figure 4. The ARPU for each telecom company in Q3 2017 & 2020 [21].

According to the above-mentioned data, revenue per month of each telecom company is calculated by ARPU price for each telecom company multiplied by the number of consumers from that company. Then we get the value of NPV for a 15-year license with the discount rate of 6.22%:

$$NPV = \sum ARPU_t / (1+6.22\%)^t. \quad (4)$$

I. SA Algorithm and RO Algorithm

In this study, the program is divided into three layers. The first layer is to get the optimal solutions for the number of iterations by SA Algorithm. We call it Times SA algorithm. The second layer is to get the optimal solutions for the number of blocks which will be auctioned in each band by SA Algorithm. We call it Blocks SA algorithm. Lastly, the third layer is to get the optimal solutions for the revenues of government from spectrum auction under the restriction that the telecom companies can bid. These solutions are obtained by RO Algorithm. We call it Bidding RO algorithm.

First of all, Times SA algorithm will get the number of iterations randomly. Blocks SA algorithm will get the number of blocks in each band randomly. Then Bidding RO algorithm will assign these blocks to telecom companies. After each allocation of blocks, the algorithm will obtain the cost and revenue for the company by cost function. If cost is higher than revenue, this block will be assigned to another company. By contrast, if revenue is higher than cost, the algorithm will definitely assign this block to the company. A round of Bidding RO algorithm is to repeat above processes until all the companies are unable to bid or all blocks are allocated. After end condition of layer three is achieved, we will get the best revenue for government by completing the Bidding RO algorithm.

The one-time Bidding RO algorithm is a one-round Blocks SA algorithm. After Bidding RO algorithm is completed, Blocks SA algorithm will randomly change the number of blocks and pass it to layer three to get the new optimal solution again. The processes are repeated until the end condition of layer two is achieved, the best revenue from all results is the optimal solution. After Blocks SA algorithm is completed, the variance will be calculated from all results of layer two. The smaller the variance, the better the looping times will be.

After that, Times SA algorithm will change the number of iterations and pass it to layer two to get the variance, best revenue, and the best number of blocks. Until Times SA algorithm stops, result of the minimum variance is the optimal solution. Then the highest revenue and corresponding number of blocks are the optimal solution from the optimal results. As a result, these variables mean the optimal spectrum cutting, the optimal allocation, and the highest revenue for the spectrum auction.

J. GA and RO Algorithm

Same as the previous section, algorithm is divided into three layers: the first, Times GA, is to optimize the number of iterations by GA. Second layer, Blocks GA, is to optimize the number of blocks from spectrum cutting by GA. Then, third layer, Bidding RO algorithm, will assign blocks to telecom companies by RO Algorithm.

At first, Times GA will get the number of population size of times randomly. And it will pass these times variable to Blocks GA one by one. When Blocks GA receives one of the times variables, it will get the number of population size of blocks randomly. Also, it will pass these variables to Bidding RO algorithm one by one. Bidding RO algorithm will randomly assign the blocks to companies when it receives one of the blocks variables. Then it will obtain the cost and revenue for the company by cost function. The processes are repeated until all the companies are unable to bid or all blocks are allocated, that is, a round of Bidding RO algorithm. The program will repeat until the Bidding RO algorithm is completed. The highest revenue in all results is the optimal solution for Bidding RO algorithm. However, the one-time Bidding RO algorithm is one of the organisms from population from blocks GA. Therefore, the program will call layer three repeatedly until the end condition is achieved. Then the best value from results is the best solution for this organism from population.

The program will pass all the organisms to Bidding RO algorithm to get revenues. After sorting, Blocks GA will remove some organisms by a certain rate. Then, algorithm will fill up the population via mutation and crossover and pass the new population to layer three. The algorithm will repeat sort, elitism, mutation or crossover until the maximum number of generations is finished. After algorithm ends, the top organism in population is the optimal solution for this times of layer two. However, the above procedure is only one time of Blocks GA. Thus, Blocks GA will repeat until the number of iterations from layer one is achived. Then it will calculate the variance by all results. The smaller the variance, the better the looping time is.

Now, Times GA will call Blocks GA and get the variances for all the organisms in population. Then it will repeat sort, elitism, mutation or crossover. After Times GA obtains new population, it will call Blocks GA again and get new variances. The processes will be repeated until the maximum number of generations is completed. After all processes are finished, the top organism in population of times GA is the optimal solution.

IV. Analysis and Results

A. Result of SA Algorithm & RO Algorithm

In this study, we use two methods to obtain the optimal solutions. The first one is using SA Algorithm and RO Algorithm. First, we use SA Algorithm at layer one to optimize the number of iterations. Then, using SA Algorithm at layer two to optimize the number of blocks in each band. Finally, the highest revenue under this number of blocks is obtained by the auction simulation by RO Algorithm.

According to the Fig. 5(a), all the variances are calculated by the best revenues under different number of iterations. The X axis is the number of iterations to get the optimal solutions.

The Y axis is the variances under the number of iterations. Each green dot is a value obtained by running the number of iterations. Since the target is to find the most stable number of iteration, the optimal solution is the red dot which has the minimum variance. In this experiment, the optimal number of iterations is 7, and the variance is 6791.

Spectrum benefits is depicted as Fig. 5(b), which shows all of the optimal revenues from the optimal time by line charts. X axis is the best number of iteration 7. Y axis is the revenue for each time. The unit is NT$ 100 million. Therefore, we could know that the best revenue is NT$ 20.05 billion at the 6th run.

Number of Spectrum is demonstrated by histogram in Fig. 5(c), which shows the number of blocks corresponding to the best solution in each of the 7 times. The X axis is the same as Fig.5(b). The Y axis is the number of blocks under different bands. Since spectrum 600 MHz, 800 MHz, 1400 MHz, and 3600 MHz are considered in this study, the chart of each time is divided into four different pillar patterns. Then we can know that the best revenue is NT$ 20.05 billion which is a combination of 10 blocks at 600 MHz, 4 blocks at 800 MHz, 8 blocks at 1400 MHz, and 15 blocks at 3600 MHz spectrum.

Finally, the spectrum combination of each company is showed in Fig.5(d), which displays the optimal situation obtained by assigned blocks to the companies under the number of blocks in Fig.5(c). First, the largest company, company A, wins 2 blocks at 600 MHz spectrum, 1 block at 800 MHz spectrum, 3 blocks at 1400 MHz spectrum, and 4 blocks at 3600 MHz spectrum from the bidding simulation. Company B wins 0 block at 600 MHz spectrum, 3 blocks at 800 MHz spectrum, 2 blocks at 1400 MHz spectrum, and 1 block at 3600 MHz spectrum. Company C wins 3 blocks at 600 MHz spectrum, 3 blocks at 800 MHz spectrum, 1 block at 1400 MHz spectrum, and 0 block at 3600 MHz spectrum. Due to the low market share of company D, it only wins 1 block at 600 MHz spectrum. Lastly, since the low market share similar to the company D, company E only wins 1 block at 600 MHz spectrum.

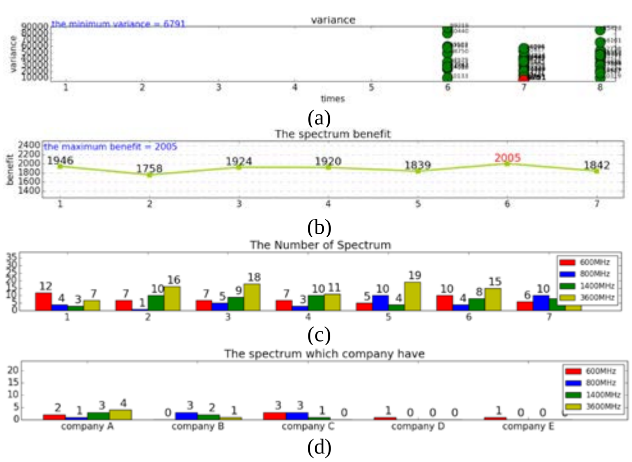


Figure 5. The result of SA Algorithm and RO Algorithm.

B. *Result of GA & RO Algorithm*

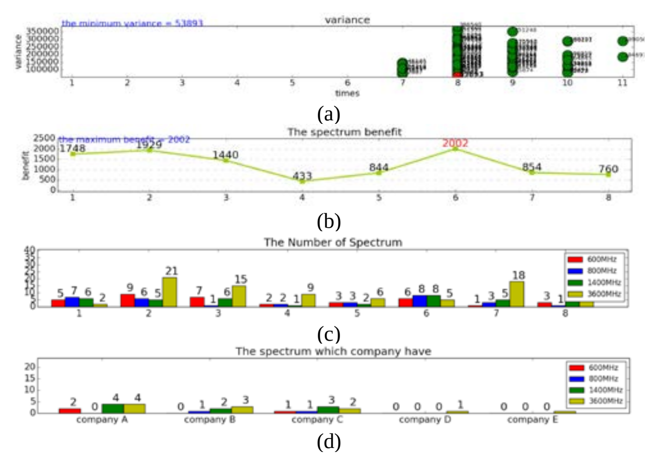
The other method is using GA and RO Algorithm. First, we use GA at layer one to optimize the number of iterations. Using GA at layer two to optimize the number of blocks in each band. Finally, the highest revenue under this number of blocks is obtained by auction simulation by RO algorithm.

According to Fig.6(a), all the variances are calculated by the best revenues under different number of iterations. The X axis is the number of iterations to get the optimal solutions. The Y axis is the variances under the number of iterations. Each green dot is a value obtained by running the number of iterations. Since we aim to find the most stable number of iteration, the optimal solution is the red dot which has the minimum variance. The optimal number of iterations is 8, and the variance is 53893.

Spectrum benefit is described by Fig.6(b), which shows all of the optimal revenues from the optimal time by line charts. X axis is the best number of iteration 8. Y axis is the revenue for each time. The unit is NT$ 100 million. Therefore, we could know that the best revenue is NT$ 20.02 billion at the 6th run.

Number of Spectrum is depicted by histogram in Fig.6(c), which shows the number of blocks corresponding to the best solution in each of the 8 times. X axis is the best number of iteration 8. Y axis is the number of blocks under different bands. Since spectrum 600 MHz, 800 MHz, 1400 MHz, and 3600 MHz are targeted, the chart of each time is divided into four different pillar patterns. Then we can know that the best revenue is NT$ 20.02 billion which is a combination of 6 blocks at 600 MHz, 8 blocks at 800 MHz, 8 blocks at 1400 MHz, and 5 blocks at 3600 MHz spectrum.

Finally, the spectrum combination of each company is showed in Fig.6(d), which display the optimal situation obtained by assigned blocks to the companies under the number of blocks in Fig.6(c). First, the largest company, company A, wins 2 blocks at 600 MHz spectrum, 0 block at 800 MHz spectrum, 4 blocks at 1400 MHz spectrum, and 4 blocks at 3600 MHz spectrum from the bidding simulation. Company B wins 0 block at 600 MHz spectrum, 1 block at 800 MHz spectrum, 2 blocks at 1400 MHz spectrum, and 3 blocks at 3600 MHz spectrum. Company C wins 1 block at 600 MHz spectrum, 1 block at 800 MHz spectrum, 3 block at



1400 MHz spectrum, and 2 block at 3600 MHz spectrum. Due to the low market share of company D, it only wins 1 block at 3600 MHz spectrum. Lastly, since the low market share of company E, it only wins 1 block at 3600 MHz spectrum.

Figure 6. The result of GA and RO Algorithm.

V. CONCLUSION

TABLE VI. RESULT INTEGRATION OF SA ALGORITHM.

The Optimal Solution by SA Algorithm		600 MHz	800 MHz	1400 MHz	3600 MHz
The Optimal Number of Blocks		10	4	8	15
The Optimal Result of Bidding	Company A (CHT)	2	1	3	4
	Company B (TWM)	0	3	2	1
	Company C (FET)	3	3	1	0
	Company D (T STAR)	1	0	0	0
	Company E (APTG)	1	0	0	0
The Optimal Revenue		NT$ 20.05 billion			

TABLE VII. RESULT INTEGRATION OF GA.

The Optimal Solution by GA		600 MHz	800 MHz	1400 MHz	3600 MHz
The Optimal Number of Blocks		6	8	8	5
The Optimal Result of Bidding	Company A (CHT)	2	0	4	4
	Company B (TWM)	0	1	2	3
	Company C (FET)	1	1	3	2
	Company D (T STAR)	0	0	0	1
	Company E (APTG)	0	0	0	1
The Optimal Revenue		NT$ 20.02 billion			

In this study we proposed two models to find the best scenario of the spectrum combination of each telecom company, the best revenue, the spectrum value of each band, and number of the blocks. These models provide good references for government in planning spectrum auction for 5G. Based on the analysis, government could have better chance to get the best revenue and to maximize the spectrum efficiency.

Based on our experiences using SA and GA algorithm, the running time of GA almost doubles the running time of SA algorithms. For example, in this study, the running time of SA algorithm was 117 minutes and 24.267 seconds, while the running time of GA was 264 minutes and 43.665 seconds over the same server.

In the future, besides focusing on revenue, more non-financial factors can be added to the constraints, such as benefits of the resource-based theory, market equilibrium, and special advantages which give to the new competitors, etc. This could make the analysis much closer to the market practices.

Additionally, many standards or references such as applications, spectrums, technologies and equipment of 5G must be published by WRC 2019. More accurate and up-to-date experiments can be carried out through updated data and analysis model in the future.

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