IRS for Multi-Access Edge Computing in 6G Networks

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1. Introduction

The last three decades have witnessed an exponential growth and tremendous developments in wireless technologies and techniques, and their associated applications. These include indoor localization techniques and related aspects [1-17], terahertz communications and signal processing applications [18-36], and antenna design and propagation characteristics [32-55].

Mobile data will rise exponentially in the forthcoming sixth-generation (6G) [56], [57] infrastructures and the majority of it is generated by edge devices including smartphones, computers, and Internet of Things (IoT) devices [58]. Since the majority of such user equipment holds low computational capacity, MEC is a potential technology that may efficiently guarantee sufficient computing resources, minimize capital expenditure, and provide scalability [59]. To preserve battery power and computing resources, wireless gadgets in the MEC architecture transfer computing-intensive or delay-sensitive operations to adjacent edge computing servers located at the edge of cellular networks.

MEC encourages the deployment of cloud processing technologies at the edge of wireless networks to relieve resource-constrained UEs from excessive computational workloads and serve them with highly-efficient low-latency computational ser-
Because of the potential to change the wireless propagation environment, IRS has already been anticipated as a revolutionary approach 6G connectivity system [61], [62]. IRS is comprised of a large number of reflecting (passive) components that may proactively reflect incident waves to boost signal strength or minimize co-channel interference by altering their phases and amplitudes. Unlike conventional relay transmissions, IRS not only functions in a full-duplex manner without introducing unwanted interference, but also it can significantly minimize energy consumption and hardware costs by utilizing passive reflecting materials. Fig. 1 illustrates the IRS-assisted communication scenario.

IRS technology has already attracted significant consideration to improve the offloading efficiency of resource-constrained UE because of its benefits of simple deployment, low cost, smart-controllable passive beamforming, and signal improvement or interference reduction [63]. The configurations of IRSs may be modified to offer a more advantageous wireless transmission environment by altering the characteristics of reflecting components on the surface. Clearly, including IRSs into MEC technology [64] is a cost-efficient and environmentally benign method of offloading the computational tasks of UE.
The research aimed to analyze the performance of MEC considering in both IRS-assisted and without IRS communication scenarios.

2. Relative Literature

The section briefed several prior research works relative to IRS-empowered MEC systems.

Wang et al. [65] studied an IRS-empowered MEC adopting the non-orthogonal multiple access (NOMA) technique. The energy efficiency is jointly optimized considering the offloading power, receiving beamforming, local computing frequency, and
IRS phase-shift. Zhou et al. [66] considered IRS-assisted MEC architecture in which IRS is employed to support computation task offloading from users (two users) to an access node linked with an edge computing cloud. Chu et al. [67] deployed and analyzed the computational performance of IRS-enhanced MEC architecture. The work formulated a problem targeting to optimize sum computational bits considering the offloading time allocation, CPU frequency, transmit power of each device, etc. Zhang et al. [68] investigated the network throughput optimization problem of IRS-aided multiple hop MEC system. The work jointly optimized resource allocation and phase-shifts of the IRS. Bai et al. [69] investigated the lucrative role of IRS in MEC architecture in which single-antenna user equipment may offload partial computational tasks or activities to the computing node (edge computing) via a multi-antenna access node with the assistance of an IRS. Latency-minimization problems are composed for both multi-device and single-device scenarios. Mao et al. [70] aimed at utilizing the IRS to escalate the efficiency of wireless energy transfer and task offloading. Specifically, the work investigated the maximization of total computation bits for IRS-assisted wireless powered MEC systems through the joint optimization of the transmission power, beamforming of IRS, and time slot assignment. Sun et al. [71] presented a new IRS-MEC
framework that jointly optimized the local computing frequencies (CPU cycles) of the UE and the offloading schedules to reduce the consumption of energy of the UE.

3. System Model

The research considered a MEC-enabled wireless network scenario. $M = \{M_1, M_2, \ldots M_n\}$ where $i$ is the serving base station (BS) from $M$. A set $U = \{u_1, u_2, \ldots u_n\}$ of the user equipment is served by the corresponding BS $i$. User equipment operating under the BS has to perform multi-varieties of computational tasks such as multiplayer gaming, facial recognition or verification, image processing or analysis, etc. The computational or computing tasks of users are indicated by $T_n = \{d_n, c_n, t_{n}^{max}\}$ where $n \in i$. $d_n$ is indicating the computation task data packet size, $c_n$ denotes the required CPU cycles to complete each task, and $t_{n}^{max}$ indicates the tolerable latency (maximum) of each task.

A. Communication Model

Communication Model without IRS: Contemplate $P_{UL}^{t}$ and $B_{UL}^{t}$ denote the power and bandwidth for uplink [72].

The uplink received power (by the BS) can be measured by (Eq. 1),
\[ P_{UL}^r = \frac{P_{UL}^r h}{D^\alpha} \]  

(1)

where \( h \) is unit mean Rayleigh fading coefficient that evolves exponential distribution \( h \sim \text{exp}(1) \). \( D \) denotes the separation distance between transmitter and receiver. The path loss factor is denoted by \( \alpha \).

The SNR for uplink can be determined by the following formula (Eq. 2),

\[ S_{UL}^r = \frac{P_{UL}^r}{N} \]  

(2)

where \( N \) indicates the interference power.

Therefore, the uplink throughput can be measured by (Eq. 3),

\[ R_{UL}^r = B_{UL}^r \log_2(1 + \frac{P_{UL}^r}{N}) \]  

(3)

**IRS-Assisted Communication Model:** In the IRS-assisted communication, the received power (uplink) can be derived by the following equation (Eq. 4) [73],

\[ P_{UL}^r(IRS) = \frac{P_{t}^{UL(IRS)} G_t G_r G M^2 N^2 d_x d_y \lambda^2 \cos(\theta_t) \cos(\theta_r) A^2}{64 \pi^3 (d_1 d_2)^2} \]  

(4)

where \( P_{t}^{UL(IRS)} \) is the transmit power of the user equipment in an IRS-aided communication scenario.
\[ d_1 = \sqrt{(x_{UE} - x_{IRS}^i)^2 + (y_{UE} - y_{IRS}^i)^2 + (z_{UE} - z_{IRS}^i)^2} \]

indicates the distance between the UE located at \((x_{UE}, y_{UE}, z_{UE})\) coordinates and IRS located at \((x_{IRS}^i, y_{IRS}^i, z_{IRS}^i)\) coordinates. \[ d_2 = \sqrt{(x_{IRS}^i - x_{BS}^i)^2 + (y_{IRS}^i - y_{BS}^i)^2 + (z_{IRS}^i - z_{BS}^i)^2} \]

is the distance between the IRS and the BS. The transmitter and receiver gains are \(G_t\) and \(G_r\). \[ G = \frac{4\pi d_x d_y}{\lambda^2} \]
denotes the scattering gain. \(M\) and \(N\) indicate the numbers of transmit-receive elements in IRS. The length and width of scattering elements of the IRS are denoted by \(d_x\) and \(d_y\). \(\lambda\) is the wavelength. Transmit and receive angles are \(\theta_t\) and \(\theta_r\). \(A\) is the amplitude respective to the reflection coefficient of IRS.

The SNR is calculated by the formula below (Eq. 5),

\[ S_{UL}^{IRS} = \frac{P_{UL}^{IRS}}{N} \]  

The uplink throughput is measured by (Eq. 6),

\[ R_{UL}^{IRS} = B_{UL}^{IRS} \log_2\left(1 + \frac{P_{UL}^{IRS}}{N}\right) \]

where \(B_{UL}^{IRS}\) is the uplink bandwidth of the user equipment in the IRS-assisted scenario.

**B. Computation Model**

**Local Computation:** Contemplating \(F^L\) is the maximum operable frequency of the CPU of user equipment. The latency of
task processing (time for processing a task by user equipment as per the computation capacity) in the local computing model can be derived by (Eq. 7) [74],

$$t^L_n = \frac{d_n c_n}{F^L - \sum_1^n f^L_n}$$  \hspace{1cm} (7)

where $f^L_n$ denotes the occupied CPU frequency by the previously ongoing task/tasks.

**Computation at the BS (without IRS):** Based on the task processing computation capacity, time (latency) constraint, and power consumption or limitation of battery level the user equipment can have a decision to offload computational task/tasks to the MEC server. In this circumstance, the task completion time $T_n$ can be partitioned into two portions; i.e. one portion denotes the task offloading or transmission time or latency and another portion stand for task processing time at the MEC server. The work disregarded the time required for the reception or the computation results from the MEC to the UE since the derived result is usually much tinier in size than the input data size for most of the cases (e.g., fingerprint recognition). $F_{BS}$ is the maximum task processing capacity (CPU frequency) of the MEC. $\sum_1^n f_{BS}$ denotes the occupied capacity of the CPU of the MEC server. Therefore, the total time for the task completion can be measured by (Eq. 8),
\[ t_{BS}^n = \frac{d_n}{RUL} + \frac{d_n c_n}{F_{BS} - \sum_{i=1}^{n} f_{BS}} \]  

(8)

**IRS-Assisted Computation:** In the circumstance of IRS-assisted communication, the overall task completion time can be derived by (Eq. 9),

\[ t_{BS(IRS)}^n = \frac{d_n}{RUL_{(IRS)}} + \frac{d_n c_n}{F_{BS} - \sum_{i=1}^{n} f_{BS}} \]  

(9)

### 4. Results and Discussions

The section of the paper includes the measurement results and corresponding discussions on the derived results. Table I includes the measurement parameters and values.
| Simulation Parameters                                      | Values                                      |
|------------------------------------------------------------|---------------------------------------------|
| Cell area                                                  | 200x200 m                                  |
| UE transmission power                                      | 5W (w/o IRS); 2W (IRS-aided)               |
| Bandwidth                                                  | 1 - 10 MHz                                 |
| Transmitter gain                                           | 20 dB                                      |
| Receiver gain                                              | 20 dB                                      |
| No. of transmit and receive elements of IRS                | 100                                         |
| Transmit and receive size                                  | 0.0038 mm                                  |
| Carrier frequency                                          | 120 GHz                                    |
| Transmit and receive angle                                 | 45°                                        |
| BS position                                                | (0, 0, 8) m                                |
| IRS position                                               | (100, 100, 8) m                            |
| UE-IRS and IRS-BS distance                                | 100 m                                      |
| Path loss factor                                           | 5.5                                        |
| IRS reflection coefficient                                 | 0.9                                        |
| Data sizes                                                 | 5000 – 20000 B                             |
| CPU cycles per bit                                         | 1000                                       |
| UE computation capacity                                     | 2-4 GHz                                    |
| BS computation capacity                                    | 80 GHz (max. 8 GHz per user)               |
The research considered 30 ms or 0.030 s as the task completion threshold for the considered data sizes.

Fig. 2 shows the numerical results of task completion time in terms of data size for different processing capacities (CPU frequency) of different user equipment.

![Task Processing at UE](image)

**Fig. 2. Task completion time vs. data size**

From Fig. 2 it is comprehensible that, UE with 2, 3, and 4 GHz computation or processing capacity can process up to 7500, 12000, and 16000 bytes of data size respectively within 30 ms task completion time (latency) threshold.
Fig. 3 illustrates the task completion time in terms of the allocated transmission bandwidth of the user equipment for both IRS-assisted and without IRS communication scenarios for 6000 bytes of data size.

Fig. 3. Task completion time vs. bandwidth (6000 B)

Fig. 4 illustrates the task completion time relative to the bandwidth of the user equipment for both IRS-assisted and without IRS communications for 17000 bytes of data size.
Fig. 4. Task completion time vs. bandwidth (17000 B)

From Fig. 3 it is perceptible that, in the case of non-IRS communication up to 6000 bytes of data can be offloaded and processed within the threshold task completion time in the case of minimal bandwidth (1 MHz). With such minimal bandwidth, up to 17000 bytes of data can be offloaded and processed within the threshold task completion time when IRS is deployed (Fig. 4). Almost 7 MHz bandwidth is required to offload and process 17000 bytes of data in the case of a non-IRS communication scenario.
Fig. 5 visualizes the task completion time relative to the bandwidth of the user equipment for both IRS-assisted and without IRS communications for 20000 bytes of data size.

With the observation of Fig. 5, it is sensible that, above 2 MHz bandwidth is required to offload 20000 bytes of data to be processed within the threshold task completion time. In the case of non-IRS communications, 8 MHz bandwidth is required to process 20000 bytes of data.

Fig. 5. Task completion time vs. bandwidth (20000 B)

Fig. 6 represents the uplink throughput relative to the trans-
mission bandwidth and transmitter-receiver separation in the context of without IRS micro cellular communication scenario.

Fig. 6. Uplink throughput in terms of bandwidth and transmitter-receiver separation (without IRS)

Fig. 7 shows the task completion time relative to the transmission bandwidth and data size in the case of without IRS communication scenario.
Fig. 7. Task completion time in terms of bandwidth and data size (without IRS)

Fig. 8 visualizes the uplink throughput relative to the bandwidth and transmitter-receiver separation distance in the context of an IRS-assisted micro cellular communication scenario.
Fig. 8. Uplink throughput in terms of bandwidth and transmitter-receiver separation (IRS-assisted)

Fig. 9 illustrates the task completion time relative to the bandwidth and data size in the case of an IRS-assisted communication scenario.
Fig. 9. Task completion time in terms of bandwidth and data size (IRS-assisted)

Through the observation and comparison between Figs. 6 and 8 it is comprehensible that, UE located at 200 m away from the BS for 1, 5, and 10 MHz bandwidths can obtain 2.001, 10.01, and 20.01 Mb/s uplink throughputs respectively in the case of non-IRS communication. On the other hand, in the case of IRS-assisted communication for the mentioned BS-UE separation distance UE can obtain 10.53, 52.63, and 105.3 Mb/s uplink throughputs for the respective mentioned bandwidths.
It is evident that the deployment of IRS offers approximately 5 times increased uplink throughput.

Inspecting Figs. 7 and 9 it becomes sensible that, in the case of non-IRS communications up to 8 MHz bandwidth is required to process the maximum size of data. On the other hand, in the case of IRS-assisted communication allocating a minimal bandwidth (up to 2 MHz) all the computation tasks can be processed (task offloading and processing at MEC) within the threshold task completion time. Deploying IRS reduces the bandwidth requirement up to 4 times. Therefore, it is evident that the incorporation of IRS ensures significant reduction of spectrum usage and offers notable spectrum efficiency.

Another important point is that compared to the non-IRS communication in which 5 W uplink transmit is considered with 2 W of uplink transmit power the IRS-assisted network performs significantly better. Reducing 40% uplink transmission power IRS-assisted communication offers remarkable energy efficiency as well.

5. Conclusion

The research targeted to analyze the performance of MEC systems under non-IRS and IRS-assisted communication scenarios. In this context, the work reviewed relative works and literature
to obtain an insight into prior works. Then, it formulated a
system model including the communication and computation to
perform the measurement campaign. The measurements are
performed through a computer-aided simulation or measure-
ment approach i.e. MATLAB is utilized for the measurements.
The research obtained that the deployment of IRS in the MEC
ecosystem can significantly improve the overall performance of
the system. The deployment of IRS remarkably reduces the
spectrum and energy usage hence increasing the spectral and
energy efficiency of the network. The authors pretend that the
work will enhance the literature on IRS-assisted communication
and will be assistive to extend research on relative topics.

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