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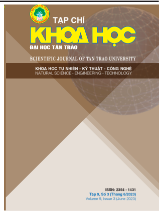

INTELLIGENT REFLECTIVE SURFACE SUPPORTS MOBILE NETWORK BEYOND 5G AND 6G

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Abstract:

When the 5G network is born, following the development trend of technology, with the same requirements for processing speed, coverage, reliability, and low latency, there will inevitably be generations of networks Beyond 5G - B5G, 6G is researched and deployed. Along with user requirements, new network applications and scopes will bring many problems and challenges, requiring different communication models, and effective coordination technologies, especially in the physical layer. An outstanding technology that helps to optimize wireless communication systems are RIS (Reconfigurable Intelligent Surfaces) reflective surfaces. RIS helps to overcome the negative impacts of traditional communication systems, reduce interference, ensure reliability, increase security, optimize transmission channels, improve spectrum efficiency, save energy, open wide coverage, meet the requirements of users' data speed and quality of service, contributing to improving the overall performance of the entire communication system. In order to provide network designers, researchers, and authors, the author will conduct a survey of works to provide information on the theory of structure and operation of this outstanding technology.

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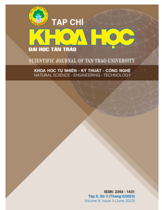

BỀ MẶT PHẢN XẠ THÔNG MINH HỖ TRỢ CHO MẠNG DI ĐỘNG SAU 5G VÀ 6G

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Từ khóa:

5G, B5G, Beyond 5G, 6G, Reconfigurable Intelligent Surfaces, RIS, Intelligent Reflecting Surfaces, RIS, bề mặt phản xạ thông minh, siêu bề mặt, bề mặt thông minh có thể cấu hình lại.

Tóm tắt

Khi mạng 5G được ra đời thì theo xu thế phát triển của công nghệ, cùng yêu cầu về tốc độ xử lý, khả năng phủ sóng, độ tin cậy và trễ thấp thì tất yếu sẽ có các thế hệ mạng sau 5G, (Beyond 5G - B5G), 6G được nghiên cứu và triển khai. Cùng với các yêu cầu của người dùng, các ứng dụng và phạm vi sử dụng của mạng mới sẽ mang lại nhiều vấn đề, thách thức, đòi hỏi các mô hình truyền thông khác biệt, các công nghệ phối hợp hiệu quả, đặc biệt là ở lớp vật lý. Một kỹ thuật hỗ trợ nổi trội, đem lại sự tối ưu cho hệ thống truyền thông không dây đó là các bề mặt phản xạ thông minh có thể tái cấu hình RIS (Reconfigurable Intelligent Surfaces). RIS giúp khắc phục các tác động tiêu cực của hệ thống thông tin liên lạc truyền thống, giảm nhiễu, đảm bảo độ tin cậy, tăng sự bảo mật, tối ưu hóa kênh truyền, nâng cao hiệu phổ, tiết kiệm năng lượng, mở rộng phạm vi phủ sóng, đáp ứng các yêu cầu về tốc độ dữ liệu của người dùng và chất lượng dịch vụ, góp phần nâng cao hiệu năng chung của toàn bộ hệ thống truyền thông. Nhằm cung cấp cho các nhà thiết kế mạng, các nghiên cứu viên, tác giả sẽ tiến hành khảo sát các công trình để đưa ra các thông tin về lý thuyết cấu tạo và hoạt động của công nghệ nổi trội này.

1. Introduction

According to Cisco's report in February 2019 [1], by 2022, the number of devices and network connections will increase to 28.5 billion and 12.3 billion, respectively, of which 77 exabytes of data traffic is expected to be generated every month, including 5G mobile networks. Besides, after years of research and development, the commercial 5G communication standard (3GPP Release 15) was completed in June 2018. As of mid-2019, 5G wireless networks have been deployed in certain countries, and compatible mobile devices are being introduced to the market. The advent of 5G has brought a new vision of mobile communication, including ultra-reliable low-latency communication (URLLC), enhanced mobile broadband (eMBB), and massive machine-type communication (mMTC). The promising physical layer technologies to meet the requirements of these applications include cognitive radio, cooperative communication, multi-output, multi-input massive multiple input multiple output (massive MIMO), millimeter waves, orthogonal frequency division multiplexing (OFDM), and more [2] However, during the standardization of the 5G wireless network, there is no single technology that can support all the application requirements. From this perspective, researchers have started to look beyond 5G (B5G) and towards the sixth generation of mobile networks (6G). It is predicted that 6G will begin commercialization in 2030 and will provide larger capacity [3] Specifically, compared to 5G, 6G allows for high-speed links of hundreds of gigabits per second to terabits per second (100-1000 times faster than 5G). This will be achieved through various technologies, such as the use of higher frequency spectrum than previous wireless generations in the terahertz range (0.06-10 THz). 6G will also be able to provide extremely low latency (<1ms) to support applications such as medical, virtual reality (VR), industrial internet of things (IIoT), connected and automated vehicles (CAV), and more. Although 5G networks have helped humans utilize AI (artificial intelligence) to optimize resource allocation and data processing with ultra-low latency of less than a fraction of a second, 6G networks can do even better by making AI smarter, with processing speeds approaching that of the human brain. Additionally, 6G networks will help reduce emissions from energy consumption.

Currently, there are many 6G research and development projects (funded by private or investment funds) taking place around the world. One of the most prominent projects is '6Genesis' worth 251 million euros in Oulu, Northern Finland - a longstanding location associated with the development of mobile networks. China has also been working on researching and developing 6G, launching the world's first 6G satellite. Samsung and Nokia are currently leading in the development of 6G networks in Korea and Europe. In addition, the UK has a new 6G development project at the 6G Innovation Centre (6GIC) at the University of Surrey. The Federal Communications Commission (FCC) provides licenses for testing frequencies from 95 GHz to 3 THz. The Institute of Electrical and Electronics Engineers (IEEE) and the International Telecommunication Union (ITU) conduct research on future network technologies. In August 2020, SpaceX launched its 9th Starlink satellite, raising a total of about 600 satellites into orbit and beginning to test satellite internet services in Canada and North America. To achieve its ambitious goal of global satellite internet coverage, SpaceX will launch approximately 12,000 satellites into orbit at altitudes ranging from 335 km to 1,325 km. So far, nearly 20 large companies/corporations are developing satellite constellations. The Japanese government has pledged to support businesses with 2 billion USD in research into 6G network technology. The NTT Group and Intel have signed a cooperation agreement to jointly develop 6G networks, among others.

In current wireless communication systems, the communication medium is considered a random operating object between the transmitter and receiver, leading to signal quality reduction due to the self-emitting factors of the radio wave. In addition, the high-speed 5th generation (5G) mobile network and the challenges of future 6G networks require effective support measures. To overcome the negative impacts of the propagation wave, some works have been proposed to optimize wireless channels control, including advanced adaptive modulation and coding, amplification and forwarding, MIMO beamforming, etc. Among these techniques, a completely new technology stands out, the Reconfigurable Intelligent Surfaces (RIS) smart reflector, which generates the concept of an intelligent radio environment, allowing us to partially control the main wireless channels to provide better transmission characteristics.

The satellite 6G technology and intelligent surfaces with the ability to reflect electromagnetic signals will bring low latency, fast connection to remote locations, and expand the coverage range of 6G to areas such as the sea, air, and even space, which can be applied to fields such as maritime, aviation, or even in space.

Driven by this emerging new technology trend, the author conducted a survey of various works and provided a comprehensive overview of the operation, design theory, and structure of RIS. The results of the article contribute to the literature for researchers to have practical solutions and deploy super surfaces to support current and future mobile network technologies.

2. The operating principle of RIS

RIS stands for Electromagnetic (EM) surface materials that can be reconfigured to control the propagation of waves in wireless environments, thereby improving the signal quality at the receiver. RIS is created from a large number of low-cost passive elements that can adjust the radio waves that natural materials cannot do. RIS is created from smart surfaces that function as a programmable reflector array, as illustrated in Figure 1 [8], where the phases (Φi) can be independently adjusted and the waves are directed towards the same reflection angle. Unlike other similar technologies, such as relays and MIMO beamforming, RIS does not require any energy source, as well as complex processing, encoding and decoding algorithms.

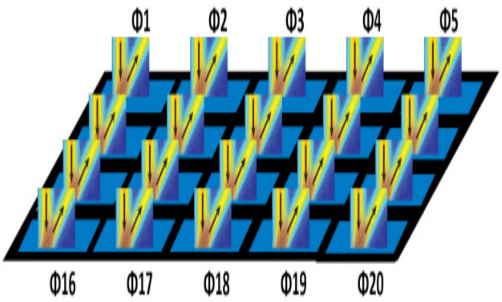

Figure 1. Illustration of the concept of RIS created from reconfigurable smart surfaces.

There are various switching technologies to control the EM reflection from smart surfaces, such as CMOS (Complementary Metal-Oxide-Semiconductor - an integrated circuit manufacturing technology) switches or MEMS (Micro Electro Mechanical Systems) switches, positive-intrinsic-negative (PIN) diodes, varactor-tuned resonant circuits, liquid crystals, etc. In a meta-surface, switch elements control super-atoms acting like antennas in and out. When EM waves arrive, they are routed based on the state of the switches, helping the RIS achieve the desired reflection [9]

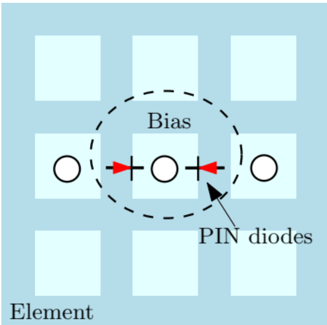

Figure 2. Controlling EM reflection using PIN diode.

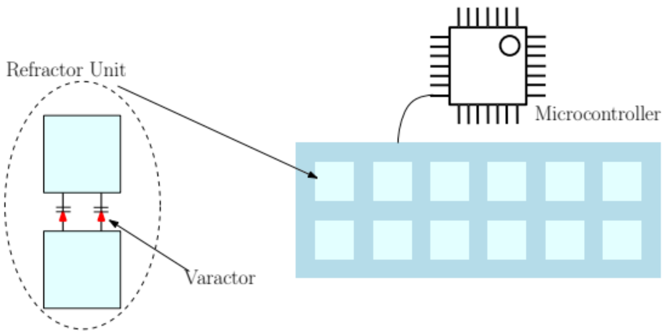

Figure 3. EM reflection control using varactor-tuned resonator

Figure 4 illustrates how wireless transmission can be controlled by creating a smart surface. The received data includes Line of Sight (LoS) signal and reflection beam. A conventional two-ray channel model is considered for free-space environment and the reflection surface is deployed on a plane [8] The radio wave travels straight in a homogeneous environment according to Fermat's principle, while the reflection beam obeys Snell's law.

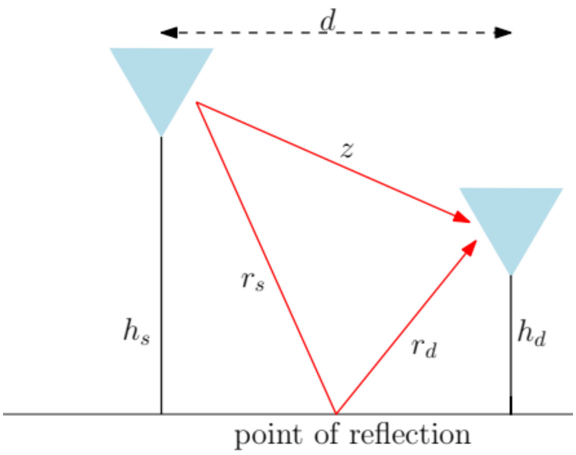

Figure 4. Basic dual-beam transmission model

3. RIS Deployment Plans

3.1. RIS Based on Passive Reflecting Array

The simplest way to deploy a reconfigurable intelligent surface (RIS) is to use a passive reflecting array, in which the antennas of the elements can be controlled to scatter or phase shift the signal [10] Each element has a limited impact on the propagation of waves, but if there are a large number of elements, it can effectively control the incoming waves and direct the beamforming to favorable positions [11]

3.2. RIS Designed Based on Metasurfaces

RIS deployment is more complex and is performed using metasurfaces [12], two-dimensional flat surfaces that use artificial electromagnetic materials. Initially, they were developed for applications in the field of optics to replace expensive customized lenses. The metasurface consists of a large number of closely spaced resonant structures with subwavelength dimensions, called pixels or meta-atoms [12] The space between two separate or adjacent meta-atoms is much smaller than the wavelength. The small size and large number of elements provide a lot of degrees of freedom in controlling the electromagnetic waves. In particular, the metasurface can customize the amplification and phase of incoming waves almost continuously [13] as well as the control of the reflected waves. The RIS contains semiconductor components (such as varactor diodes or liquid crystal displays) that can be dynamically reconfigured to change the structure and operation of the metasurface in real-time [14] The ability to adjust dynamically is crucial in wireless applications to adapt to channel variations.

4. Structure and control mechanism of RIS

4.1. RIS controller and reconfigurable chip

RIS reconfigures the behavior of EM by controlling the collective phase of individual scatter elements. This implies the integration of chips that can adjust the internal structure of the meta-surface through software, in which each chip interacts with the scatter element and communicates with the central control unit [15] For example, the RIS controller can be deployed in an array of FPGA (Field Programmable Gate Array) programming gates, and the adjustable chips can be PIN diodes as shown in Figure 5. The embedded RIS controller communicates and receives reconfiguration requests from peripheral devices, then optimizes and allocates phase control to the chips. When receiving control information, each chip will change its state and allow the corresponding scatter element to reconfigure its behavior. RIS can also be equipped with embedded sensors with environmental sensing capability to automatically update its structure and maintain EM behavior in dynamic environments.

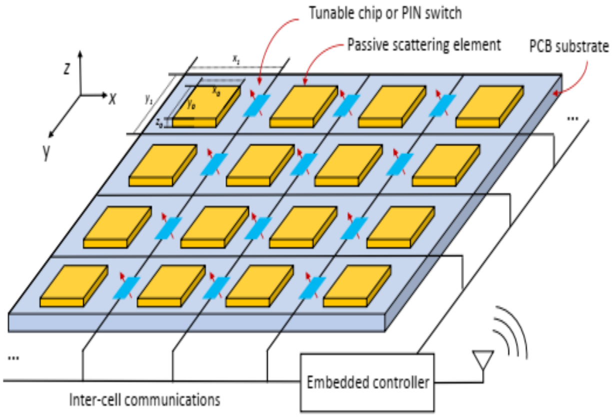

Figure 5. RIS consists of a large array of passive scatter elements.

PIN diodes have two states, on and off, to change the impedance of the input. Integrated circuits (ICs) with continuously variable impedance are used to control the phase shift of individual scattering elements. Changes in connections at different positions in the control network will reconfigure the physical structure of the RIS.

4.2. Cell-to-cell communication

The reconfigurability of the RIS depends on wired or wireless communication between cells and chips to control the surface scattering elements according to desired functions. Wired communication is preferred because it can be integrated with controllers in the same chip. Wireless intercellular communication becomes a solution in densely packed large-scale meta-surfaces. The design of communication protocols must comply with strict requirements for energy, latency, and durability. To ensure reliable connections between embedded controllers in the meta-surface structure, the traditional Network On Chip (NoC) method can be applied and adaptive routing algorithms with error tolerance can be developed, allowing for the exclusion of faulty links using routing data with suitable design.

4.3. Phase Control Mechanism

The reconfigurability of RIS depends on the phase control of individual scattering elements. When external stimuli (electricity, magnetism, light, heat, etc.) change, the physical parameters of the scattering elements will be adjusted accordingly to control the electromagnetic characteristics such as absorption level, resonance frequency, polarization of waves, or more complex operations such as three-dimensional beam steering, focusing, etc. [15]

The simplest way to locally adjust is to change the physical size of the scattering element, leading to changes in the resonance frequency and phase shift, as shown in Figure 6 [16] The structural parameters of the interconnect and basic size (dx, dy, dz, x0, y0, z0, g0) can be selected for operations in different frequency ranges. A chip can be adjusted (like a diode and varactor) combined to provide continuous variable impedance. The cells on the metasurface can be designed to cover a thin layer of liquid crystal to control waves and steer beams in real time [17] By controlling the voltage deviation on each cell, the effective dielectric constant will change and thus lead to the desired phase shift at different positions on the surface.

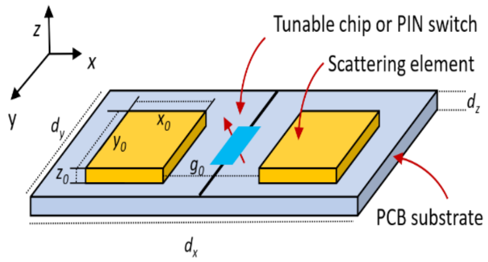

Figure 6. Unit cell diagram for RIS.

4.4. Adjustable Typical Functions

RIS can support a range of adjustable functions such as perfect absorption, anomalous reflection, beam shaping, and steering [18] as shown in Figure 7. Moreover, it has the ability to sense and communicate with peripheral devices, allowing integration with wireless communication systems to serve various applications.

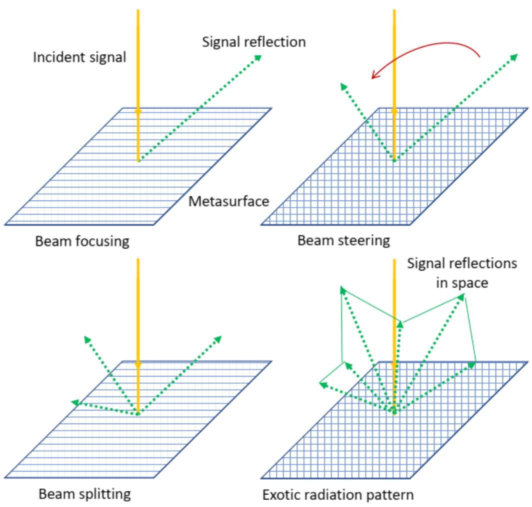

Figure 7. Illustration of typical adjustable functions of RIS.

- Perfect absorption: The phase shift of the metasurface can be designed to ensure minimum reflection or diffraction of electromagnetic waves. This is achieved by ensuring the angle of reflection is the same as the incident angle at every point on the surface. A metasurface absorber can be configured using chip-based optical capacitors to change the capacitance for each cell [19], operating at a speed of 5.5 GHz and achieving adjustable bandwidth of 150 MHz.

- Anomalous reflection: Anomalous reflection is observed when a light beam is directed at optical metasurfaces, reflecting two orthogonal polarization states over a wide range of wavelengths.

- Wave manipulation: Wavefront modulation can generate multiple reflections in different directions based on perfect phase control of the metasurface. The power of the reflected waves can be distributed over time and space to create a form of radiation. The use of binary-state PIN diodes for each scattering element is then optimized for the binary encoding matrix to generate different wave operations, including anomalous reflection, diffraction, steering, and beamforming. A genetic algorithm is used to customize wave modulation to create desired radiation patterns for the application requirements [20] The effectiveness of the genetic algorithm is verified by experiments at a frequency of 10 GHz, showing that the accuracy of wave modulation increases with the size of the scattering elements.

- Computing with waves: RIS can also perform more complex operations such as spatial differentiation, integration, convolution or neural network training, as the impinging wave passes through the scattering elements. This is called wave-based analog computing, achieving higher energy efficiency than conventional digital signal processing models. Optical metamaterials to perform operations in the Fourier space [21] promise to serve various applications including high-throughput image processing, fast equation solving, and real-time information processing.

5. Potential of RIS

Reconfigurable Intelligent Surfaces (RIS) is a new technology in the field of wireless communication, designed to solve problems related to signal degradation and noise in communication networks. RIS is an array of antennas capable of adjusting the phase and amplification of electromagnetic waves. By changing these parameters, RIS can create points of reflection for electromagnetic waves, thereby improving signal quality and increasing the efficiency of communication networks.

Numerous studies have shown that RIS can significantly improve the performance of 5G and 6G communication networks. According to the study in [22], the use of RIS can increase the transmission speed by up to 500% compared to networks without RIS. This study conducted experiments with various network scenarios, and the results showed that RIS can improve signal strength and reduce signal degradation.

In [23], the authors proposed a system using RIS in 6G networks. This study simulated and analyzed the performance of the system with and without RIS. The results showed that RIS can improve the transmission speed by up to 400%, while reducing signal degradation and increasing network stability.

In [24], a study simulated and evaluated the performance of a system using RIS in 5G networks. The results showed that RIS can improve transmission speed by up to 300% and reduce signal degradation by up to 70%.

Furthermore, there are many other studies that have researched various applications of RIS in different fields such as IoT, enhancing coverage and improving the quality of communication in mobile networks, etc. However, it should be noted that the results of these studies may vary depending on the environmental conditions and the design of the RIS system. Additionally, deploying RIS requires coordination and interaction between elements in the communication network. Therefore, applying RIS in 5G and 6G communication networks needs to be carefully executed and thoroughly prepared to ensure the effectiveness and stability of the network.

The application scenarios of RIS are quite diverse, ranging from Wi-Fi media sharing systems to mmWave and THz regions, even including optical communication, covering wide bandwidth ranges, etc. Some potential applications of RIS in new technologies are: effective solution for connecting the base station (BS) to users in areas with poor signal, where RIS acts as a virtual PSK (Pre-Shared Key) access point, an RF signal generator that transmits an unmodulated carrier wave to RIS with no power amplifier, mixer, or filter, RIS that responds to spatial modulation in both transmission and reception, a replacement for massive MIMO, a virtual MISO/MIMO system based on RIS, RIS that enhances PHY security (an important feature still lacking in 5G), RIS in vehicular networks to increase reliability, security, overcome LOS congestion, and detect pedestrians, RIS in NOMA networks, in low-complexity MIMO systems, to reduce noise and increase power, RIS in UAV networks to overcome LOS congestion, support ground networks, users in the air and backhauling cargo transportation, RIS that improves the secondary user/receiver (SU-Rx) ratio in CR cognitive radio networks, reduces Doppler effect, RIS that expands coverage in 5G, B5G, and 6G networks, the potential of RIS in OFDM systems, RIS that supports posture recognition, indoor radio localization (indoor positioning) RL (Radio Localization), mobile edge computing MEC, etc., and many applications in other hybrid systems.

In summary, RIS is an advanced and promising technology in the field of wireless communication, which can significantly improve the performance of 5G and 6G communication networks. The application of RIS in communication networks needs to be carefully implemented and rigorously evaluated to ensure the effectiveness and stability of the network.

6. Conclusion

The article conducted a brief survey on the theory of designing smart surfaces that can be reconfigured to control electromagnetic waves, turning traditional communication systems into intelligent wireless environments. With the potential applications of RIS and the development of science and technology, RIS manufacturing technology will gradually improve its features, aesthetics, and become more widespread in the field of communication, promoting the emergence of new generations of mobile networks and wireless network systems in general.

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