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# Further Propagation Investigation of a Low Density Urban Environment with Drains

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**Abstract**—In South East Asian countries, particularly in a developed Asian city, open-trench drains systems are prominent due to climatic differences. Open-trench drain structures occupy a great part of the terrain topography in Malaysia, and therefore this project aims to further investigate the impacts that open-trench drain systems have on radio propagation prediction in a low density urban environment. Towards that end, we have engaged an interactive 3D ray-tracing tool to build the environment depicting a low density setting with clusters of low rise building structures oriented far apart from each other. The existence of open-trench drains is incorporated into a mock city model to obtain propagation prediction results for different operating frequencies. One of the primary differences this study in comparison to the existing studies on ray-tracing modeling of an urban city with open-trench drains is that the quantity of building models and open-trench drain structures are generated over a wider area to mimic actual low density city settings. When such scenarios are considered, the impacts of open-trench drain structures fade away.

## 1. INTRODUCTION

Wireless communication has assumed an essential and integral role in daily activities, and it is embraced by consumers globally. The increasing growth of civilization has led to tremendous usage of cellular mobile radio systems, escalating the demand and usage for wireless communications in the present and towards the future. This growth is proliferated by the increase of technological advancements directed at making radio equipment more reliable, compact, and affordable. A pattern and awareness of radio waves propagation characteristics contributes considerably to the effectual design and implementation of wireless communication systems in cities. Therefore, it is important that the propagation of electromagnetic waves is analyzed in depth with relation to complex and irregular environments.

Wireless communication can be described as the transmission of information between two or more points without connected by an electrical conductor. The information is transmitted through open space by radio waves from the electromagnetic spectrum. The transmitter radiates radio waves through a device called antenna. On the receiving end, a receiver intercepts the radio waves with a receiving antenna. Commercial uses of radio waves include communication satellites, computer networks, deep space radio communications, television, mobile radio communications, among others.

During message transmission, losses occur between the transmitter and the receiver. This type of loss is known as propagation path loss. Path loss can be defined as the unwanted reduction in power density of the transmitted signal. This path loss arises from various transmission properties such as reflection, refraction, diffraction, and scattering [1].

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A well-designed and positioned cellular structure is very important in ensuring a successful and effective cellular mobile radio system. Thus, mean path loss behavior and fading characteristics have to be predicted to ensure that the communication pathway has optimized characteristics.

This paper approaches the operating frequency range of Ultra High Frequency (UHF), where indirect propagation also known as non-line-of-sight (LOS) propagation is rampant. Indirect propagation describes terrestrial propagation whereby LOS is absent. Cases where non-LOS is present involve the use of electromagnetic wave properties such as reflection on planes and diffraction around buildings to provide a possible technique for signal transmission. Mainly, Very High Frequency (VHF) and UHF frequencies travel by LOS propagation and ground bounce propagation [2]. Hence the receiver will receive a signal of the vector sum of a direct wave from free space and a ground-reflected wave. The numerous factors that affect radio wave propagation are diffraction, multipath reflection, refraction, and scattering. These factors occur due to various parameters on space wave propagation listed below [3]:

a) Curvature of the earth [4].
b) Effects of terrain irregularities (rough surfaces and vegetation) [5].
c) Effects of obstacles (hills and buildings) [6].

The range of the frequency determines its viability of non-LOS propagation. In free space, lower frequency signals travel at a longer distance due to the signal experiencing diffraction from the ground or reflection by the upper atmospheric layers and can penetrate buildings more effectively. High frequencies are more sensitive to reflection and diffraction off of objects visible in its field, and they will have a more difficult time passing through walls and obstacles in general. At the same time, their small wavelengths enable them to easily leak through holes and gaps if the aperture is the size of the wavelength; therefore, it is worth noting that high frequency electromagnetic waves are more suitable for transmission in short distances. Because we are interested in seeing the path loss in longer ranges, the frequencies selected for this work are 1.8 and 2.4 GHz.

In this paper, a model of an ideal low density city environment with and without open-trench drains is created. The power gain is observed for a variety of scenarios at the two aforementioned frequencies by engaging an interactive 3D ray-tracing tool developed by the Hawaii Center for Advanced Communications (HCAC). We have previously engaged the same ray-tracing tool to create a simple city model comprising four buildings and observed how waves propagate differently in two distinct scenarios [7]. The open-trench drain, in and by itself, makes up a legitimate channel in which waves can satisfactorily travel for a reasonable distance [8]. Beyond what was previously reported, in this work we have considered three distinctive scenarios in the low density city model, namely, variation of the receiver (Rx)-transmitter (Tx) distance under the circumstances whereby the drain structures and building structures are remote, varying the depth of the open-trench drains and varying the transmitter height. Each scenario encapsulates a different setting whereby the location of the Tx, the direction the Rx maneuvers, the operating frequency deployed by the Tx, the separation distance between the Rx and the open-trench drains, and the structures of the building surrounding the Rx are altered to diversify the simulations.

For validating our ray-tracing tool, we have applied it to generate simulation result compared against the field measurement result of vertical-vertical polarization of signal at 2.4 GHz based on the geometry in [8]. This validation is shown in Fig. 1, where a good agreement is reached. In our ray-tracing tool, the basic geometry entity is a **plate** which is a planar polygon. A **plate** is represented by the primitive geometric objects **triangles**. A **plate** can be used to simulate a wall, a rooftop, or a piece of terrain. In this ray-tracing tool, the concept of **building** is not used, but a restriction for the **plate** is forced based on a building, i.e., the normal direction of a **plate** is defined as the unit vector normal to the **plate** and pointed outwardly from the building. For terrain **plate**, the normal directions are pointed toward the air from the earth. The input file to the ray tracing engine is a description of the model, the electric parameter, and the antennas. Further mathematical formulation of our ray-tracing method is available from [9].

It should be pointed out that ray-tracing method has its own limitation in that it is site-specific, but it comes with an advantage, that is, enhanced accuracy. The current condition in the world is that the views on propagation precision are divided. On one hand, some researchers think that the more accurate is the environment description, the more reliable is the propagation prediction; on the other

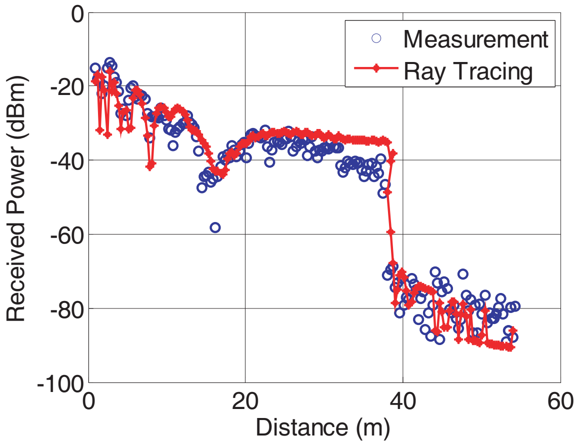


**Figure 1.** Validation of the measurement and ray-tracing results.

hand, some researchers argue that a rougher representation of the propagation environment can perform better because the lack of some details can somehow compensate for the lack of others, so that the final outcome can be surprisingly better. There is no de facto say on this as yet.

## 2. VARIATION OF THE RX-TX DISTANCE UNDER THE CIRCUMSTANCES WHEREBY THE DRAIN AND BUILDING STRUCTURES ARE REMOTE

The scenario in Fig. 2 depicts the possible position of a Tx-Rx in an open terrain distant from open-trench drain structures and building sites whereby interest is generated in discovering how well the Rx picks up signal. As illustrated in Fig. 2, the Rx follows a circular path at regular intervals of 2 m on the perimeter of the circle with a total of 377 points of power gain. In this specific scenario, the Rx is positioned on the radius of the circular path, whereby the center of the circle has coordinates (300, 250, 12) for the 3-D plane $(x, y, z)$, and the value of the radius is 60 m. The Tx is located on the rooftop of Building A at a towering height of 80 m and generates an operating frequency of 1.8 GHz. The height of the Rx is 12 m, and its initial position has coordinates (360, 250, 12). The Rx travels in an anti-clockwise direction with the power gain plotted in Fig. 3.

The graph in Fig. 3 indicates no variance between the power gains received by the Rx in an environment with the presence of drain structures and in a setting without the presence of drain structures. The mean value of the power gain for the low density urban model is $-82.941$ dB with the presence of open-trench drains and $-82.938$ dB without the existence of open-trench drains. The relative variation of power gain is 0.00393% which informs us that the presence of open-trench drains does not administer any substantial increase or decrease in power gain. This value is obtained between the power gains with the presence of drain and without the presence of drain, and the formula used is [(With Drain — Without Drain)/Without Drain)*100%. The power gain roughly displays the shape of an inverse sine-waveform with multiple noticeable and distinguishable spikes throughout the first half of the waveform.

As can be observed in Fig. 3, the Rx at both minimum path gain (approximately $-101$ dB) and maximum path gain (approximately $-77$ dB), receives multiple propagating rays. The location of the Rx at minimum path gain (353, 277, 12) is directly in LOS and travels the maximum distance therefore receiving minimum signal strength. The propagating signal is unable to interact with any neighbouring building structure or open-trench drains ensuring that the existences of edge-diffracted rays and reflected rays from drain structures are not present in the simulations. However in Fig. 4(a), a reflected propagating ray from the surface of the roof contributes to a participating propagating ray at minimum path gain. In Fig. 4(b), the scenario for maximum path gain occurs at the Rx location (240, 240, 12) and constitutes both a LOS ray and an edge-diffracting ray from the roof. There is also a possibility whereby the Rx receives three different types of propagating ray, i.e., a direct LOS ray, an edge-diffracted ray and a roof surface-reflected ray as displayed in Fig. 4(c). As can be seen, when the

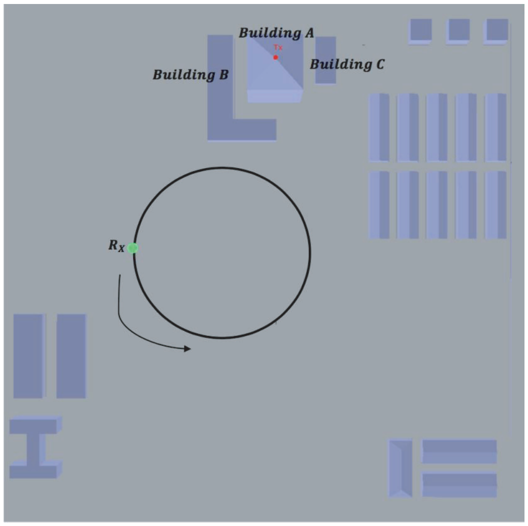


**Figure 2.** Plan view of the motion of the receiver indicates the direction is circular in an open space. (not to scale).

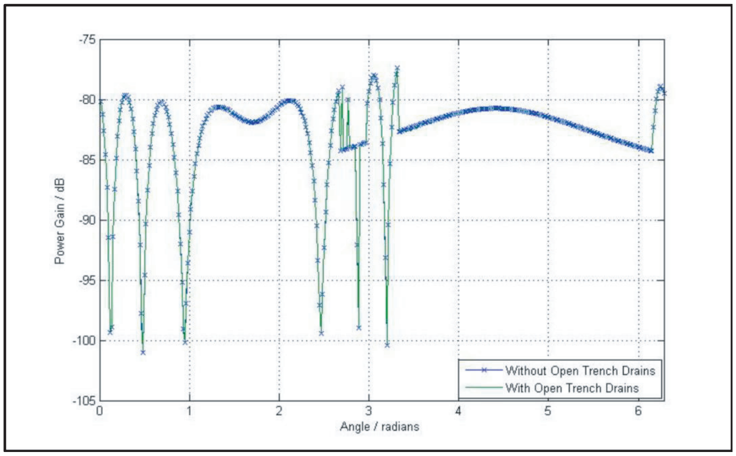
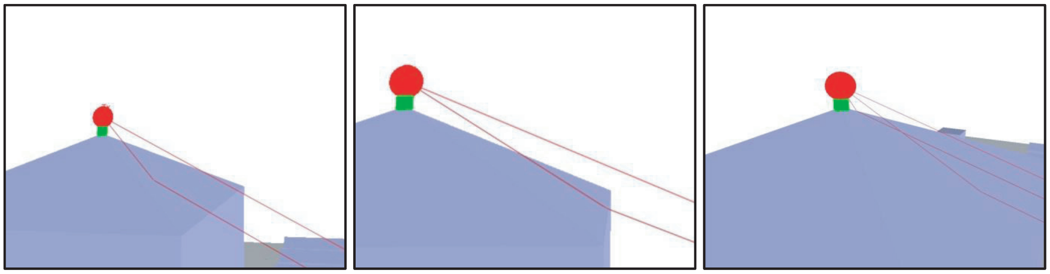


**Figure 3.** The power gain (dB) along the receiver's circular path at 1.8 GHz for two different scenarios.



(a) (b) (c)

**Figure 4.** (a) Propagating rays at minimum path gain. (b) Propagating rays at maximum path gain. (c) Different types of propagating rays present.

drain structures are present but completely distant from the transmission interaction between the Tx and Rx, the open-trench drains can be considered absent in the terrain. The participating rays observed in this specific scenario is produced from the distinguished geometry of the building whereby the Tx is located.

## 3. VARYING THE DEPTH OF THE OPEN-TRENCH DRAINS

This simulation analyses the behaviour of power gain when being exposed to open-trench drains at different depths. The drain depth of this particular scenario is varied, and the simulations are performed for drain depths of 0.2 m, 0.4 m, and 0.6 m. The scenario depicts the movement of a pedestrian as it travels a distance of 80 m away from the Tx in a straight path on a flat terrain at a regular interval of 0.5 m with a total of 161 points of power gain. Specifically, the situation indicates a person walking adjacent and equidistant, 5.4 m away from the nearest edge of the open-trench drain as the open-trench drains are located adjacent to the walls of each building structure. Tx is located on the corner of the rooftop of Building A at a height of 27 m for an operating frequency of 1.8 GHz. The height of the Rx is analogous with the height of a pedestrian of 1.7 m. Fig. 5 shows the buildings layout while Fig. 6 plots the path gains results for varying drains' depth. In Fig. 7, an illustration of the participating rays when the Rx is at a distance of 35 m in an environment with open-trench drain is shown.

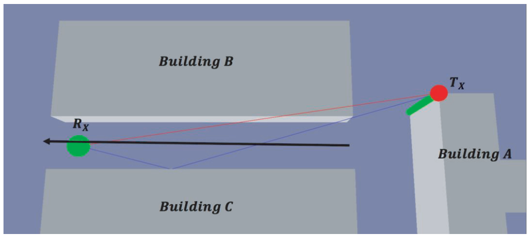


**Figure 5.** View of the participating rays when the receiver location is at a distance of 35 m in an environment without open-trench drains.

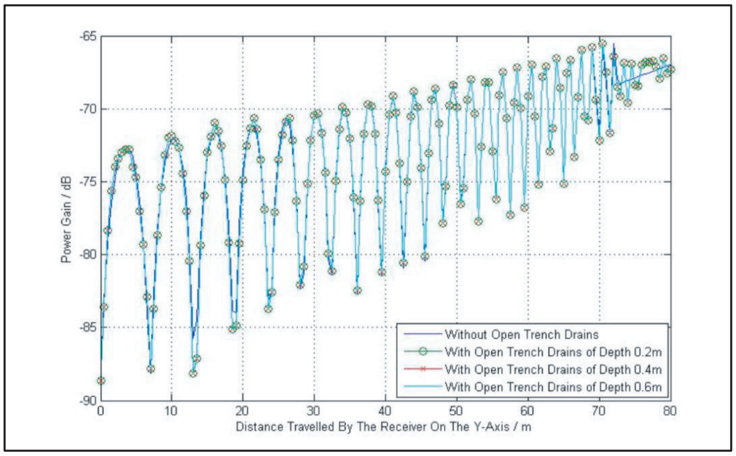


**Figure 6.** Path gain when the receiver is at a distance of 35 m with differing drain's depth.

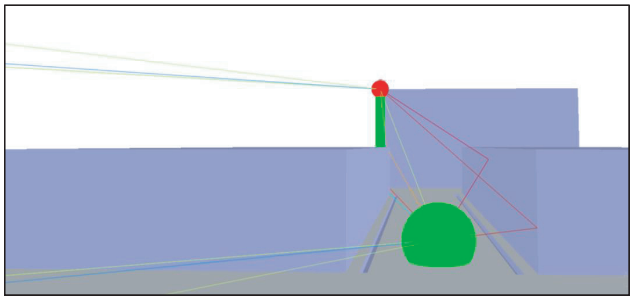


**Figure 7.** View of the participating rays when the receiver location is at a distance of 35 m in an environment with open-trench drains.

The general trend in Fig. 6 indicates a gradual increase in signal strength as the separation distance between the Tx and Rx increases. This is so because for this particular scenario, when the Rx moves further away from the initial starting point, a richer multipath environment is recorded thanks to the surrounding buildings' walls. In other words, in the first several Rx locations, the surrounding walls from Buildings B and C do not play a part in the total path gains. It can be observed that although the power gains in both the models with and without the presence of open-trench drains are similar, the participating rays in both the environments are nevertheless different from each other. In the former, the participating rays contain LOS ray, edge-diffracted rays and wall-reflected rays in neighbouring buildings; whereas for the latter, they contain only a LOS ray and a wall-reflected ray from Building C. The mean values of the power gain at drain depths 0.2 m, 0.4 m and 0.6 m are identical and have a value of −73.132 dB. In comparison, the scenario without the presence of an open-trench drain has a mean value of −73.072 dB. The relative variation of power gain is 0.0821%. There are no significant changes as the drain depth varies from 0.3 m to 0.6 m indicating that the drain depth is independent of the power gain in the Rx.

## 4. VARYING THE TRANSMITTER HEIGHT

This scenario depicts the movement of a pedestrian as it travels a minimal distance of 30 m away from the Tx in a straight path on a flat terrain surrounded by high rise infrastructure at a regular interval of 0.2 m delivering a total of 152 points of power gain. The Tx is located with varying height in free space

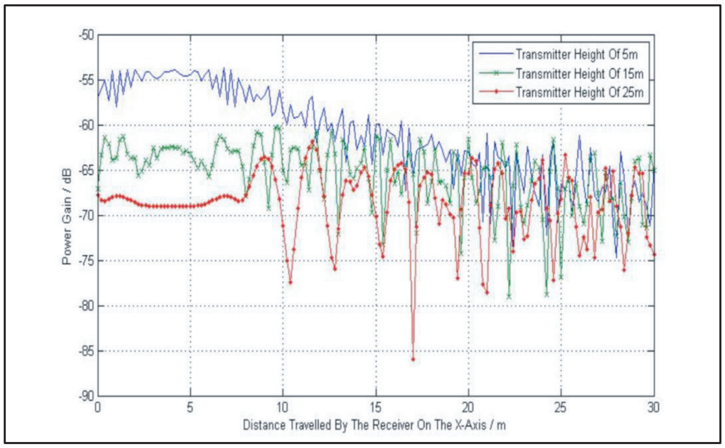


**Figure 8.** The power gain recorded with varying transmitter height in an environment with open-trench drains.

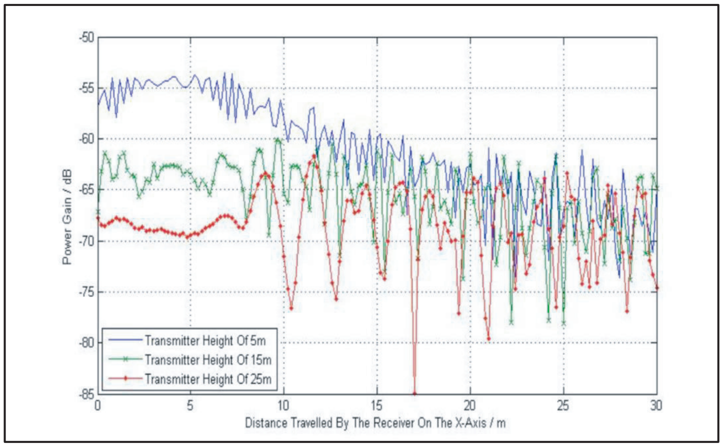


**Figure 9.** The power gain recorded with varying transmitter height in an environment without open-trench drains.

above ground for an operating frequency of 2.4 GHz. The height of the Tx is established at 5 m, 15 m, and 25 m. The height of the Rx is analogous with the height of a pedestrian of 1.7 m. The figures below depict the propagation characteristics between the Tx and the Rx at varying height in two conditions, namely, with open-trench drains (Fig. 8) and without open-trench drain (Fig. 9). Figs. 10 to 12 further illustrate the participating rays at the three Tx heights, namely, 5 m, 15 m, and 25 m, respectively.

The mean values of the power gain obtained at a transmitter distance of 5 m for the environments with and without an open-trench drain are −61.1636 dB and −61.1604 dB, respectively. When the transmitter distance is increased to 15 m, the power gain for the environment with an open-trench drain is −65.4467 dB, and that without the open-trench drain is −65.4543 dB. When the height of the transmitter is further increased to 25 m, the mean value of the power gain is −68.7704 dB in the setting with the existence of open-trench drains and −68.7579 dB without the presence of open-trench drains. On the other hand, the highest relative variation of power gain obtained is 0.0181%, in which the discrepancies are considered negligible. It implies that the presence of an open-trench drain structure in a scenario where the Rx is enclosed in a dense environment (surrounded by towering building structures) does not contribute to any power gain difference in comparison to an environment without the presence of an open-trench drain.

In Fig. 10, the participating rays are dense, and the wall-reflected rays are the primary propagating

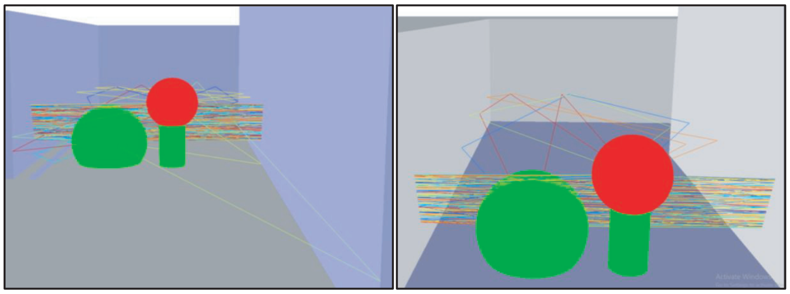

(a) (b)

**Figure 10.** View of the participating rays with a transmitter height of 5 m (a) with open-trench drain, (b) no drain.

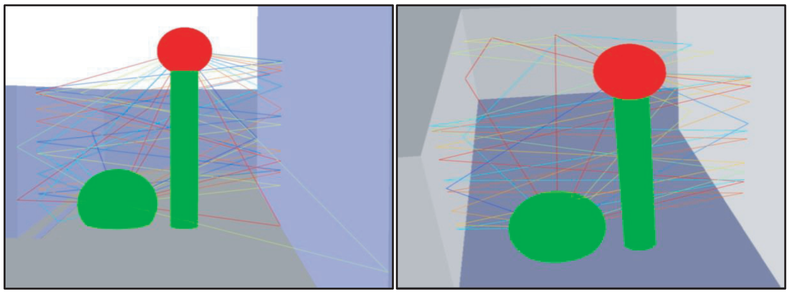

(a) (b)

**Figure 11.** View of the participating rays with a transmitter height of 15 m (a) with open-trench drain, (b) no drain.

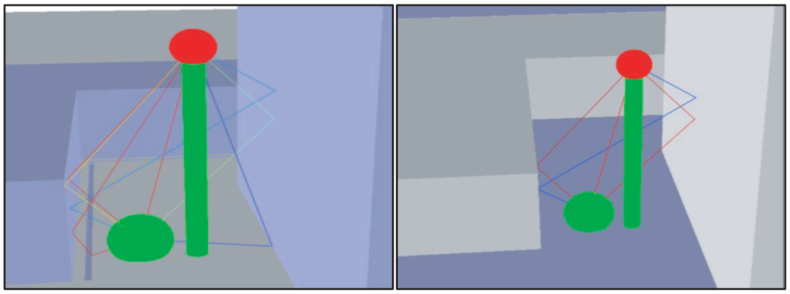

(a) (b)

**Figure 12.** View of the participating rays with a transmitter height of 25 m (a) with open-trench drain, (b) no drain.

rays. There are three scenarios demonstrating multiple diffractions. The participating hybrid rays in the first case are made up of a drain edge-diffracted ray and numerous wall-reflected rays. The second scenario consists of a wall edge-diffracted ray and numerous wall-reflected rays. The third scenario consists solely of wall-reflected rays. In Fig. 11, the participating rays are more scattered; however, the number of reflection and diffraction cases is seen more clearly in this case. In Fig. 12, the participating rays are less, and the number of reflection and diffraction cases drops immensely.

The general trend in Fig. 8 and Fig. 9 shows that when the Tx is closest to the Rx, the obtained power gain is the highest. However, when the Rx moves away from the Tx of height 5 m, the power gain decreases at a steeper gradient than a Tx of height 25 m. This could be due to the effect of multipath whereby an increase in the number of participating rays contributes to a greater increase or decrease in power gain.

## 5. CONCLUSION

In this paper, we have reported further investigations on the impacts of open-trench drains in a low-dense urban environment setting and reported their findings, including "negative" results. The first scenario in Section 2 indicates that when the drain structures are present but very distant from the transmission interaction between the Tx and Rx, the open-trench drains can be considered absent in the terrain. The second scenario in Section 3 describes that the power gains received with varying drain depths are similar; however, the participating rays in their respective environments are nonetheless different from each other. Finally, the third scenario in Section 4 indicates the correlation between the number of participating rays and the number of multiple reflections and diffractions cases, which contributes to a greater increase or decrease in power gain depending on the situation and environment as the number of participating rays decreases with an increase in Tx height. In summary, unlike what was previously considered when towering structures are prominent near the open-trench drain structures with the Rx moving just right next to the said drains, in this work we present three distinct scenarios where the drains effects cannot be clearly seen.

## ACKNOWLEDGMENT

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