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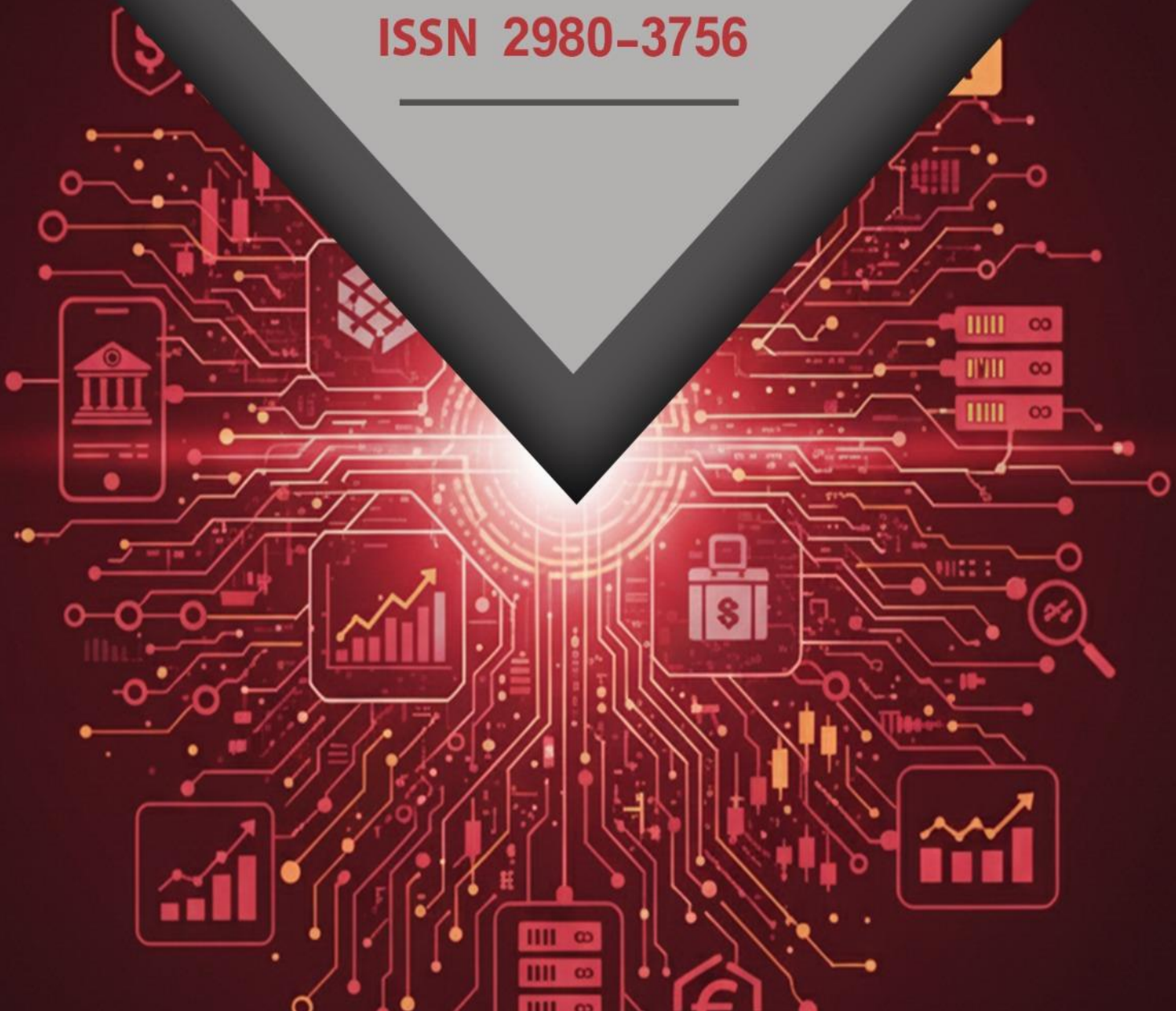
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## **REINFORCEMENT LEARNING AND Q LEARNING FOR RESOURCE ALLOCATION IN MIMO NETWORK WITH INTELLIGENT REFLECTIVE SURFACES**

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**Abstract:**

In the last decade, modern wireless communication system is widely developed to enhance the channel performance and overcome the issue of fading. However, with new infrastructures of modern cities, the issue of multipath reflections from buildings and obstacles has become a significant problem that reduces the quality of the signal and the bit error rate. In such circumstances, many paths to the signal between the user and the node could be generated that limit the accuracy of modulation/ de-modulation process. Therefore, it is a subject of this research to invoke a hybrid technique based on combining two intelligent algorithms of R-learning and Q-learning processes. Such technique could be applicable to modern wireless communication systems based on IRS and MIMO networks. In this matter the use of R-learning starts the action to determine whether is desired according to the criteria of signal quality or not. The Q-learning comes to localize the user with best action through generating a criterion based on minimum BER response. It is observed from such combination; a significant reduction is achieved in the BER of the received signal that almost realizes an enclosed resonance to the ideal case without noise or fading effects. Later, an analytical study is introduced by increasing the number of IRS elements as hardware solution to be compared with the achieved results from the previous solution. It is found that a significant enhancement is accomplished in the signal quality with increasing the number of IRS elements, however, the system complexity is increased rapidly. This gives an indication on how much such algorithms is an effective solution to maintain minimum hardware complexity with low cost.

**Keywords:** AI, ML, communication, BER, CC, MIMO, 6G, 5G.

**Abbreviations:**

- BER: Bit Error Rate
- BS: Base Station
- CSI: Channel State Information
- EE: Energy Efficiency
- IRS: Intelligent Reflective Surfaces
- MIMO: Multiple-Input Multiple-Output
- QoS: Quality of Service
- RL: Reinforcement Learning
- SE: Spectral Efficiency
- SNR: Signal-to-Noise Ratio
- 5G: Fifth Generation
- 6G: Sixth Generation
- AI: Artificial Intelligence
- ML: Machine Learning
- CC: Channel Capacity (though not explicitly defined in the text, it appears in keywords)

## I. INTRODUCTION

Wireless networking is one of the technologies that is changing and growing swiftly these days. New services and products come out almost every day. These new technologies are making it harder for communications engineers to keep up with the growing demand for more wireless bandwidth. In truth, designers have a lot of challenges to deal with when it comes to wireless communication. This is due to the difficulty of working with the physical medium and the complexity of the network dynamics. The most significant technological challenge in wireless communications networks is multipath-induced fading, which denotes unpredictable fluctuations in channel gain due to the dispersion of transmitted signals by objects situated between the transmitter and the receiver. Because of this, multipath scattering is frequently thought to be bad for wireless communication. But now it may be considered as a possibility to greatly improve the capacity and reliability of these systems, including intelligent reflecting surfaces (IRS) and other sophisticated wireless technologies. and multiple input multiple output (MIMO) technologies, which are recommended for use in next-generation wireless networks. The new radio standard for the fifth generation (5G) says that as the frequency goes over 6GHz, Because high-frequency signals are very sensitive and can be blocked by things like trees and buildings [2], it would be very effective and cheaper to use a reflective surface that is built into the city's infrastructure. For an IRS to work, the incident signals must pass through reflective elements, each of which might change the phase shifts and maybe the amplitude of the incident signals. By adjusting the global channel state information, the IRS can either add or subtract the user received signals and base station (BS) signals by aligning the signals reflected by the IRS [4].

People have been paying a lot of attention to reinforcement learning (RL) recently. It has been effectively used in several domains, including operations research, game theory, simulation-based optimization, information theory, control theory, and statistics [5]. Reinforcement learning (RL) is a kind of machine learning that has become an essential technique in the area. This is a plan in which machines decide what to do on their own in a certain situation, without knowing anything about the past or being instructed what to do [6]. AI will make everything better and quicker by giving superior solutions. Education that is better will keep changing and adding new factors [7]. The best score for each action in each state is the best score for Q-Learning as it goes on. Because the process starts with no information, a blank value should be immediately loaded into the database. Because of this, the agent learns about the place he wishes to work in by doing a few odd things and seeing how others respond. He receives a reward for doing something nice and a punishment for doing something bad. The next action will be dependent on what he learned from prior actions and the status of the environment. It's a lot like how people act; we'll choose anything at random and watch what occurs. That is how Q-Learning works, yes. We will make the right choices based on what we know from past choices or experiences that we will choose at random. As humans, our experience grows with each experience that comes our way, and we make choices based on what we have learned from past choices more than we rely on fate or luck [8]. In the past several decades, the use of wireless communication apps and gadgets has grown a lot. Because so many people are using mobile devices, the existing wireless network infrastructure has to be able to handle a lot of traffic, be reliable, and cover a lot of ground. To improve energy efficiency (EE) and spectral efficiency (SE)

[9], wireless networks require a lot of access points to be installed quickly right now. The use of (MIMO) technology as a leading contender has a lot of promises to help wireless communication systems attain tremendous levels of power, hardware efficiency, and spectrum efficiency. To achieve this goal, [10] offers ideas for making cellular networks more spectrally efficient, along with examples. The book goes into detail on important issues including spatial, channel estimation, signal processing spatial, geographical resource allocation, and power. It was also pointed out that massive MIMO may improve both spectrum and energy efficiency. Multiple-input several research have also suggested that multiple-output (MIMO) antennas might be a possible option. This is because MIMO technology has the potential to provide the very high network reliability and high data rates that are required, which would improve the quality of service (QoS) for mobile consumers and let them keep using their applications that use a lot of data [11].

MIMO is a wireless technology that uses multiplexing to extend the range and capacity of wireless signals. Using the algorithms in a radio chip, MIMO can send data via two or more antennas. When a wireless signal travels from an access point to a wireless card, it will bounce off of walls, ceilings, and other things along its way, causing further reflections of the initial signal. This also indicates that the original signal will reach its target by taking many alternative routes [12]. The signals come at various times because they traveled different lengths instead of the same distance. If we just use one antenna, there would be interference, therefore we utilize MIMO multi-antenna technology. We can also enhance the signal by having many copies of it. We may pick from a lot of different signals. MIMO also gives you access to bigger and wider ranges, which makes the signal strength quicker and better [13]. IRS is a new hardware technology that has garnered a lot of attention in the last few years. Its aims are to increase signal range, lower power use, and lower the total cost of deployment [14]. IRS is a two-dimensional surface Made composed of several tiny antennas that reflect light at different wavelengths. Each antenna is connected to a tunable chip (such a PIN diode or varactor) that lets you change its load impedance. The change in load impedance creates a phase shift of [15], which depends on whether the PIN diodes are on or off. Each element may be regulated to vary how it reflects light, such as its angle of reflection and transmissivity. The angle of incidence is the same as the angle of reflection when light hits a mirror. You may change the angle of reflection at will, which lets RISs send the reflected radio signal in any direction you like [16]. The received signal from both the base station (BS) and the users may be either constructively or destructively overlaid by making the right changes to the global channel state information (CSI) [17].

## II. SYSTEM MODEL WITH METHODOLOGY AND ANALYSIS

This paper presents a MIMO system in which multiple antennas facilitate the connection between the user and the base station (BS). The user is in a dead zone characterized by weak signal strength, resulting in unmet demands. To address this issue, we employ an intelligent reflective surface (IRS) to enhance signal reflection to the user, thereby improving efficiency. In the proposed networks, a base station (BS) utilizes M transmitter antennas (TAs), while users employ K reception antennas (RAs). L IRS elements are co-located on an IRS array situated on the building at the center of the disc. This enables M users to be served concurrently by L IRS components. Manipulating the electromagnetic signal can

be achieved by appropriately adjusting the phase shifts and amplitude coefficients of the IRS components.

The IRS and BS remain constant and unaltered, as they serve as infrastructure components on the opposite side of the user, who is mobile and whose location is variable. The distance from BS to the IRS is denoted as  $d_1$ , while the distance from the IRS to USER is denoted as  $d_{2,m}$ . Typically, the distance exceeds 1, which serves to simplify the analytical outcomes [13]. Cross-training reinforcement learning (RL) and Q-learning through a multiple-input multiple-output (MIMO) network utilizing smart reflective surfaces enables the algorithms to enhance their intelligence, ultimately optimizing system performance and resource utilization in response to varying network conditions. Consequently, the vertical length and the IRS length will be disregarded as they are inferior to the horizontal distance and the IRS antenna array location, particularly in relation to  $n$  users  $M$  who are focused on the thickness of the cigarette paper with radius  $R$ . The binomial point process and the consequent power attenuation occur along a path that adheres to the product law of distance, which can be articulated as follows:

$$L_m = (d_1 \cdot d_{2,m})^{-\alpha} \quad (1)$$

The  $\alpha$  here means the path loss exponent [19]. The Nakagami fading channel theory is used as a matrix to connect the BS and the IRS. The  $G$  here mean  $K \times L$  matrix It is a channel connecting the antennas in the BS and the element in the IRS. The Probability density function of the elements is given by:

$$f(g) = \frac{2t_1^{t_1} |g|^{2t_1-1}}{\Gamma(t_1)} \exp(-t_1 |g|^2) \quad (2)$$

Where  $t_1$  is the fading parameter [20]. Also, the Nakagami fading channel theory will be applied to the channel that exists between the IRS elements and the user, and this theory may be expressed by:

$$f(h) = \frac{2t_2^{t_2} |h|^{2t_2-1}}{\Gamma(t_2)} \exp(-t_2 |h|^2) \quad (3)$$

$H_{m9}$  here means  $K \times L$  which is the channel between IRS elements ( $L$ ) and the antenna at user ( $K$ ) in this channel it will be associated by fading parameter ( $t_2$ ) [21]. In addition, we consider the fact that there is a limited set of discrete values that may be used for the phase shift at each element of the IRS, which simplifies practical implementation. Let's call the number of bits ( $b$ ) utilized to represent the number of bits ( $L_m$ ) of phase shifts ( $L_m = 2^b$ ). Assuming for the purpose of argument that such quantized phase-shift values are created by uniformly quantizing the interval  $[0, 2\pi]$ , we may focus on the latter assumption. The discrete phase-shift values at each element are given by:

$$\theta_l \in \{0, \Delta\theta, 2\Delta\theta, \dots, (L_m - 1)\Delta\theta\}, \quad \text{where} \quad \Delta\theta = \frac{2\pi}{L_m} \quad (4)$$

Where, the  $\Delta\theta = \frac{2\pi}{L_m}$ . The number of possible beam patterns is  $(L_m)^N$  for an IRS  $L_m$  with  $N$  elements, where each element has a phase shift level of  $L_m$ . After that the signal will be received at USER  $m$  and that can be given by:

$$y_k = \sqrt{L_m} \mathbf{h}_k^H \Phi \mathbf{G} \mathbf{w}_k s_k + \sum_{j \neq k} \sqrt{L_m} \mathbf{h}_k^H \Phi \mathbf{G} \mathbf{w}_j s_j + z_k \quad (5)$$

The matrix of reflection coefficients is a diagonal matrix The same as the commonly agreed beliefs, Where  $\Phi$  is the reflection-coefficient matrix which is  $diag [\beta_1 \phi_1, \beta_2 \phi_2, \dots, \beta_L \phi_L]$ ,  $\beta$  here is the amplitude coefficient of IRS elements which is  $\in (0, 1]$ , we assumed that  $\beta = 1$ , and the  $\phi_L$  is the phase shift of IRS element which is  $= \exp(j\theta_L)$ ,  $j = \sqrt{-1}$ ,  $\theta_L \in [0, 2\pi)$ . We assumed that both the amplitude coefficients and the phase shifts of the IRS components are continuous, which allows for them to be controlled in an ideal manner.  $\sqrt{L_m}$  is the path loss induced amplitude attenuation of user,  $Z_K$  represents independent and identically distributed additive white Gaussian noise (AWGN) with zero mean and variance  $\sigma_k^2$  at the receiver of user K. We will analyze the conventional continuous linear precoding at the base station (BS), where  $w_k \in \mathbb{C}^{m \times 1}$  will stand in for the transmitted precoding vector for user K. The complex baseband signal that is sent from the base station (BS) may thus be written as:

$$P_{\text{total}} = \sum_{k=1}^K \|w_k\|^2 \quad (6)$$

where  $S_K$  which signifies the information-bearing symbols of users. These symbols are modeled as independent and identically distributed (i.i.d.) random variables that have zero meaning and unit variance [20]. As a result, the overall transmit power that was used in the base station (BS) may be calculated as.

$$\text{SINR}_k = \frac{L_m |h_k^H \Phi G w_k|^2}{\sum_{j \neq k} L_m |h_k^H \Phi G w_j|^2 + \sigma_k^2} \quad (7)$$

Also, the SINR at the user k is given by:

$$Q(s_t, a_t) \leftarrow Q(s_t, a_t) + \alpha \left[ r_{t+1} + \gamma \max_a Q(s_{t+1}, a) - Q(s_t, a_t) \right] \quad (8)$$

Data transmission and reception in a MIMO (multiple input) network is accomplished via the employment of antennas. As a result, experts in the field of radio spectrum charge more for their services as network quality increases. Passive devices known as inductive loop switches may redirect and alter the propagation of radio waves [22]. Its applications include multicast data transmission in MIMO networks, user experience enhancement, and service quality improvement [23]. By integrating the IRS framework, the resource allocation issue may be solved using RL and Q-learning in a MIMO network. Because it entails distributing resources like electricity, bandwidth, and time among users in a way that makes the most efficient use of each, resource allocation is an essential part of the resource allocation issue [24]. In conclusion, MIMO networks that use reflecting surfaces supported by IRS may benefit greatly from the use of RL and Q-learning, two very effective learning algorithms. Network performance may be enhanced using these strategies, leading to a better user experience [25]. This ray tracing visualization shows a complex fractal patch antenna system with a reflector. The fractal geometry of the patch element allows it to work on multiple bands and be made smaller [26]. The strategically placed reflector improves directional gain by systematically redirecting electromagnetic waves, as shown by the incident, reflected, and direct ray paths [27]. This optimizes radiation patterns and improves

overall antenna performance in the X-Y coordinate plane as seen in Fig. 1, which is scaled in millimeters for microwave frequency applications.

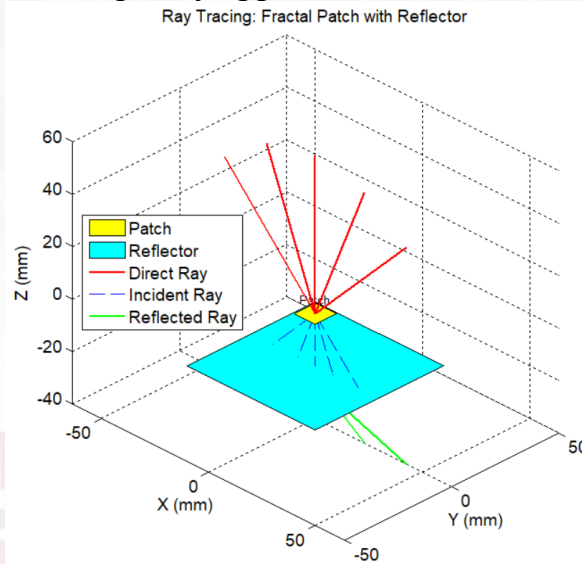


Fig. 1: Configuration of ray tracing to be optimized.

### III. RESULTS AND DISCUSSION

Using RL and Q-learning may help MIMO networks with smart reflecting surfaces utilize their resources better, which can make the network run better in terms of throughput and energy efficiency. Bit error rate (BER) is a way to find out how good the signal is in a transmission system. It is important to find the right training parameters for RL and Q learning techniques for distributing resources in MIMO networks with IRS so that they may do so while keeping the BER value as low as possible [28].

To get the best BER in MIMO networks with IRS, the state space should include information about the network, such the condition of the links, the location of the users, and the resources that are accessible. The action space is the collection of possible actions that an RL-based agent may take to allocate resources. For example, it can assign power levels to users, adjust the phase changes of IRS elements, or choose data transmission ranges. The reward function should use optimization methods to find policies that decrease BERs. You may either consider the reward function as a reward or make a function whose value is directly related to the drop in BER. A simulation has to be made to mimic the MIMO network. This should include channel models, IRS reflection patterns, and a resource allocator that gives BER [29]. The Q learning method should be used to teach the RL agent to make choices about how to use resources. The agent should adjust its activities and update its Q values depending on the rewards it gets. This will help it make better decisions over time. The suggested strategy is used in situations when three users are at various distances and have varying capabilities. For testing, the transmitter is positioned at the origin with SNR=20 and 32 reflecting elements in the IRS layer. The modulation mechanism is QPSK of 2-QAM order, and the three users have Gaussian noise and Rayleigh fading channels. For the three users, the message is made up of random binary data, and the reward signal depends on the current condition and signal quality:

### A. The evaluated BER with invoking Q-learning algorithm

The next step was to test the BER for the suggested scenario by solely using the Q-learning technique to get rid of the noise in the channel that was affecting the demodulated signal. Based on the estimated BER results in Fig. 2, we see a big drop in the volatility of the results. However, the average BER values are still quite high, about 50%, which makes it seem like the suggested method doesn't work when called on its own.

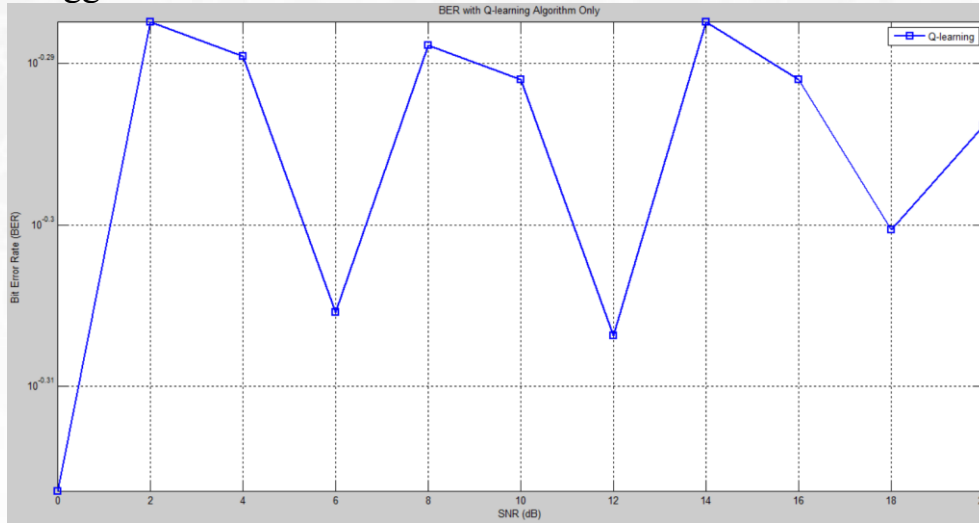


Fig. 2; The evaluated BER with invoking Q-learning algorithm only.

### B. The evaluated BER with invoking R-learning algorithm

The suggested scenario will only look at R-learning later on. It is thought that an improvement on the BER assessed, as shown in Fig. 3, may be made. The suggested approach improves the estimated BER up to an SNR of 25dBm; nevertheless, above this threshold, channel noise increases significantly, rendering the proposed work ineffective. This discovery is ascribed to the impacts of channel noise, which escalates fast when the SNR level is amplified by the system.

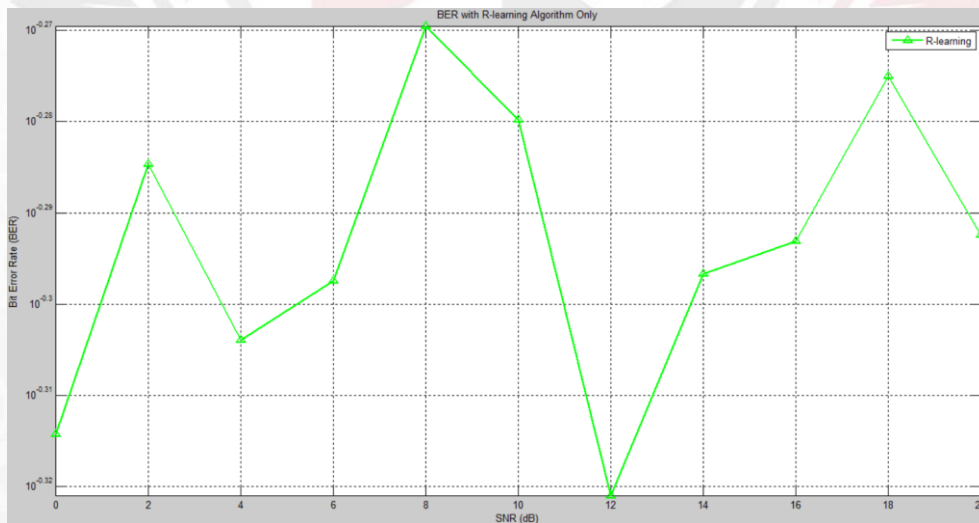


Fig. 3. The evaluated BER with invoking L-learning algorithm only.

### C. The evaluated BER with invoking R-learning and Q-learning algorithms

The findings we got in the previous sections made us want to employ both strategies to improve the estimated BER condition and get around the noise channel. It is true that the assessed findings are based on running both methods on the users in question and comparing the results to the perfect BER estimates displayed in Fig. 4. The findings show that there is a big improvement throughout the whole SNR range.

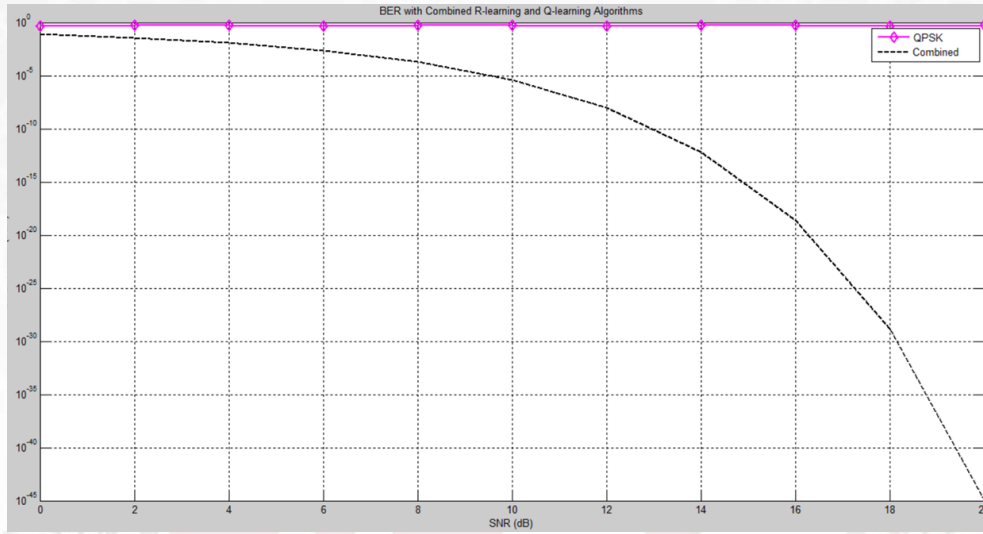


Fig. 4. The evaluated BER with invoking both R-learning and Q-learning algorithms consequently.

### D. The influence of increasing antenna number

The suggested research is expanded to assess the Bit Error Rate (BER) at a consistent Signal-to-Noise Ratio (SNR) while varying the antenna array sizes to 8, 16×16, 32×32, and 64×64. Fig. 5 shows that increasing the array size may quickly lead to a big decrease in the BER. This is because the antenna array gain to the main lob increases as the number of array size increases [11].

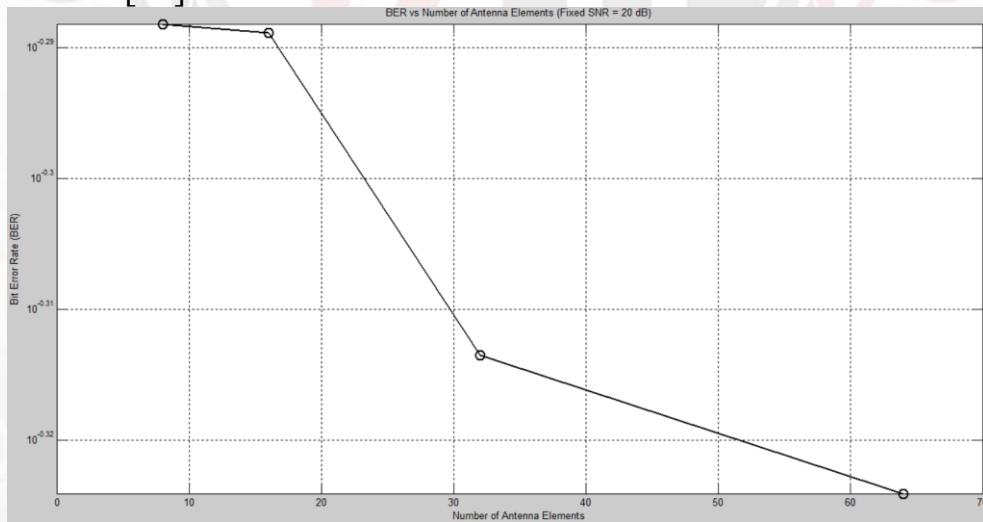


Fig. 5. The evaluated BER with increasing the number of antenna elements in a planner array.

#### IV. CONCLUSION

The IRS layer is suggested to localize the usage and the relative signal with an exact phase. Localization is accomplished by clever algorithms that use R-learning and Q-learning methods. The design of IRS from analytical viewpoint research is tried by employing 32 elements with a modulation procedure of QPSK based on 2-QAM. The IRS method is also used by three people who are at various places and have different power levels. The methods that are used are used to find the signal quality by looking at the BER level. There is a big change in the BER response when the system is set up without the R-learning or Q-learning algorithms. Later, the introduction of the Q-learning process removes the impacts of fluctuations. Then, it is thought that adding R-learning would lower the BER level. We discovered that the suggested technique achieves a significant decrease in the BER level, making it ideal for lowering system costs in comparison to similar systems with higher IRS elements. It is proven that the suggested method provides an excellent solution to surpass standard strategies that rely on increasing the number of unit cells. This study contends that the intricacies of resource allocation in Intelligent Reflecting Surface (IRS)-assisted MIMO networks can be proficiently managed not solely by augmenting hardware, but also through intelligent, AI-driven control algorithms. We posited that a hybrid reinforcement learning strategy, which strategically integrates the exploratory capabilities of Q-learning with the policy-driven decision-making of an additional reinforcement learning agent, offers a superior approach to optimizing signal quality, as quantified by Bit Error Rate (BER). Our research strongly backs this claim. The findings indicate that although independent Q-learning or policy-based (R-learning) approaches yield marginal enhancements, they are inadequate in addressing significant channel impairments at elevated SNR levels. The suggested hybrid method, on the other hand, greatly lowered the BER over the whole SNR range, making it very close to the performance of an ideal channel. We also found that this algorithmic improvement can give performance boosts that are similar to those that can be achieved by greatly increasing the number of IRS elements. This makes it a cost-effective way to solve a major engineering problem. The results show that the design of next-generation networks is changing in a big way: intelligence can replace brute-force hardware scaling. As we get closer to the complicated world of 6G, depending only on dense infrastructure will not be good for the economy or the environment. So, future research needs to look into deep reinforcement learning and transfer learning in a big way to make controllers that are even more adaptable and efficient. This will make sure that the smart networks of the future are built with not only more parts, but also smarter brains.

#### AKNOLEGMENTS

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