Maximization of User Association Deploying IRS in 6G Networks

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1. Introduction

Connectivity technologies and processes, as well as the services that use them, have undergone exponential development and tremendous progress throughout the last decades. Examples include indoor localisation and related characteristics [1-39], terahertz transmitting and signal processing strategies [40-65], and antenna architecture and propagating properties [66-100].

The aims of sixth-generation (6G) wireless networks are projected to be disruptive and revolutionary, including applications such as data-driven, rapid, ultra-massive, and pervasive wireless networking [101], [102]. As a result, new transmission technologies are required to enable these emerging services and applications.

Emerging wireless systems will put a load on the existing single-tier macro cell-based networks to meet rising mobile data traffic demands. Currently, academic and industrial experts have presented a viable approach for mobile networks in which an increasing number of low-cost, low-power consuming, and short-extent tiny base stations (BSs) are installed under the traditional macro BSs. This advancement transforms standard single-tier communication networks into multi-tier networks. Therefore, the multi-tier network design appears as one of the po-
potential solutions to the evolving traffic growth problem. Various low-power base stations (e.g., micro, pico, and femto base stations) are implemented in a multi-tier network to alleviate macro cell users, establishing a multi-tier network layered with numerous tiny cells [103]. Fig. 1 visualizes a typical multi-tier (two-tier) network.

IRS also termed as RIS, large intelligent surfaces (LIS), software-controlled metasurfaces [104], [105] has recently emerged as a new potential solution for improving the functioning of wireless systems. IRS may automatically modify the wireless transmission environment for improved directional signaling. IRS is similar to a full-duplex amplify-and-forward (AF) relay that is
composed of a large quantity of passive reflecting components that may forward incident signals via passive beamforming [106]. Furthermore, IRS can modify propagation channels dynamically based on real environmental circumstances by fabricating phase shifts of the incoming signals. As a result, the IRS component cost and energy consumption are significantly lower compared to the AF relay. Research derived that the deployment of IRSs can highly enhance the evolving network improvement schemes such as (unmanned aerial vehicle) UAV-assisted communication [107], backscatter communication [108], etc. Moreover, IRS can facilitate application scenarios such as vehicle-to-everything (V2X) services [109], multi-access edge computing (MEC) [110], etc.

The extensive implementation of small base stations pushes network access points nearer to user devices (UD) or equipment (UE), resulting in improved traffic dispatching from the macro cell base station to the small cell base station. However, to fully realize its potential, several crucial challenges must be solved. One of the most significant issues is user association [111], which entails deciding which base station the device should be linked to.

Although IRS can provide numerous benefits to the mmWave transmission systems, it is important to note that IRS has a
substantial influence on user associations. The received power strength-based user association technique is commonly employed in mmWave communications, which may result in wasteful resource consumption (e.g. transmit power of the BS). There are several research initiatives underway to increase system performance by taking into account issues such as fairness of coverage and load balancing in mmWave transmission networks. The study’s goal is to increase network utility by maximizing user association.

Therefore, the target of this research is to maximize the user association for mmWave carriers in a two-tier 6G network. The work deployed IRS in a micro cell to maximize or enhance the probability of user association and compared it with a conventional non-IRS micro cell.

2. Related Literature

The section briefed several prior research works relative to IRS-assisted multi-tier networks.

Hashida et al. [112] proposed and analyzed an IRS-assisted user association scheme considering the mobility of devices in the context of multi-beam (IRS-aided) transmissions for 6G networks. Zhao et al. [113] analyzed the IRS-assisted user association in mmWave-based multi-base station 5G systems. The
work maximized the sum rate through the joint optimization of user association, passive beamforming, and power allocation. Taghavi et al. [114] proposed a novel user association scheme for load balancing for mmWave-based 5G and beyond transmission networks where IRS is implemented to escalate the coverage. Mei et al. [115] considered an IRS-assisted multi-tier (base stations) network and investigated user association in the case of the downlink. Belaoura et al. [116] analyzed the user association optimization problem for the relay-UAV-based massive multi-input multi-output (mMIMO) mmWave 6G communication systems. However, IRS is not considered in this network. Munir et al. [117] proposed and analyzed dual-slope path loss model-based user association considering a 5G two-tier network.

During the literature review, the authors found a limited number of works related to the user association analysis for 6G networks. The number of literature relative to IRS/RIS-assisted user association is still much lower as well. The notable thing is that the previous articles have considered a single carrier frequency for measurement. This work considered multiple carrier frequencies from a vast range of frequencies (i.e., 28-90 GHz) for measurement and analysis.
3. Measurement Model

Contemplating a two-tier network consisting of a set of micro base stations functioning under a macro base station. The macro and micro base station is serving the corresponding user devices. In the context of an IRS-enhanced micro cell, the micro base station will serve the user through an IRS. $P_t$ is the transmit (or transmission) power of the micro base station.

A. Conventional Model

The downlink received power of a conventional micro base station is measured by the following equation (Eq. 1) [118]-[120],

$$P_{r_{Micro(Conv.)}} = \frac{P_t \lambda^2 h}{16\pi^2 d^\alpha}$$

where $h$ is the Rayleigh fading coefficient that follows unit mean-exponential distribution, i.e., $h \sim exp(1)$. The wavelength is denoted by $\lambda = c/f_c$. $c$ is the speed of light in $ms^{-1}$. $f_c$ is the frequency in Hz.

$$d = \sqrt{(x^n - x^u)^2 + (y^n - y^u)^2 + (z^n - z^u)^2}$$

denotes the distance between the user located at $(x^u, y^u, z^u)$ and the micro base station placed at $(x^n, y^n, z^n)$ coordinates. $\alpha$ is the attenuation exponent representing the degradation of the transmitted signal.
B. IRS-Assisted Model

The received power in the downlink of an IRS-assisted micro base station can be formulated by (Eq. 2) [121],

\[ P_{\text{Micro(IRS)}} = P_t \frac{G_{5c}G_tG_rM^2N^2d_xd_y\lambda^2\cos\theta_t\cos\theta_r\lambda^2}{d_1^2d_2^264\pi^3} \]  

(2)

where \( d_x \) and \( d_y = \lambda/2 \). The IRS elements’ scattering gain is \( G_{Sc} = \frac{4\pi d_x d_y}{\lambda^2} \). The gains of transmitter and receiver are indicated by \( G_t \) and \( G_r \).

\[ d_1 = \sqrt{(x^n - x^i)^2 + (y^n - y^i)^2 + (z^n - z^i)^2} \]

is the distance between the micro base station at \((x^n, y^n, z^n)\) coordinates and IRS at \((x^i, y^i, z^i)\) coordinates.

\[ d_2 = \sqrt{(x^i - x^u)^2 + (y^i - y^u)^2 + (z^i - z^u)^2} \]

denotes the separation between the IRS \( i \) and the user at \((x^u, y^u, z^u)\) coordinates. The numbers of the IRS’s transmitter and receiver elements are indicated by \( M \) and \( N \), respectively. The length and width of the scattering elements are \( d_x \) and \( d_y \), respectively. \( \theta_t \) denotes the angle between the micro base station and IRS and \( \theta_r \) is the angle between IRS-to-user equipment. \( A \) is the reflection coefficient of the IRS.
C. User Association

The work includes the equations to measure and analyze the probability of user association (UA) for both conventional and IRS-assisted micro base stations.

Conventional UA: For a conventional (non-IRS) micro base station the probability of user association is measured by the equation below (Eq. 3) [122],

\[ A^{\text{Micro(Conv.)}} = \left( 1 + \frac{\lambda_{\text{Macro}}}{\lambda_{\text{Micro}}} \left( \frac{P_{r}^{\text{Macro}}}{P_{r}^{\text{Micro(Conv.)}}} \right) \right)^{2\alpha_{\text{macro}}} - 1 \]  

where \( \lambda_{\text{Micro}} \) and \( \lambda_{\text{Macro}} \) are the densities (per \( m^2 \)) of the micro base station and macro base station, respectively. \( P_{r}^{\text{Micro(Conv.)}} \) and \( P_{r}^{\text{Macro}} \) denote the received power from the serving conventional micro base station and the macro base station (by the user), respectively. \( \alpha_{\text{macro}} \) indicates the exponent representing the attenuation for the macro base station.

IRS-Assisted UA: The probability of user association for an IRS-empowered micro base station is determined by (Eq. 4) [122],

\[ A^{\text{Micro(IRS)}} = \left( 1 + \frac{\lambda_{\text{Macro}}}{\lambda_{\text{Micro}}} \left( \frac{P_{r}^{\text{Macro}}}{P_{r}^{\text{Micro(IRS)}}} \right) \right)^{2\alpha_{\text{macro}}} - 1 \]
where $P_{r}^{\text{Micro(IRS)}}$ is the received power from the serving IRS-enhanced micro cell.

4. Numerical Results and Discussions

The section incorporates the numerical results and corresponding discussions on the simulated results. The work considers that the micro base station is placed at the cell center namely (100, 100) coordinates in the case of a conventional micro cell, and in the case of an IRS-assisted micro cell the IRS is placed at the cell center. Furthermore, the research contemplates that, in the case of an IRS-assisted micro cell the micro base station serves all users through the IRS. Table I represent the simulation parameters and values for the measurements.

Fig. 2 (a) and (b) illustrate the probability of user association corresponding to the selected mmWave carriers in the context of a conventional non-IRS micro cell for 4 W and 6 W of transmission (or transmit) powers, respectively.

Fig. 3 (a)-(d) represent the probability of user association corresponding to the 28, 50, 70, and 90 GHz mmWave carriers, respectively for 6 W of transmit power of the conventional (non-IRS) micro base station.

According to the observation of Figs. 2 and 3 it is com-
Table 1: Parameters and Values

| Parameters                      | Values                                      |
|---------------------------------|---------------------------------------------|
| Macro cell area                 | 1000x1000m                                  |
| Micro cell area                 | 200x200m                                    |
| Transmit power of the Macro BS  | 50 W                                        |
| Transmit power of the Micro BS, $P_t$ | 4-6 W (conv.), 1-2 W (IRS-assisted)        |
| BS’s position, $(x^n, y^n, z^n)$ | Conv.: (100, 100, 5) and IRS-assisted: (0, 0, 5) coordinates |
| Users position, $(x^u, y^u, z^u)$ | Randomly distributed                       |
| IRS’s position, $(x^i, y^i, z^i)$ | (100, 100, 5) coordinates                  |
| Transmitter and receiver gain, $G_t$ and $G_r$ | 20 dB [123]                               |
| Parameters                                      | Values                                      |
|------------------------------------------------|---------------------------------------------|
| Transmitter and receiver elements, $M$ and $N$, | 128, 256                                   |
| Transmit angles, $\theta_t$                   | $45^\circ, 60^\circ$ [121], [124]          |
| Receive angles, $\theta_r$                    | $45^\circ, 60^\circ$ [121], [124]          |
| mmWave carriers, $f_c$                        | 28, 50, 70, 90 GHz                         |
| Reflection coefficient of the IRS, $A$         | 0.9 [21]                                   |
| Micro cell tier BS density, $\lambda_{micro}$ | $500/(\pi(100)^2)$ per $m^2$; where 100 m is the cell radius |
| Macro cell tier BS density, $\lambda_{macro}$ | $\lambda_{micro}/5$ per $m^2$              |
| Path loss exponent (Micro cell), $\alpha$     | 2.5                                         |
| Path loss exponent (Macro cell), $\alpha_{macro}$ | 4.5                                         |
prehensible that, for 4 W of transmission power of micro base station (non-IRS), 28 GHz carrier achieves a maximum of 0.96 and a minimum of 0.28 probability of user association, 50 GHz carrier achieves a maximum of 0.92 and a minimum of 0.16 probability of user association, 70 GHz carrier achieves a maximum of 0.90 and a minimum of 0.13 probability of user association, and 90 GHz carrier achieves a maximum of 0.86 and a minimum of 0.09 probability of user association. An important clarification is that the maximum and minimum values are representing the probability of user association at the cell center and cell edge, respectively.
Figure 2: (a) Probability of user association (4 W), (b) Probability of user association (6 W).
In the case of 6 W of transmission power of micro base station, 28 GHz carrier achieves a maximum of 0.97 and a minimum of 0.31 probability of user association, 50 GHz carrier achieves a maximum of 0.93 and a minimum of 0.19 probability of user association, 70 GHz carrier achieves a maximum of 0.92 and a minimum of 0.15 probability of user association, and 90 GHz carrier achieves a maximum of 0.88 and a minimum of 0.11 probability of user association. It can be said that the enhancement of the transmission power increases the probability of user association a bit but it is not much significant or sufficient for the cell-edge users.
Figure 3: (a) Probability of user association (28 GHz), (b) Probability of user association (50 GHz), (c) Probability of user association (70 GHz), (d) Probability of user association (90 GHz).
Fig. 4 (a) shows the probability of user association for 1 W of transmit power of the IRS-assisted micro base station, 128 transmitter-receiver elements of the IRS, and $45^\circ$ of transmit-receive angles. Fig. 4 (b) shows the probability of user association in an IRS-assisted micro base station for 2 W of transmit power, 128 transmitter-receiver elements, and $45^\circ$ of transmit-receive angles. Fig. 4 (c) shows the probability of user association in an IRS-assisted micro base station for 2 W of transmit power, 128 transmitter-receiver elements, and $60^\circ$ of transmit-receive angles. Fig. 4 (d) shows the probability of user association in an IRS-assisted micro base station for 2 W of transmit power, 256 transmitter-receiver elements, and $45^\circ$ of transmit-receive angles.

Fig. 5 (a) visualizes the probability of user association in the context of an IRS-enhanced micro cell for 1 W of transmit power of the base station, 128 transmitter-receiver elements of the IRS, $45^\circ$ of transmit-receive angles, and a 28 GHz carrier. Fig. 5 (b) visualizes the IRS-enhanced micro base station’s probability of user association for 1 W of transmit power, 128 transmitter-receiver elements, $45^\circ$ of transmit-receive angles, and 90 GHz carrier. Fig. 5 (c) visualizes the probability of user association in the case of an IRS-enhanced micro base station for 2 W of transmit power, $45^\circ$ of transmit-receive angles, 128 transmitter-receiver elements, and 90 GHz carrier.
receiver elements of the IRS, and a 90 GHz carrier. Fig. 5 (d) visualizes the probability of user association in the case of an IRS-enhanced micro base station for 2 W of transmit power, 256 transmitter-receiver elements, 45° of transmit-receive angles, and a 90 GHz carrier.

Observing Fig. 4 (a)-(d) it is realizable that, for 1 W of transmission power of IRS-assisted micro base station, 128 transmitter-receiver elements of IRS, and 45° transmit (base station-to-IRS)-receive (IRS-to-user) angles the maximum and minimum values of the probability of user association for 28, 50, 70, and 90 GHz carriers are 0.9945 and 0.87, 0.9846 and 0.70, 0.9724 and 0.57,
Figure 4: (a) Probability of user association (1 W, 128 transmitter and receiver elements, 45° transmit and receive angles), (b) Probability of user association (2 W, 128 transmitter and receiver elements, 45° transmit and receive angles), (c) Probability of user association (2 W, 128 transmitter and receiver elements, 60° transmit and receive angles), (d) Probability of user association (2 W, 256 transmitter and receiver elements, 45° transmit and receive angles).
User Association (IRS); $P = 1W; f = 28GHz$

(a)

User Association (IRS); $P = 1W; f = 90GHz$

(b)
and 0.9575 and 0.45, respectively.

In the case of 2 W transmission power, 128 transmitter-receiver elements of IRS, and 45° transmit-receive angles the maximum and minimum values of the probability of user association for 28, 50, 70, and 90 GHz carriers are 0.9959 and 0.90, 0.9887 and 0.77, 0.9796 and 0.64, and 0.9684 and 0.53, respectively.

In the case of 2 W transmission power, 128 transmitter-receiver elements of IRS, and 60° transmit-receive angles the maximum and minimum values of the probability of user association for 28, 50, 70, and 90 GHz carriers are 0.9976 and 0.94,
Figure 5: (a) Probability of user association (1 W, 128 transmitter and receiver elements, 28 GHz), (b) Probability of user association (1 W, 128 transmitter and receiver elements, 90 GHz), (c) Probability of user association (2 W, 128 transmitter and receiver elements, 90 GHz), (d) Probability of user association (2W, 256 transmitter and receiver elements, 90 GHz).
0.9933 and 0.85, 0.9879 and 0.75, and 0.9812 and 0.66, respectively.

In the case of 2 W transmission power, 256 transmitter-receiver elements of IRS, and 45° transmit-receive angles the maximum and minimum values of the probability of user association for 28, 50, 70, and 90 GHz carriers are 0.9988 and 0.97, 0.9967 and 0.92, 0.994 and 0.86, and 0.9906 and 0.80, respectively.

Through the observation, it can be stated that, with a lower level of transmission power (i.e., 1 W), a lower number of transmitter-receiver elements (128 elements) the lower level mmWave carrier such as 28 GHz can provide sufficient coverage to the entire coverage region. For higher-level mmWave carriers such as 90 GHz a bit high transmission power (i.e., 2 W), an increased number of transmitter-receiver elements (i.e., 256 elements) are required to ensure sufficient coverage to the entire coverage region, especially for the cell-edge users. The performance of the network depends upon transmit-receive angles as well (Fig. 4(c)). The research obtained that, by maintaining an efficient trade-off among network resources namely carrier, transmit power, number of transmitter-receiver elements, etc. a significantly enhanced coverage can be achieved in an IRS-enhanced micro cell compared to the conventional micro cell.
The cell-edge users are as well achieving significant association probability through the deployment of IRS.

Comparing the measurement results of both the conventional non-IRS and IRS-assisted micro base stations the work figures out that the deployment of IRS maximizes or enhances the probability of user association significantly with a reduced transmit power of the micro base station. For example, in the case of a conventional non-IRS micro base station, for 6 W of transmission power of micro base station, 28 GHz mmWave carrier achieves a maximum of 0.97 and a minimum of 0.31 probability of user association. Whereas, in the case of an IRS-assisted micro base station with 1 W of transmission power, 128 transmitter-receiver elements, and 45° transmit (base station-to-IRS)-receive (IRS-to-user) angles the maximum and minimum values of the probability of user association for the 28 GHz carrier are 0.9945 and 0.87. If the transmit power is increased to 2 W (128 transmitter-receiver elements and 45° transmit-receive angles) the maximum and minimum values of the probability of user association for the 28 GHz carrier are 0.9959 and 0.90.

The deployment of IRS in a micro cell reduces the energy consumption up to 67% - 83% by reducing the transmit power of the micro base station from 6 W (conventional micro cell [125]) to 1-2 W (IRS-assisted micro cell). Due to the placement
of IRS with such a reduced power the cell-edge users achieve significantly favorable coverage when an efficient resource orchestration is confirmed and this is better realizable through Fig. 5(a)-(d).

Another notable finding of the research is that for the mmWave-based transmission utilizing IRS is one of the most favorable solutions to enhance the entire network capacity.

Notable information is that the work during the literature review found a total of thirty-five articles in scholarly research databases such as IEEE Xplore, Science Direct, and Springer Link relative to the analysis of user association in 6G networks. The review found four articles on IRS/RIS-assisted user association analysis for mmWave networks and only two specific to 6G.

5. Conclusion

The work aimed to maximize the probability of user association of a micro cell of a two-tier network assuring energy efficiency. Therefore, the research formulated a measurement model including required equations to measure and compares the probability of user association in the context of a conventional micro cell and IRS-assisted micro cell of a two-tier network in which the micro base stations are operating under macro cell. The work
derives that the deployment of IRS significantly maximizes the performance of the micro base stations or cells assuring significant energy efficiency. Moreover, the IRS notably enhances the probability of user association for cell-edge users as well when an efficient orchestration of network resources is assured.

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