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Research Article

5G Development in China: From Policy Strategy to User-Oriented Architecture

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5G encompasses the development of various key wireless communication technology standards. The development entails both technological advancement and social interaction. This paper analyzes 5G development and its significant shift from a strategy policy to a user-oriented development showing the coplay of technology and society in China. Based on this theory, relevant proposals are recommended for future technical development and industrial regulation. Also, to increase the throughput and spectrum efficiency, channel assignment and load balance are considered. A hybrid routing protocol TOHRP (tree-based and on-demand hybrid routing protocol) and a distributed channel assignment algorithm LBCA (Load Based Channel Assignment) in the multichannel environment are proposed and they solve the traditional problem of (1) waste of spectrum and (2) self-interference. The computer-simulated experiment shows that the algorithm improves the performance.

1. Introduction

5G encompasses the development of various key wireless communication technology standards. The development entails both technological advancement and social interaction. Numerous scholars have worked in this field, for developing improved technical standards through an understanding of the interaction between technology and society. Actor network theory is one of the important theories in this regard.

Scientists and scholars are working on new approaches for energy-efficient and cost-effective 5G technologies, for example, using reduced radio spectrum. They also seek to commercialize 5G technologies in 5 years. In China, from 1G to 5G, the development of each generation is highly competitive. 2G mainly uses Time Division Multiple Access (TDMA), providing digital voice and low-speed data services. 3G provides high speed voice and data services using for instance Code Division Multiple Access (CDMA). 4G has a peak data rate from 100 Mbps to 1 Gbps, using Orthogonal Frequency Division Multiple Access (OFDMA) and supports various mobile broadband data services. Technical research on 5G focuses on system architecture design, millimeter wave, new air interface, light MAC (Media Access Control), RRM (Radio Resource Management), multicell joint processing, large-scale massive multiple-input multiple-output (MIMO), antennas and propagation, intelligent devices, Machine-to-Machine (M2M) communication, and so forth.

To provide theoretical support for 5G development based on the actor network theory, this paper offers an extensive review of current literature, discusses the relevant topics, and provides an overview of China's Information and Communications Technology (ICT) development. It highlights the importance of the close interaction between society and technology. Based on the analysis for preliminary 5G standardization both in China and abroad, participating actors in China and their relationship changes have shown a shift from a policy strategy to user orientation. The relevant key issue is analyzed, such as spectrum efficiency. Also, to increase the throughput and spectrum efficiency, channel assignment and load balance are considered. A hybrid routing protocol TOHRP (tree-based and on-demand hybrid routing protocol) and a distributed channel assignment algorithm LBCA (Load Based Channel Assignment) in the multichannel environment are proposed and they solve the traditional problem of (1) waste of spectrum and (2) self-interference.

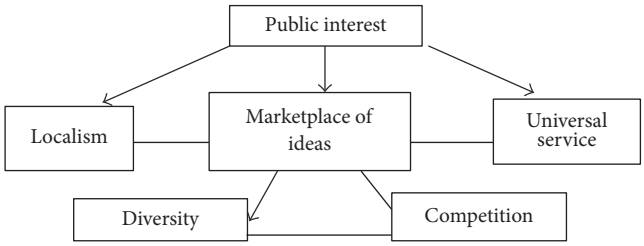

Figure 1: Foundation principles of communications policy [1].

2. Related Work

2.1. The Foundation Principles of Telecommunications Policy. Government departments and international organizations have played policy and standard makers' role in the recent decades. Scholars have tried to define the influence policymakers could have on communication policy. Napoli (2001) stated 6 principles of communications policy in his book, *Foundations of Communications Policy Principles and Process in the Regulation of Electronic Media*, which is also applicable to telecommunications policy. It contains public interest, marketplace of ideas, localism, universal service, diversity, and competition. In his book, the 6 parts are the central motivators or justification for policy decisions. Each of them has endured for decades as an important concept in communications policy making but has remained in contested territory. They are prominent, enduring, and also controversial [1].

Napoli (2001) indicated that "public interest" was the most important concept, and three policy principles would extend from it: "marketplace of ideas", "localism," and "universal service." "Diversity" and "competition" were similar but they differed from each other. Universal service is what the Chinese government had been keen on for decades. An alternative for public interest is the idea of collective users in the 5G era as shown in Figure 1. These principles will be employed in this paper for analyzing the development of ICT and of 5G.

2.2. 5G Academic Research in a Preliminary State. 5G related researches have covered varied topics. The very first book on 5G was published in June 2016. This book *5G Mobile and Wireless Communications Technology* covered different topics varying from special cases to spectrum, describing 5G system architecture [2]. Some most cited papers have shown a variety of perspectives: general concepts, basic infrastructure, and disruptive technology directions [3]. For a more efficient use of the spectrum in the millimeter wave bands, 5G cellular communications were studied with outdoor and indoor penetration tests and a beam-forming prototype was conducted [4]. Emphasizing millimeter wave mobile communications, scholars from USA collected data from experiments around the University of Texas at Austin (38 GHz) and New York University (28 GHz) and proved that indoor networks would be isolated from outdoor networks and a large number of devices should be installed. They found that consistent coverage could be reached when the base stations had a cell-radius of 200 m and dense urban environment could cause path losses. Reflection coefficients and penetration losses for outdoor materials were significantly higher and larger [5].

On the Web of Science platform, there were a total number of 2,577 5G related academic papers covering computer science, engineering, and telecommunications: engineering electrical and electronic field (2,019), telecommunications (1,683), computer science information systems (520), computer science hardware architecture (375), and computer science theory methods (172), respectively. By using the CiteSpace software the 5G key citation situation is studied. 5G academic papers exhibit scattered citation relations and some papers are cited within a small group. Certain authors have more reputation, such as Andrews JG and Rappaport TS. However, for 3GPP, Bhushan N and Demestichas P are different, although they are cited frequently, but they are normally cited along together. This implies a preliminary state and a diversity of research directions.

2.3. Research around the World. The distribution of relevant research institutions around the world includes some of the most prestigious ones, for example, NASA, Machine-to-Machine Intelligence (M2Mi) Corporation, and South Korean IbjngT R&D program focusing on 5G technology researches back in 2008.

Research centers of universities also participated. NYU WIRELESS center from New York University and UK's University of Surrey had pioneering work in 5G technology.

These academic research centers have also collaborated with key industry partners, including Telefonica, Vodafone, regional SMEs, EM3, Huawei, Samsung, Fujitsu Laboratories Europe, Rohde & Schwarz, and Aircom International [6].

"Mobile and wireless communications Enablers for the Twenty-twenty Information Society" (METIS) project started for 5G standardization and definition in 2012, trying to build consensus worldwide. Since then, many projects have emerged out with different focuses: the iJOIN EU project launched for "small cell" technology, ITU-R Working Party 5D (WP 5D) started for a better understanding of future technical issues, EU research project focusing on a CROWD ubiquitous, ultrahigh bandwidth "5G" infrastructure, the TIGRE5-CM (integrated technologies for management and operation of 5G networks) project for future mobile network architecture design, and METIS-II project on 5G radio access network.

Key stakeholders in the industry have made heavy research investments into 5G technology R&D, including the following: Samsung Electronics, Huawei, NTT DoCoMo, Alcatel Lucent, Ericsson, Fujitsu, NEC, Nokia, Verizon, Orange (French Operator), and Google. Moreover, NTT (Nippon Telegraph and Telephone) is operating the world's first 5G networks. NTT DoCoMo and Ericsson pioneered on the 5G outdoor trials, with a cumulative 20 Gbps, and Samsung and Verizon joined late in February 2016.

3. History of China's Telecommunications from 3G to 5G

3.1. Histories of Telecommunication Development in China. By looking back at the history, we can visualize the trend and tendency, so as to generate new knowledge for future development. 5G technology trend can be studied through the following six phases:

3.1.1. 1949–1993: A Tough Beginning—Planned Economy and Regulation from the Central Government. China was founded in the year 1949, October 1. And the Ministry of Posts and Telecommunications (MTP) was established right after that on November 1 in the same year. The newly founded government did not plan for the telecommunications development. Thus, the infrastructure building of telecommunications was given the back seat. With limited poor financial resources, the development of telecommunications was slow. China's national economy got back on track at the time of the first Five-Year Plan, from 1953 to 1957. With 3 years of development after the second Five-Year Plan, covering 1958 to 1962, the most important long-distance telephone building in Beijing exhausted the fund and had to be put off.

In the third Five-Year Plan of 1966–1970 and the fourth Five-Year Plan of 1971–1975, relatively large investments were given to the telecommunications and post industry. Unfortunately, the cultural revolution took place.

In the Fifth Five-Year Plan of 1976–1980 and with the reform of the economics, dramatic changes took place in the economic structure. The telecommunications industry experienced rapid growth. In Paul's (1997) book on telecommunications and development in China, he emphasized that this period "had a tremendous impact on future 5-year plans and on the development of the telecommunications in China" [7].

3.1.2. 1993-1994: Telecommunications Liberalization—The Rise of Operators. The development of private networks and the introduction of China Unicom in 1994 and of Ji Tong in 1993 marked the milestone for the liberalization of China's telecommunications industry. Foreign investments increased the telecommunications competition.

China Unicom was established in July, 1994. It was a joint venture with stakeholders from MEI (Ministry of Electronic Industry), the MOR (Ministry of Railway), the MEP (Ministry of Electrical Power), and 13 other corporations. The origination of China Unicom was a milestone in the Chinese government's telecommunications policy, because it stopped the monopoly model that Xu and Douglas (2002) claimed [8].

Ji Tong was established as a corporation in June 1993, with one aim of seeking joint ventures with overseas companies. Stakeholders include China International Trust and Investment Corporation and 30 other state-owned enterprises and research institutes.

About the emergence of Lian Tong and Ji Tong, Mueller and Tan (1997) indicated that it mixed ministerial politics and business.

> In some ways they are perfect embodiment of China's reform process, and their policy rationale incoherently mixes socialist industrial policy with market competition, they are supposed to be a national, state-centered initiative, but any real energy they have comes from local activities that hardly seem related to the purpose of the central government. Where this process will be leading, is almost impossible to predict. (Mueller and Tan, 1997, p. 63-64)

3.1.3. 1995–1998: The Internal Regroup of MPT—The Transfer of Power from the Central Government. China started its journey of separating the government from enterprise, in the year of 1995. MPT formally separated government functions from enterprise management. It was a huge turning point that the central government officially transferred some of its management power to the public. Thus, the administration power turned out to be a supervision power. In 1998, the post and telecom entities got separated. Since then, China Telecom has focused on telecommunications.

3.1.4. 1998–2002: Entering WTO and Restructuring of China Telecom—Open Market Influence. The entry into WTO in December 1, 2001, has provided significant opportunities for China's telecommunications development. Competition in an open market largely contributes to the improvement of the national services.

In 2000, after the separation of paging, satellite, and mobile services, the services in China Telecom were divided into four parts, thus ending the initial monopoly. The four parts were run by different companies: China Unicom was responsible for paging services, China Telecom was responsible for fixed lines, China Mobile and China Satellite were responsible for mobile and satellite services, respectively. In 2001, China Telecom was further divided into the south part and north part, to optimize the competition inside the industry. In May 2002, China Telecom was formed. With the development, upstream and downstream manufacturers got strengthened.

3.1.5. 2003–2013: 3G to 4G—New Reform Was under Deliberation in MII and Vendors and Suppliers Become More Influential. China's State-owned Assets Supervision and Administration Commission (SASAC) was established in March 2003. It accelerated the change of management and development of the state-owned China Telecom. Since then, ownership, manufacturing rights and management were separated from each other. The development of China's telecommunications was thus better regulated.

3.1.6. 2013–Now: 5G Technology Standardization, Preliminary Stage—User Oriented. From 1G to 5G, the telecommunication development history has shown key components of the 5G research group. The IMT-2020 (5G) established in 2013, Ministry of Industry and Information Technology, National Development and Reform Commission and Ministry of Science and Technology have exhibited great influence on

the development of 5G technical standards in the global context. 5G as a transformative technology calls for many universities, operators, research institutes and manufacturers to participate. Telecommunication is driven by not only government agencies, the operators or manufacturers, but also by users. For example, customers request for very high speed and uninterrupted usage scenarios. Drastic challenges and huge changes will occur to reshape the stakeholders' weight in the future.

3.2. Existing Players: Actor Analysis. After analyzing the 6 phases in the history of telecommunication in China, we could conclude that there has been an obvious shift from planned economy to free market, from policy strategy to customer-oriented strategy. In the actor network theory, these important stakeholders are constantly distributing interests as well as power, in order to form a stable and sustainable environment for 5G growth.

Actor network theory belongs to the category of scientific philosophy [9]. The main scholars of this theory are Latour and Laur and Caron [10]. The actor network theory provides a perspective of the social construction for the interpretation of technical standardization [10]. It is a process-oriented, description-relational theory (Law, 1992) [11] that could be used to describe the process of social construction of science and technology, with different actors being influencing factors. In order to classify these stakeholders, the important concept in the actor network is quoted as "punctualization," which Callon (1991) [12] puts forward, arguing about "the process of punctualization thus converting an entire network into a single point or node in another network" and that "everything is an actor as well as a network—it simply depends on the perspective."

Wireless industry, as an important part of industrial ecology, was divided into market systems, regulatory systems, and innovation systems in academic literature [13]. This paper is based on the classification, forming three systems: the regulatory system, the innovation system, and the market system.

3.2.1. Innovation System. Each system is equivalent to an actor node, which is equivalent to a black box, which encapsulates more components, connected to the network. The subcomponents of the innovation system include regulation of subordinate innovation institutions, manufacturers' research and development departments, and other independent innovation institutions [14]. As a more specific actor, the subdivision component is actively involved in the construction of the actor network, interacting with other actors in the network and embodying their own independent functional attributes.

Through several in-depth interviews, it is revealed that innovation systems, especially private enterprises, call for the continuity in innovation. In an interview, a former technology leader of Huawei Technologies and Microtech described the innovative work of chip and terminal manufacturers in the industry, describing innovation work focusing on integrating the existing technologies, rather than on revolutionary innovation. The original words are quoted as follows:

> For the chip industry, the domestic chip cannot be said to possess independent property rights. They are based on existing technology. We are only processing integration. For the chip, we use the CPU from the ARM (UK); EDN tools from the United States. Chip design language is also from the United States. From front to back they are all westernized. What we do is only to integrate and the core work technology is still dominated by foreign countries. Our advantage lies in its integration capabilities. National chip manufacturers need to have revolutionary innovation to seek stronger role in the 5G development.

Thus, the demand for innovative systems is not just regulatory system funds for stimulation, because the innovation itself is driven by interests and it is impossible to separate innovation from the market system. Also, the innovative continuity is highly demanded for the long-term interests of the innovation system.

3.2.2. Regulatory System. Regulatory systems in China include MII (Ministry of Information Industry), Ministry of Science and Technology, Science and technology commission of the Beijing municipal government, SARFT (State Administration of Radio, Film, and Television), and SASAC (State-owned Assets Supervision and Administration Commission of the state council). In many countries, when facing the basic interests of infrastructure of telecommunication, the government intervenes in the free market. This is the only reason why the Chinese government has a strong system to supervise and manipulate the industry in every aspect, including intellectual property rights protection, innovation encouragement, and asset value management. However, in the 5G initiating phase, a shift of power away from the government was observed.

3.2.3. Market System. In the market system, the components are the service providers, manufacturers, content providers, users, and so forth. It is still early to get solid information, as the 5G technologies are still immature.

Service providers always play important roles in telecommunications development, and this issue becomes even more critical in China's 5G development where China Telecom, China Mobile, China Unicom, and China Net Com are major players. China Unicom already provides unlimited data packages for users to form user habits for future 5G technology in selected developed cities. Customers could enjoy unlimited data package for 139 RMB per month. Content providers also emerge as a significant player in the fields, as 5G enables high speed good quality data everywhere. IoT (Internet of Things), VR (Virtual Reality), and other technologies with high data requirements also boomed recently with content creation.

Manufacturers play an important role in the development of 5G, developing from 3G and 4G, and Da Tang successfully

established the TD-SCDMA standard. To support new 5G air interface and spectrum together with LTE and WiFi, a large numbers of devices are needed to ensure high-rate coverage and a seamless user experience. Manufacturers are striving hard to improve themselves to grasp this 5G opportunity. Based on the insight and understanding of the future development of mobile broadband (MBB), Huawei commercialized its 4.5G Giga-radio solution in June 2016, which continued to innovate with distributed base stations, SingleRAN base stations, and Blade Site base stations and with mobile broadband solution, aiming to help the development of 5G.

In the actor network theory, the meaning of the individual is huge. As Latour described, it is "more complex than the whole," when an individual is no longer a self-sufficient atomic structure but has a series of differences and complexities, such as the properties of a variety of information [15]. Also, in the 5G key network technologies, users play a vital role. The customer-centric network requires customer-centric access, simplifying the multiconnection management mechanism and the service provisions are to be based on user preference as well. In the distribution of interests among different actors (innovation system, regulatory system, and market system), it is important to maintain the balance. In the user-centric orientation, there is a demand for more scenarios for dealing with the technological development challenges. Data traffic explosion is the main driver behind 5G and could be handled through three key technologies: (1) increased area spectral efficiency with extreme densification and offloading, (2) improved bandwidth with mmWave spectrum, and (3) increased spectral efficiency with MIMO [16].

4. Background and Methods

4.1. Background Description. From 1G to 5G, the development of global technical standards has been based on both technology and social interaction. The move from 1G to 4G has paradigm shifts breaking backward compatibility. 5G as a transformative technology requires very high carrier frequencies with numerous base stations and antennas. It will also drastically affect our private lives with the deployment of 5G-based social applications such as Internet of Things (IoT). The 4G technology widely used at present is referred to as the 4th-generation mobile communication system, which mainly includes TD-LTE (Long-Term Evolution, LTE) and FDD-LTE modes. TD and FDD modulation differ by air interface, which could be considered as one type of technology. Regarding the performance, 4G technology, which integrates 3G and WLAN, supports speed of downloads or data transference up to 100 Mbps. Furthermore, it is expandable and easy to be deployed. It however has a few shortcomings. One major disadvantage is that it has too many bands of frequency ranging from 700 MHz to 3.6 GHz, which leads to the complications for terminal design.

The fifth-generation (5G) mobile communication system is the next generation of technical standard. 5G fixed many of the technical weaknesses in 4G technologies, which significantly improved the quality of service, time delay, I/O speed, energy efficiency, and system performance. 5G communication technologies is 10 to 100 times faster than 4G, which reaches 10 Gbps at maximum data transference rate compared to 100 Mbps for 4G technology. And the terminal-to-terminal time delay was shortened by 5 to 10 times compared to 4G. As far as the network capacity is concerned, the mobile data per unit area for 5G is 1000 times more than 4G. And the frequency efficiency of 5G is 5 to 10 times higher than 4G.

The development of 5G has two schemes. One is to improve the technology step by step, which means developing the technology based on currently used 4G LTE technologies to improve the network capacity and performance. This scheme employed unitary TDD and FDD technologies, enhanced relay, 3D-MIMO, enhanced CoMP, LTE-Hi with small sized base, and so forth. Another scheme is to design completely new network structures and wireless technologies to construct a whole new mobile communication network, which requires the following key technologies.

(1) The Employment of High Frequency Bandwidth. To mobile communication, most of the function frequency is below 3 GHz, which provides limited spectrum for more users. The bandwidth spectrum over 3 GHz however has not been fully used. The employment of communication frequency higher than 3 GHz will effectively relieve the shortage of available spectrum resources. High frequency spectrum (60 GHz, e.g.) has the feature of high anti-interference, sufficient bandwidth with reusable bandwidth, smaller size equipment, and antenna with high gain rate. On the other hand, it also has some disadvantages such as shorter broadcasting range and stronger diffraction to the signal, which is also easily affected by the weather or larger obstacles. Therefore it is necessary to consider the work condition for high frequency bandwidth, which is often used cooperatively with other communication techniques.

(2) Innovative Multiantenna Technologies. With the rapid development of wireless communications, the demand for data traffic is growing, and the available spectrum resources are limited. Therefore, it is very important to improve the efficiency of spectrum utilization. Multiantenna technology is an effective way to improve network reliability and spectrum efficiency. At present, it is being applied to all aspects of wireless communication, such as 3G, LTE, and LTE-A. The increased number of antennas provides guarantee for the reliability of data transmission as well as spectral efficiency.

(3) Cofrequency Cotime Full Duplex (CCFD). Traditional wireless communication technology has limitations; it cannot realize bidirectional communication of the same frequency at the same time. This results in great waste of resources and CCFD technology can realize simultaneous use of the same upload and download frequency resources for two-way communication. It theoretically utilizes the system two times. But CCFD also encounters a technical problem of serious self-interference; hence the primary problem is to eliminate interference. In addition, there is also the problem of cofrequency interference with adjacent cells and full duplex. The CCFD application in multiantenna environment will be more difficult and it requires further research.

Table 1: 5G scenarios.

Scenarios	Main applications	Objectives	User requirements	MIMO	UDN	Novel multiple access	All-spectrum access
Wide-area coverage	Everywhere	Consistency	100 Mbps user experienced data rate	V			V
Hot spot	Bus station, football fields, theater,	Tens of Gbps peak data rate and tens of Tbps/km^2 traffic volume density	1 Gbps user experienced data rate	V	V	V	V
Massive-connections	IoT	Low-power massive-connections Low-latency high-reliability, low-power	Reduce device cost Air interface latency: 1 ms End-to-end latency: ms level Reliability: nearly 100%				V

(4) Dense Network. In the future 5G communications, the wireless communication network is evolving towards network diversification, broadband, and integrated, intelligent direction of evolution. With the popularity of a variety of intelligent terminals, data traffic will experience exponential growth. The future of data services will be mainly distributed in the indoor and hot spots, which makes the ultradense network the main method to achieve 1000 times of the mean demand for data traffic for 5G in the future. Ultradense networks will be able to improve network coverage, significantly increase system capacity, and shunt traffic, with more flexible network deployment and more efficient frequency reuse. In the future, for high-band large bandwidth, one will adopt a more intensive network solution for the demand of high frequency spectrum and large bandwidth, which might deploy up to 100 small districts/sector.

(5) Device-to-Device (D2D) Techniques. Traditional cellular communication system is based on the base station as the center to achieve cellular coverage, and while the base stations and relay stations cannot move, the flexibility of the network structure has some restrictions. With the increasing number of wireless multimedia services, the traditional base station, as the center of the business, has been unable to meet the business requirements of massive users in different environments.

D2D technology can achieve direct communication between communication terminals, expanding network connectivity and access methods without the help of the base station.

Due to short-range direct communication, D2D technology can realize higher quality data communication, lower latency and lower power consumption, improve coverage and efficient use of spectrum resources through widely distributed terminals, and support more flexible network architecture and connection methods to enhance link flexibility and network reliability. Currently, D2D technology uses broadcast, multicast, and unicast technological solutions. More technologies will be enhanced in the future, including D2D-based relay technology, multiantenna technology, and joint coding technology.

4.2. Scenarios. 5G can offer high speed, quality, and seamless service, meeting the needs for different applications as well as scenarios. Typical applications include connected gadgets, robotics, social web of things, autonomous vehicles, micropayments, retail logistics, shopping assistance, pollution surveillance, smart grid, water/waste management, remote monitoring, assisted living, integrated environments, optimized operations, and automation [17]. Reduced device costs, better performances, improved coverage, higher speeds, higher capacity, and improved battery life are required for different scenarios; three typical scenarios could be derived from the main applications mentioned above, according to drastically different objectives, performance requirements, user requirements, service requirements, and key challenges. They are as follows: wide-area coverage scenario, hot-spot scenario, and massive-connections scenario as shown in Table 1.

4.2.1. Wide-Area Coverage Scenario. Wide-area coverage scenario is the basic seamless scenario providing service everywhere at anytime, with data rate exceeding 100 Mbps. Some extreme situations could be moving vehicles, such as highway situations which require seamless services on moving vehicles with a speed of 500 km/h. In order to achieve spectral efficiency with a large number of users, massive MIMO technology is needed and it requires more antennas and low-cost implementation. Novel multiple access technology could be applied to improve spectral efficiency and access capability: sparse code multiple access (SCMA), multiuser shared access (MUSA), pattern division multiple access (PDMA), and nonorthogonal multiple access (NOMA) are the possible future schemes.

4.2.2. Hot-Spot High-Capacity Scenario. Hot-spot scenario provides high-capacity as well as quality ultrahigh data

rates, where ultrahigh volume traffic is being handled. Via deploying dense base stations, ultradense networking will increase capacity with novel multiple access technologies. All-spectrum access could also be applied to a variety of spectrum resources, with enhanced data rates and system capacity.

4.2.3. Massive-Connections IoT Scenario. Massive-connections scenarios are mainly IoT, sensing/collecting data, and vertical industries. IMT-2020 concluded it with low-latency high-reliability and low-power massive-connections. Their scenarios require low-power and low costs for a large number of devices applied. Low-latency with high-reliability is required for IoT and vertical industries.

4.3. Methodology. In this paper, a mixed method containing science and social science is used. The method of field study is used and is supported by in-depth interview and document collection and historical data comparison, so as to reveal the trend in the 5G development: an obvious shift from policy strategy to user-oriented architecture. A hybrid routing protocol TOHRP and a distributed channel assignment algorithm LBCA in the multichannel environment are proposed and they solve the traditional problem of (1) waste of spectrum and (2) self-interference.

Field study is a very suitable research method. The purpose of this paper is to analyze the formation and diffusion of 5G technical standards in the 5G's preliminary stage. Semistructured in-depth interviews were used with document collection and comparison of historical data in this study for combining historical data, like the historical changes in regulatory agencies, the evolution of the telecommunications broadcasting system, and so on.

Also, to increase the throughput and spectrum efficiency, channel assignment and load balance are considered. A hybrid routing protocol TOHRP and a distributed channel assignment algorithm LBCA in the multichannel environment are proposed. They solve the traditional problem of (1) waste of spectrum and (2) self-interference. The tree base protocol and the traditional AODV (Ad hoc On-demand Distance Vector) routing protocol are integrated together to reduce delay in the routing protocol, which is proposed by HWMP (Hybrid Wireless Mesh Protocol). A new routing metric is used in this routing protocol and the computer-simulated experiment shows that the algorithm improves the performance.

The relevant computer-simulated experiment follows the selection, preparation, environment, steps, and assessment procedures.

4.4. Experiment

4.4.1. Selection of the Experiment. As the amount of data processing and transmission is enormous in 5G network and the performance is closely related to routing protocol, the key solution for a network with optimized throughput and spectrum efficiency is to choose the best path for large amounts of data to transmit. To improve efficiency, Multiradio Multichannel system is selected, and each node has both the receiving function and the sending function to simulate the 5G scenarios. To solve the problem of self-interference, different information channels are assigned and load balancing issue is also considered.

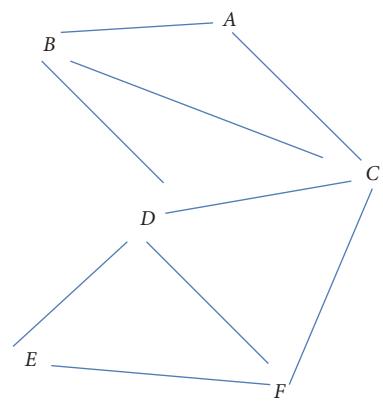

Figure 2: A 5G network transmission model.

A 5G network transmission can be simulated as a model of weighted graph $G = \langle V, E \rangle$, in which weight of edge $e \in E$ is to be determined with each line (shown in Figure 2). There are several traditional algorithms to calculate the optimal path [18–21].

4.4.2. Preparation of the Experiment

ETT (Expected Transmission Time) Algorithm. On link AB, set a time window with length of s at node B to record the number of times (c) that B successfully receives detected packets from node A in the past s seconds. c/s is set to be p_f, the success rate of forward packet transmission on link AB. Similarly, node B regularly sends detective packets to node A and p_r the success rate of backward packet transmission on link AB can be estimated. The ETX (Expected Transmission Count) for a single-hop link is

$$\begin{aligned} \mathrm{ETX} &= \sum_{r=1}^{\infty} r \times p^{r-1} \times (1-p) = (1-p) \sum_{r=1}^{\infty} \frac{dp^r}{dp} \\ &= (1-p) \frac{d \sum_{r=1}^{\infty} p^r}{dp} = \frac{1}{1-p} = \frac{1}{1-p_f-p_r}. \end{aligned} \tag{1}$$

Here r is defined as the resending times after the failure of packet transmission. Then the ETT (Expected Transmission Time) for a single-hop link is

$$\mathrm{ETT} = \mathrm{ETX} \times \frac{S}{B}. \tag{2}$$

Here S is the size of the detective packet and B the bandwidth of the link. ETT is the Expected Transmission Time Algorithm.

ETTI (Expected Transmission Time with Interference) for a single-hop link is

$$\mathrm{ETTI} = \mathrm{ETTI}_{\mathrm{Inter}} + \mathrm{ETTI}_{\mathrm{Intra}}. \tag{3}$$

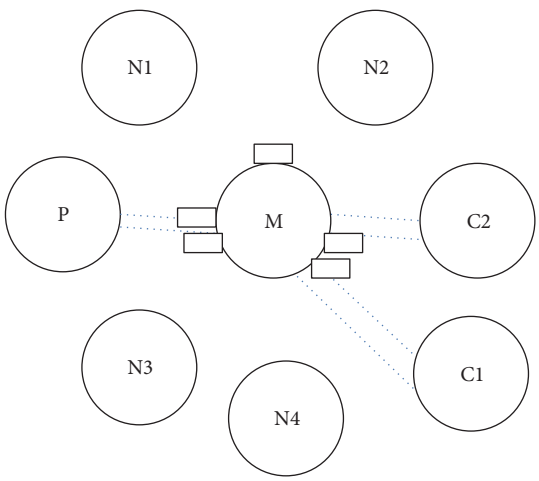

Figure 3: Bind neighbor node to the T transceiver.

Define I_A (and I_B) as the collection of nodes that interferes with the communication of node A (and node B) within A's (and B's) coverage of interference. Thus,

$$\mathrm{ETTI}_{\mathrm{Inter}} = \mathrm{ETT} \times \left| I_A \cup I_B \right|. \tag{4}$$

Equation (4) shows that the interference towards a link is caused by outside data flows, and the interference within the link is determined as (5) shows:

$$\begin{aligned} \mathrm{ETTI}_{\mathrm{Intra}} &= \sum_{i=1}^{k} \mathrm{ETTI}_i \times e, \\ e &= \begin{cases} 1 & \mathrm{channel}_i = \mathrm{channel}_{AB},\ i \cap \left(I_A \cup I_B\right) \neq \varphi \\ 0 & \text{otherwise}, \end{cases} \end{aligned} \tag{5}$$

where k means that AB is the kth hop on the route.

The calculation method of $\mathrm{AETTI}_{\mathrm{Intra}}$ is the same as that for $\mathrm{ETTI}_{\mathrm{Intra}}$. AETTI (All Expected Transmission Time with Interference) takes into account not only traditional factors such as delay but also channel interference and node load.

$$\mathrm{AETTI} = \sum_{i=1}^{n} \mathrm{ETTI}_i. \tag{6}$$

Through the routing protocol, nodes on the network can communicate with other nodes and establish a path to connect to the Internet. Neighbor nodes transferred on the same channel will interfere with each other. This is a key problem of 5G network, and the channel allocation needs to be addressed. In this paper, a distributed algorithm called Channel Load Based Channel Assignment (LBCA) is proposed to eliminate interference and improve channel utilization.

According to the characteristics of the tree topology, each node can be classified as transceiver to a parent node (marked as P in Figure 3) or a child node (marked as C in Figure 3). Each node needs a common transceiver (marked as M in Figure 3) for the transmission of various control information.

As shown in Algorithm 1, each node has public transceiver and two other parts: an upstream transceiver for communicating with the parent node, and a downstream transceiver for communicating with the child nodes. When the channel of the downstream transceiver of each node changes, it only affects the upstream transceiver of its child node and will not cause the channel dependency problem. And the LBCA algorithm code is as Algorithm 1 shows.

For Algorithm 1,

(1) each node is responsible for allocating the downstream transceiver channel of its own, and the upstream transceivers channel is the same as the downstream transceiver channel of the corresponding parent nodes;

(2) the closer it is to the gateway, the heavier its load is. So each node must also be assigned a priority according to the hops to gateway node. A node with a lower value has a higher priority;

(3) each node periodically sends a CHANUSAGE packet to $(k + 1)$ hop neighbor nodes (k is the ratio of the node interference radius to the communication radius), or when the channel used by a node changes, to broadcast its own channel usage;

(4) each node will recalculate the channel load of the neighbor node according to the channel load received in the CHANUSAGE packet. The calculation method is as follows:

$$\mathrm{LOAD}_{\mathrm{new}} = \frac{\mathrm{LOAD}_{\mathrm{old}} + \mathrm{LOAD}_{\mathrm{current}}}{2}; \tag{7}$$

(5) the node periodically determines the vector of an optimal channel according to the channel usage of the neighbor node in its neighbors table and the priority of the neighbor node:

$$\begin{aligned} &V_{\mathrm{optimal}} \\ &\quad = \left\{\mathrm{channel}_1, \mathrm{channel}_2, \mathrm{channel}_3, \ldots, \mathrm{channel}_n\right\}. \end{aligned} \tag{8}$$

4.4.3. Specification of Environment. To verify Revised Channel Selection Algorithm, simulation has been conducted with NS2. Comparison on average delay and throughput of mesh network estimated with other frequently used algorithms are carried out. Parameters of the simulated environment are shown in Table 2.

4.4.4. Steps and Subjective Assessment of the Data. Revised Channel Selection Algorithm is tested in this experiment and the result is compared with frequently used metrics hop count and ETT.

In the simulated experiment, every node is set as fixed and changes of throughput and end-to-end delay are compared at different rates of packet transmission under different routing metrics.

```
Set m = any channel in Voptimal
Set k = the count of the channels
Set Timer Tsend to T1
If Tsend is expired
    broadcast CHANUSAGE message to its (k + 1) hop neighbors
End If
Set Timer Tchange to T2
If Tchange is expired
    Look up the neighbor table
     use heap sort to find the most idle channel vector Voptimal
    Set n = the element count of the Voptimal
    If n > k
        For Each channel m in Voptimal
            If m is not used
                change the channel of one DOWN-RADIO to m
                End If
        End For Each
     Else
        For Each channel m in the first n channels of Voptimal
            If m is not used
                change the channel of one DOWN-RADIO to m
            End If
        End For Each
    End If
    If any radio has changed
        broadcast CHANCHANGE message to its (k + 1) hop neighbors
    End If
End If
If receive a CHANUSAGE message
    update its neighbor table
End If
If receive a CHANCHANGE message
    If the sender is parent and its DOWN-RADIOs changed
      change UP-RADIOs to the channels of parent's DOWN-RADIOs
        broadcast CHANCHANGE message to its (k + 1) hop neighbors
    End If
    update its neighbor table
End If
```

Algorithm 1: LBCA algorithm code.

5. Key User-Oriented Issues

To meet users' extreme requirements and to suit a variety of 5G scenarios with efficiency and performance, the key issue to be addressed is spectrum efficiency and throughput.

Increased spectrum efficiency and throughput could be achieved through Cofrequency Cotime Full Duplex (CCFD), all-spectrum access technology, Device-to-Device (D2D) technology, and other technologies. Spectrum efficiency is supposed to be at least three times that for 4.5G. Innovation is needed for achieving that goal. Cooperation among global organizations, universities, and research institutes should be enhanced. Enterprises, especially small and medium-sized ones, should be promoted and mobilized, so as to form a better industry alliance as a healthy actor network, shaping the consensus.

This paper simulates a 5G network, and, through the experiment, a hybrid routing protocol TOHRP and a distributed channel assignment algorithm LBCA in the multichannel environment are proposed and they solve the traditional problem of (1) waste of spectrum and (2) self-interference.

Simulated experiment results shown in Figures 4 and 5 illustrate the comparison of throughput. Hop count, ETT, and AETTI listed together, we could easily observe a higher rate of packet transmission, throughput of AETTI, followed by ETT. Figure 5 demonstrates the comparison of the end-to-end delay. Hop count has the longer delay.

Table 2: Specification of the environment.

Parameters	Set value
Campaign topology	1000 m × 1000 m
Number of nodes	60
Data rate	100 Mbps
Number of channels	3
Number of radios	1
Range of data transmission	250 m
Range of interference	500 m
Length of packet	1024 bytes
Type of flow	UDP
Ways of data transmission	CBR

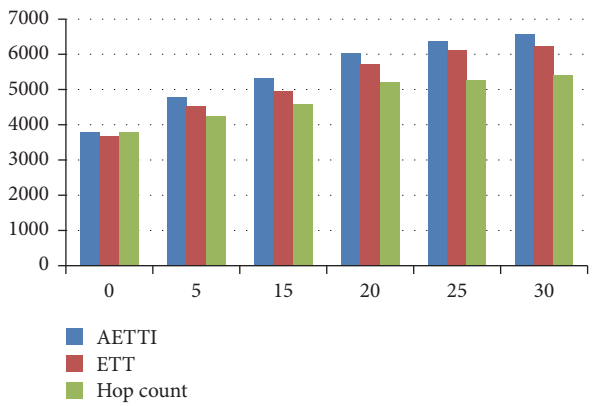

Figure 4: Comparison of throughput.

The analysis above indicates that AETTI has taken channel information interference and node load into consideration. AETTI has better performance than hop count and ETT in the multichannel situation.

6. Conclusion and Suggestions

In China, the current status of the 5G test is limited to technology assessment and related technologies, including Cofrequency Cotime Full Duplex (CCFD), Device-to-Device (D2D) technology, all-spectrum access, massive MIMO, and ultradense network. Innovation systems including corporations and government supported research centers, as well as colleges, are working on the related research for power in the standardization process. Only by satisfying interests to each actor with actual involvement could the 5G development grow healthily. As different scenarios require different technology approaches and in order to meet user's needs, the following issues need to be addressed.

6.1. Smooth Evolution from 4G to 5G Requires More Private Enterprises Enrollment in Spectrum Efficiency Research as Innovation System. Support to the development of small and medium-sized private enterprises, for sustainable and revolutionary innovation, especially in spectrum efficiency

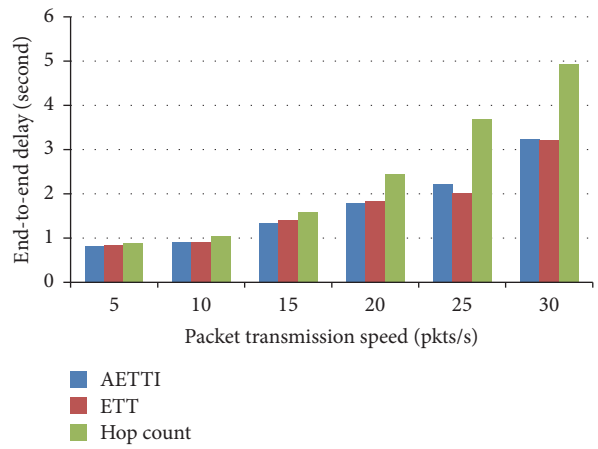

Figure 5: Comparison of end-to-end delay.

researches is needed. A smooth transition from 4G to 5G should be put to schedule. The market demand for data services growth will not be slowed down because 5G is not yet a mature technology. Thus operators must continue to improve the existing 4G networks and to take full account of the smooth transition for the future.

Spectrum efficiency should be improved at least three times that of 4.5G now, and related technologies will be applied directly so as to serve a more smooth transition from 4G to 5G.

6.2. Standardization in a Global Context Needs Cooperation. Standardization work should pay attention to both international and local aspects at the same time. Under the framework of the Union and 3GPP, it has to emphasize both eMBB and IoT. Only by generating compatible, reliable, and efficient technologies, standards could be recommended by 3GPP and ITU. Premature overseas agendas will outweigh the benefits.

The standardization of 5G requires cooperation and sharing of results. Experimental results sharing program is indispensable and cooperation platform should be enhanced.

6.3. User-Oriented Architecture Requires High Throughput and Spectrum Efficiency. As the main observation of a shift from policy strategy to being customer oriented is revealed, service providers, content providers, and manufacturers could benefit by scientifically collecting, studying, and considering user-needs at the initiating stage for a more satisfying end user experience.

Improving throughput and spectrum efficiency especially for 5G data is an important issue to be addressed in the vast growing network in 5G scenarios.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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