Simulation of Signal Coverage for Terahertz Communications

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***Abstract*— Recent progress in wireless communication technology has started to see proposals for spectrum operation in the Terahertz band (0.1 THz to 10 THz), which will lead to data rates close to Terabit per second (Tbps). However, there are a number of challenges with the signals operating in the THz band, and this includes the requirements of Line-of-sight, signal attentuation due to molecular absorption, as well as signal scattering upon reflection from rough surfaces. This paper addresses a software-defined reflector solution for mirror-assisted terahertz communications. The paper also discusses future outlook that further improve reflectos for terahertz communications.**

I. INTRODUCTION

In the next decade, the development and deployment of wireless communication technologies are expected to have a major impact, due to expectation of data rates that are close to wired links, enabling a variety of new bandwidth-intensive applications and services connecting not only between humans but also serving machine-to-machine communications. Next generation wireless communications are envisioned to provide ultra-high-speed data communications reaching Terabit per second (Tbps), at least within small coverage areas of up to 10 m (e.g., small cells) [1]. However, in order to achieve these targeted rates, the carrier frequency are expected to increase. Most recently, researchers have been experimenting with *mm-wave* (60Ghz). Increasing this further will reach the *Terahertz* (THF) bands (0.1 - 10 THz), which can support future wireless networks beyond 5G [2]. Besides providing high bandwidth to conventional services that we see today (e.g., multimedia services), new emerging services could result from using THz band communication. An example is new forms of human-machine interconnection, and in particular connectivity for the Internet of Bio-Nano Things (IoBNT) [8] and Internet of Nano Things [9].

There exist numerous technological challenges in the THz band, and this includes, (i) requirements for Line-of-sight (LoS) propagation due to the scattering effects, which becomes a major issue for small objects and rough services (this does not result in multipaths that are found in lower frequencies, where very small wavelengths can also suffer from considerable doppler shifts), (ii) signal attenuation due to ambient effect that is caused by free space losses, and (iii) sensitivity to atmospheric effects such as molecular absorption. These limitations have been extensively studied leading to development of channel models that can be used to design appropriate transceivers as well as efficient ultra-broadband antennas [1].

In this paper, we focus on the problem of NLoS propagation in terahertz band, due to the presence of obstacles. In order to mitigate the NLoS problem, a number of studies have already been carried out on the reflectors or mirror-assisted transmission in an indoor environment to support directed signal paths [3-5] (this mirrors will act as passive transmitters). Using the mirror-assisted approach, a new antenna architecture coupled to dielectric mirror, presents the ability to beam and concentrate signal strength in specific locations, in order to enhance the coverage area. This in turn could lead to new indoor architectures that are based on **Software-defined Reflectors** for controlling and configuring the mirrors.

The objective of this paper is to determine the signal coverage of Thz signals within an indoor environment, and its effects due to objects and obstacles. Through the development of a ray-tracing simulator of the terahertz propagation, the paper investigates the performance of the multi-reflector coverage area, to determine if there is scope for future software-defined reflectors for terahertz-band communication. The simulator has various functions such as drawing a room, creating obstacles, positioning the THz transmitter and calculating the ray paths for both direct LoS and reflected rays and signal coverage area. A particular focus is on the configurations of the reflectors, where simulation analysis focused on the different locations, size of the reflectors, and the maximum coverage of rotatable steering angles. Towards the end of the paper, future outlook is discussed for new emerging concepts and paradigms that can be integrated into software-defined reflectors.

The rest of this paper is organized as follows: Section II describes the software-defined reflector archiecture. In Section III, the THz ray tracing simulator is introduced, and Section IV presents the future outlook. Finally, Section V is the conclusion.

II. SOFTWARE-DEFINED REFLECTOR ARCHITECTURE

Our proposed architecture for the reflective environment is illustrated in Fig. 1. As shown in the diagram, the confined space includes a terahertz base station that consist

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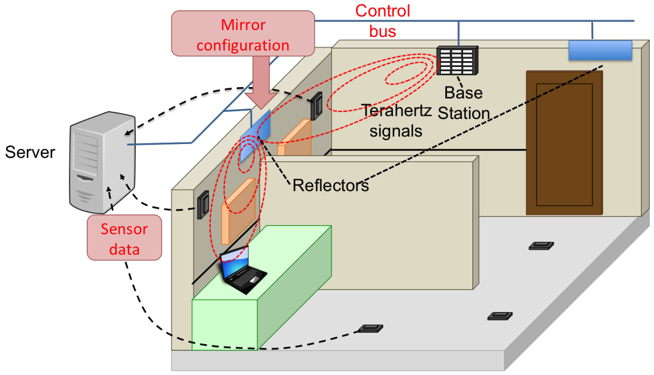


Fig. 1: Indoor Software-Defined Reflector architecture for wireless terahertz communications.

or an array of antennas. Each of these antenna strips emit terahertz waves, and can be constructed from metamaterials such as graphene. Recent studies have shown that graphene has superior properties for emitting terahertz waves [1][7]. As described earlier in the introduction, given the highly unstable nature of this particular high frequency signals, the indoor environment will consist of reflectors to assist in reflecting the signals towards the device. At the same time, given the highly temporal and spatial instability effects of the signals, there is a need to have a full view of the signal propagation and its strength. This is achieved by placing sensors in the environment, and these sensors will not only sense the signal strength of the terahertz signals, but also other atmospheric effects that can affect the quality of the signals. The sensor data are sent to a server, which in turn analyzes the condition and location of the device, before automating the configuration of the reflectors as well as transmitting antenna strip on the arrays. Effectively the reflectors will produce virtual LoS signals between the base station and the device.

III. TERAHERTZ RAY-TRACING SIMULATOR

A. *Simulator*

A THz ray tracing simulator using Python has been developed to simulate the signals and analyze the propagation and reflection paths. Fig. 2 presents the block diagram of the simulator modules, that includes the properties of the terahertz signals as well as the configuration of the reflectors. The main features of the simulator includes, (i) dimensioning of the indoor space and placements of objects by specifying their vertex position, (ii) placement of the base station transmitter, as well as position, size, and configurable angles of the reflectors, (iii) simulating the rays that are emitted from the base station, as well as from the reflectors, and (iv) calculating the coverage areas and displaying this into multiple layers in order to analyze the details of interests.

Figure 3 shows an example of THz received power for different locations inside a room, where there are no obstacles (a), and when there are obstacles (b). The power has peak level at the *Tx* and dramatically decays with respect to the distance and shows total outage when the signal is obstructed.

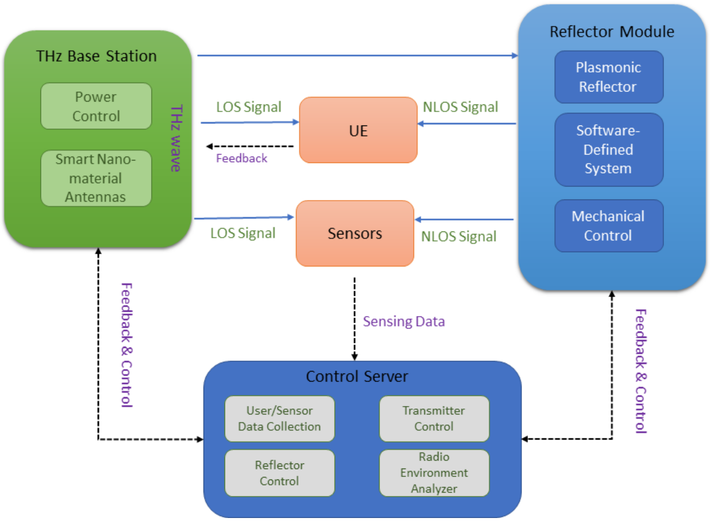
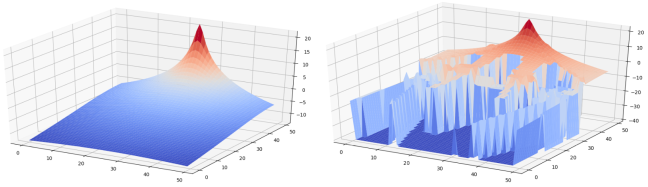
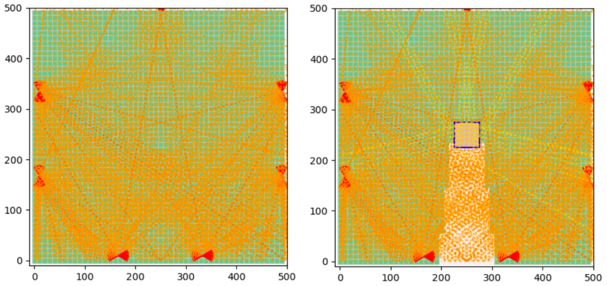


Fig. 2: Block diagram of THz Software-Defined System.



(a) (b)

Fig. 3: Indoor THz signal strength scenarios for both cases of no-obstacles (a), and with obstacles (b).



(a) (b)

Fig. 4: Ray tracing of signals with mirror-assistances in both scenarios of no-obstacles (a) and with obstacles (b).

Fig. 4 represents the simulated effect of the mirrors to help improve the signal coverage area for both the free space (a), and shadowed areas (b). In this paper, our simulation is based on a living room environment as can be seen from Fig. 5. The Figure illustrates the signal beams that varies with the position of the reflectors to demonstrate how signals can reach specific locations with the assitance of the mirrors.

B. *Results*

The presence of the THz signal coverage area under different criterions is conducted by simulation and results were analyzed by varying the size, and locations of the reflectors. The parameters are defined as follows: room size: 5m x

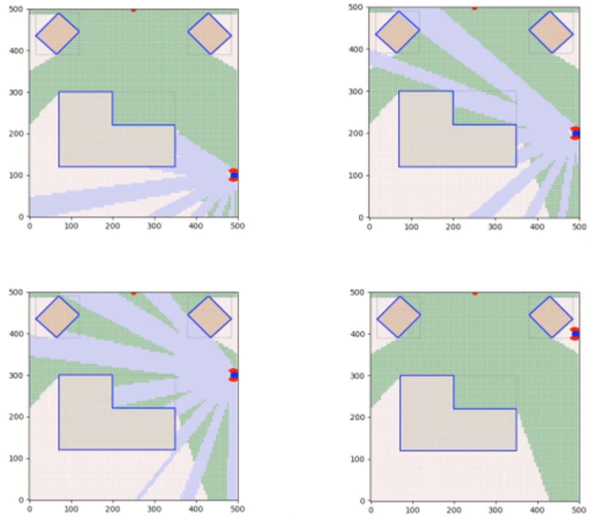


Fig. 5: Illustration of dynamic reflectors at different positions and at different angles.

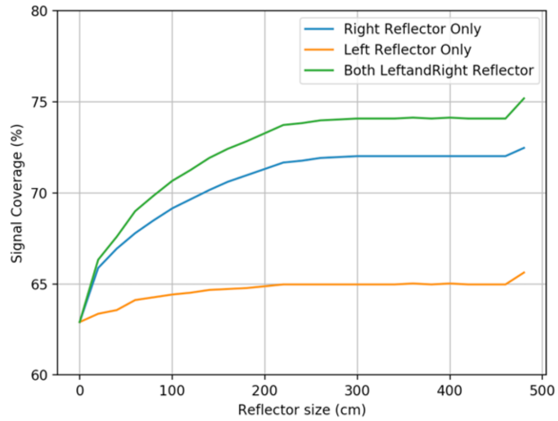


Fig. 6: Simulation result of the coverage area using different reflector sizes.

5m, mirror sizes: 0-500 cm, maximum angle: 45 degrees, maximum number of mirror: 4, and obstacles: 3. The performance of multi-reflectors coverage area is demonstrated by an example of a simulated room with identical furnished obstacles. In the following subsections, the comparison of the coverage area with a variety of reflectors sizes attached to each side of the wall is first described followed by the analysis of the results.

C. Varying reflector size on each side of the wall

To compare the signal coverage area, we modify the size of the reflector from small to large. As can be seen in Fig. 6, the function of the different reflector size at three different wall side - right wall, left wall, and both right and left wall are different. From fig. 6, the results show that the large size of the reflector obviously provides greater signal coverage area than the small size. However, after the reflector size exceeds 200 cm, the increasing size will not always provide increased coverage. We found that we can obtain an appropriate size of the reflector owing to the rooms size and obstacles properties. Moreover, we also test the different possibilities of when only one reflector is installed on the right side, only one is on the left side, and when two reflectors are installed on each wall. From these tests, when installing on the right side, more area is covered compared to the left. Conclusively, this assumption about the coverage area still depends on the factors such as the shape and size of the obstacles.

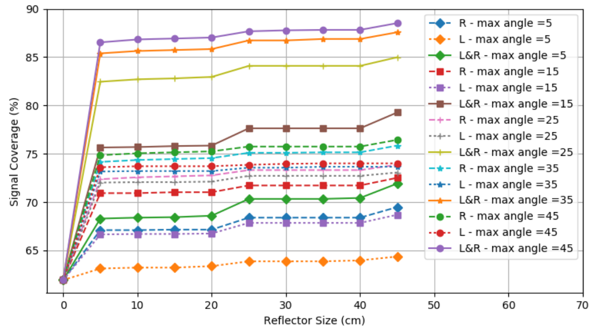


Fig. 7: Simulation result of the coverage area using different sizes and different rotatation angles.

D. Rotatable reflectors with different sizes and maximum angles

We have compared the signal coverage area where the size, the location and the maximum rotatable angle are different. As a result, shown in Fig. 7, the signal coverage area approaches 90 percent when the rotatable reflectors are installed on both sides of the walls (illustrated as a solid lines). Also, the maximum rotatable angle is another significant factor required in order to obtain a greater coverage area. Additionally, using the rotatable reflectors could virtually reduce the reflector size. In Fig. 5, the graph depicts that the large size of reflectors does not necessarily influence an increase in the signal coverage area, thus, we could then probably design more realistic and practical system with small-size reflectors that at distributed at strategic points within the room.

E. Multi-rotatable reflectors with different sizes and maximum angles

In this simulation, we add 2 rotatable reflectors onto both walls of the room. The configurations are identical as the previous subsection. Fig. 8 presents the results. Regarding the added reflectors, the coverage area would be further increased to almost 100 percent of the free-space area. However, this comes at a cost resulting from increasing the number of mirrors, and also increased configuration complexity when coordinating the rotation of the mirrors.

IV. FUTURE OUTLOOK

In previous sections we have describe the effect of wireless signal blockages and scattering dur to the obstacle and a solution to mitigate this problem using a mirror-assisted system.

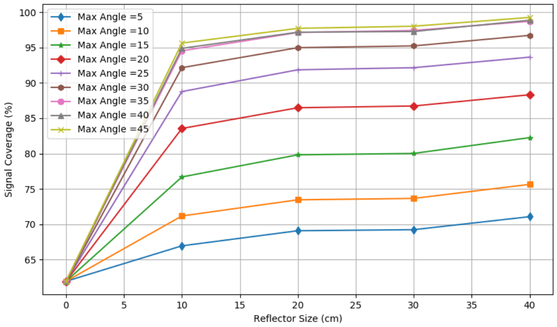


Fig. 8: Simulation result of the coverage area using different sizes and different rotation angles for 4 reflectors (2 reflectors on each side of the wall).

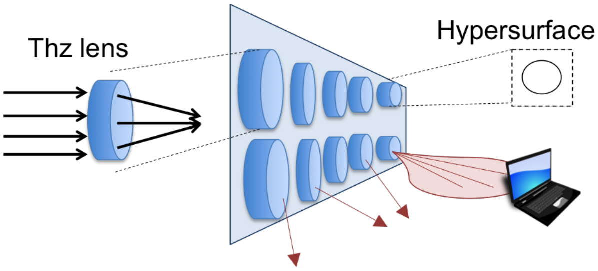


Fig. 9: Future perspective of programmable reflectors with specialized materials.

For future outlook, further performance improvements can be incorporated through multi-disciplinary research that incorporates concepts from Physics. This may include the design and fabrication of dielectric lenses for Terahertz focal plane arrays [6] to improve THz transmission coefficient, or the most recent state-of-the-art software-defined HyperSurface, which is a material with programmable behavior[7] that can smartly reflect wireless signals in an indoor environment. The HyperSurface system is a new assisting component for terahertz communication, where planar artificial metasurface structures are utilized to control the reflected effects of the electromagnetic waves. This is achieved through the placements of HyperSurface tiles on the walls, where they are then be controlled by a central server. The software control of the tiles is by altering the structure of the meta-atom on each of the tile, which in turn allows the electromagnetic waves to be controlled in terms of their reflected direction and power. This also provides a new level of multi- frequency operation. However the study in [7] has evaluated only two ranges of frequencies, 2.4 GHz and 60 GHz. As illustrated in Fig. 9, the lens and the HyperSurface control of meta-atoms can provide new capabilities of directing the terahertz waves if they are incorporated into the steerable reflectors. This could be developed in conjunction with the base station arrays of antennas that are emitting the waves.

V. CONCLUSION

Non-Line-of-sight (NLOS) problem in high frequency communications is one of the key factors that need to be considered, which in turn requires novel solution that can lead to practical future applications. The expected Terahertz band for the next evolution of wireless communication technology will face a similar challenge. In this paper we propose the use of reflectors as part of the software-defined reflector system. This system will enable the mirrors to be rotated depending on the dynamic obstacles within the room to help reflect signals towards the device. The system will collect sensor information from the room to determine the optimum angles of the mirrors. In order to validate the feasibility of using the mirrors, we have developed a THz ray tracing simulator that analyzes the proposed rotatable reflector(s) in an indoor environment. The results show that the size of the reflectors can improve the signal coverage in the system; and that larger reflectors results in larger coverage area. However, when using small and rotatable reflectors, the coverage area can also be extended. In addition, from the result of our study, the coverable areas will be increased to almost 100 percent in the event that we install an appropriate number of reflectors at suitable location. Its capability to rotate to any area and to reflect signal into any specific (i.e. no-signal) location can be controlled through the software-defined system.

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