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EFFICIENCY ENERGY ANALYSIS FOR 6G COMMUNICATION SYSTEMS USING INTELLIGENT REFLECTING SURFACE ARCHITECTURE

*The **subject** of this 6G communication system research is expected to form a hyper-connected network in which various electronic devices can connect continuously without interruption. Several technologies have been built to support 6G communication systems, such as intelligent reflecting surface (IRS). An IRS is a reflector equipped with several two-dimensional passive elements that perform a phase shift by each element, which can reflect electromagnetic (EM) waves coming from the base station (BS) to the user equipment (UE), which is controlled via a controller to increase the signal strength at the UE and overcome poor propagation conditions. IRS can be placed anywhere, such as on a wall or on the roof of a building. The **aim** of the IRS research is expected to reduce the energy consumption and increase the spectral efficiency of wireless networks using artificial intelligence (AI) with low costs, energy savings, no thermal noise, and fairly small levels of interference. The **objective** of this research is to evaluate and analyze the energy efficiency (EE), including the achievable rate (AR) and signal-to-noise ratio (SNR), by applying the IRS architecture in a 6G communications system, which uses an operating frequency of 95 GHz and a bandwidth of 800 MHz. Then, **the method** was based on computer simulation using the Matlab software. In this paper, 6G communication system modeling was proposed. This model uses an urban microcell (Umi) that consists of one base station (BS) with multiple antennas, varying the number of IRS reflecting elements and one user. In this research, AR, SNR, and EE, using the frequency of 95 GHz and simulations with MATLAB@2021a software. **The results** show that the number of elements as many as 400 is 39% more optimal than the number of elements as many as 40 for the AR results. The SNR results without electromagnetic interference (EMI) are higher than SNR values affected by EMI with SNR results of 100 dBm, and the number of reflecting elements is directly proportional to the SNR results. For 800 elements, the EE value is 26% higher than for 40 elements. **Conclusions.** The application of IRS in 6G communication systems can increase the AR, SNR, and EE.*

Keywords: *6G; IRS; EMI; achievable rate; SNR; energy efficiency.*

Introduction

Motivation. 5G communication technology has been implemented since 2018 in various countries, including South Korea. The promotion of 6G communication systems can improve network quality more than 5G communication systems, according to a study by the Korean Institute of Communication and Information Sciences (KICS) [1]. 6G communication can meet the maximum data rate of up to 1 Tbps with a date rate for users of up to 1 Gbps. The latency in 6G communication is less than 0.1 ms and 10 times lower than that in 5G communication, which provides a latency of 0.1 s [1].

There are three main types of 5G technology: enhanced mobile broadband (eMBB), ultra-reliable low-latency communication (uRLLC), and massive machine-type communication (mMTC). In its implementation, two main problems are high energy consumption and the cost of maintaining or developing a network, which is very expensive and complicated when there is interference [2, 3].

In the implementation of 5G communication, there is also a mutual coupling effect due to the distance between base station (BS) antennas, which causes a decrease in antenna performance and high interference, which adversely affects the quality of service (QoS) on the user side [4, 5]. In addition, users in locations with non-light-of-sight (NLOS) conditions often receive low signal power because the direct path of the transceiver and receiver is blocked by obstacles [6, 7]. This motivates the update of cellular network technology to 6G technology [4, 6].

State of the Art. An intelligent reflecting surface (IRS) is a reflector that is equipped with several two-dimensional passive elements, and it performs a phase shift by each reflecting element that can reflect electromagnetic (EM) waves coming from the BS to the receiver controlled through the controller to increase the signal strength at the user and overcome poor propagation conditions [2, 8]. IRS can be placed anywhere, such as on the wall or on the roof of a building or rooftop [9]. IRS is predicted to reduce energy consumption and increase the spectral efficiency of

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wireless networks in artificial intelligence (AI) with low cost, energy efficiency, thermal noise, and less interference [2].

Research by Ji Sun Jung, et al [10] investigated the IRS for spectral efficiency maximization in the multi-user miso communication systems: the precoded is used, which is the minimum mean squared error (MMSE). The number of BS antennas was 16 with the number of users, i.e., 4 users, with NLOS conditions between BS users. The study analyzed the effect of the number of elements on the spectral efficiency. The result is that the number of reflection elements was 256, resulting in an SE value of 52 bits/s/Hz. It was demonstrated that the proposed MMSE precoded can achieve high SE because each reflector element is designed with an optimal phase.

In another study by Qurrat Ul Ain Nadeem et al [11], multi-user miso communication supported on a smart reflective surface: channel estimation and beamforming design, using state information imperfect channel (CSI) where MMSE is used as a precoded with LOS conditions. In this study, the effects of the mean squared error (MSE) and bit error rate (BER) is analyzed. It was found that the BER decreased as the BER decreases with increasing signal-to-noise ratio (SNR) up to 10-6 at an SNR of 17 dB. It was found that IRS can increase the reliability of communication systems compared to MIMO.

Objectives and approach. This paper analyzes the energy efficiency, including the achievable rate (AR) and SNR, by implementing IRS in 6G communications under LOS conditions. Then, a system model is introduced based on one multi-antenna base station (BS), one IRS, and one user. The number of IRS reflecting elements was varied from 10 to 800 reflecting elements. The performance metrics focus on AR, SNR, and energy efficiency with the application of IRS architecture in 6G communication systems. This paper focuses on EE, paying attention to the number of IRS cells without relays. The operation frequency is 95 GHz and the bandwidth is 800 MHz. The 6G communication system is expected to operate at very high frequencies around 95 GHz. This high frequency allows bandwidths greater than 800 MHz. Greater bandwidth means that more data can be transmitted simultaneously, which is essential for achieving higher data rates and supporting more devices in future communication networks. Therefore, EE is essential in modern communication systems, especially as frequencies increase and bandwidth expands. The challenge lies in maintaining or improving energy efficiency using higher data transfer rates provided by wider bandwidths. Additionally, IRS technology has attracted attention for its potential to improve the efficiency of communication systems, especially at higher frequencies. IRS consists of passive elements (such as reflective elements or metamaterials) that can manipulate electromagnetic waves to improve signal quality, range, or power efficiency without traditional relays. Therefore, this paper investigates how to apply IRS technology in a 6G system operating at 95 GHz to improve EE, including adjusting the number of IRS elements. It addresses broader wireless goals to support faster data speeds and higher capacity networks while effectively managing power consumption.

1. Materials and Methods

1.1. Intelligent Reflecting Surface (IRS) Architecture

An IRS is a reflector with a two-dimensional passive element and a full duplex. It operates by changing the incident signal from the BS via reflection and phase shifting. In this way, it improves signal quality and is cost-effective. The IRS is equipped with passive reflecting elements, in addition to the reflecting elements, and also has a controller that is used to adaptively adjust the on or off state and phase shift of each passive reflecting element of the IRS [2, 12].

In general, the IRS hardware architecture is based on the concept of a "metasurface" made of two-dimensional elements that can be controlled. The metasurface is a planar array consisting of several meta-atoms with the electrical flow in the order of sub-wavelength of the operated frequency [13]. In the implementation of IRS, reflection coefficients: phase shift, and reflection amplitude tuning, must be adjusted in real-time. Therefore, positive-intrinsic-negative (PIN) diodes, field-effect transistors (FETs), or microelectromechanical system (MEMS) switching are used [14].

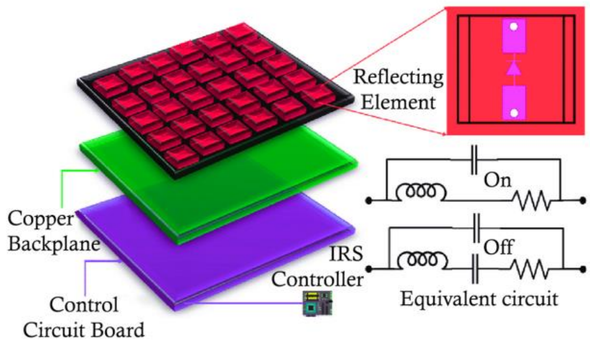

Fig. 1. IRS Architecture With PIN Diodes [12]

Figure 1 shows the basic architecture of the proposed multilayered IRS hardware. The first layer is a metasurface layer with a dielectric substrate layer, glass epoxy or G10/FR4, made from glass fiber or polyvinyl butyral (PVB), which is an insulating and cost-effective material consisting of several passive reflecting elements that reflect the signal coming from the BS [15]. The second layer uses copper plates to reduce the energy loss. Finally, the third layer is the control circuit board, which is used to adjust the reflection amplitude and phase shift of each element. These adjustments are connected to the controller in the IRS [14].

When switching between PIN diodes, the bias voltage on the PIN diode is controlled through direct current (DC), where the current is one-way. The PIN diode is set between the "on" or "off" state as shown in the equivalent circuit state shown in Figure 1. This results in different phase shifts π and different load impedances. Thus, different phase shifts in the controller of each element can be realized through a bias voltage control system. To control the reflection amplitude, a load resistor was applied during element design. For example, by changing the resistor value in each reflecting element, a part of the incident signal is dissipated to achieve the desired reflection amplitude of (0,1). Each IRS reflection element is connected to a controller that adjusts the reflection amplitude and phase shift of each IRS element [13, 14].

In the signal transmission process with the application of IRS, there is $\alpha_n \in [0, 1]$ and $\theta_n \in [0,2\pi)$ which are to determine the reflection coefficient of the passive element of IRS and control the reflected signal amplitude and phase shift. By efficiently adjusting the reflection coefficient, IRS can spatially control the reflected signal, thereby increasing the signal strength at the user [11, 13].

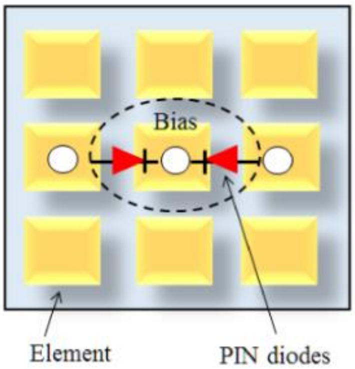

Fig. 2. EM reflection through PIN diode [14]

Figure 2 shows that the PIN diode is soldered Figure 2 shows the PIN diode soldered between two metal strips in the middle substrate layer. Each top and bottom substrate layer on the element is equipped with a PIN diode to maximize bias tuning. The layers were made of FR4 epoxy substrate material with a relative permittivity of ϵ_r = 4.4 and $tan\delta$ = 0.02 [14, 16].

When the phase shift is zero, the reflected current is in phase with the current in the IRS element, thereby improving the electric field and current flow in both elements. However, there is an increase in dielectric loss, metallic loss, and ohmic loss in the use of G10/FR4 material which can cause high energy losses that cannot be avoided in future applications, it should be noted that the energy loss in the IRS element is smaller than the wireless propagation loss which reaches up to 100 dB [17, 18].

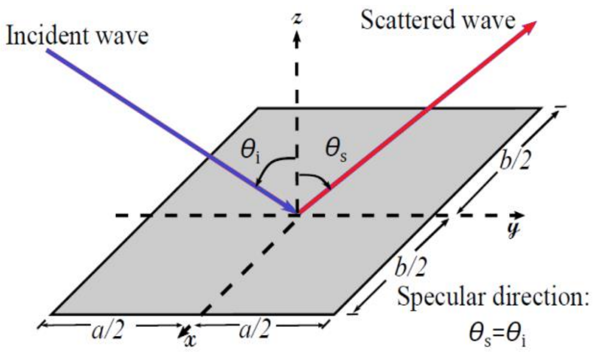

Fig. 3. Snell's l for the aw on IRS element [19]

Figure 3 presents the signal reflection by the IRS with Snell's Law applied. The waves reflect in different directions and intensities, which are determined by the sub-wavelength structure of the reflecting element. When an EM wave propagates into the passage between two element substrates, the reflected wave will apply Snell's Law as it relates to the incident and reflected signals [13, 14, 19].

When the same incident wave reaches the metasurface layer, the controller adjusts the amplitude and phase shift so that the reflected wave undergoes a phase shift. Figure 3. shows the coordinate system of one IRS reflecting element. There are three axes the z-axis is the center of the IRS or normal line, the y-axis is aligned with the incident angle, and the x x-axiss the bias angle. The notation θ_i denotes the incident wave, θ_s denotes the scatter or reflected wave, $a/2$ and $b/2$ denotes the element surface size [19].

The IRS reflects the incident signal from the BS and converts it to scatter waves; thus, the IRS reflection also includes the specular reflection condition $(\theta_s = \theta_i)$ which means that the incident angle is equal to the reflected angle. Therefore, the IRS can reflect optimally and spatially toward the intended user [19, 20].

IRS can improve the range, spectral efficiency, and energy efficiency of massive MIMO systems [1, 21]. Therefore, considering the channel design for 6G communication, an MMSE precoded is proposed for data transmission via the IRS. MMSE estimation can be used to estimate the phase-shift vector of each element over BS-IRS, BS-user, and IRS-user channels [11]. In the MMSE precoded, there is a Bayesian Monte Carlo method that generates MMSE values between actual and estimated channels.

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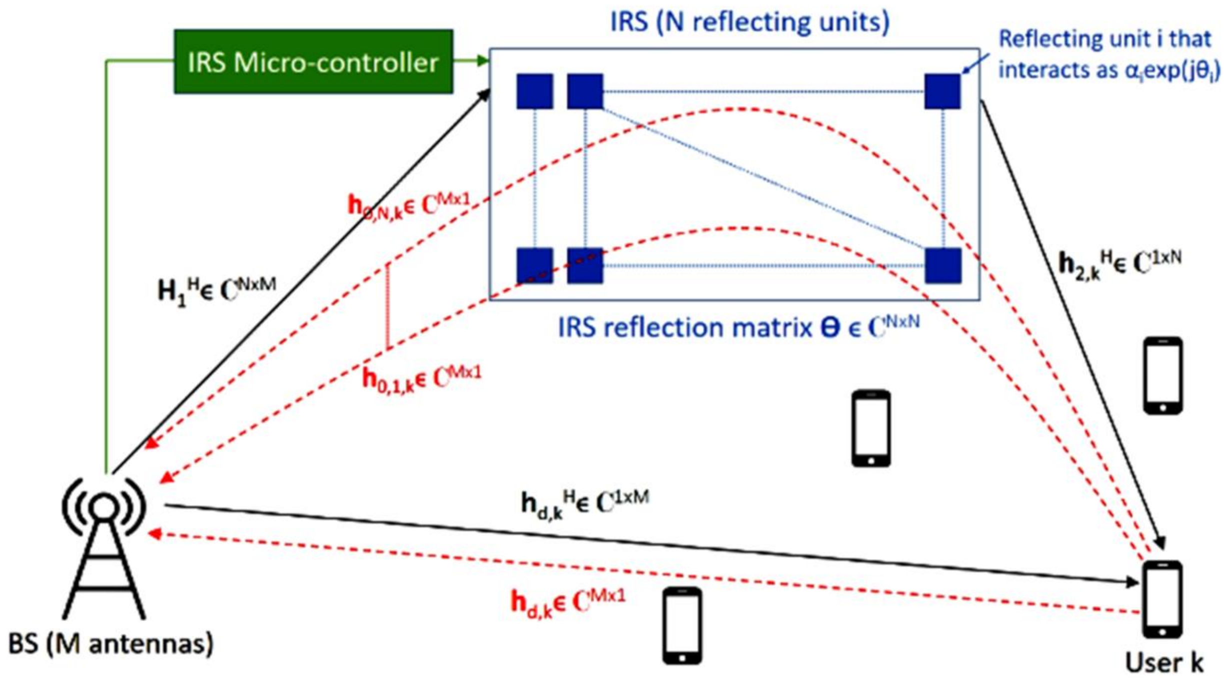

Fig. 4. Multi-user MISO system with IRS [11]

In the calculation technique to determine the availability of information, such as achievable rate (AR) performance, perfect CSI is used to find out information about the state of the channel by designing the precoding vector at the BS and the phase shift matrix at the IRS reflecting element. The process of calculating AR is related to Normalized Mean Square Error (NMSE). NMSE is the relative error in channel estimation. The NMSE value of 1 indicates that the error value in the estimated channel has the same strength or result as that of the actual channel. In wireless transmission, beamforming that is estimated to have an NMSE value of 1 or more is appropriate for isotropic transmission in the BS-IRS channel without the help of CSI [11].

Figure 4 shows a cellular communication consisting of a BS with multiple antennas. The BS is denoted by *M*, for single antenna users it is denoted by *K*, and the number of IRS reflecting elements is denoted by *N*. There are two transmission directions, i.e., uplink and downlink conditions. The uplink is defined by the channel from BS to the user, from BS to IRS, and from IRS to user respectively indicated by $\mathbf{h}_{d,k} \in \mathbb{C}^{M \times 1}$, $\mathbf{H}_1 \in \mathbb{C}^{M \times N}$, $\mathbf{h}_{2,k} \in \mathbb{C}^{M \times 1}$. The downlink is defined as the channel from BS to the user, from BS to IRS, and from IRS to user, italics, lowercase, and uppercase letters denote scalar, vector, and matrix, respectively, denoted by $\mathbf{h}_{2,k} \in \mathbb{C}^{M \times 1}$, $\mathbf{H}_1 \in \mathbb{C}^{M \times N}$ and $\mathbf{H}_{0,k} \in \mathbb{C}^{M \times N}$ is that the metrics space is complex-valued.

There is in the IRS part $\mathbf{\Theta} \in \mathbb{C}^{N \times N}$ which is a diagonal complex reflection matrix with the notation of the IRS reflecting element equation $\mathbf{\Theta} = \mathrm{diag}(\alpha_1 \exp(j\theta_1), \dots, \alpha_N \exp(j\theta_N))$ which is a diagonal matrix with reflection coefficient elements on its main diagonal. In the transmission process of the signal with the implementation of IRS, there is $\alpha_n \in [0, 1]$ and $\theta_n \in [0, 2\pi)$ which are to control the reflection amplitude of the reflected signal and the phase shift of each IRS element [11].

In the case of single-user transmission with LOS conditions, the BS and user do not experience significant obstacles. However, in the opposite case, where the BS-user channel is blocked by an obstacle, the IRS receives the signal from the BS and transmits it to the user under this condition. With the aim of receiving signals with good quality, IRS has the special advantage of being able to be placed anywhere, such as on rooftops or walls; thus, it is very space-efficient in its application [10].

1.2. System Performance for IRS

Achievable rate (AR)

The achievable rate (AR) is the maximum number of bits that can be reliably transmitted on a particular channel per second in units of bits/Hz/s [22]. Achievable Rate is part of the channel capacity concept from Shannon's Theory [23].

The signal reception power at the IRS is [4].

$$y = (\mathbf{h}_r^H \mathbf{\Phi} \mathbf{G} + \mathbf{h}^H)\, \mathbf{f} x + n, \quad (1)$$

where $\mathbf{h}_r \in \mathbb{C}^{M \times 1}$ is the channel vector reflecting from the IRS to the user, $\mathbf{G} \in \mathbb{C}^{M \times N}$ is the channel matrix from BS to IRS, $\mathbf{f} \in \mathbb{C}^{N \times 1}$ is the linear beamforming vector in the BS, $\mathbf{h} \in \mathbb{C}^{N \times 1}$ is the LOS Vector between BS and user, x is the transmitted signal, where $\mathbb{E}\,[|x|^2] = 1$ without loss, n is the addictive white Gaussian noise (AWGN) received by the IRS, represented as $\mathcal{CN}(0, \sigma^2)$ with mean 0 and variance σ^2, $\mathbf{\Phi} = \text{diag}(e^{j\theta_1}, e^{j\theta_2}, \dots, e^{j\theta_N})$ denotes the phase shift matrix of the IRS element, and θ_i denotes the phase shift of the reflecting element ith IRS, $i = [1, 2, 3, \dots, N]$.

The AR with the application of the IRS can be calculated as follows [4]

$$R = \log\left(1 + \frac{|(\mathbf{h}_r^H \mathbf{\Phi} \mathbf{G} + \mathbf{h}^H)\, \mathbf{f}\,|^2}{\sigma^2}\right), \quad (2)$$

and the resulting optimization problem can be formulated as [4]

$$\begin{aligned} &\text{maximize } \mathbf{f}, \mathbf{\Phi}\ \left\|(\mathbf{h}_r^H \mathbf{\Phi} \mathbf{G} + \mathbf{h}^H)\, \mathbf{f}\,\right\|^2 \\ &\text{subject to } \|\mathbf{f}\|^2 \le P \\ &\mathbf{\Phi} = \text{diag}\left(e^{j\theta_1}, e^{j\theta_2}, \dots, e^{j\theta_M}\right), \end{aligned} \quad (3)$$

where $P > 0$ is the given total transmitting power.

Signal-to-noise ratio (SNR)

IRS technology does not amplify signals and only reflects signals from the BS to the intended user. Thus, a large surface area is required to achieve the SNR. In transmission processes, it is not immune to Electromagnetic Interference (EMI). When the number of IRS reflecting elements and IRS surface area increases, EMI can affect the SNR in IRS applications [24].

EMI is a phenomenon that occurs when an electronic device is dependent on electromagnetic (EM) radiation and usually occurs when it is too close to the EM field so that it disrupts the radio frequency spectrum and loses the quality of the device, either at the source or receiver. EMI can arise from various natural or artificial causes, such as natural radiation, lightning, or lightning, and electronic devices; EMI can be reduced by shielding on devices with conductor materials, such as copper and grounding [25].

The SNR is expressed as follows [24]

$$\text{SNR} = \frac{P\,|(g_2^H \mathbf{h}_1 + h_d)|^2}{A\sigma^2 (g_2^H \mathbf{R} g_2 + \sigma_w^2)}, \quad (4)$$

where A is the IRS surface area (m), $\mathbf{R}$ denotes the IRS correlation matrix, σ^2 is the population variance (W/m^2), and P is the transmit power (dBm).

SNR with thermal noise has an optimal phase configuration as follows [24]

$$\text{SNR} = \frac{1}{\frac{A\sigma^2}{\sigma_w^2} g_2^H \mathbf{R} g_2 + 1} \overline{\text{SNR}}, \quad (5)$$

where $\overline{\text{SNR}}$ is the achieved SNR without EMI and can be calculated by [24]

$$\overline{\text{SNR}} = \frac{P}{\sigma_w^2}\left(\sum_{n=1}^{N} \gamma_n |h_{1n} h_{2n}| + |h_d|\right)^2. \quad (6)$$

Efficiency energy (EE)

Energy efficiency is the number of bits that can be transmitted in units of bits/Joule and is determined by the power required to transmit data [26]. The energy efficiency can be obtained by [22]

$$\text{EE} = \frac{R}{P_{total}}, \quad (7)$$

where EE is the energy efficiency (bits/Joule), R is the data rate (bit/s), and P_{total} is the consumed power in the system (Joules/s).

Channel Gain β with LOS condition, i.e [23].

$$\begin{aligned} \beta\,(d)\,(dB) &= Gt + Gr + (-37.5) \\ &\quad -22\log_{10}\left(\frac{d}{1m}\right). \end{aligned} \quad (8)$$

Channel Gain β with NLOS condition, i.e.[23]

$$\begin{aligned} \beta\,(d)\,(dB) &= Gt + Gr + (-35.1) \\ &\quad -36{,}7\log_{10}\left(\frac{d}{1m}\right), \end{aligned} \quad (9)$$

where G_t is the gain at the BS (dBi), G_r is the gain at the IRS (dBi), and d is the distance (m).

The SINR obtained by implementing IRS is [23]

$$\text{SINR} = (2^{\bar{R}} - 1), \quad (10)$$

where $\bar{R}$ is the achievable rate (AR).

The optimal number of elements for the application of IRS [23] can be expressed as follows

$$N^{opt} = \sqrt[3]{\frac{(2^{\bar{R}} - 1)}{\alpha^2 \beta_{IRS} P_e}} - \frac{1}{\alpha}\sqrt{\frac{\beta_{sd}}{\beta_{IRS}}}, \qquad (11)$$

where N^{opt} is the optimal number of elements, β_{IRS} is the phase of the IRS channel to the user, β_{sd} is the phase of the BS channel to the user, $\alpha \in (0, 1)$ is the fixed amplitude reflection coefficient, and P_e is the power dissipation of each IRS element (5 mW).

The transmitting power of IRS application is defined as follows [23].

$$p_{IRS}(N) = \left(2^{\bar{R}} - 1\right)\frac{\sigma^2}{(\sqrt{\beta_{sd}} + N\,\alpha\sqrt{\beta_{IRS}})^2}, \qquad (12)$$

where N is the IRS element and σ^2 is the noise power. The total power consumption P_{total} of the system consists of the transmitted power and power dissipation in hardware components; the equation for P_{total} in IRS is [23]

$$P_{total}^{IRS}(N) = \frac{p_{IRS}(N)}{v} + P_s + P_d + N\,P_e, \qquad (13)$$

where $v \in (0,1]$ is the power amplifier efficiency (0.5), P_s is the power dissipation at the BS, P_d is the power dissipation at the receiver, and P_e is the power dissipation at each IRS element.

2. System Model and Simulation Parameters

The simulation system model was performed at a frequency of 95 GHz using LOS and massive MIMO technology [27]. The system operates at a high frequency of 95 GHz, which is in the millimeter wave range. The simulation assumes a LOS propagation environment at higher frequencies such as 95 GHz. The system operates at a bandwidth of 800 MHz to achieve higher data rates, which is important for supporting high-throughput applications envisioned in future wireless networks. The relative permittivity (ϵ_r) is 4.4 and $tan\delta$ is 0.02. The dielectric substrate is glass epoxy, which is a common dielectric material known for its electrical insulation properties and stability. These parameters are important to accurately model the electromagnetic properties of the substrate material in the simulation, especially in antenna design and propagation.

In this paper, Matlab@2021 was chosen for its various advantages in solving problems related to communication systems, including 6G technology. It provides the flexibility and ease of use necessary for studying telecommunication systems, which often involve custom algorithms like signal processing. Matlab is a user-friendly programming language with powerful computer tools and libraries specifically designed for computing, signal processing, and simulation of communication systems. It is compatible with Windows operating systems, allowing flexibility to accommodate user requirements. MATLAB can run efficiently on a variety of devices, from standard desktop computers to powerful computing clusters. This flexibility allows simulations and experiments to be tailored to the computer's requirements without requiring complex hardware. Therefore, this study uses Matlab to investigate 6G EE in high-frequency and broadband technology.

This model uses urban micro (UMi) cells consisting of a multi-antenna BS, one IRS, and a multi-antenna user. The distance between BS and IRS was 200 m, the distance between IRS and user was 10 m, and the distance between BS and user was 50 m. Figure 5 is a modeling plot to determine the performance of the 6G communication system with an IRS. The blue and black lines show the uplink and downlink transmission systems, respectively. It is assumed that the AR calculation occurs with the uplink transmission. The SNR and EE are with the downlink transmission.

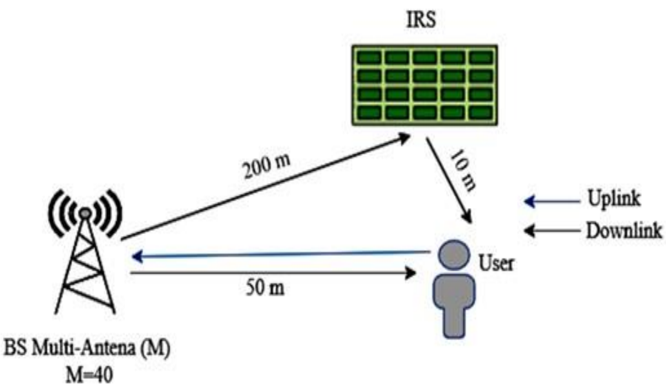

Fig. 5. Simulation System Model of IRS

The simulations calculate several performance parameters. To analyze the achievable rate by implementing IRS in the 6G communication system, the parameters listed in Table 1 are required. The SNR analysis by applying IRS to the 6G communication system, paying attention to the influence of electromagnetic interference (EMI), is presented in Table 2. Then, to analyze the energy efficiency of implementing IRS in the 6G communication system, the parameters listed in Table 3 were used.

Table 1

Parameters for achieving Achievable Rate Calculation

Parameter	Value
Number of antenna BS	40
Number of users	1
Number of N IRS	40, 200, 400
Transmit power	36 dBm [28]
Distance BS-IRS	200 m
Location of BS	0^0, 0^0, 25^0 [29]
Location of IRS	0^0, 80^0, 40^0 [29]
Location of User	10^0, 200^0, $1{,}5^0$ [28]

Table 2

Parameters for SNR Calculation

Parameter	Value
Wavelength (λ)	0.003 m [27]
Max Number of IRS Elements	50 elements
Number of Channels	200
Bandwidth	800 MHz [27]
Transmit Power	43 dBm [28]
Total Radiated Power (TRP)	63 dBm [28]
Vector rho ρ	5 dB [30]
The standard regression coefficient of destination β_d	0(-∞ dB) [22]
Power spectral density thermal noise (N_0)	-174 dBm/Hz [22]
Power spectral density bandwidth (N_0B)	-3.82 dBm/Hz [22]

Calculation and comparison of EE in 6G communication systems with various numbers of IRS elements at 95 GHz and 800 MHz bandwidth. IRS is used to improve channel quality without relays. The number of IRS elements can be varied to observe the impact on EE. Path loss models and channel characteristics specific to 95 GHz can be integrated to provide realistic simulations. For a given SNR, the achievable data rate can be calculated using the Shannon-Hartley theorem or appropriate modulation and coding schemes suitable for 95 GHz and 800 MHz.

Table 3

Parameters of EE Calculation

Parameter	Value
Frequency	95 GHz [27]
Bandwidth	800 MHz [27]
Noise Figure	75 dB [31]
Gain Source	25 dBi [31]
Gain IRS	25 dBi [31]
IRS Amplitude Reflection Coefficient (α)	1 [22]
Power Dissipation at BS (P_s)	80 mW [22]
Power Dissipation at IRS (P_e)	0,5 mW [22]
Power Dissipation at Rx (P_d)	80 mW [22]
Power amplifier efficiency at source (v)	5 mW [22]
Distance of BS and IRS	200 m
Distance of IRS and user	10 m
Distance of BS and user	50 m

3. Results and Discussion

3.1. Achievable Rate (AR)

In the simulation results, beams in the 6G communication system were received within 200 m and 50 m. The beam uses the Passive Beamforming and Information Transfer (PBIT) technique, which transmits IRS information while improving the quality of mobile communications. The accuracy of the analysis was validated by Monte-Carlo simulation of the achievable rate of IRS implementation. The AR with IRS implementation is obtained by observing the channel estimation error value called normalized MSE in the 6G.

The simulation results are shown in Fig. 6. The thick line shows the optimal phase shift of $(-1, 0)$, and the dotted line shows the random phase shift of $(0, 2\pi)^N$ with the number of elements used from 40 to 400 reflecting elements. It can be observed that the AR value is better when an optimal phase shift is considered compared to a random phase shift. This is because the random phase shift cannot optimize the spatial signal to the user, whereas when the phase shift is optimal , i.e. $(-1, 0)$ which is defined as -1 is without IRS and 0 is the optimal phase shift. When the phase shift is zero, the reflective current is in one phase with the element current; thus, the electric field and the current flow in the element can both be enhanced, resulting in higher information received by the user. Therefore, the AR value at the optimal phase-shift was higher.

The number of IRS-reflecting elements has an impact on the AR value results. For the number of IRS elements of 400 elements and NMSE of -40 dB, the AR value obtained is 23 bits/s/Hz, whereas for the number of

IRS elements of 40 elements and NMSE of -15 dB, the AR value obtained is only 16 bits/s/Hz. 400 elements are more optimal by 39% compared to 40 elements, indicating that the number of transmitted bits improves as more IRS elements are used.

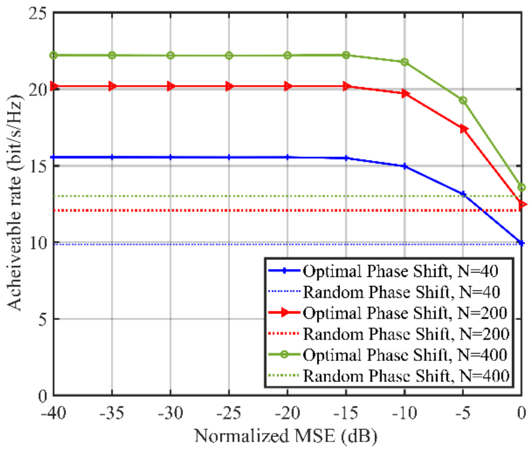

Fig. 6. Achievable rate results with IRS implementation

Figure 6 also shows that the Normalized MSE (NMSE) value affects the AR value. The NMSE value is closer to the value of 1, and the estimated channel estimation error is more similar to the actual channel. It can be seen that at an NMSE value of 0 dB, the AR value for each number of elements, namely 40, 200, and 400, decreases from the stable value at NMSE -40 dB to -15 dB, namely from 23 bit/s/Hz to 13 bit/s/Hz, from 20 bit/s/Hz to 12 bit/s/Hz, and from 16 bit/s/Hz to 9 bit/s/Hz.

3.2. Signal-to-Noise Ratio (SNR)

Using Equations (4)…(6) and an algorithm in MATLAB, the SNR can be obtained by looking at the number of reflecting elements in the IRS application and the conditions of the EMI effect, where the IRS is assumed to reflect EMI signals from unwanted signals close to the user. The amount of reflecting elements was 50 with a frequency of 95 GHz. The SNR values for 200 channel realizations are shown in Figure 7. The dashed red line is the signal condition with EMI effect (w/ EMI), and the black line is the signal condition without EMI effect (w/o EMI).

Figure 7 shows the SNR value against variations in the number of IRS reflecting elements. In the graph, it can be seen that the use of 50 reflecting elements has better performance at 100 dB. In contrast, for the amount of reflecting elements of 30 elements and 40 elements, the resulting SNR value is lower, which is below 21 dB and 65 dB. It can be said that the more the amount of reflective elements used, the higher the SNR. This has a positive impact because IRS with a large surface, i.e. the use of several reflecting elements) benefits the user by providing better signal quality.

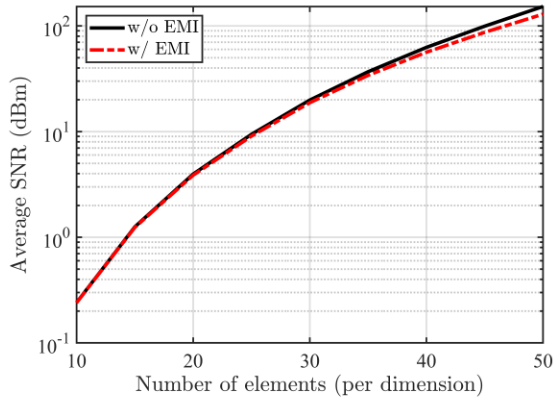

Fig. 7. SNR results with IRS implementation

Figure 7 also shows the SNR value results for EMI (w/EMI) and without EMI (w/o EMI); the SNR value w/EMI is lower at 90 dB than the SNR value results w/o EMI at 100 dB. This indicates that EMI has an adverse effect on signal transmission. However, it can be seen that the graph of SNR results for w/EMI and w/o EMI increases with the use of several reflective elements. However, under the w/EMI condition, the resulting SNR is lower at 90 dB. This is an undesirable effect because a large IRS is physically required to compensate for propagation losses and improve SNR.

3.3. Efficiency Energy (EE)

The results of the energy efficiency (EE) with the application of IRS by examining the Achievable Rate (AR) value for the 6G system are shown in Figure 8. It can be observed that at an AR value of 2.9 bit/s/Hz, the energy efficiency value starts to increase at 1342 Mbit/Joule. When the AR value was 3.4 bit/s/Hz, it gave a peak energy efficiency value of 1376 Mbit/s/Hz, and the energy efficiency value decreased most drastically at an AR value of 9.9 bit/s/Hz, with an energy efficiency value of only 832.3 Mbit/Joule. Increasing the transmitting power can cause the energy efficiency value to rise to a maximum of 1376 Mbit/s/Joule; however, after a certain limit, the energy efficiency value decreases because of the large power consumption.

In this paper, the EE value was also determined using the SNR value and the variation in the amount of IRS reflecting elements. Figure 9 shows that the EE value increases with an increase in the SNR until the SNR reaches 75 dB for all variations in the number of IRS reflective elements, while the EE value decreases after an SNR of 80 dB reaches the SNR of 120 dB. It can be seen that the lowest EE value was 2034 bits/Joule at 40 elements, whereas for 800 elements, the EE value increased by 26% to 2421 bits/Joule.

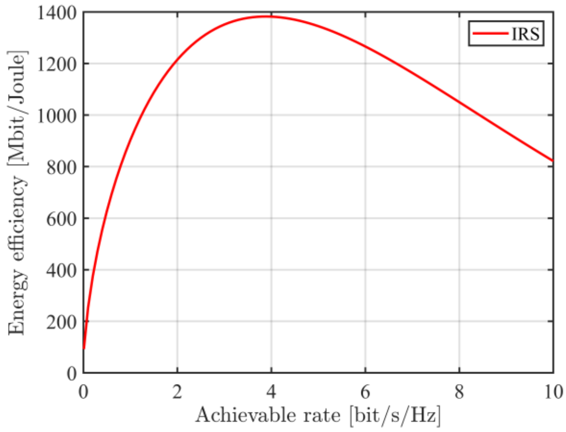

Fig. 8. EE results with IRS implementation

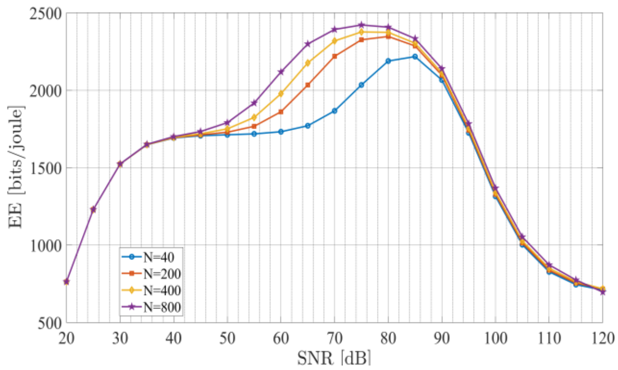

Fig. 9. Result of EE with a variation of N elements in aided-IRS

Conclusions

In this paper, we have analyzed the energy performance parameters of 6G communication systems using IRS, including the achievable rate (AR) and SNR. The research method is based on computer simulations for a 6G communication system with an operating frequency of 95 GHz, bandwidth of 800 MHz, varying IRS elements, and the influence of EMI and no EMI.

The result of AR using 400 IRS elements is 39% more optimal compared to 40 elements that produce an AR value of 16 bit/s/Hz. There are two SNR results. The first SNR without the influence of EMI is higher (100 dB) than the SNR affected by EMI (90 dB and the use of elements is directly proportional to the SNR results in the application of IRS. The efficiency energy results obtained using 800 IRS elements are 26% more optimal compared to only 40 elements, which only produce an efficiency energy value of 2034 bits/Joule.

Future research development. The authors suggest using different network technologies, techniques, precodes, and scenarios in future studies on this topic. It is also recommended to employ more antennas and reflective elements to simulate the use of IRS more accurately.

Contributions of authors: conceptualization – **Nasaruddin Nasaruddin, Ramzi Adriman, Yuwaldi Away**; methodology – **Nasaruddin Nasaruddin, Ramzi Adriman, Yuwaldi Away, Hubbul Walidainy;** formulation of tasks – **Nasaruddin Nasaruddin;** analysis – **Nasaruddin Nasaruddin, Ramzi Adriman, Yuwaldi Away, Hubbul Walidainy;** development of model – **Hubbul Walidainy, Siti Raihan**; software – **Hubbul Walidainy, Siti Raihan**; writing – original draft preparation – **Hubbul Walidainy, Siti Raihan;** writing – review and editing – **Hubbul Walidainy, Ramzi Adriman, Yuwaldi Away, Nasaruddin Nasaruddin.**

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship, or otherwise, that could affect the research and its results presented in this paper.

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Data availability

The manuscript contains no associated data.

Use of Artificial Intelligence

The authors confirm that they did not use artificial intelligence methods in their work.

All the authors have read and agreed to the publication of the finale version of the manuscript

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АНАЛІЗ ЕФЕКТИВНОСТІ ЕНЕРГЕТИКИ ДЛЯ СИСТЕМ ЗВ'ЯЗКУ 6G З ВИКОРИСТАННЯМ ІНТЕЛЕКТУАЛЬНОЇ АРХІТЕКТУРИ ВІДБИВАЮЧОЇ ПОВЕРХНІ

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Очікується, що об'єкт дослідження системи зв'язку 6G сформує гіперз'єднану мережу, щоб різні електронні пристрої могли безперервно з'єднуватися безперервно. Було створено декілька технологій для підтримки систем зв'язку 6G, таких як інтелектуальна відбиваюча поверхня (IRS). IRS – це рефлектор, оснащений декількома двовимірними пасивними елементами, він здійснює фазовий зсув кожним елементом, який може відбивати електромагнітні (ЕМ) хвилі, що надходять від базової станції до обладнання користувача (UE), яке керується через контролер для збільшення потужності сигналу в UE та подолання поганих умов розповсюдження. IRS можна розмістити де завгодно, наприклад на стіні чи даху будівлі. Очікується, що мета дослідження IRS – знизити рівень споживання енергії та підвищити спектральну ефективність бездротових мереж з використанням штучного інтелекту (ШІ) з низькими витратами, економією енергії, відсутністю теплового шуму та досить малими рівнями перешкод. Метою цього дослідження є оцінка та аналіз енергоефективності, включаючи досяжну швидкість (AR) і відношення сигнал/шум (SNR), шляхом застосування архітектури IRS у системі зв'язку 6G, яка використовує робочу частоту 95 ГГц з смуги пропускання 800 МГц. Метод базується на комп'ютерному моделюванні з використанням програмного забезпечення Matlab. У цій статті було створено моделювання системи зв'язку 6G. Ця модель використовувала міську мікрокомірку (Umi), яка складалася з однієї базової станції з декількома антенами, що змінювалася кількістю відбиваючих елементів ДІВ, і одного користувача. Це дослідження аналізувало AR, SNR і EE з використанням частоти 95 ГГц і моделювання за допомогою програмного забезпечення MATLAB@2021a. Результати: кількість елементів до 400 на 39% більш оптимальна, ніж кількість елементів до 40 для результатів AR, результати SNR без електромагнітних перешкод (EMI) вищі, ніж значення SNR, на які впливає EMI з результатами SNR 100 дБм, а кількість відбиваючих елементів прямо пропорційна результатам SNR. З 800

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елементами значення EE на 26% вище, ніж з 40 елементами. Висновки. Застосування IRS в системах зв'язку 6G може збільшити AR, SNR і EE.

Ключові слова: 6G; IRS; EMI; досяжна норма; SNR; енергоефективність.

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