A 5G Spectrum Demanding Estimation Framework Considering Coalition Formation of Taiwan Telecommunication Operator

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Abstract

With the mobile broadband spectrum allocation for 5G completed in 2020 around the world, the start of commercial operations for the 5G network is just around the corner. However, of the many issues discussed during the spectrum auction process, one core problem remained: Is enough spectrum allocated? Countries currently use the ITU-R M.2290 model without considering (1) the coalition formation of telecommunication operators in each country, (2) the minimum amount of spectrum required for individual telecommunications operators to survive, and (3) urban-rural differences in terms of spectrum requirement. These issues have made it difficult for regulatory authority to answer the question: How much spectrum is required for 4G/5G mobile services? This study proposes a 5G coalition-formation spectrum estimation framework based on ITU-R M.2290 model and using Taiwan as a case study. It is estimated that the basic spectrum requirement for mobile broadband services in urban areas falls within the range of 174-223 MHz, roughly 1.2-1.9 times that required for rural areas. The country's basic mobile broadband needs should be met if an individual operator is allocated 220-330 MHz, and the six telecommunication operators in Taiwan will form three coalitions.

Keywords: 5G, Spectrum, Spectrum licensing, Telecommunications industry

1 Introduction

t is often likened to airborne real estate. As the foundation of national telecommunications policy, spectrum is vital to the growth of the digital economy and governs its development and transformation; spectrum can also be used to soften the impact of the international telecommunications market on the domestic industry. As a critical aspect of the country's medium- to long-term policy for telecommunications technologies and industry policy, spectrum policy should be planned with an eye to sustainability and must take national security, social welfare, commercial value, and technological development into account. The purpose of spectrum policy is to maximize the benefits of spectrum use and guide the country's public, private, academic, and institutional sectors in carrying out medium- to long-term strategic planning for the communications, technology, and service industries.

To accelerate the development of 4G/5G technology in the Republic of China, the Executive Yuan promoted a complete 4G upgrade and facilitated 5G development in the domestic industry, and also initiated a series of mobile broadband spectrum licensing operations: first, for the 700, 900, and 1,800 MHz frequency bands in 2013; next for the 2,500-2,690 MHz band in 2015; then for the 1,800 and 2,100 MHz bands in 2018; and for the 1,800, 3,500, and 28,000 MHz bands in 2019 (NCC, 2019). A total sub-6GHz bandwidth of 870 MHz [1] was allocated through these four auctions to meet the needs of domestic telecommunications operators' mobile broadband services.

The auctions generated a great deal of discussion and response. In this paper, the authors explore the rationale for spectrum auctions and the fundamental problem that has long plagued the government and telecommunications operators alike: How much spectrum is required for the mobile broadband market in the Republic of China (R.O.C.)?

Since the days of 3G spectrum licensing, the government has utilized quantitative and qualitative analysis to determine its spectrum supply strategy and formulate responses to spectrum supply issues. To achieve this, think tanks are regularly commissioned to assess the country's mobile broadband spectrum requirement using the International Telecommunication Union (ITU) spectrum estimation model, and experts in the public, private, academic, and institutional sectors have jointly developed the Frequency Supply

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Plan [2]. According to the ITU-R M.2290 model [3], it is currently estimated that the country's mobile broadband spectrum requirement is approximately 1,625 MHz [4]. The four aforementioned mobile broadband spectrum licensing auctions along with the Radio Frequency Allocation Table of the Republic of China and the Frequency Supply Plan were developed from this estimate.

However, the estimation of spectrum supply requirement relied entirely on market demand and the number of consumers and operators. While it serves as a reference for spectrum resources, it is not a suitable foundation for the R.O.C.'s spectrum management and telecommunications market regulatory policies; nor does it reflect the correlation between spectrum resources and market competition. This is because the telecommunication market, from the operator's viewpoint, demands spectrum as much and cheaper as possible. However, from the government's viewpoint, this may cause liquidity trap [5-6] that spectrum is overissued to the telecommunication market, leading that the government cannot use spectrum supply to absorb cross-ISPs/border shocks of telecommunication related economic activities and lead the nation telecommunication industry to long-term domestic economic growth.

Based on above issues, in conclusion, even with the estimated spectrum requirement of 1,625 MHz acquired through the ITU-R M.2290 model, the government and operators are still unable to answer one fundamental question: How much total bandwidth is required for mobile broadband services in the Republic of China? To be specifically, what is the minimum spectrum requirements for individual telecommunications operators?

This study proposes a 5G coalition-formation spectrum estimation framework based on ITU-R M.2290 model. The proposed framework contains a coalition formation algorithm (CFA) to conjecture the coalition strategies of each operator considering the decreasing spectrum demands of ageing society. The expected contributions of this study are as follows:

(1) Estimating the spectrum demanding based on the status of coalition formation and utilizing spectrum policy to facilitate transformation of the digital economy.

(2) Assessing the minimum amount of spectrum needed for an individual telecommunications operator to provide services.

(3) Establishing a differentiated policy for regional development.

This study extends the results obtained during the authors' employment with the Board of Science and Technology's Spectrum Policy Team [5-6], Executive Yuan (2014~2016) as well as the conclusions from a study commissioned by the Ministry of Transportation and Communications (MOTC)) to explore solutions to problems that have arisen in regard to estimating spectrum requirement [7-8]. Further investigation into the spectrum requirement of each operator and of different areas in the country was also carried out [9-10]. The authors also worked with the Telecom Technology Center—a telecommunications policy and technology think tank and long-time collaborator of the National Communications Commission (NCC)—to determine the significance of the data obtained and put forward policy recommendations based on data-driven decision-making. The model and data offered in this study will provide the nation's regulatory authorities with a quantitative basis for their telecommunications policy decision-making.

This study consists of five parts: Section 2 shows the related work about spectrum requirement estimation model, Section 3 describe spectrum estimation model, Section 4 Results and analysis to do a quantitative analysis of the spectrum requirement needs, and Section 5 discussion the use of the impossible trinity model (often referenced in monetary policy) as a reference for the planning and implementation of spectrum and telecommunications policy after the fourth spectrum licensing. Conclusion is provided in Section 6.

2 Related Work

2.1 Policy-making Process for Spectrum Policy

Since the formation of the Economic Innovation Committee (June 1~November 30, 1985) by the Executive Yuan, policymakers have been applying qualitative and quantitative methods to the formulation of economic and technology policy. To extract knowledge from the public, private, and academic sectors, experts from the three sectors are invited to reach a consensus on innovative measures and policies utilizing quantitative data. Quantitative methods used for medium to long-term policy-making include rate prediction and statistical analysis of probability. Qualitative methods are used for policy adjustments in response to short-term market fluctuations and technological changes; these include the nominal group technique and the Delphi method. Ever since spectrum licensing for the 3G network began, the government has been using qualitative and quantitative methods in the spectrum supply policy-making process, has regularly commissioned think tanks to assess the country's spectrum requirement for mobile broadband through the ITU's spectrum requirement estimation model, and invited experts from the public, private, academic, and institutional sectors to draft the Frequency Supply Plan.

The planning of national communications resources and the provision of guidance and incentives for industrial development shall be conducted in accordance with the law by subordinate agencies under the Executive Yuan. It can therefore be deduced that the country's communications affairs are separated into "regulatory affairs involving communications" and "the planning of national communications resources and the provision of guidance and incentives for industrial development."

2.2 Previous Coalitional Game Theory in Wireless and Spectrum Problems

Game theory is an axiomatic-mathematical theory that presents a set of axioms that the game player's action follows, and each game player's success in making a decision depends on the decisions of others. Game theory has a wide range of applications, including economics, engineering, political science, and, more recently, for the issues of wireless resource management. The wireless resource allocation problem can be modeled as a bargaining game, with several game players, a set of bargaining solutions, and a prescription assignment of an alternative to each game player [11-12].

The conventional game theories proposed for wireless resource management has various types including Cournot competition based scheme, Bayesian game based scheme, evolutionary game based scheme, and cooperative game based scheme.

The Cournot competition based scheme applies an economic model used to describe that the two players have the same view of market demand, have good knowledge of each other's cost functions, and choose their profit-maximizing output with the belief that their rival chooses the same way [13-14].

The Bayesian game-based model applies Bayesian Probability model to simulate that the players have incomplete information [15]. On the other hand, the evolutionary game-based scheme extended the Bayesian game-based model that continuously update the system parameters according to the changing environment of the wireless communication system [16].

A cooperative game-based scheme (or coalitional game) is a game of acquiring wireless resources with competition between groups of players ("coalitions") due to the possibility of cooperative behavior [17-18].

These methods are well designed to solve the radio resource management problem. However, 5G networks apply network slicing technology to tailored services to satisfy their specific business requirements. This means that the wireless resource does not limit to the spectrum/bandwidth, but also includes the corresponding network functionalities, such as protocol, service guarantee, and core network resource, based on different isolation strategies shown in Figure 1 [19-21]. The conventional game theory model, though in well-form, are therefore hard to capture the coalition decision between operations in 5G network with network slicing technology.

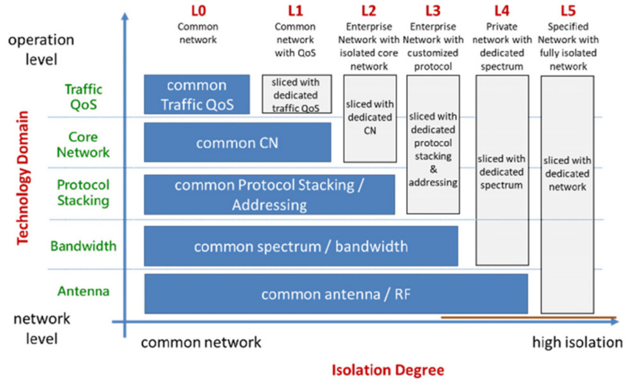

Figure 1. Architecture of 5G network slicing

3 Spectrum Estimation Model Based on the Characteristics of the Domestic Telecommunications Market

The authors were previously employed with the Spectrum Policy Team of the Board of Science and Technology, Executive Yuan (2014-2016), which expanded on the ITU-R M.2290 model to include functionalities for demographics and usage behavior. The authors also proposed the Adjust User Density Spectrum Requirement Estimation Model (AUD) to better fit the current developmental status of the telecommunications market [5-6]. However, AUD does not answer the very fundamental problem: what is the minimum spectrum requirements for individual telecommunications operators?

This study expands on the AUD model to propose the Enhanced AUD (E-AUD) Model, which takes the following into consideration: (1) the characteristics of the R.O.C. telecommunications market, including technology neutrality in spectrum management and the separation of television/radio broadcasting from mobile broadband services; (2) the minimum amount of spectrum required for individual telecommunications operators to survive; and (3) urban-rural differences in spectrum requirements. The following figure (Figure 2) illustrates the systemic framework of the E-AUD model.

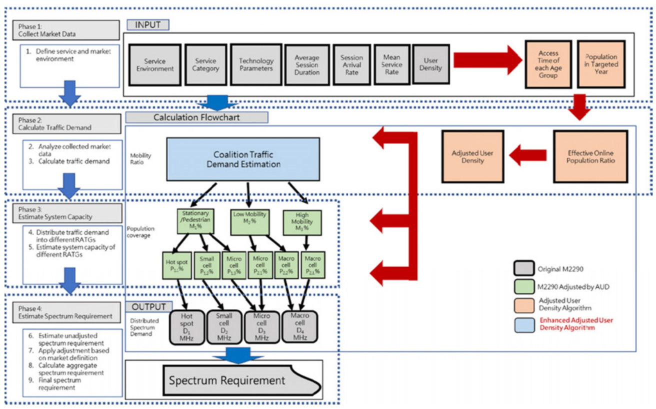

Figure 2. E-AUD model framework [6]

E-AUD model attempts to answer the following questions:

(1) Minimum spectrum requirements for individual telecommunications operators: The minimum spectrum requirement refers to the amount of spectrum required for an operator to provide adequate telecommunications service and survive in a competitive market. The ITU-R M.2290 model can only estimate overall spectrum requirement given a fixed number of previously identified telecommunications operators; the model cannot assess the minimum amount of spectrum for an individual telecommunication operator which may require to maintain operation. Assessing the minimum amount of spectrum individual telecommunications operators need to maintain operations can help operators determine the amount of spectrum they need to acquire from existing spectrum auctions to establish a stable foundation to compete in the market, and can also help them decide how to compete or cooperate with other operators in the future. The government can assess the significance of the amount of spectrum acquired by various operators in the telecommunications market. Are the bands too crowded? How are collaborations between operators affecting the market? What regulatory measures should be taken to manage competition in the telecommunications market?

(2) The urban-rural disparity in spectrum requirement: No information regarding the spectrum requirement of other administrative areas based on their respective population density and base station distribution was provided. Only applying the highest population density in the country as input of the spectrum estimation process. It was based on the argument any mobile broadband service that satisfies that district's telecommunications needs can achieve the same in any other place in the country. As this affected the amount of spectrum licensed, the target bandwidth set by operators for spectrum auctions, and the fees operators set for their data plans, applying a standard based on the data of highest population and business operation to other administrative areas with different demographics can cause the government and telecommunications operators to overshoot the mark when formulating policy and establishing data plan pricing, thus affecting spectrum availability.

(3) The coalition formation of telecommunication operators in each country: As the country becomes an aged society (14% of the total population is aged 65 years and older), and with the steady decline of its birth rate, Taiwan is expected to see negative population growth starting in 2021. However, the current telecommunication operators are organized individually to support positive population growth society. The coalition formation of telecommunication operators will be the trend in a negative population growth society. We should take demographic changes into consideration when allocating spectrum to ensure steady socio-economic development.

In Figure 2, the gray blocks are part of the original ITU-R M.2290 model [5-6]; the green blocks are the AUD's additional spectrum estimation components for different demographics and user behaviors; and the blue blocks are the additional E-AUD components included in this study. The new E-AUD components include:

(1) a separation component for unicast and multicast service traffic in the center of the chart that better fit the separation of television/radio broadcasting and mobile broadband services in the R.O.C.;

(2) a distribution component for non-standalone and standalone 4G/5G network traffic on the right of the chart that better fits the R.O.C.'s technology neutral policy of spectrum management, which does not specify the use of 4G/5G technology among operators; and

(3) an output component that provides the minimum amount of spectrum required for non-standalone 4G/5G or standalone 5G network services, the minimum amount of spectrum required for an individual operator to meet national demand for 4G/5G or 5G network services, and the spectrum needed for different administrative areas with different demographics and network user behaviors.

The blue blocks at the top of the chart represent the four-phase spectrum estimation process of the E-AUD model. The four phases are: (1) the collection of market data, (2) the calculation of traffic demand, (3) the estimation of system capacity, and (4) the estimation of spectrum requirement.

Phase one, the collection of market data, involves radio and service environment parameters. Radio environment parameters include radio-related parameters for Radio Access Technology Groups (RATGs) such as macro cell, micro cell, pico cell, and hot spot. Service environment parameters include service categories (e.g., super-high multimedia, high multimedia, medium multimedia, low rate data, and very low rate data), data rates (e.g., high data rate and low data rate), usage scenarios (e.g., home, office, or public area), and user density (e.g., dense urban, suburban, or rural area).

Phase two is the calculation of traffic demand and involves two steps: (1) analysis and conversion of collected market data into market attribute settings (e.g., user density, session arrival rate per user, mean session duration, mean service bit rate [bps], and user mobility class); and (2) calculation of traffic demand (bps) based on market attribute settings.

Phase three is the estimation of system capacity and involves two steps: (1) distribution of traffic demand in every service category to available RATGs; and (2) evaluation of the system capacity (bps/cell) required to support the estimated traffic for different RATG services under different tele densities.

Phase four is the estimation of spectrum requirement and involves two steps: (1) calculation of the original spectrum requirement of different system capacity requirements (bps/cell) using spectral efficiency values (bps/Hz/cell); and (2) revised spectrum requirement based on the minimum amount of spectrum allocated to RATG/ISP operators and the number of operators establishing overlay networks.

Furthermore, we also designed a coalition formation algorithm (CFA) within E-AUD to conjecure the coalition strategies of each operator considering the decreasing spectrum demands of ageing society. CFA consists of five steps as following:

Step 1. Building the payoff table T_k for each operator *k*.
Step 2. Pick up a decision criterion C_k for each operator *k*.
Step 3. Explore the corresponding alternatives of each operator *k*
Step 4. Get the overall profit based on the alternatives & states chosen by each operator
Step 5. If the overall profit of current strategy combination of all operator $Prof_{curr}$ is larger than $Prof_{max}$, set $Prof_{max}$ to $Prof_{curr}$ and $Spec_{max}$ to $Spec_{curr}$
Step 6. Go to step 2 until all strategy combinations are explored

where the profit (*Prof*) is sum of all operator's profit calculated by

$$Prof = \sum_{\text{each operator } k} Prof^k \quad \textbf{(1)}$$

The *k*-th operator's profit ($Prof^k$) is the profit based on chosen coalition alternative (a_i^k) and the desired 5G spectrum (S_j^k) according to the decision criterion (C^k) this *k*-th operator intends to adopt. All possible coalition alternative (a_i^k) and the desired 5G spectrum (S_j^k) are aggregated as an payoff table (T^k) calculated by E-AUD as described as following:

$$\begin{bmatrix} val(a_1^k, S_1^k) & \cdots & val(a_1^k, S_m^k) \\ \vdots & val(a_1^k, S_j^k) & \vdots \\ val(a_n^k, S_1^k) & \cdots & val(a_n^k, S_m^k) \end{bmatrix} \quad \textbf{(2)}$$

where $val(a_i^k, S_j^k)$ is the profit of corresponding a_i^k and S_j^k, *n* and *m* means the number of possible decision making criterions and the amount of the required spectrum.

The decision making criterions applied in CFA includes Max-Max, Max-Min, Savage Regret, and Laplace criterions which are well-known criterions in Operation Research domain.

The Max-Max criterion describes the decision making behavior is overly optimistic. The selected alternative $a^{\max}$ of Max-Max criterion is therefore:

$$a^{\max} = \arg_{ai} \max(\max(val(a_i, S_j))) \quad \textbf{(3)}$$

where (3) consists of two steps that first determines the maximum profit, *i.e.*, $\max(val(a_i, S_j))$, of all possible demanded spectrum for each alternatives, and then chooses the alternatives with hightest profit, *i.e.*, $\arg_{ai} \max(\max(val(a_i, S_j)))$.

The Max-Min criterion demonstrates the decision making behavior is overly pessimistic. The selected alternative $a^{\min}$ of Max-Min criterion is:

$$a^{\min} = \arg_{ai} \min(\max(val(a_i, S_j))) \quad \textbf{(4)}$$

where (4) consists of two steps that first determines the maximum profit, *i.e.*, $\max(val(a_i, S_j))$, of all possible demanded spectrum for each alternatives, and then chooses the alternatives with lowest profit, *i.e.*, $\arg_{ai} \min(\max(val(a_i, S_j)))$.

The Laplace criterion means that the decision making behavior focuses on the likelihood of occurrence of the status. Therefore, the selected alternative a^{Lap} of Laplace criterion is:

$$a^{Lap} = \arg_{ai} \max(avg(val(a_i, S_j))) \quad \textbf{(5)}$$

where (5) consists of two steps that first determines the average profit, *i.e.*, $avg(val(a_i, S_j))$, of all possible demanded spectrum for each alternatives, and then chooses the alternatives with highest average profit, *i.e.*, $\arg_{ai} \max(avg(val(a_i, S_j)))$.

The Savage criterion focuses on minimizing regret. The regret is defined as the opportunity loss $r(a_i, S_j)$ when alternative a_i is choosen and spectrum S_j is acquired. The $r(a_i, S_j)$ is defined as:

$$r(a_i, S_j) = \max\{val(a_i, S_j)\} - val(a_i, S_j) \quad \textbf{(6)}$$

The selected alternative a^{sav} of Savage criterion is therefore:

$$a^{sav} = \arg_{ai} \min\{sum(r(a_i, S_j))) \quad \textbf{(7)}$$

where (7) consists of two steps that first determines the sum of the regret value, *i.e.*, $sum(r(a_i, S_j))$, of all possible demanded spectrum for each alternatives, and then chooses the alternatives with lowest opportunity loss, *i.e.*, $\arg_{ai} \min\{sum(r(a_i, S_j)))$.

4 Results and Analysis

The E-AUD model proposed in this study was used to assess a spectrum requirement estimate based on the characteristics of the R.O.C. telecommunications market. The parameters used and the resulting spectrum requirement estimate are as follows:

4.1 Parameter Settings

The authors designed the E-AUD model by expanding upon the authors' previous AUD model and the ITU-R M.2290 model. The E-AUD model requires both radio- and market-related parameters.

Since the country's 4G/5G communications devices follow international standards, the radio-related parameters used by the E-AUD model are the international standards provided by the ITU [3]. These include standards for spectral efficiency and radio parameters (e.g., guard band between different types of base stations, minimum deployment per operator per radio environment, and other radio-related parameters).

Market-related parameters must be adjusted based on the actual status and condition of the domestic telecommunications market. The parameters are: (1) sector area, (2) distribution ratios among available RATGs (the ratio of 4G/5G service usage [%]), (3) population coverage percentage (the ratio of the population that is in the service area of a given base station [%]), and (4) adapted user density (the user density based on demographics [user/km2]).

Sector area is the area (km2) covered by macro cell, micro cell, pico cell, and hot spot radio environments in dense urban, suburban, and rural areas. With the number of base stations in each area provided by the NCC, we can determine, via the base station output power, the number of macro cells (greater than 10 W), micro cells (between 1 and 10 W), and pico cells (less than 1 W) in an area; the number of hot spots can be determined through market surveys. The macro cell, micro cell, pico cell, and hot spot base station coverage area (km2) in dense urban, suburban, and rural areas can subsequently be determined. The estimated sector areas are listed in the Table 1.

Table 1. Sector area (area of base station coverage [km^2])

Area of base station coverage [km^2]	Dense urban	Suburban	Rural
Macro cell	0.037	0.15	0.22
Micro cell	0.037	0.1	0.15
Pico cell	1.60E-03	1.60E-03	1.60E-03
Hot spot	6.50E-05	6.50E-05	6.50E-05

Population coverage percentage is the ratio of the population that is in the service area of a given base station (macro cell, micro cell, pico cell, or hot spot). This parameter is determined by calculating the ratio of the population that is in the service area of a given base station in a given service environment (SE) using the number of base stations in each area and their theoretical area of coverage provided by the NCC. The data are listed in the Table 2.

Table 2. Population coverage percentage (the ratio of the population that is in the service area of a given base station [%])

Service environment	Usage scenario	Living environment	Macro cell	Micro cell	Pico cell	Hot spot
SE1	Home	Dense Urban	100	90	20	80
SE2	Office	Dense Urban	100	90	20	80
SE3	Public Area	Dense Urban	100	95	40	40
SE4	Home	Suburban	100	35	0	80
SE5	Office, Public Area	Suburban	100	50	35	20
SE6	Home, Office, Public Area	Rural	100	0	10	50

The ratio of 4G/5G service usage denotes the distribution ratio of 4G/5G traffic when users are accessing online services. Two sets of data are used for this parameter: (1) non-standalone 4G/5G networks, in which 80% of the traffic goes through 4G and 20% goes through 5G; and (2) standalone 5G networks, in which all traffic goes through 5G. These data can provide government agencies and operators with information on the bandwidth resources needed for both non-standalone 4G/5G networks and the future standalone 5G networks.

Adapted user density is an additional parameter required by the AUD algorithm added to the ITU-R M.2290 model by the authors [5-6]. The parameter denotes the population accessing online services in various service environments based on demographics and usage behaviors (e.g., watching videos, instant messaging, reading news, using e-mail, browsing social media, uploading files, etc.) The required parameters include the population density of an area, its demographics [8], the activities of internet users in different age groups [5-6], and the amount of time spent accessing the internet via smartphone on a daily basis by internet users in different age groups [9]. The data is summarized in the Table 3.

Table 3. Parameters for the calculation of user density based on demographics [user/km2] Source: Department of Household Registration [9], Ministry of the Interior; TWNIC; NDC [10]

National demographic data of 2019; Source: Department of Household Registration, Ministry of the Interior (2019)							
	Republic of China	Daan District Taipei City	Taipei City	Northern Taiwan	Central Taiwan	Southern Taiwan	Eastern Taiwan
Population	23,598,776	307,631	2,666,908	10,743,634	5,808,594	6,244,735	543,335
Area	36,197.07	11.4	271.8	7,353.0	10,506.0	9,882.0	8,143.0
Population dENSITY	652.0	27,076.9	9,812.0	1,461.1	552.9	631.9	66.7

Activities carried out by internet users in different age groups [%]; Source: TWNIC (2019)					
	Mean	12-23 years	24-38 years	39-54 years	55 years and older
Instant messaging	94.8	94.0	97.5	95.2	91.9
News	87.9	81.9	93.1	89.9	83.7
Video/live streaming	84.5	96.4	92.4	83.3	70.1
E-mail/search engines	82.5	90.6	95.9	85.7	59.8
Social media or forums	79.2	95.5	94.5	81.0	51.3

Time per day (in minutes)spent accessing the Internet via smartphone by internet users in different age groups in 2019 [min] Source: NDC [9]						
Mean	12-19 years	20-29 years	30-39 years	40-49 years	50-59 years	60 years and older
206	312	262	235	179	142	116

4.2 Comparison of the Spectrum Requirement Estimates of the E-AUD and ITU-R M.2290 Models

The comparison of the spectrum requirement estimates of the E-AUD and ITU-R M.2290 models is shown in Table 4. As previously stated, in the MOTC-commissioned study that used the ITU-R M.2290 model, the amount of spectrum needed was calculated using data from Daan District, Taipei City. Therefore, the authors also used data from Daan District for this study's calculations with the E-AUD model. Since the original spectrum requirements were not disclosed in the study using the ITU-R M.2290 model, "N/A" has been entered into the corresponding cell in Table 4.

Table 4. Spectrum requirement estimates of the ITU-R M.2290 and E-AUD models (the latter takes into account the characteristics of the country's telecommunications market) Source: Chih-Jen Chen et al., 2016 [4]

Spectrum requirements for Daan District, Taipei City (MHz)			
Estimation methodology	Mobile broadband service	Original spectrum requirements	Total spectrum requirements of the five domestic operators
M.2290	Non-standalone 4G/5G network; includes television/radio broadcasting	N/A	1,625
E-AUT	Non-standalone 4G/5G network; includes television/radio broadcasting	538	1,400
	Non-standalone 4G/5G network; includes television/radio broadcasting not included	223	1,100
	Standalone 5G network; television/radio broadcasting not included	174	800

When calculating for non-standalone 4G/5G networks and taking television/radio broadcasting services into account, the E-AUD model estimates an original spectrum requirement of 538 MHz. If the size of spectrum blocks (20 MHz) in various cells and independent mobile broadband services provided by the five domestic operators are included, a total of 1,400 MHz is needed, which is 225 MHz higher than the original estimate calculated using the ITU-R M.2290 model (1,652 MHz). The difference stems from Daan District's aging demographic and differing usage behaviors among different age groups, which are not considered in the ITU-R M.2290 model.

Additionally, if the domestic telecommunications market-non-standalone 4G/5G networks for mobile broadband services that are separated from television/ radio broadcasting services (i.e., television/radio broadcasting services are not included in the calculation) is taken into account, the original total spectrum requirement is only 223 MHz (or 1,100 MHz if the five domestic operators operate their mobile broadband services independently). The reason for this is that a lower modulation order and coding rate (or, equivalently, a lower spectral efficiency) are required for television or radio broadcasting in order to ensure the delivery of a television/radio signal to every user. As a lower spectral efficiency means that a greater spectrum requirement is needed, forgoing the transmission of television/radio signals drastically decreases the amount of spectrum needed. If the national telecommunications regulatory authority wishes to consolidate television/radio broadcasting services with mobile broadband services, the authors suggests that domestic telecommunications operators collaborate with existing broadcast television/radio operators to fully utilize existing television/radio broadcasting spectrum and maximize the efficiency of spectrum utilization.

Furthermore, if the future displacement of 4G networks by 5G networks is considered, the original spectrum requirement drops from 223 MHz to 174 MHz. This is because 5G technology utilizes a higher modulation order and coding rate (or, equivalently, a higher spectral efficiency). As a higher spectral efficiency means not as much spectrum is needed, the amount of spectrum required can be drastically lowered through the use of standalone 5G networks. Taiwan's telecommunications regulatory authority and the Directorate General of Budget, Accounting, and Statistics, Executive Yuan should consider this factor, since the shutdown of 4G services can lead to the over-allocation of spectrum. This means that, for the same amount of data, the use of 5G networks can greatly reduce smartphone data costs and download times, which reduces the profit of operators, especially if the cost of deployment and bidding prices for 5G spectrum exceed the expectation of the national telecommunications regulatory authority. Such circumstances can lead to unexpected consequences as the original estimates for spectrum licensing can raise the country's policy goals for economic growth.

4.3 Analysis of the Present and Future Situations of Telecommunications Operators Via An Estimation Using the E-AUD Model and the Amount of Spectrum Allocated to Each Operator

Table 5 details the spectrum requirement estimates calculated with the E-AUD model using data from Daan District, Taipei City. The data in the table include the original spectrum requirement, the spectrum requirement for individual operators to satisfy user demand for mobile broadband services, the total spectrum requirement of the three corporate group operators, and the total spectrum requirement of all five operators. The spectrum requirement estimates calculated with the ITU-R M.2290 model was not listed in the comparison since the relevant information was not disclosed. Table 6 lists the current spectrum resources allocated to each domestic telecommunications operator [1].

Table 5. Spectrum requirement estimates calculated with the E-AUD model, which takes the characteristics of the domestic telecommunications market into account

Spectrum requirement estimates for Dann District, Taipei City calculated using the E-QUD model (MHz)				
Mobile broadband services	Original spectrum requirement	Spectrum requirement for individual operators to satisfy user demand for mobile broadband services	Total spectrum requirement of the three corporate group operators	Total spectrum requirement of all five operators
Non-standalone 4G/5G networks; television/radio broadcasting not included	233	300	660	1,100
Standalone 5G networks; television/radio broadcasting not included	174	220	480	800

Table 6. Current sub-6 GHz spectrum resources allocated to domestic telecommunications operators Source: NCC [1]

Operator	Specturm allocated in the first to third spectrum autions (MHz)	Spectrum allocated in the fourth spectrum auction in 2020 (MHz)	Total (MHz)
Chunghwa Telecom	180	90	270
Taiwan Mobile	100	60	160
Asia Pacific Telecom	85	0	85
Far EasTone Telecommunications (FET)	155	80	235
Taiwan Star Telecom (TSTAR)	70	40	110
Total	590	270	860

As shown in Table 5, if the size of each spectrum block (20 MHz) in 4G/5G networks is considered, a minimum of 223 MHz (optimally, 300 MHz) of spectrum is needed for individual operators to satisfy demand for 4G/5G service and a minimum of 174 MHz (optimally, 220 MHz) of spectrum is needed for individual operators to satisfy demand for 5G service.

Through this approach, it can be determined that for each major telecommunications operator to independently satisfy future demand for 4G/5G service without being constrained by other operators, at least 223 MHz of spectrum must be acquired, and operators should aim to acquire 300 MHz of spectrum in the fourth spectrum auction

Based on Table 5 and Table 6, the authors of this study assessed the future situations of telecommunications operators after the fourth spectrum licensing auction to serve as a basis for government countermeasures:

(1) The goal of the fourth spectrum auction for mobile broadband licenses was to promote 5G development. Nevertheless, operators need to consider how to acquire the minimum amount of spectrum needed to operate in the 4G network market to provide independent 4G service unconstrained by other operators. This explains why the bids at the fourth spectrum licensing auction for mobile broadband licenses exceeded expectations despite the amount of spectrum allocated.

(2) Chunghwa Telecom has currently acquired 270 MHz of spectrum, which is quite close to the optimum amount (300 MHz). The company can independently satisfy user demand for 4G/5G services by making slight adjustments to its base station distribution, which makes it the telecommunications operator least constrained by competition.

(3) Far EasTone Telecommunications (FET) has acquired 235 MHz of spectrum, which barely exceeds the minimum amount (223 MHz) of spectrum required. By adjusting its cell deployment strategy, FET should be able to independently satisfy user demand for 4G/5G services. With the complete roll-out of 5G networks in the future, the spectrum acquired by FET shall exceed the optimum amount needed for standalone 5G networks (220 MHz), which means it is less likely that FET will be constrained by competition.

(4) Asia Pacific Telecom did not acquire any spectrum in the fourth spectrum auction and only has 85 MHz of spectrum. This means that Asia Pacific Telecom may set the provision of specialized 5G services as its primary goal and actively form strategic alliances with other operators that are also short of the minimum amount of 223 MHz spectrum needed for 4G/5G services and the minimum amount of 174 MHz needed for 5G services.

(5) Taiwan Star Telecom (TSTAR) only acquired 110 MHz of spectrum and may find it difficult to operate independently, as the amount of spectrum is far less than the 223 MHz needed for 4G/5G services and the 174 MHz needed for 5G services. TSTAR may provide its spectrum to domestic operators as supplementary frequency bands for 4G/5G networks, coordinating with domestic operators to provide them with spectrum resources that they lack and serving as a middleman for roaming services to help foreign operators meet demand on the part of foreign tourists or businesses for roaming service.

(6) Taiwan Mobile acquired 160 MHz of spectrum, which is less than the minimum amount needed for either 4G/5G or 5G services (223 MHz and 174 MHz, respectively) but only slightly less than the latter. Taiwan Mobile may act to form a strategic alliance with the other two operators to acquire supplementary frequency bands for the 4G and 5G networks, so as to provide 4G/5G services.

(7) The government has currently allocated 860 MHz of spectrum, which already exceeds both the total amount needed for the 4G/5G services provided by the three corporate group operators (660 MHz) and the total amount needed for 5G services independently provided by all five operators (800 MHz). It is, however, far less than the total amount needed for the 4G/5G services independently provided by all five operators (1,100 MHz). This means that the telecommunications market will either be split between three major and two minor telecommunications operators or strike a balance between the three corporate group operators. We are unlikely to see a market shared by five independent operators. However, after the fourth spectrum licensing auction, the public and academic sectors may start planning for a fifth spectrum licensing auction to help the five operators provide 4G/5G services. If the five operators have been consolidated into three major corporate groups and the market has achieved equilibrium by then, the operators may be less motivated to bid as additional spectrum will not be needed.

(8) Market collaborations and policy management measures involving spectrum- and infrastructure sharing have yet to come to fruition in the R.O.C. Taiwan Mobile, TSTAR, and Asia Pacific Telecom are therefore likely to enter into talks with the government regarding the implementation of spectrum and infrastructure sharing among operators. However, Chunghwa Telecom may reserve its opinion due to its ample spectrum resources, while FET, whose spectrum amount barely exceeds the minimum requirement might remain on the fence on this matter.

4.4 Assessment of Spectrum Evaluation in Various Regions of the Country Using the E-AUD Model

Table 7 details the estimated amount of spectrum requirement for the northern, central, southern, and eastern regions of the R.O.C. calculated using the E-AUD model. According to the National Development Council's Comprehensive Development Plan for the Taiwan Region, the northern region includes Taipei, New Taipei, Keelung, Taoyuan, Yilan, and Hsinchu; the central region includes Miaoli, Taichung, Changhua, Nantou, and Yunlin; the southern region includes Chiayi, Tainan, Kaohsiung, and Pingtung; and the eastern region includes Hualien and Taitung.

The following implications regarding the telecommunications market may be drawn from the data in Table 6 and Table 7:

(1) If the telecommunications operators consolidate into three corporate groups, the current amount of allocated spectrum (870 MHz) has far exceeded the total amount of spectrum needed for all four regions, meaning there is an over-allocation of spectrum. This may lead to a widening of the urban-rural divide as

Table 7. Estimate of spectrum requirement in the nation's northern, central, southern, and eastern regions calculated using the E-AUD model

	Spectrum requirement (MHz)	Daan District, Taipei city	Northem region	Central region	Sourthen region	Eastern region
Non-standalone 4G/5G networks; television/radio broadcasting not included	Original total spectrum requirement	223	195	189	190	182
	Spectrum requirement for individual operators to independently meet user demand for mobile broadband services	300	240	240	240	240
	Total amount of spectrum requirement of the three corporate group operators	660	540	540	540	540
	Toral amount of spectrum requirement of all five operators	1100	800	800	800	800
Standalone 5G networks; television/radio broadcasting not included	Original total spectrum requirement	174	105	99	99	92
	Amount of spectrum requirement for individual operators to independently meet user demand for mobile broadband services	220	160	160	160	160
	Total spectrum requirement of the three coporate group operators	480	480	480	480	480
	Total spectrum requirement of all five operators	800	800	800	800	800

value-added telecommunications services are concentrated in urban areas, while government- or operator-subsidized telecommunications services are developed in non-urban areas.

(2) Currently, only Chunghwa Telecom and FET are capable of independently providing for the spectrum requirement of the eastern region. If the government wishes to promote the construction of telecommunications infrastructure in the eastern region, Chunghwa Telecom and FET may be the only operators with enough resources to provide mobile broadband services. Other operators may only be able to provide mobile broadband services via roaming or spectrum sharing. From this, the government can deduce the stance of each operator towards the construction of rural infrastructure and plan accordingly for the corresponding discussion and policy tools for operators of differing circumstances, thus helping them actively invest in building infrastructure in the eastern rural region and bridging the digital urban-rural divide.

(3) The current basis for determining spectrum licensing and auctions is demand for mobile broadband services in areas similar to Daan District, Taipei City, where spectrum requirement is about 1.2-1.9 times the spectrum requirement in rural areas. Applying this estimate to the entire country means that the eastern region shoulders higher data plan costs and mobile broadband costs than it should. When this is coupled with the unified data plan pricing model adopted for the entire Taiwan region, users in the eastern region have to pay higher prices for excess spectrum. The government may need to work with operators to set reasonable data plan pricing based on regional differences in the amount of spectrum requirement.

4.5 Assessment of Spectrum Evaluation in Most Three Aging Counties

Table 8 evaluates the spectrum requirement in the most three aging counties, which are Chiai, Yulin, Nantou counties. All of these counties only required less than 120 MHz for 4G and 5G network, and less than 100 MHz for 5G network. This is because the aging population (> 65 years old) of these counties is higher than 16%, which is the highest aging population ratio in Taiwan. The higher the aging population is, the more retired citizens stay in the home, the less telecommunication requirement is, and the less spectrum is required. This also means that the telecommunication operators can easily solely satisfy the spectrum requirement in these three counties without any coalition operation between these operators.

Table 8. Estimate of spectrum requirement in the three most aging counties

Region	4G+5G Spectrum Requirement (MHz)	5G Spectrum Requirement (MHz)
Chiai County	120	94.47
Yulin County	114	99.04
Nantou County	112	94.08

5 Discussion

This section further explores the issues underlying the result and analysis in Section 4 that the country's basic mobile broadband needs should be met if an individual operator is allocated 220-330 MHz.

5.1 Estimating the Spectrum Demanding Based on the Status of Coalition Formation and Utilizing Spectrum Policy to Facilitate Transformation of the Digital Economy

Quantitative analysis based on the characteristics of Taiwan's telecommunications market was carried out to help the government expand spectrum policy from the telecommunications industry to the large-scale transformation of the digital economy. Just as the money supply has an impact on the macro-economy, spectrum allocation has a material impact on the telecommunications market. The Central Bank regulates the macro-economy by monitoring the price index, and guides industrial development and softens impacts from the global market by regulating the money supply. With the spectrum supply and demand model put forward in this study, the authors hope to steer the government's spectrum policy-making away from the current model of "allocating spectrum to reduce digital economic costs and facilitate industrial development and transformation" and toward "monitoring data plan pricing and regulating spectrum allocation to stabilize the development of the telecommunications market, guide digital transformation, and soften the impact of the global market on the domestic market."

5.2 Assessing the Minimum Amount of Spectrum Needed for An Individual Telecommunications Operator to Provide Services

On one hand, the data allows operators to assess the future development of competitors in the telecommunications industry and formulate corresponding short-, medium-, and long-term competitive and developmental strategies; on the other hand, should the relevant governmental department wish to implement digital convergence policies that entail horizontal and vertical integration of the media industry, a comparison between the estimated and actual amount of spectrum held by each operator can be used to determine its current standing in the telecommunications market and the potential impact on it of other industry alliances. The regulatory authority can then decide what regulatory measures to take in order to manage competition in the telecommunications market and facilitate successful digital convergence and transformation in the industry.

5.3 Establishing a Differentiated Policy for Regional Development

This study can be used to assess the spectrum requirement of different demographics and base station distributions. This will allow the regulatory authority to help operators develop regional data plans with pricing that is acceptable to local residents by exploring the costs of spectrum supply based on the spectrum requirement of individual administrative regions. The need for base stations can also be assessed based on the demographics of rural areas, allowing the government to bridge the urban-rural divide with mobile broadband services set up using the Telecommunications Universal Service Fund or rural broadband infrastructure policies and thus preserving local characteristics while facilitating digital inclusion for rural areas and the disadvantaged.

5.4 Generalizability of Proposed E-AUD

Two aspects of E-AUD are applied for generalizability.

First, for technical matters, the researchers or government staffs of other countries only need provide two more inputs to estimate their spectrum requirement compared to the original ITU-R M.2290 model. The two inputs described in Section 3 are (1) access time of each age group and (2) population in targeted year for each geographic region.

Once the country's basic mobile broadband needs for an individual operator is estimated, for policy draftingmatters, the government staffs may draft the spectrum policy as a macroeconomic monetary policy.

That is, rather than simply respond to telecommunication market spectrum needing, but directly decide an explicit target variable, *i.e.*, data access price, and announces this target to the public in order to maintain price stability [5-6]. Once the targeted data access price higher than the expected valuce, the spectrum authority can release spectrum the market to lower the data access price. On the other hand, the spectrum authority may retract the spectrum supply to rise the data access price, if the price is lower than the expected value.

This spectrum policy drafting method, therefore, ensures the telecommunication investors can easily factor in the changes of data access price, anticipate development direction of the market, adjust their investment strategy to support long-term growth, and the market uncertainty will be therefore reduced. Futhermore, mediating spectrum supply to boost certain industries or cooling some overheating ones also ensures economic growth and stability of the domestic market in advance.

6 Conclusion

In this study, the authors attempted to establish a model for estimating the amount of spectrum requirement in the mobile broadband market in order to resolve a long-standing issue between telecommunications operators and the government of the R.O.C.—the relationship between the supply of spectrum and market trends. Using the E-AUD model designed in this study, the authors estimated the minimum amount of spectrum requirement for mobile broadband services in dense urban areas to be between 174-223 MHz, which is 1.2-1.9 times the spectrum requirement in rural areas. A single operator with 220-330 MHz of spectrum should be able to independently meet basic national demand for mobile broadband if the limitations of the 4G/5G standards and the spectrum requirement of the general public are taken into account. Additionally, if the government wishes to boost post-licensing digital transformation in the telecommunications market and its related industries based on the estimates of this study, the impossible trinity theory can be utilized to examine the relationship between and benefits of policy objectives and measures. In conclusion, the R.O.C. may bring stability to the telecommunications market and its data plan pricing through regulating the spectrum supply, so as to guide the transformation of the digital industry and soften the impact of the international market on the domestic market.

As a preliminary investigation into the benefits of applying quantitative analysis to spectrum policy, this study has several limitations, including:

(1) The spectrum requirement estimates calculated in this study may change in the future due to possible changes in the number of base stations and coverage area, improvements in 5G transmission speeds, and adjustments to the technical parameters of the 5G network. Follow-up investigations shall rely on data collected by the government's telecommunications agencies.

(2) The authors only considered sub-6 GHz spectrum resources in this study, and will further examine the feasibility of implementing wide-area mobile broadband services via telecommunications technologies utilizing super-6 GHz frequencies in the future.

7 Future Work

This study focuses on the Taiwan telecommunication market and discusses the coalition operation between 5 telecommunication operators based on a heuristic game theory. In the future, a more formal game-based solution to coalition formation considering the telecommunication spectrum coordination is required. Furthermore, considering the difficulty to validate the proposed model in a straightway, since we cannot return to the past and then replicate the spectrum policy, more comprehensive economic and novel technology data [22-24] is also required as evidence to a formal game-based solution.

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References

[1] National Communications Commission (NCC), *Spectrum licensing for mobile broadband services*, 2019. Retrieved from https://www.ncc.gov.tw/chinese/gradation.aspx?site_content_sn=3492.

[2] Department of Posts and Telecommunications, Ministry of Transportation and Communications, *Laws and regulations*, Retrieved from https://www.motc.gov.tw/post/home.jsp?id=515&parentpath=0,270&mcustomize=onemessage_view.jsp&dataserno=201112150001&aplistdn=ou=mlaw,ou=post,ou=ap_root,o=motc,c=tw&toolsflag=Y&imgfolder=img.

[3] International Telecommunication Union (ITU), *Future Spectrum Requirements Estimate for Terrestrial IMT*, Report ITU-R M.2290-0, December, 2013. Retrieved from https://www.itu.int/dms_pub/itu-r/opb/rep/R-REP-M.2290-2014-PDF-E.pdf.

[4] C.-J. Chen, C.-W. Chang, L.-T. Kuo, H.-H. Wang, P.-C. Chuang, *The Research Report for the Upcoming 3G Spectrum Release Planning and the Development Trend in B4G/5G Era, Ministry of Transportation and Communications*, 2016, ISBN: 978-986-05-0990-8.

[5] Y.-H. Chen, P.-T. Jan, Impossible Trinity: A Guideline to Shape Telecommunication Policy by Mediating Bandwidth Supply, *Computer Standards & Interfaces*, Vol. 65, pp. 167-179, July, 2019. DOI: https://doi.org/10.1016/j.csi.2019.03.006.

[6] Y.-H. Chen, Drafting Spectrum Policy in an ACcess-price Targeting Perspective and Exploring Its Embedded Biological Nature, *Computer Standards & Interfaces*, Vol. 62, pp. 128-139, February, 2019. DOI: https://doi.org/10.1016/j.csi.2018.11.003.

[7] Taiwan Network Information Center (TWNIC), *Taiwan Internet Report 2019*, 2019. Retrieved from https://report.twnic.tw/2019/.

[8] Department of Posts and Telecommunications, Ministry of Transportation and Communications, *Frequency Supply Plan*, 2019. Retrieved from https://www.motc.gov.tw/post/home.jsp?id=282&parentpath=0,268&mcustomize=multimessages_view.jsp&dataserno=201606230001&aplistdn=ou=data,ou=bulletin,ou=chinese,ou=ap_root,o=motc,c=tw&toolsflag=Y&imgfolder=img.

[9] Department of Household Registration, Ministry of the Interior, *Demographic Statistics*, 2019. Retrieved from https://www.ris.gov.tw/app/portal/346.

[10] National Development Council (NDC), *Digital Opportunity Divide Research Report*, 2019. Retrieved from https://www.ndc.gov.tw/cp.aspx?n=55C8164714DFD9E9.

[11] A. Kumar, K. Kumar, Multiple Access Schemes for Cognitive Radio Networks: A Survey, *Physical Communication*, Vol. 38, Article No. 100953, February, 2020. https://doi.org/10.1016/j.phycom.2019.100953.

[12] S. Kim, Heterogeneous Network Spectrum Allocation Scheme Based on Three-phase Bargaining Game, *Computer Networks*,

Vol. 177, Article No. 107301, August, 2020. https://doi.org/10.1016/j.comnet.2020.107301.

[13] D. Niyato, E. Hossain, A Game-theoretic Approach to Competitive Spectrum Sharing in Cognitive Radio Networks, *IEEE Wireless Communications and Networking Conference*, Kowloon, China, 2007, pp. 16-20.

[14] H. S. Mohammadian, B. Abolhassani, Optimal Quality Competition for Spectrum Sharing in Cognitive Radio Networks, *IEEE 18th Iranian Conference on Electrical Engineering*, Isfahan, Iran, 2010, pp. 231-236.

[15]A. Iftikhar, Z. Rauf, F. A. Khan, M. S. Ali, M. Kakar, Bayesian Game-based User Behavior Analysis for Spectrum Mobility in Cognitive Radios, *Physical Communication*, Vol. 32, pp. 200-208, February, 2019. https://doi.org/10.1016/j.phycom.2018.12.002.

[16] D. Niyato, E. Hossain, Z. Han, Dynamics of Multiple-Seller and Multiple-Buyer Spectrum Trading in Cognitive Radio Networks: A Game-Theoretic Modeling Approach, *IEEE Transactions on Mobile Computing*, Vol. 8, No. 8, pp. 1009-1022, August, 2009. https://doi.org/10.1109/TMC.2008.157.

[17] J. Cao, T. Peng, Z. Qi, R. Duan, Y. Yuan, W. Wang, Interference Management in Ultradense Networks: A User-Centric Coalition Formation Game Approach, *IEEE Transactions on Vehicular Technology*, Vol. 67, No. 6, pp. 5188-5202, June, 2018, doi: 10.1109/TVT.2018.2799568.

[18] A. K. Bairagi, S. F. Abedin, N. H. Tran, D. Niyato, C. S. Hong, QoE-Enabled Unlicensed Spectrum Sharing in 5G: A Game-Theoretic Approach, *IEEE Access*, Vol. 6, pp. 50538-50554, September, 2018, doi: 10.1109/ACCESS.2018.2868875.

[19] 5G Americas, *Network Slicing for 5G and Beyond*, November, 2016. Available online: https://www.5gamericas.org/network-slicing-for-5g-networks-services/.

[20] GSMA, *Network Slicing Use Case Requirements*, April, 2018. Available Online: https://www.gsma.com/futurenetworks/wp-content/uploads/2018/07/Network-Slicing-Use-Case-Requirements-fixed.pdf.

[21] FCC Technological Advisory Council, 5G Network Slicing Whitepaper, 2018. Available Online: https://www.fcc.gov/technological-advisory-council-2018.

[22] L. Tan, J. Shi, X. Tang, X. Lian, H. Wang, 3dDABA: An Algorithm Covering a Three-dimensional WSN Area, *Journal of Internet Technology*, Vol. 21, No. 7, pp. 1949-1956, December, 2020.

[23] Z. Zhang, J. Gong, X. Chen, T.-Y. Hsu, Reinforcement Learning Based Computation-aware Mobility Management in Ultra Dense Networks, *Journal of Internet Technology*, Vol. 21, No. 6, pp. 1785-1794, November, 2020.

[24] M. Guan, L. Wang, Intelligent Recognition of Subcarrier for Wireless Link of Satellite Communication, *Journal of Internet Technology*, Vol. 20, No. 6, pp. 1871-1877, November, 2019.

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