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Integration of SDR and SDN for 5G

HSIN-HUNG CHO[1], (Student Member, IEEE), CHIN-FENG LAI[2], (Senior Member, IEEE), TIMOTHY K. SHIH[1], (Senior Member, IEEE), AND HAN-CHIEH CHAO[1,3], (Senior Member, IEEE)

[1]Department of Computer Science and Information Engineering, National Central University, Zhongli 32001, Taiwan
[2]Department of Computer Science and Information Engineering, National Chung Cheng University, Chiayi 62102, Taiwan
[3]Department of Computer Science and Information Engineering, National Ilan University, Yilan 26041, China

Corresponding author: H.-C. Chao (hcc@niu.edu.tw)

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ABSTRACT Wireless networks have evolved from 1G to 4G networks, allowing smart devices to become important tools in daily life. The 5G network is a revolutionary technology that can change consumers' Internet use habits, as it creates a truly wireless environment. It is faster, with better quality, and is more secure. Most importantly, users can truly use network services anytime, anywhere. With increasing demand, the use of bandwidth and frequency spectrum resources is beyond expectations. This paper found that the frequency spectrum and network information have considerable relevance; thus, spectrum utilization and channel flow interactions should be simultaneously considered. We considered that software defined radio (SDR) and software defined networks (SDNs) are the best solution. We propose a cross-layer architecture combining SDR and SDN characteristics. As the simulation evaluation results suggest, the proposed architecture can effectively use the frequency spectrum and considerably enhance network performance. Based on the results, suggestions are proposed for follow-up studies on the proposed architecture.

INDEX TERMS Fifth generation network, software defined networks, software defined radio.

I. INTRODUCTION

Technology begins with humanity, and many technical advances were developed with the aim for creating a more convenient life. One example in the field of communications is the development from a wired network into a wireless network. After generations of development, wireless networks have evolved from the initial 0G to today's 4G [1], rendering smart devices indispensable to the public. In addition to exchanges between individuals, the Internet of Things (IoT) is the trend of the times. Communications between things allow people to easily master all information usually difficult to obtain. Although 4G technology is becoming more mature, there are some bottlenecks. Scholars have begun to explore the next generation of the Internet.

According to the prediction of the International Telecommunication Union (ITU), mobile phone users will exceed the number of the world's population in 2014. Currently the global population is 7.1 billion, while mobile phone users have reached 6.9 billion, representing that the global mobile phone penetration rate has reached 96%. ITU also indicated that network service users account for 39% of the world's population, and experts forecast that IoT devices will reach its peak in the next ten years. The communication between most of IoT devices is mainly based on RFID as the main communication protocol. However, communication with the management end must rely on high demand for wireless networks. In the development process, importing IoT devices into IPv6 and formulating standards have been the current focus of development. Many equipment suppliers have also invested heavily in technology to develop more devices, and 2012 is expected to be the most mature moment. This data is evidence of major scientific and technological progress, as well as a major challenge to future network management.

Future Internet refers to the collection of various data communication network technologies of the future. According to the summary in the report by CERP-IoT (the Cluster of European Research Projects), future Internet can be defined as a dynamic global network infrastructure. It must have standards-based self-configuration capabilities, and integrate various virtual or actual objects. The Figure.1 shows that the difference between 4G and 5G. Moreover, 5G technology is the integration of 802.11, 802.16, and ad-hoc, and is thus called the World Wide Wireless Web (WWWW). Its core technology is developed based on the LTE of 4G, and is LTE-Advanced according to future needs. For Internet service providers, it increases re-utilization of the frequency spectrum and maintains network QoS [9]–[11].

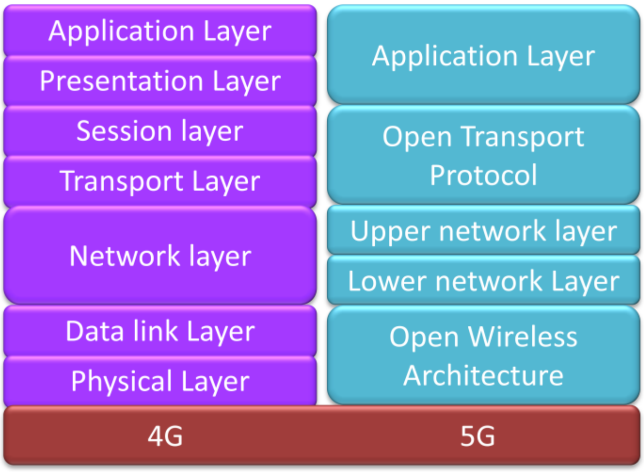

FIGURE 1. The difference between 4G and 5G.

Overall, 5G is a technology for mobile communications [2], [3], [8], [10], [14], [15], and takes precedence over service mobile consumers, as well as any mobile device, which is a revolutionary change. It is expected to save wiring costs to achieve higher convenience and efficiency. As described above, the 5G technology spectrum and bandwidth will face inevitable challenges in the future [13]. "Integration" between the frequency spectrum, and bandwidth has become an inevitable topic. "Integration" not only exists in a variety of different network protocols, but between suppliers and consumers, including QoS, frequency spectrum re-utilization rate, and security. Software defined radio and Software defined networks will be the best choice for integration. However, these two techniques belong to different layers, so they are difficult to interact the information. Therefore, our ultimate goal is that designing a completely cross-layer integration mechanism and process to combine the superiorities of SDN and SDR so that the composite problem from the access network and the network edge can be solved.

II. BACKGROUND

SDR and SDN are two different technologies, but both have a "software-defined" feature, namely, the capability of reconfiguration. This allows administrators to easily collect signals or change parameters within the packet, and quickly find a suitable frequency band or path, as based on the gathered results, and ultimately move forward to a self-adaptive environment.

A. SDR

Radio exists everywhere, but does not exist in a witless manner. It is a complete system, where each base station has access to radio features; it has problems of scheduling, resource allocation, troubleshooting, load balancing [29], and security [3]. Without considering the details, the most direct relationship between radio, consumers, and suppliers is to allow suppliers to use the least cost to enable consumers to enjoy spectrum resources. As spectrum resources are limited [22], there will be a trade-off relationship. As there must be competition between consumers, and service providers must respond to the needs of users to make fair rules, which may also involve commercial practices and complicate this problem.

The development of SDR overcomes the disadvantages of radio hardware. In general, radio hardware devices are very expensive, and include the following components: filter, modulation demodulator, and converter for handling the different frequency attributes of networks that have different network protocols. Hardware equipment may come from different hardware manufacturers, thus causing possible compatibility problems. Facing the rapidly growing needs of users, Internet service providers cannot afford huge upgrades, integration, or building costs, as these elements are indirectly or directly related. In addition to cost savings, to integrate these components can enhance efficiency, as suggested by research experts.

The main difference between SDR and hardware radio is the use of the user end to scan available frequency bands, and integrate different connection technologies in a single interface. This means that a user can use only one device to receive signals of WiMAX, Wi-Fi, GSM, or LTE. Providing the rules for use are embedded in the chip, the user can use a frequency band according to the norms. Although each signal has different coding and analysis methods, it requires a download of the latest standard modules, such as importing a Library to general compliers, in order to normally receive and interpret radio. In this way, it can reduce costs and save space. From the management perspective, the management of radio hardware is flexible because it can only manage connections and change TCP/IP and applications. On the contrary, the range of management of SDR can cover the physical layer, as shown in Figure 2. And Figure 3 illustrates the simple Software defined radio type.

Spectrum is an invisible thing. How to efficiently manage such invisible substance is a very formidable challenge. Therefore, we must have some of the available tools and methods. If SDR is a problem-solving tool for spectrum access, Cognitive Radio (CR) [30] is an actual solution to a problem that the obtained spectrum information are provided to user-oriented mechanism to allocate spectrum resource. Based on the approach of self-perception and learning, CR defines the spectrum use policy. The policy may vary according to the sensed spectrum utilization opportunities and environmental parameters. However, the goal is to find the most suitable network and configuration restructuring [4].

For today's networks, too many services, devices, or special protocols have their own dedicated frequency band. As there are certain bottlenecks in hardware switches it has been unable to converge. Therefore, for the 5G network's vision of the future, network providers prefer more simplicity, as compared with the previous multi-band. All the above will start from frequency spectrum sharing or reuse to a single spectrum allocation problem, and the use of software-defined

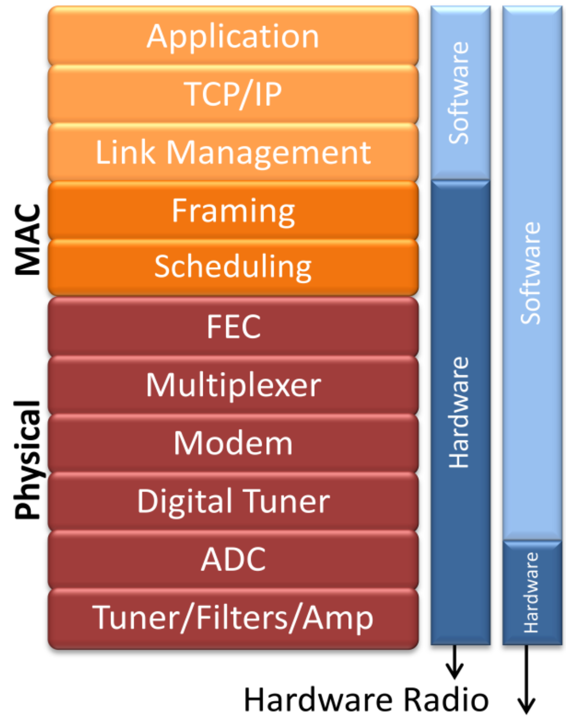

FIGURE 2. The software wireless support multi-layer control.

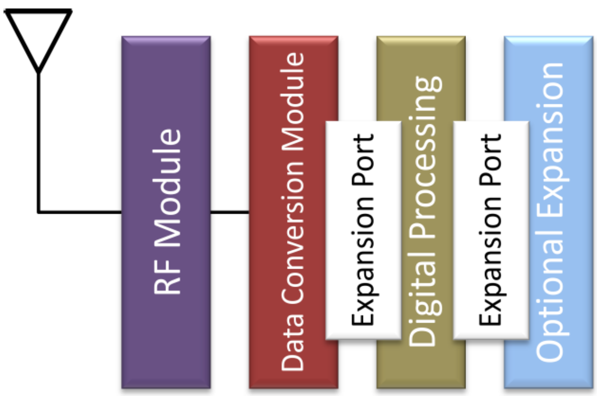

FIGURE 3. The software radio.

characteristics will dynamically distinguish interference and collision [5].

B. SDN

Spectrum resources and network resources have minor difference. Therefore, the software-defined approach is an appropriate method [21], as the main purpose is to construct a flexible service in order to reduce hardware limitations [12], [16], [18], [19], and thus, is also called a "virtual network" [6]. However, as both have a specific area of responsibility they are indispensable. The future network traffic, as predicted by major enterprises and experts, will be multiple times the current traffic [20], [23]. Although, in some cases, adding hardware to increase the bandwidth is required, the key to the problem is to reduce the waste of network utilization. Otherwise, the cost of purchasing the hardware will exceed the benefit of service providers. The main reason for wasted traffic is that a Router will run the L3 protocol upon receiving a packet and analyze the terminal end to send the packet to the destination, which not only results in increased cost to build the Router, but is also accompanied with the characteristics of the Router protocol. It is similar to creating routing tables, handshaking, certification mechanisms, etc. These mechanisms will continuously send out requests and signaling messages when sending packets, which waste bandwidth. Moreover, if increasing the VLAN, old and new L2 Domain conversion efficiency will decrease. With Google as an example, before the import of SDN, the bandwidth utilization rate was only 30%, and the performance was improved by three times, proving the cost effectiveness of importing SDN to achieve the same quality at 1/3 the cost.

In general, there is a router in the organization or unit serving as the door-keeper and telephone operator. In simple terms, it forwards received packets to the destination end-point, or opens a direct path for its use, which means that the router can parse the packet, and use packet information to allocate resources, troubleshoot, and build security measures. However, an organization or unit's network is a tree structure, where the Router is the Root, and Leaf communication should be conducted through the switch. A Router cannot directly control or manage the switch, which means it is powerless in dealing with unexpected switch errors. The most common condition is a Loop.

SDN, in the seven layers of OSI, can step over the MAC layer to the application layer, as shown in Figure 4. Like SDR, it can generally save redundant interfaces, hence, administrators can use the controller to easily assign policy to any router and switch to achieve monitoring functions, and it can be the

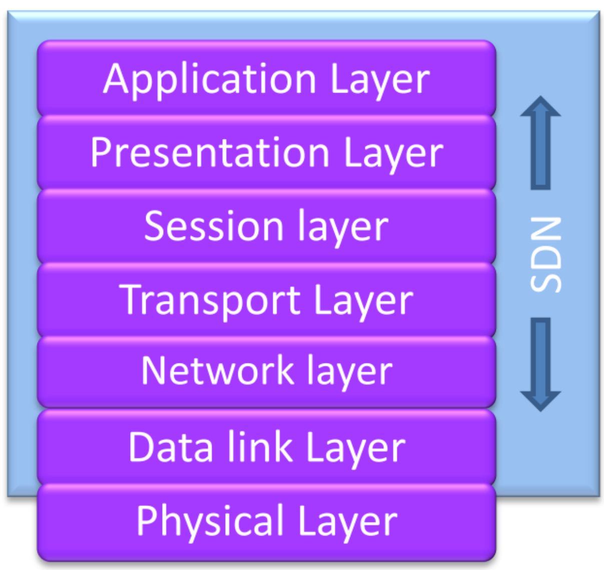

FIGURE 4. SDN supports MAC layer to the application layer.

parsing component of IPv4 and IPv6. In simple terms, the major contribution of SDN is that the network can be reconstructed. The ideal situation is to achieve a fully automated administration without the design and adjustments of the administrator intervention policy. Policy is the rule for reconstruction, and SDN has a cooperative concept, which indicates easily controlled network problems by defining a good policy set, with a self-learning policy change mechanism. The simple SDN architecture diagram is as shown in Figure 5.

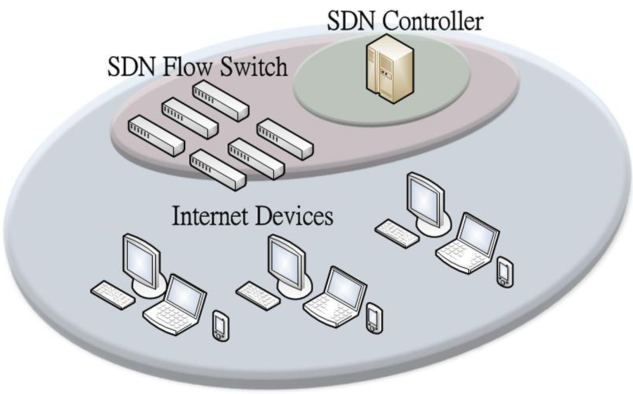

FIGURE 5. **SDN architecture.**

III. RELATED WORKS

SDN and SDR have become a hot topic since the mobile network improves every day. Because the increased users carried the great traffic that this environment must need a strong management scheme to coordinate any information and requests from all sides. This shows a centralized management is indispensable. Otherwise most of the information and requests cannot be coordinated in fair. Briefly, a entire network like a human that there are many complex systems distribution. Each system has unique capabilities and they usually communicate, coordinate and even affect with each other. These phenomena can survive for human. But in some cases, it could evolve into mutual competition between systems if there are imbalances phenomenon since a system snatched the system resources. Usually, such situation cannot be happened because we have a cerebrum helps us to adjust those disputes. Unfortunately, if it occurs, it represents that this guy is sick. In the network world, such system ecology also existed. Such as SDR system must schedule the user's channel priority, and SDN system must monitor and distributes traffic. Both these two systems are have own architectures, elements and connection. Invariably, they are also in a relationship with a centralized management if they want to integration.

We have to understand current development of SDR and SDN before to discuss the integration of SDR and SDN in 5G network. Because the centralized management must know all of systems feature firstly then to make fair and efficient decision. It is like the human cerebrum which must know the details of all systems. Note that such centralized concept

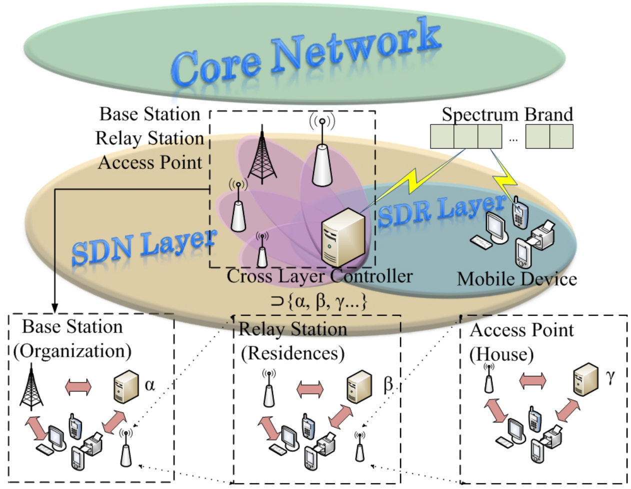

FIGURE 6. **Hybrid architecture of SDN and SDR.**

can distribute to any organizations. In simple terms, there may many people in an area, so there are also have many cerebrums. Whatever, we will introduce some centralized methods of SDR and SDN in this section.

In 2011, the most popular technique research is 4G. Although it is difference with 5G, but both they also the same type techniques. In this moment, some researchers proposed service-oriented cognitive networks over IP multimedia subsystems (IMS) [24]. It represents that the radio channel scheduling can over a centralized platform thus obtains more efficient service experience.

In [25], a Markov-chain-based spectrum handoff solution is proposed. The main idea of this method is that the design a centralized decision maker which is responsible for coordination of obtained information of average throughput and average interference time. In order to suit the multi-SUs environment, they used Markov chain to predict the behavior of the SUs. Then the unobstructed channels of spectra lead the whole network gets more throughputs without too much sensing times. These two papers not only show the importance of centralized management, but also express the spectra computation has a relationship with some impacts in the network layer.

Open Networking Foundation (ONF) proposed a new communications protocol called OpenFlow [26] that any forwarding switches adds the flow table for traffic forwarding. Any OpenFlow switches handle the own area and report to the controller. The controller provides to the network administrator the ability of monitoring, decision-making, debugging, and other network-related functions. These abilities exactly depend on the centralized control. According to the previously mentioned analogy, we can mapping that the controller corresponds to the cerebrum of human and the organization which switch belongs are express by the human organs. In short, the concept of OpenFlow controller is a centralization me approach. Though the SDN did not define it must be centralized, but in general it need a synchronization mechanism even there is a distributed architecture. And the OpenFlow is a representative protocol of SDN currently [27].

In [17], the authors put SDN controller onto cloud platform that all of complex process are disposed by powerful computing capabilities from cloud. The cloud computing is a centralized platform exactly. Its type coincides with OpenFlow that is why SDN controller suitable to place to cloud platform.

In fact, we hope that our expected method can like previous case that two different systems are integrated very well without additional components. By our observation, we consider that both of SDR and SDN are have a own control unit, and these controllers maybe exchange information with each others.

IV. INTEGRATION OF SDR AND SDN FOR 5G

In a 5G network, the relationship between spectrum and flow will become increasingly obvious as spectrum reuse can relieve traffic between different frequency bands. In other words, if the flow is well-processed, the spectrum will avoid competition, and overloading of bandwidth can also be avoided. Therefore, it is expected that SDR can consider monitoring results when perceiving the frequency spectrum or switching bands, while SDN can refer to the SDR frequency spectrum conditions when changing the policy. To realize the expected results, this study suggests that the controller in the original SDN architecture should cross the SDN Layer and SDR Layer, as shown in Figure 6. Overall, when faced with a 5G network environment, it simply means allowing more devices to enjoy high quality services at the least cost. SDR or SDN alone is not enough, and there must be cross-layer architecture.

The process of building a network environment includes two parts: consider the spectrum and then the bandwidth. Using cars on the highway as an analogy, the highway is like a spectrum, lanes are like the channels, and whether the car should be on the highway is determined based on the existence of holes, interference, or other factors of the channel. The lane to be used and when to switch lanes can also be determined. In a network environment, such behavior results from direct contact with the radio section. This study defines this as the SDR Layer, and the main work is the perception of the available spectrum and bandwidth.

The size of each expression can be seen as network bandwidth, where the car can freely switch lanes, unless there are special restrictions. In general, there are road traffic rules. It is the same in a network. There should be some units to maintain order, similar to traffic police, speed cameras, and semaphores, to relieve traffic pressures and maintain the smoothness of the road. SDN also has such units, as it can detect the usage of a channel. It uses a controller to monitor the packet flow of the switch, and restricts packet transmission rules according to the policy. In this way, any packets in violation of the rules can be determined and errors can be prevented. This study incorporates them into the SDN Layer in order to meet the needs of the terminal.

A. SDR LAYER

The SDR Layer contains all the devices that can access radio. The future of mobile phones will be paired with USRP, which indicates a direct scan radio function that can sense ambient spectrum usage. Since SDR is of terminal-oriented perception architecture, it can only be used when the frequency spectrum can be used by the Spectrum hole and nearby interference, and it cannot change the usage of the spectrum. This means that it cannot conduct effective channel scheduling and switching because the administration level should have a centralized hub. The administration component is used as the arbitrator to determine the frequency band or take measures to avoid interference. The Cross Layer Controller role knows who sent a request for frequency spectrum usage; hence, it can easily determine whether the device is authorized. This can avoid many cases of illegal access to spectrum resources, and monitoring all frequency users and interference. According to these messages, it can deduce whether a Spectrum hole should be provided to the next user.

B. SDN LAYER

In any network architecture, units that can send and receive packets should be stored in the SDN Layer, in simple terms, to achieve a full wireless 5G environment, WiMAX, LTE, and 802.11 different heterogeneous networks, it is able to transmit or route data of different architectures forward to a Controller in a standardized manner. Coupled with Mobile IP, it can help to bridge different interfaces. In this way, the inability of mutual access of heterogeneous networks can be solved. This means that any base station and access point are of the layer. According to the purpose of SDN, to achieve Reconfigurable, all wireless network devices will be taken into consideration, and should be stored in the Router or Switch under the Controller in order to allow the Controller to monitor network packets, publish policy, or eliminate errors according to the monitoring results. Moreover, the SDR layer can be built on the SDR layer. Wireless information should be one of the factors under consideration in SDN, in other words, future networks will be of the SDN architecture.

C. CROSS LAYER CONTROLLER

The Cross Layer Controller is an important component of this architecture, as it is a decision-maker, supervisor, and administrator, and is the only component across the two layers. This study expects radio access or network usage can be of mutual reference, and therefore, there should be one unit to simultaneously receive information from two layers in order to make a trade-off analysis of the conditions of the two layers. In the workflow, when users want to access spectrum resources, users should request the Cross Layer Controller whether the band can be accessed. In addition to the confirmation of the user authorization, the Cross Layer Controller will review the flow traffic information of the band, and allow the access or suggest switching to a better band. Moreover, in a dynamic network environment, the Controller can make self-adaptive adjustments according to spectrum use and overall network information. Overall, correspondence of the two layers can result in more perfect planning. The precondition is that the Cross Layer Controller should have USRP, while the Base Station, Relay Station, and Access Point sub-network, should have the Cross Layer Controller to form the tree structure. The topmost Root Controller can query the downstream controllers to observe the conditions of the entire route. Later, the condition can be used for preparation of automatic Reconfiguration, with the detailed process as shown in Fig.7.

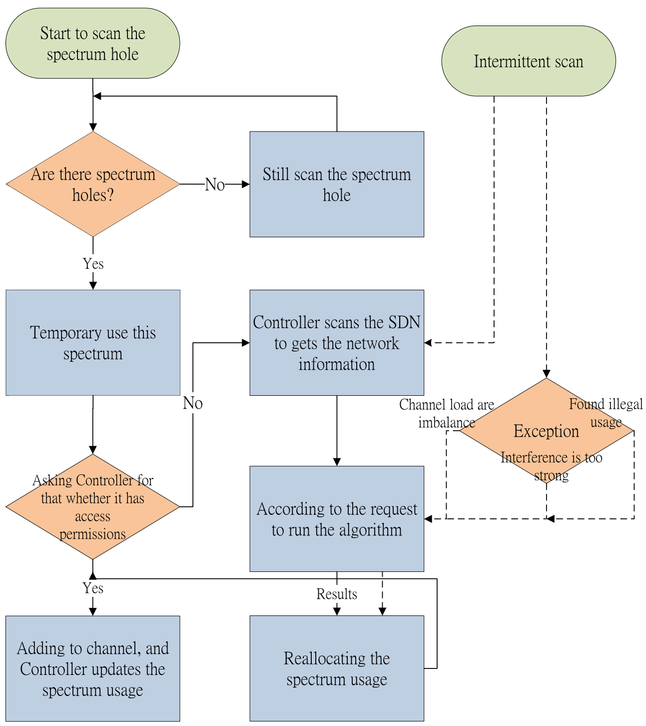

FIGURE 7. Detailed process of cross layer controller.

V. EVALUATION

It is undeniable that SDR and SDN have the ability to improve network performance; however, the bandwidth and the spectrum have an indirect relationship. Combining their advantages can create a better architecture, thus, the proposed architecture considers the individual relationships and mutual impacts. To prove the effectiveness of the architecture, and allow readers to clearly understand the trade-off relationship between SDR and SDN, this study compares the proposed hybrid mechanism (SDN+SDR), which has SDN and SDR only. As there is no 5G simulator, this paper simplifies it into a trade-off problem, and uses MATLAB for simulation. The parameters are designed by following the specifications of IMT 2100: Download frequency is 2140(MHz), UpLink frequency is 1950(MHz), and bandwidth is 60(MHz). Most importantly, interference parameters are included to allow the simulation to present the actual conditions and highlight the effectiveness of the proposed mechanism on self-adaption.

TABLE 1. Simulation parameters.

Parameters	*Values*
Number of evaluated spectrums	4
Download frequency	2140(MHz)
UpLink frequency	1950(MHz)
Bandwidth	60(MHz)
Number of evaluated devices	10~100
Interference parameter	1~10

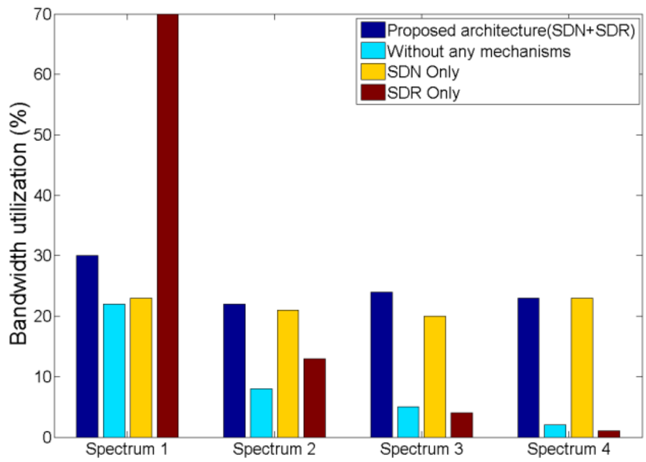

FIGURE 8. Relationship between spectrum and bandwidth utilization rate.

The interference's equation 1 is as shown below [7]. The details are shown in Table 1.

$$SINR = 10 * \log_{10}\left(\frac{P_t}{I} * \left(\frac{c}{4\pi fd}\right)^2\right) \tag{1}$$

Figure 8 shows the relationship between spectrum and bandwidth utilization rate, and the equation 2 is used for calculating the bandwidth percentage of all services. In the architectures without mechanisms, devices cannot avoid interference and other conditions during access to the frequency spectrum, and thus, are very chaotic. In such chaotic conditions, almost every frequency spectrum is occupied by the device. Without smooth monitoring or administration, the overall bandwidth performance is very poor, and the total bandwidth utilization rate can be only 37%, which is not far from the experimental results of Google. In the case of an SDN mechanism, about 13% of the bandwidth utilization rate will be wasted, as there is only one very smooth channel. Even if the channel is administered, it is powerless to packet loss caused by interference. In the case of an SDN mechanism, although it can determine the most capable frequency spectrum to considerably improve the spectrum utilization rate, it wastes more cost due to the L3 mechanism. Under optimal conditions, it still has a 7% loss of bandwidth. In the case

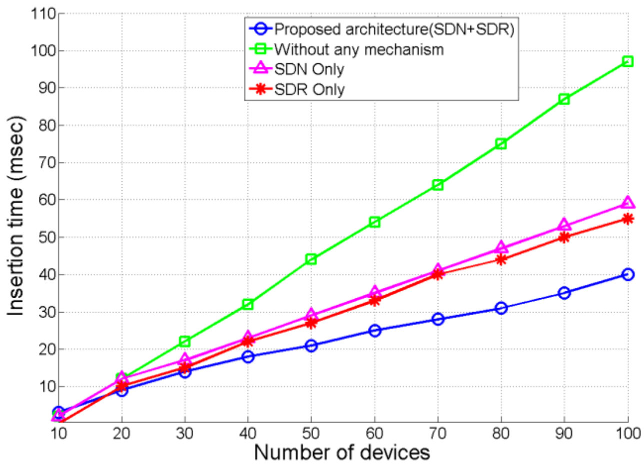

FIGURE 9. Relationship between spectrum and bandwidth utilization rate.

of the proposed mechanism, during the process of searching the spectrum, in addition to considerations regarding interference, it will observe and analyze channel conditions, and can reach 100% of the bandwidth utilization rate (without any attack or error) in perfect conditions. Figure 9 evaluates the proposed architecture and other three conditions in terms of insertion time and delay time. The insertion time represents the time of a service to enter the network and is able to be calculated by the summation of flow time in Figure 7. With the exception of the case of 10 devices, due to the time to establish a relationship with the controller, the insertion time of the proposed mechanism is shorter. When the number of devices increases, the slight difference is covered by the problems of interference or bandwidth loading of other mechanisms. Figure 10 illustrates the total delay time that the formula is as shown below. According to previous analysis, if the maximum number of users cannot result in frequency overuse or bandwidth overloading, the proposed architecture

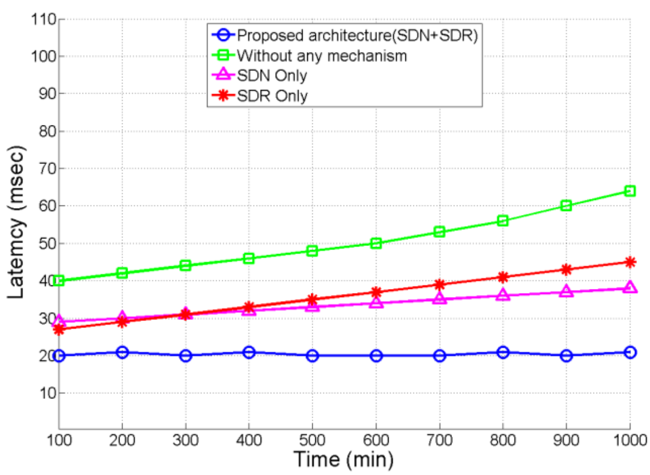

FIGURE 10. Relationship between spectrum and bandwidth utilization rate.

can determine the most suitable spectrum to establish the most appropriate channel for the requesting device; hence, performance can be maintained. By comparison, other mechanisms are affected by the frequency spectrum and bandwidth, and result in longer search times.

In 5G mobile network, the spectra computing is very important in order to improve the issue that the spectra is shortage. Therefore, we analyze the impact of interference between whether our proposed mechanism. Of course, we cannot be too intuitive. So we must consider to the factor from network layer which is control by SDN, then we choose the generation rate as our continuous variables. In Fig. 11, we can see the throughput of our proposed mechanism can directly reflect the increasing generation rate when interference is short. Even if the interference parameter is increased, our proposed mechanism will not have much impact. Because it still find out the most suitable channel which has less users who is using the bandwidth resource even it can import the concept of service-oriented to allocate the network resource.

$$\text{Bandtidth utilization} = \frac{\sum_{i=1}^{n} \text{bandwidth}_i}{\text{Bandtidth}_{total}} \tag{2}$$

$$\text{Delay time} = \sum_{j=1}^{m} \text{Insertion Time}_j - \min(\text{Insertion Time}) \times m \tag{3}$$

VI. SUGGESTION FOR FUTURE WORKS

A. CROSS LAYER CONTROLLER

Service-oriented services represent that, each service will be one of the factors that affect the policy, as different services or applications have different features, which directly reflect the habits of using network resources. For example, network traffic of viewing web pages may be intermittent or video conferencing must use a lot of bandwidth during a fixed period of time. The SDN Layer can be used to collect the information, and algorithms are applied to analyze the optimal allocation of spectrum and bandwidth, and then change the policy SDN Layer.

B. ENERGY-AWARE

The future is a green computing world, with mobile devices as the mainstay. However, limited battery power remains an indisputable fact. When consumers are accessing a network, if they are requested to provide power consumption information to the Cross Layer Controller as the goal of the algorithm, it can save power consumption. Maintaining a good QoS is the main challenge.

C. SECURITY

The web services are provided by ISPs, and the users need to follow the norms of spectrum access. However, as CR is a client-oriented technology, how to avoid illegal use of others' frequency will be a major issue. The SDN Controller documents the frequency information and use conditions of each user; therefore, control of SDN and privacy issues should be discussed. In addition, SDR also has security issue such as

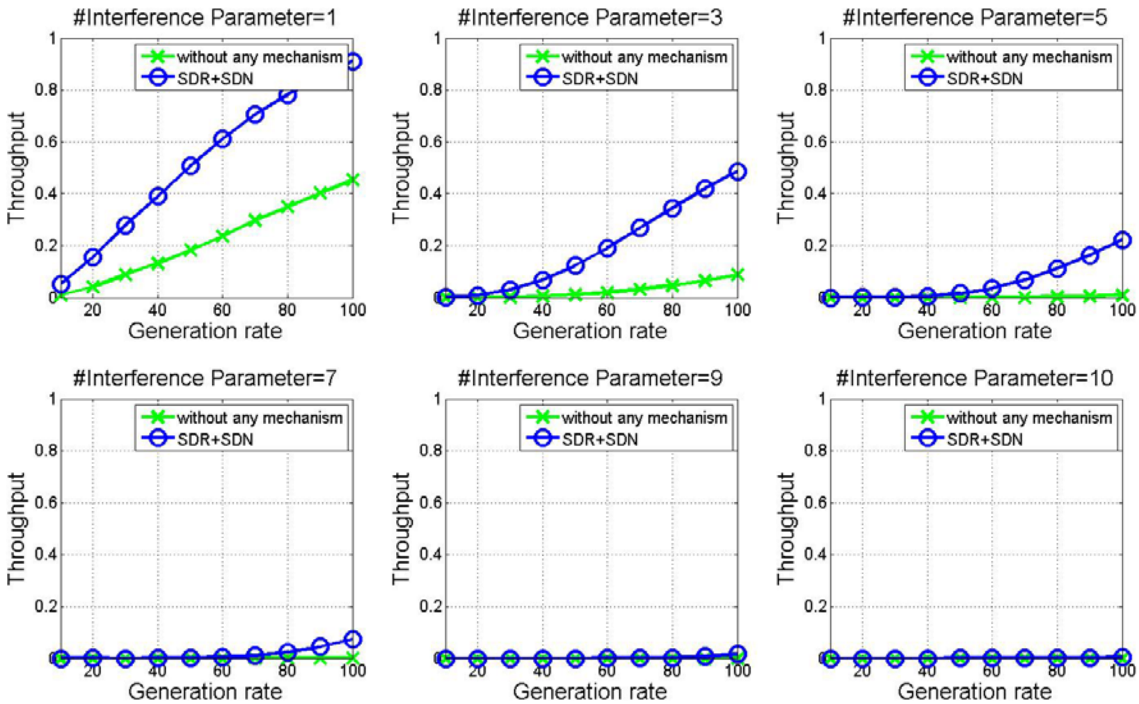

FIGURE 11. **Relationship between spectrum and bandwidth utilization rate.**

that the attackers may try to interfere other users or stealing the spectra resource [28].

VII. CONCLUSION

Because the 5G wireless network is an actual environment, mobile devices are expected to be several times that of the present, thus, there will be inevitable challenges in accessing a network. Meanwhile, the frequency spectrum, bandwidth, security, and various factors pose a trade-off issue. This study believes that the co-existence of SDR and SDN is necessary, and the best effect can be achieved only by co-existence and mutual compliments. The evaluation of this study simplified the problem of SDR and SRN into a two-value trade-off problem in order to confirm the feasibility of the proposed architecture. The performance, power saving, security, and optimization problems derived from the interactions of the controller and two layer policy should be explored with greater effort in the future.

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HSIN-HUNG CHO received the B.S. degree from the Department of Applied Mathematics, Hsuan Chuang University, Hsinchu, Taiwan, in 2010, and the M.S. degree from the Institute of Computer Science and Information Engineering, National Ilan University, Yilan, Taiwan, in 2011. He is currently pursuing the Ph.D. degree with the Department of Computer Science and Information Engineering, National Central University, Zhongli, Taiwan. His research interests include wireless sensor network, mobile P2P, and cloud computing.

CHIN-FENG LAI (SM'14) has been an Assistant Professor with the Department of Computer Science and Information Engineering, National Ilan University, Yilan, Taiwan, since 2011. He received the Ph.D. degree from the Department of Engineering Science, National Cheng Kung University, Tainan, Taiwan, in 2008. His research interests include multimedia communications, sensor-based healthcare, and embedded systems. After receiving the Ph.D. degree, he has authored or co-authored over 80 refereed papers in journals, conferences, and workshop proceedings about his research areas within four years. He is currently making efforts to publish his latest research in the IEEE Transactions on Multimedia and the IEEE Transactions on Circuit and System on Video Technology. He is also a Senior Member of the IEEE Circuits and Systems Society and the IEEE Communication Society.

TIMOTHY K. SHIH (SM'03) is currently a Professor with National Central University, Zhongli, Taiwan. He is a fellow of the Institution of Engineering and Technology (IET). He is also the founding Chairman of the IET Taipei Interim Local Network. In addition, he is a Senior Member of the Association for Computing Machinery (ACM). He was the Founder and Co-Editor-in-Chief of the *International Journal of Distance Education Technologies* (Idea Group Publishing, USA). He is an Associate Editor of the IEEE Transactions on Learning Technologies. He was an Associate Editor of the *ACM Transactions on Internet Technology* and the IEEE Transactions on Multimedia. He has been invited to give over 40 keynote speeches and plenary talks in international conferences, and tutorials in the 2001 and 2006 IEEE International Conference on Multimedia and Expo, and the 2002 and 2007 ACM Multimedia Conference.

HAN-CHIEH CHAO (SM'04) is currently a jointly appointed Professor with the Department of Electronic Engineering and the Institute of Computer Science and Information Engineering, National Ilan University, Yilan, Taiwan. He also holds a joint professorship with the Department of Electrical Engineering, National Dong Hwa University, Hualien, Taiwan. His research interests include high-speed networks, wireless networks, and IPv6-based networks and applications. He received the M.S. and Ph.D. degrees in electrical engineering from Purdue University, West Lafayette, IN, USA, in 1989 and 1993, respectively. He is a fellow of the Institution of Engineering and Technology and the British Computer Society.