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Shape adaptive IRS Enhanced SAG IoT Network

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Abstract—As 6G technology bridges the physical and digital worlds, ubiquitous 6G services will provide users with ease wherever they are. The concept of the space, air, and ground integrated network (SAGIN) is to seamlessly integrate these three subnets to better adapt to future Internet. This paper addresses the use of shape-adaptive IRS antenna, which is made of flexible materials. As a result, the physical shape of the antenna can be changed according to the differentiation of RF environment and user distribution. Our simulation study shows that specific radiation beams of IRS can be optimized according to the designated requirements, and correspondingly the network performance is improved.

Keywords—SAGIN, IoT, 6G, IRS

I. INTRODUCTION

Thanks to the Internet of Things (IoT) technology, every object on the earth will be able to communicate with each other, satisfying various demands and requirement [1]. However, the service range of the terrestrial network is limited, and the existing network cannot cover remote areas such as remote mountainous areas, deep space, deep sea, and polar regions. At present, the global industry's expectations for 6G have gradually become unified. For Ubiquitous Intelligence, "ubiquitous" means that 6G services will serve global users all the time. The current terrestrial network cannot expand the breadth and depth of the communication range, and at the same time, the cost of providing global connectivity is very high. In order to expand the scope of human activities to a broader field, scholars have proposed the concept of an integrated network of heaven and earth, and through this concept, these three sub-networks are seamlessly integrated.

For a long time, telecommunication universal service and social sustainable development have been attached great importance to by all countries. Global ubiquitous service is one of the main goals of establishing communication network. In the future, the telecommunication universal service will be extended from the ground to the three-dimensional space of space, air and ground. At this stage, both academia and industry have great expectations for the realization of the concept of ground-to-air network interconnection. At the same time, it is the most feasible method to realize this concept with the help of modern information network space. The integrated heterogeneous network of space, air, and ground (SAGIN) will play an important role in some important social and production environments. For example, in no man's land, earthquake/flood and other situations, satellite communication is used to obtain information in specific areas, and the information is widely transmitted through the interconnection with the ground cellular network, so as to realize large area rapid rescue and emergency communication. For another example, UAVs and other flying equipment are equipped with a variety of sensors and high-definition cameras to realize ubiquitous Internet of Things (IoTs) applications based on radar integration technology.

Now, many companies are beginning to use the concept of SAGIN to carry out projects. SAGIN's wide coverage, large processing capacity and flexibility make it useful in areas such as geographic information processing, highly sensitive traffic command (ITS) [1], military operations, and rescue of the wounded [2]. In particular, the satellite system will connect mountains, deep seas, polar regions and villages into one. The use of airspace networks will improve the ability of high service requirements, and the high data rate access benefits from the massive deployment of systems in a region. The technology foreshadowing will provide a path for future communication development, especially for 5G and 6G [3-11].

As 6G technology bridges the physical and digital worlds, ubiquitous 6G services will provide users with ease wherever they are. SAGIN is to seamlessly integrate three subnets, i.e., space, air, and ground, to better adapt to future development. This paper investigates the shape-adaptive IRS antenna, which is made of flexible materials. The physical shape of the antenna can be changed according to different situations, and specific radiation beams can be generated according to functional requirements.

The rest of this paper will cover the following. Section II introduces the basis of SAGSIN, including its overall structure and four sub-networks. Section III presents the structure and implementation of shape-adaptive IRS, after which the simulation results of a variety of scenarios will be demonstrated and discussed in Section IV. Finally, Section IV concludes the paper.

II. MULTI-LAYER ARCHITECTURE OF SAGIN

2.1 The components of SAGIN

Space, air and ground are the three-tier structure of SAGIN. As shown in Figure 1, these three-tier structures can work without relying on others, or cooperate with each other to play a role, and by integrating heterogeneous networks between them, layered broadband wireless networks can be easily built [12].

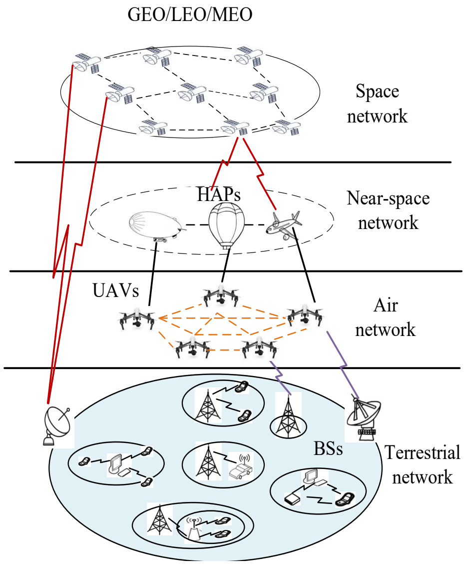

Figure 1 An architecture for space-air-ground integrated network

A. Space: Satellites

A typical satellite communication system consists of three main components: ground, space segment, and space-to-ground link Multi-layered satellite networks [13]. By connecting multiple satellites to each other and combining with layers, a multi-layer satellite network (MLSN) can be formed [14], which is the key technology of satellite systems in the future.

Three types of satellites: high-orbit satellites (GEO), medium-orbit satellites (MEO) and low-orbit satellites (LEO) [3]. High-orbit satellite single star coverage, coverage relative to the ground fixed, a single star can cover up to 42% of the Earth's area. High-orbit satellites are moving towards high-throughput. The single star coverage area of the medium-orbiting satellite covers an area of about 12%-38% of the surface area of the Earth, Mid-orbit satellites are designed to provide high-bandwidth, low-cost, low-latency satellite Internet access for $1.2 billion, with transmission delays of approximately 150ms and system capacity of up to 15Gbps. Low-orbit satellites have low cost and small coverage, requiring multiple satellites to form large satellite constellations to complete global coverage, due to their low orbital altitude, have a small transmission delay, usually around 30ms.

B. Near-space: HAPS

Aviation network is a mobile communication system that uses aircraft as a tool for information acquisition, processing and dissemination. Intersecting the ground network base station (BS), it has the characteristics of low cost, fast laying, wide service range, and convenient regional wireless access.

At present, the energy supply of the HAPS system is mainly provided by solar energy plus energy storage, because solar panels are suitable for installation on it, and HAPS can provide wireless services to network users due to its low latency characteristics.

The era of portable data centers, smart signal conditioners, and smart machine learning is getting closer. HAPS can make the best choice for a large number of drones and smart cars. As shown in Figure 2, the framework proposed in this article is as follows.

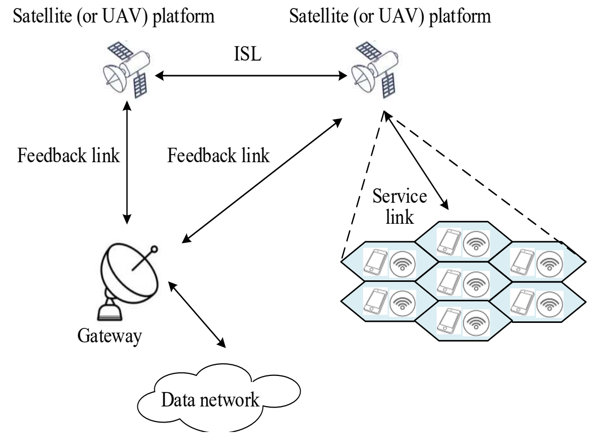

Figure 2 Satellite communication network diagram

Compared with the original technology, HAPS no longer needs to install thousands of relay stations on the ground and can achieve efficient and reliable long-distance communication between satellites. At the same time, it can also be used as a data center to be distributed in various places. The satellite's trajectory, collision and other information. In addition, with the help of satellites, HAPS can realize the function of fast handover. HAPS uses technologies such as edge intelligence to simplify calculations and manage large-scale unmanned aerial vehicles (UAV) groups, which will greatly facilitate the flow of goods. At the same time, the HAPS layer provides high-speed Internet and wireless communication systems in cities, mountains, oceans and other areas to reduce dependence on satellites.

C. Air: Mid- to low-altitude UAVs

Single UAV network has been widely used in military, civil and public fields [15]. A single satellite communications hop (or double hop) provides command and control on the forwarding link, while monitoring product and drone parameters for simultaneous delivery on the return link. One of the main reasons for using multi-drone networks is the distributed processing capability of multi-drone networks. Specifically, they separately search for a number of suspicious targets and share information through collaborative communication. In addition, a transceiver-equipped drone can act as an aerial base station to expand communication coverage and increase network capacity. In addition to be a mobile relay or flight base station, the UAV can be used as a mobile cloud and fog computing system. The UAV mounted cloud/fog provides a low latency application unload opportunity for the mobile terminal. Drones can also enable Fog Computing to deliver high-quality streaming media, moving users through nearby wireless proxies and access points.

D. Terrestrial network: Cellular network

A terrestrial network consists primarily of terrestrial communications systems, such as cellular networks, mobile ad hoc networks (MANET) [16], worldwide interoperability for microwave access (WiMAX)[17], wireless local area networks (WLAN), etc. Cellular networks, in particular, have evolved from the generation 1 (1G) to the generation 2 (2G) and the generation 3 (3G) after the generation 4 (4G) or advanced long-term evolution (LTE-A)[18], now, it is moving toward a 5G wireless network to support a variety of services. As for standardization, the Third Generation Partnership Project (3GPP) has created a set of standards for cellular/mobile networks.

5G is the latest generation of cellular mobile communication technology, which is an extension of 4G (LTE-A, WiMAX), 3G (UMTS, LTE) and 2G (GSM) systems. The performance goals of 5G are high data rates, reduced latency, energy savings, reduced costs, increased system capacity and large-scale device connectivity.B5G has increasingly higher requirements for high data rate, high capacity, seamless coverage, low latency, high reliability, low power consumption and low cost, and the interconnection of everything. In the future, the demand for ultra-high-speed data transmission is not limited to land. With the development of technology, the space for human existence and activity is becoming wider and wider, and there are also communication needs in sea and airspace.

The 6G network will be a fully connected world, combining wireless terrestrial and satellite communications. Global seamless coverage is achieved by integrating satellite communications into 6G mobile communications, 6G communication technology is no longer a simple breakthrough in terms of network capacity and transmission speed, what's more important is to narrow the digital divide and connect everything.6G will use the terahertz (THz) frequency range, and the "densification" of 6G network will also reach the level that can't be achieved before.

III. SAGIN SPECIFIC KEY ISSUES

A. Spectrum management

In SAGIN heterogeneous networks, different networks may use different wireless spectrum resources. Efficient management of the radio spectrum in SAGIN networks is required to make more efficient use of the radio spectrum and avoid inter-system interference in the future. Dynamic spectrum sharing is an important means to improve spectrum effectiveness and optimize network deployment. By adopting intelligent and distributed spectrum sharing access mechanism, the available spectrum range can be flexibly expand and the spectrum usage rules can be optimized to meet the future demand of large bandwidth, ultra-high transmission rate and multi-scene in three-dimensional space. At the same time, it is necessary to actively promote blockchain cooperation, AI, dynamic spectrum sharing and other technologies to achieve intelligent spectrum sharing and supervision of SAGIN network.

B. Mobility management and network switching

Mobility management is the management of mobile terminal location information, security, and business continuity, and strives to achieve the best contact status of the terminal and the network to provide a guarantee for the application of various network services. Compared with the terrestrial communication network, the satellite network has a small overall capacity and limited single-star capacity, and to ensure the user experience, the satellite communication system needs to design suitable user access and switching strategies. This includes selecting suitable satellite beams and suitable satellite channels for the user. At the same time, because of the high-speed movement of satellites of low-orbit satellite systems relative to the ground, each satellite may serve a length of only a few tens of seconds, and multiple satellite switching may be included in one operation. Satellite system switching can be divided into switching between beams within the same satellite and between beams of different satellites, as well as switching between stations across the ground. Besides, switching between different communication systems can be involved in air, sky, and earth.

C. New generation antenna and radio frequency technology

Compared to traditional antennas, the future antenna has the characteristics of miniaturization and large scale. It is said that the 6G system antenna will be "nano antenna", which will subversively change and traditional antennas and radio, integrated electronic products and new materials, empower ultra-large antenna technology, integrated RF front-end system key technologies.

At present, the theory and engineering design of VLAS are still faced with a large range of cross-band, space-space-earth coverage and other problems. At the same time, it is necessary to actively explore the key components of high efficiency and easy integration of the front-end transceivers and receivers, as well as key technical issues such as the radiation and scattering of antennas, so as to break through the super-large-scale MIMO front-end system. In addition, the power consumption of the antenna system and the interference between the array elements are also the research hotspots. Intelligent reflector and configurable antenna system are some of the most promising technologies.

IV. METHOD OF SHAPE ADAPTIVE IRS

A. Basic introduction to IRS

Along with the rapid development of information metamaterial technology and the huge demand for 5G millimeter wave and 6G terahertz communications, the combination of information metamaterial technology and cellular mobile network technology has become a research hotspot in the wireless communication field. The "passive" reflection characteristic of IRS technology is one of the main research directions.

Generally, the function of the IRS plane is to reflect incident electromagnetic waves, and it is composed of a large number of artificial units. The reflection characteristics (including amplitude, phase, etc.) of each artificial unit are independently controllable. IRS can produce different numbers of reflected beams, and can also beam-form the reflected waves. With this feature, deploying IRS in a wireless network can artificially change the propagation environment of wireless signals to complete communication.

Figure 3 shows a typical IRS structure, including three layers and an intelligent controller. The first layer is the reflecting surface of the IRS, which is composed of a large number of artificially designed electronic reflecting units. Each reflecting unit has at least two states to represent binary information. A large number of artificial units reflect the incident wave and form different reflected beams as a whole. The second layer is a metal shielding layer, they can prevent the leakage of energy behind the IRS signal. The third layer is the control circuit board, which can be designed and implemented by FPGA, etc., which is responsible for stimulating the simulation unit and adjusting the reflection characteristics of the simulation unit in real time. In addition, the IRS also includes an intelligent controller, which is the core control unit of the IRS. The intelligent controller is connected to the base station of the wireless network through a feeder or wireless and receives the IRS channel information sent by the base station, thereby completing the control circuit board to adjust the reflection characteristics of the artificial unit.

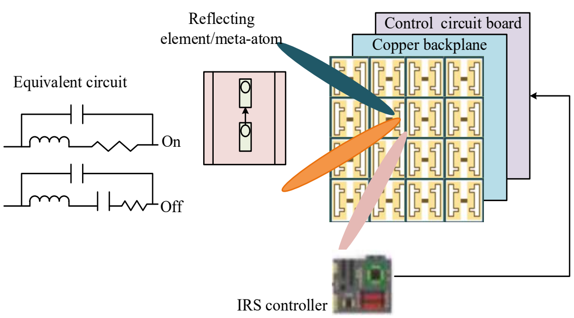

Figure 3 The typical architecture of IRS

As a new auxiliary wireless network communication method, IRS has many advantages. First, the reflected signal is directed to the "blind" or weak coverage area of the wireless network through beamforming to enhance the energy of the received signal and improve the channel transmission rate, thus enhancing the wireless network coverage. Secondly, by adjusting the phase of the infrared reflected beam, it can reduce the energy of the interference signal and improve the spectral efficiency. Moreover, the IRS itself does not have any interference. Third, IRS allows full duplex mode to work with high efficiency of upstream and downstream transmission. Fourth, the IRS does not have radio frequency transmitting unit, the artificial unit is passive, the reflection of the incident wave does not consume energy. So IRS is a way of green communication. Fifth, IRS is made up of a large number of low cost manual units, which are low cost to implement. In addition, IRS is relatively easy to deploy in both indoor and outdoor environments.

In general, IRS has signal enhancement capability and signal neutralization capability. The infrared signal enhancement function can improve the information transmission rate and expand the coverage range of wireless signal. The signal neutralization capability can reduce intercell interference and multi-user interference and improve the SNR of received signals. At the same time, by suppressing the signal energy of "eavesdropper" users, secure communication can be realized. In addition, the simultaneous transmission of data and energy can also be achieved by deploying infrared spectra near the energy collection nodes, since energy can be obtained from wireless signals.

B. Shape adaptive IRS

From the physical structure point of view, the surface of the IRS is composed of a large number of sub-wavelength artificial units. Logically, these artificial units can be periodically arranged horizontally or vertically in one dimension, or they can be arranged periodically in two dimensions. This is similar to the appearance of a traditional array antenna. Because in wireless communication systems, IRS is mainly used to reflect incident waves, so IRS can also be called a passive reflect array.

As a typical antenna array technology, phased array antenna array (PAA) technology has achieved great success. Generally, PAA is composed of radio frequency circuit, power divider, phase shift circuit and power amplifier, antenna unit and so on. In the drive type of the radio frequency circuit, the phase shift circuit sequentially shifts the phase of the signal transmitted from each antenna unit. At the same time, according to the desired beam, the power divider and amplifier distribute different signal energy in the number of antenna elements.

Learning from the implementation of PAA technology, IRS can also reconstruct the reflection characteristics of the IRS surface by changing the phase of the artificial unit in real time, thereby generating beams with different directions and different numbers of beams to support simultaneous multi-user communication. As shown in Figure 4.

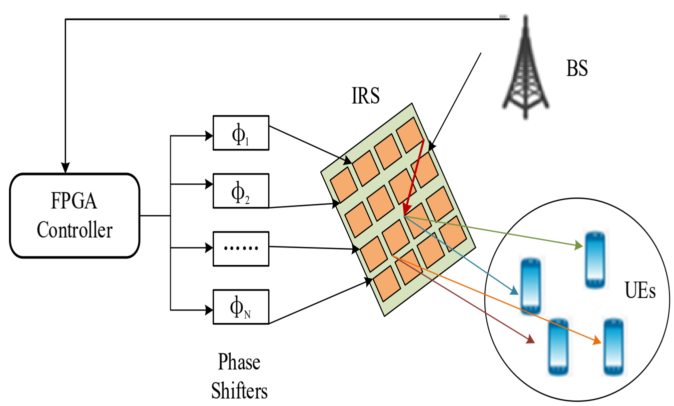

Figure 4. Phase-shift controlled IRS-assisted communication

In an IRS-assisted wireless communication system, the base station informs the FPGA controller of the number of reflected beams and the direction of beamforming through wireless or dedicated feeders. The latter calculates the phase of each artificial unit in reverse and adjusts the phase of each unit. Electromagnetic state, so as to obtain the desired pointing beam.

Unlike PAA, which is usually suitable for narrowband applications, IRS with phase shift control can implement a variety of wideband applications.

IRS can realize communication similar to multi-user MIMO [19]. We consider performing linear transmission precoding on the AP. Therefore, the complex baseband transmission signal at the AP can be expressed as

$$x_k = \sum_{j=1}^{k} \boldsymbol{w}_j s_j, \tag{1}$$

where s_j is the j-th user transmission data and [redacted] $\in \mathbb{C}^{M+1}$ is the corresponding beamforming vector. It is supposed as an independent random variable, whose mean and variance are zero and 1, respectively. The system model of a single user in MIMO IRS is

$$y_k = \left(\boldsymbol{h}_{r,k}^H \boldsymbol{\Theta} \boldsymbol{G} + \boldsymbol{h}_{d,k}^H\right) \sum_{j=1}^{K} \boldsymbol{w}_j s_j + n_k \tag{2}$$

where the baseband channels from AP to IRS, IRS to user k, and AP to user k are denoted as $G \in \mathbb{C}^{N\times M}$, $\boldsymbol{h}_{r,k}^H \in \mathbb{C}^{1\times N}$ and $\boldsymbol{h}_{d,k}^H \in \mathbb{C}^{1\times M}$, respectively, $k = 1,\ldots,K$ and $n_k \sim CN(0,\sigma_k^2)$ denotes the additive white Gaussian noise (AWGN).We denote

$$\boldsymbol{S} = \begin{bmatrix} s_1 \\ \vdots \\ s_k \\ \vdots \\ s_K \end{bmatrix}, \boldsymbol{Y} = \begin{bmatrix} y_1 \\ \vdots \\ y_k \\ \vdots \\ y_K \end{bmatrix}, \boldsymbol{h}_{r,k} = \begin{bmatrix} h_{r,k,1} \\ \vdots \\ h_{r,k,n} \\ \vdots \\ h_{r,k,N} \end{bmatrix}, \boldsymbol{h}_{d,k} = \begin{bmatrix} h_{d,k,1} \\ \vdots \\ h_{d,k,m} \\ \vdots \\ h_{d,k,M} \end{bmatrix},$$

$$\boldsymbol{w}_k = \begin{bmatrix} w_{k,1} \\ \vdots \\ w_{k,m} \\ \vdots \\ w_{k,M} \end{bmatrix}.$$

The parameters $\mathbf{G}$ and $\mathbf{\Theta}$ are as follows:

$$\underset{(\mathrm{NM})}{\mathbf{G}} = \begin{bmatrix} g_{1,1} & \cdots & g_{1,M} \\ \vdots & \ddots & \vdots \\ g_{N,1} & \cdots & g_{N,M} \end{bmatrix} \tag{3}$$

$$\begin{aligned} \underset{(\mathrm{NN})}{\mathbf{\Theta}} &= \mathrm{diag}\left(\beta_1 e^{j\theta_1} \quad \cdots \quad \beta_n e^{j\theta_n} \quad \cdots \quad \beta_N e^{j\theta_N}\right) \\ &= \begin{bmatrix} \beta_1 e^{j\theta_1} & & & & \\ & \ddots & & & \\ & & \beta_n e^{j\theta_n} & & \\ & & & \ddots & \\ & & & & \beta_N e^{j\theta_N} \end{bmatrix} \end{aligned} \tag{4}$$

And $\mathbf{\Theta}$ represent the reflection coefficient matrix of the IRS, where $\theta_n \in [0, 2\pi)$ and $\beta_n \in [0,1]$ respectively represent the phase shift and amplitude reflection coefficient of the n-th element of the IRS. Therefore, the composite APIRS-user channel is modeled as a series connection of three components, namely the AP-IRS link, the IRS reflection with phase shift, and the IRS-user link. Accordingly, the system model MIMO IRS is

$$\mathbf{Y} = \left(\underset{(\mathrm{KN})}{\mathbf{H}_r^H} \underset{(\mathrm{NN})}{\mathbf{\Theta}} \underset{(\mathrm{NM})}{\mathbf{G}} + \underset{(\mathrm{KM})}{\mathbf{H}_d^H}\right) \underset{(\mathrm{MK})}{\mathbf{W}} \mathbf{S} + \mathbf{N} \tag{5}$$

Where

$$\underset{(\mathrm{KN})}{\mathbf{H}_r^H} = \begin{bmatrix} \mathbf{h}_{r,1}^H \\ \vdots \\ \mathbf{h}_{r,\mathrm{k}}^H \\ \vdots \\ \mathbf{h}_{r,\mathrm{K}}^H \end{bmatrix}, \tag{6}$$

$$\underset{(\mathrm{KM})}{\boldsymbol{H}_d^H} = \begin{bmatrix} \boldsymbol{h}_{d,1}^H \\ \vdots \\ \boldsymbol{h}_{d,k}^H \\ \vdots \\ \boldsymbol{h}_{d,K}^H \end{bmatrix}, \tag{7}$$

$$\boldsymbol{N} = \begin{bmatrix} n_1 \\ \vdots \\ n_k \\ \vdots \\ n_K \end{bmatrix}, \tag{8}$$

$$\underset{(\mathrm{MK})}{\mathbf{W}} = \left[\mathbf{w}_1 \ldots \mathbf{w}_k \ldots \mathbf{w}_K\right] = \begin{bmatrix} w_{1,1} & \cdots & w_{K,1} \\ \vdots & \ddots & \vdots \\ w_{1,M} & \cdots & w_{K,M} \end{bmatrix}. \tag{9}$$

The SINR_k of the single user and the SINR of the system are respectively

$$\mathrm{SINR}k = \frac{\left|\left(\boldsymbol{h}_{r,k}^H \boldsymbol{\Theta} \boldsymbol{G} + \boldsymbol{h}_{d,k}^H\right) \boldsymbol{w}_k\right|^2}{\sum_{j\neq k}^{K} \left|\left(\boldsymbol{h}_{r,j}^H \boldsymbol{\Theta} \boldsymbol{G} + \boldsymbol{h}_{d,j}^H\right) \boldsymbol{w}_k\right|^2 + \sigma^2} \tag{10}$$

From the above model, it can be known that for an IRS containing N antenna elements, its receiving channel matrix $\mathbf{G}$:

$$\underset{(\mathrm{NM})}{\mathbf{G}} = \left[\mathbf{g}_1 \quad \cdots \quad \mathbf{g}_m \quad \cdots \quad \mathbf{g}_M\right], \tag{11}$$

Its reflection matrix $\mathbf{H}_r^H$:

$$\underset{(\mathrm{KN})}{\mathbf{H}_r^H} = \begin{bmatrix} \mathbf{h}_{r,1}^H \\ \vdots \\ \mathbf{h}_{r,k}^H \\ \vdots \\ \mathbf{h}_{r,K}^H \end{bmatrix} \tag{12}$$

Suppose the channel vector is as follows:

$$\boldsymbol{h}_x^H = (\boldsymbol{R}_x \boldsymbol{V}_x)^H = \boldsymbol{V}_x^H \boldsymbol{R}_x^H \tag{13}$$

where $\boldsymbol{V}_x^H \in CN\left(0, \boldsymbol{I}_{D_k}\right)$, D_k is the number of ray.

$$\boldsymbol{R}_x^H = \frac{1}{D_k} \begin{bmatrix} \boldsymbol{a}^H\left(\theta_{x,1}\right) \\ \vdots \\ \boldsymbol{a}^H\left(\theta_{x,D_k}\right) \end{bmatrix}, \tag{14}$$

For a linear antenna array vector $\mathbf{a}$ is as follows:

$$\boldsymbol{a}^H\left(\theta_{x,i}\right) = \left[1 \quad \cdots \quad e^{j2\pi\frac{d}{\lambda}(n-1)\sin\theta_{x,i}} \quad \cdots \quad e^{j2\pi\frac{d}{\lambda}(N-1)\sin\theta_{x,i}}\right], \tag{15}$$

Suppose the IRS is a rectangular antenna array, the number of antenna elements is $N = N_{ROW} \times N_{COL}$, vector $\mathbf{a}$ is as follows:

$$\mathbf{a}^H\left(\theta_{x,i},\ \phi_{x,i}\right)=\text{vec}\left\{\begin{bmatrix}1 & \cdots & e^{j2\pi\frac{d}{\lambda}(n_{ROW}-1)\sin\theta_{x,i}} & \cdots & e^{j2\pi\frac{d}{\lambda}(N_{ROW}-1)\sin\theta_{x,i}}\end{bmatrix}\otimes\begin{bmatrix}1\\ \vdots\\ e^{j2\pi\frac{d}{\lambda}(n_{COL}-1)\sin\phi_{x,i}}\\ \vdots\\ e^{j2\pi\frac{d}{\lambda}(N_{COL}-1)\sin\phi_{x,i}}\end{bmatrix}\right\}, \tag{16}$$

Where $\phi_{x,i}\in[0,2\pi)$ is direction angle and $\theta_{x,i}\in(-\frac{\pi}{2},+\frac{\pi}{2})$ is pitch angle.

Suppose the antenna configuration of the rectangular antenna array is $N=N_{ROW}\times N_{\text{RING}}$, The arc length between the two elements is d. The projection distance of the n_{RING} unit in the beam direction is $d_{n_{RING}}\left(\phi_{x,i}\right)$:

Suppose the Shaped IRS is a barrel-like structure. The arc length d between two elements is a fixed value, and the radius of the barrel is R. The curvature of the Shaped IRS can be changed by adaptively adjusting the length of R. The number of elements in Shaped IRS is $N=N_{ROW}\times N_{\text{RING}}$. The projection distance of the elements in the beam direction is :

$$\begin{aligned}d_{n_{RING}}\left(\phi_{x,i}\right)&=R\left(\cos\frac{n_{RING}-1}{N_{RING}}2\pi\frac{d\left(N_{RING}-1\right)}{2\pi R},\sin\frac{n_{RING}-1}{N_{RING}}2\pi\frac{d\left(N_{RING}-1\right)}{2\pi R}\right)\bullet\left(\cos\phi_{x,i},\sin\phi_{x,i}\right)\\&=R\left(\cos\frac{d\left(N_{RING}-1\right)\left(n_{RING}-1\right)}{N_{RING}R},\sin\frac{d\left(N_{RING}-1\right)\left(n_{RING}-1\right)}{N_{RING}R}\right)\bullet\left(\cos\phi_{x,i},\sin\phi_{x,i}\right)\end{aligned}, \tag{17}$$

Vector $\mathbf{a}$ is as follows:

$$\mathbf{a}^H\left(\theta_{x,i},\ \phi_{x,i}\right)=\text{vec}\left\{\begin{bmatrix}1 & \cdots & e^{j2\pi\frac{d}{\lambda}(n_{ROW}-1)\sin\theta_{x,i}} & \cdots & e^{j2\pi\frac{d}{\lambda}(N_{ROW}-1)\sin\theta_{x,i}}\end{bmatrix}\otimes\begin{bmatrix}1\\ \vdots\\ e^{j2\pi\frac{d_{n_{\text{RING}}}\left(\phi_{x,i}\right)}{\lambda}}\\ \vdots\\ e^{j2\pi\frac{d_{N_{\text{RING}}}\left(\phi_{x,i}\right)}{\lambda}}\end{bmatrix}\right\}, \tag{18}$$

Then we can get:

$$\boldsymbol{h}_{r,k}^H=\text{NEW}(\boldsymbol{h}_x^H|x=k), \tag{19}$$

$$\boldsymbol{g}_m=\text{NEW}(\boldsymbol{h}_x|x=m), \tag{20}$$

where NEW() indicates that a new vector is generated.

By flexibly changing the electromagnetic state of each artificial unit, IRS can realize different applications. However, this has very high requirements for the calculation and control capabilities of the IRS controller and the design of the IRS manual unit. In order to reduce the complexity of IRS technology implementation, a physically deformable IRS can be designed to meet different application requirements.

In order to realize a physically deformable IRS, it is necessary to connect various artificial units on the surface of the IRS by an expandable soft material. The shape-adaptive IRS can flexibly change the shape through mechanical control, thereby alleviating the requirements for IRS controller and manual unit design. As shown in Figure 5.In fact, the ability to adjust the direction of the IRS reflected beam through phase control is limited. When the UE moves outside the coverage of the IRS reflected signal, the shape of the IRS can be adjusted adaptively, such as the shape of the IRS according to the transformation form of the cylindrical patch antenna array, so that most of the artificial unit's reflected signal on its surface Pointing to the current location of the UE can provide the UE with continuous and uninterrupted high-quality communication services.

By changing the shape of the IRS, a larger adaptive shape gain can be obtained and the ability of the IRS to reflect signals can be enhanced. The general procedure is to first search for the signal range and open the antenna as large as possible to collect as many signals as possible. For a cylindrical patch antenna array, its shape will change from the original plane to a cylindrical shape [20]. Then, the base station analyzes the signal received by the IRS and determines the direction of the signal to the IRS. Next, the base station instructs the IRS controller to change the shape of the IRS so that it faces the target user area.

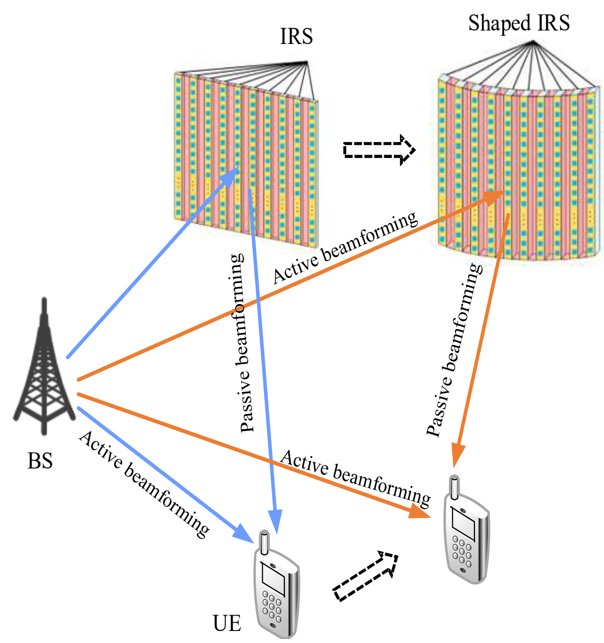

Figure 5 Deformable IRS that meets application requirements

C. IRS Beam-forming by DRL

To increase system performance, the phase-shift configuration of IRS is critical. However, due to the nonconvex limitations of IRS reflective components and a variety of complicated nonconvex optimization objective functions, optimum beamforming design is a difficult task. Based on the semi-infinite relaxation (SDR) methodology, most traditional phase-shift design methods produce a poor solution (no closed-form solution). Because of the SDR approach's high computing cost, the optimization problem can be solved using a fixed-point iterative method. Furthermore, the greedy method, where the phase shift of individual cells is adjusted repeatedly, is a potential option to deal with the loss of high performance as the user walks away from the BS. Because the resultant suboptimal iterative algorithms are complicated, they are unsuitable for real-time implementation. The DL, RL, and FL methods for

RIS-assisted phase shift design of wireless communication systems were developed on this premise.

We present in this paper a novel DRL technique with better learning efficiency for improving the transmission efficiency of access points (APs) in IRS-assisted multiple-input single-output (MISO) systems. As shown in Fig.5, we first design a robust IRS-assisted MISO problem by active and passive beamforming, and then we construct a Markov decision process (MDP) to solve the problem by learning from past experiences. We develop an optimization-driven DDPG algorithm that integrates model-based optimization into the framework of the model-free DDPG method to improve learning efficiency. When the DDPG algorithm produces a partial action, the model-based optimization module can be used to quickly find the second half of that action. By solving an approximate convex problem, the optimization module provides an achievable lower bound on the original robust problem, leading the DDPG method to seek an optimal action more quickly.

V. SIMULATION STUDY

Regarding the simulation part, Table-1 shows the main system configuration parameters. There will be 1 IRS in each cell and the antenna configuration of IRS is a rectangular antenna array with 8×8 elements. IRS is deployed under UAV and the deployment height is 100m, with downtilt angle of 90°. 3 UEs will be deployed in each cell, and each UE's antenna will be configured with 1 element of 1.5m high. Each BS has 3 cells, each of which covers a width of 120°. The antenna configuration of BS is a 30m meter high rectangular antenna array with 8×8 elements, BS transmit power is 50 dBm/cell, carrier center frequency is 3.5 GHz, antenna downtilt angle is 10°.

Table 1 CONFIGURATION

Parameter	Value
IRS Number	1/Cell
IRS Antenna	8*8
IRS height (m)	100
IRS Antenna downtilt angle	90°
UE Number	3/Cell
UE Antenna	1*1
UE height (m)	1.5
UE Antenna downtilt angle	0°
BS Power (dBm)	50
BS Antenna	8*8
Frequency (GHz)	3.5
BS Antenna downtilt angle	10°
BS height (m)	30
Cell width	120°

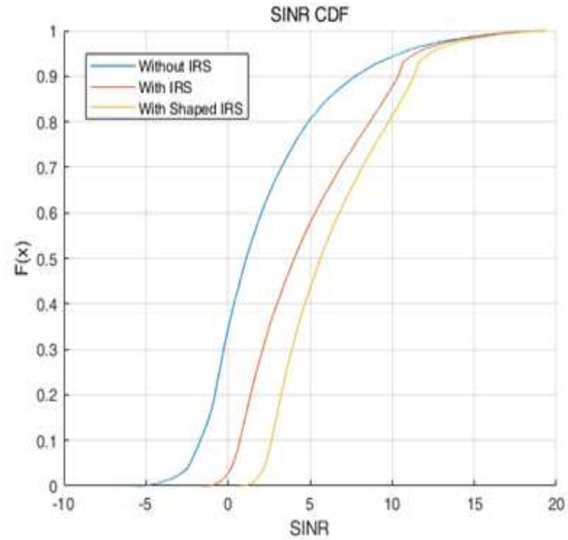

Figure 6 SINR CDF vs SINR

In the simulation process, 7 BSs are first deployed in fixed positions, and the No.1 cell of each BS is fixedly deployed towards the west direction, and the No. 2 and No. 3 cells are deployed counterclockwise, with an interval of 120 degrees. After that, 3 UEs are evenly and randomly scattered in the hexagon of each cell. Then randomly deploy an IRS near the center of the hexagon of each cell. Each snapshot of the simulation will re-deploy the UE and IRS in accordance with the above principles. In the simulation, the BS will beam-forming towards the UE and IRS, the receiving beam of the IRS will point to the BS, and the transmitting beam will point to the UE, and then the useful signal power received by the UE and the intra-system interference from other BSs will be calculated.

The simulation results are shown in Figure 6, where the three CDF curves represent the three situations where IRS is not deployed, IRS is deployed, and shaped IRS is deployed. From the Figure 6, we can see that IRS can improve the SINR of the coverage area. At the same time, because the beamforming is more flexible, Shaped IRS has more advantages than IRS in improving SINR.

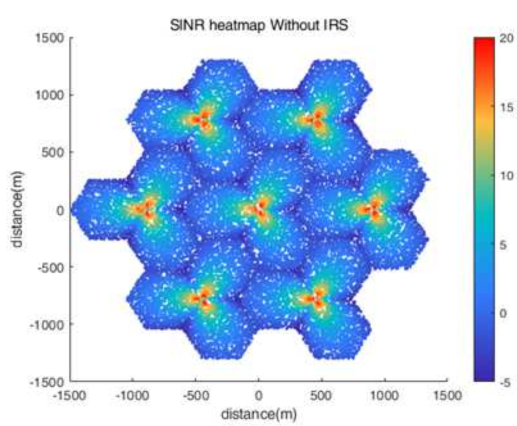

Figure 7 SINR heatmap without IRS

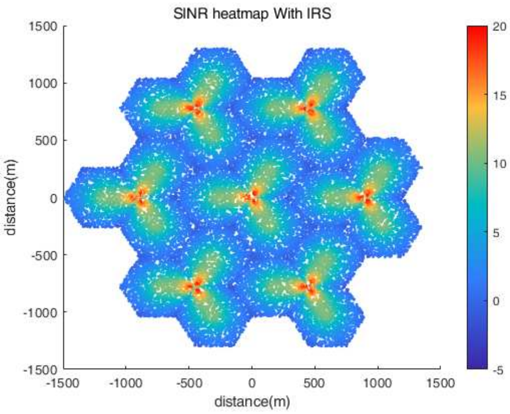

Figure 8 SINR heatmap with IRS

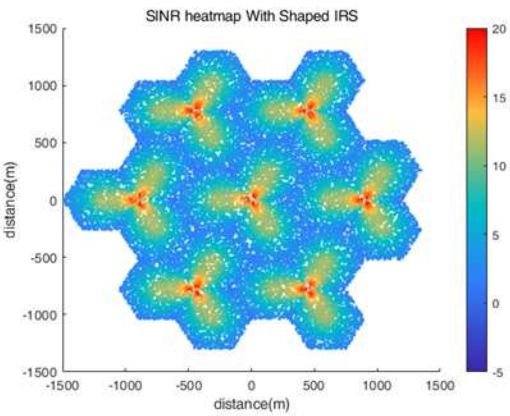

Figure 9 heatmap with shape adaptive IRS

From Figure 7 to Figure 9, it can be seen that the received SINR of UE has increased due to the existence of IRS. In fact, IRS adds a reflection ray to the channel and thus will increase the received power of UE and improve the overall system throughput.

VI. Conclusions

The research of IoT will evolve from a two-dimensional terrestrial architecture to a future 6G multi-dimensional architecture with space, air, ground and sea. In this paper, we introduce the technology critical to Space-Air-Ground-Sea Integrated Network, i.e., shape adaptive IRS. In our study, the physical form of the antenna can change according to the varying of RF environment and user distribution. Our simulation results justify that optimized IRS beams can be adapted to meet specified criteria, and therefore network performance is improved.

LIST OF ABBREVIATIONS

SAGIN	Space, Air, and Ground Integrated Network
IoT	Internet of Things
ITS	Highly Sensitive Traffic Command
MLSN	Multi-layer satellite network
RF	Radio Frequency
CR	Cooperative Receiver
BD	Backscatter Device
PT	Primary Transmitter
PR	Primary Receiver
ANN	Artificial Neural Network
CNN	Convolutional Neural Network
ECG	Electrocardiogram
SBP	Systolic Blood Pressure
DBP	Diastolic Blood Pressure
TP	True Positives
FN	False Negatives
FP	False Positives
TN	True Negatives

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AVAILABILITY OF DATA AND MATERIALS

The author keeps the analysis and simulation datasets, but the datasets are not public.

COMPETING INTERESTS

The authors declare that they have no competing interests.

AUTHORS' CONTRIBUTIONS

In this paper, Fei Qi conceived, designed and wrote the study. All authors read and revised the manuscript.

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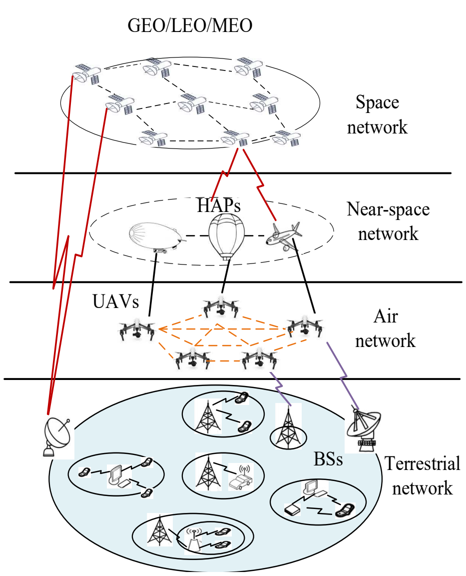

Figure 1 An architecture for space-air-ground integrated

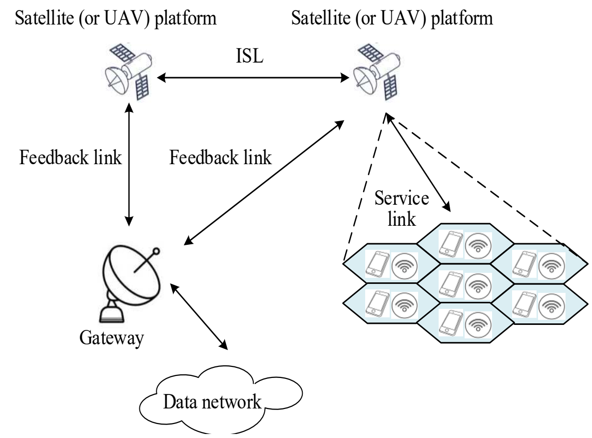

Figure 2 Satellite communication network diagram

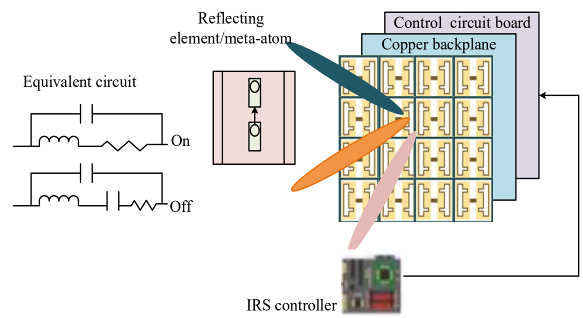

Figure 3 The typical architecture of IRS

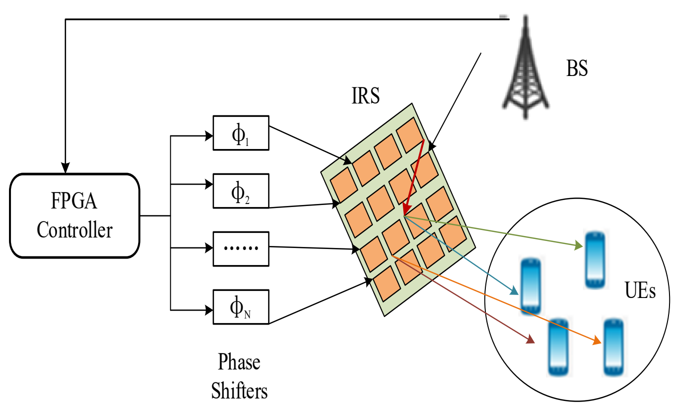

Figure 4. Phase-shift controlled IRS-assisted communication

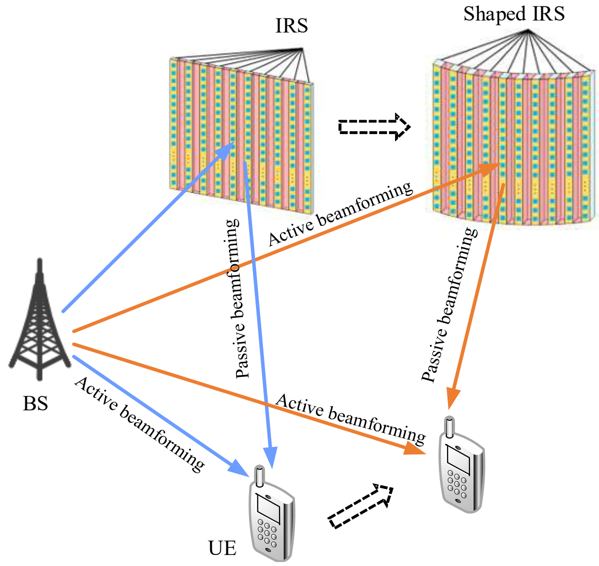

Figure 5 Deformable IRS that meets application requirements

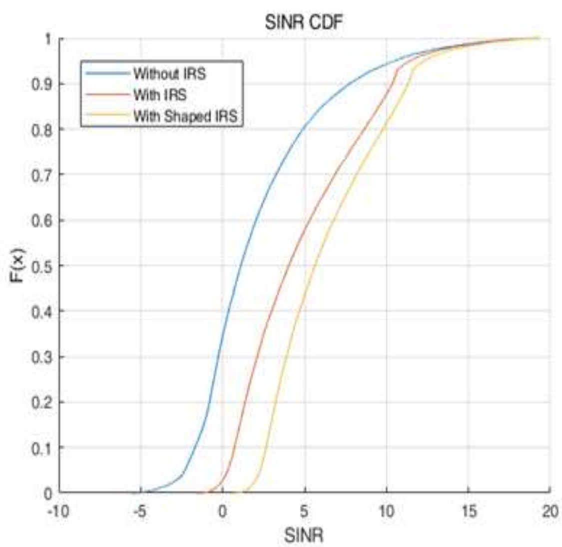

Figure 6 SINR CDF vs SINR

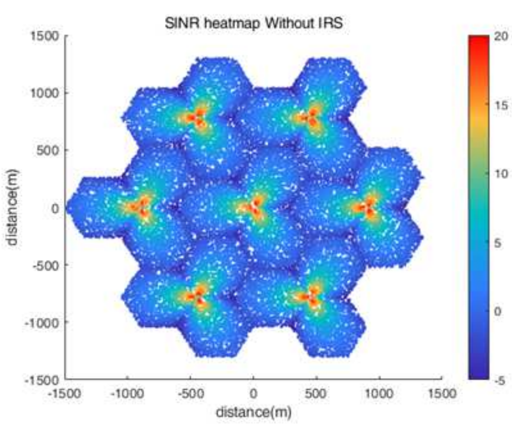

Figure 7 SINR heatmap without IRS

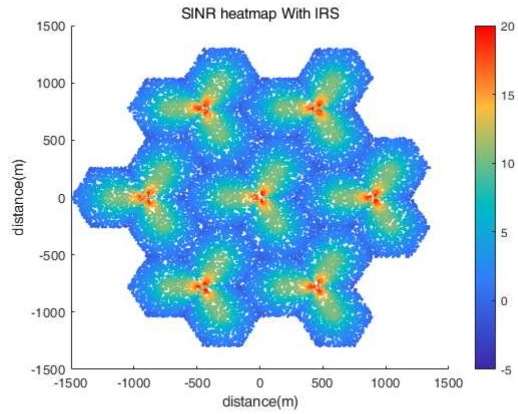

Figure 8 SINR heatmap with IRS

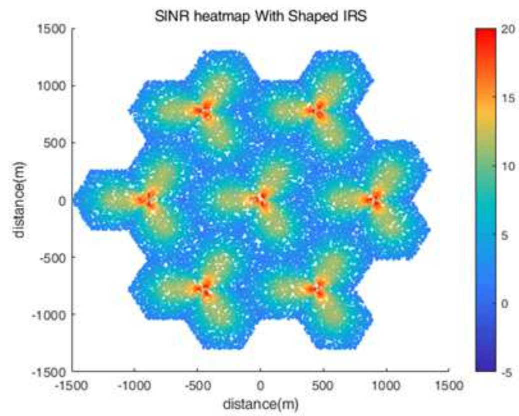

Figure 9 heatmap with shape adaptive IRS