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Research Article

Direction-of-Arrival Analysis for Radio Signal Detection from under Real Collapsed Building after Several Earthquakes

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Abstract – This paper investigates how radio signals travel through earthquake rubble to assist search-and-rescue teams in locating trapped survivors. The experiment focuses on both antenna performance and accurate localization of a buried transmitter by scanning multiple points around collapsed buildings. A continuous wave signal (500–2000 MHz) was transmitted from under the rubble, and signal strength was measured at different positions. The dipole antenna was first used to scan large disaster areas, such as Tall Rifat, where entire neighborhoods were destroyed, making it difficult to determine the exact locations of collapsed buildings. Its omnidirectional nature allowed for broad signal detection. Once a signal was identified, the LOG-Periodic antenna was used to precisely determine the transmitter's location. By directing the LOG-Periodic antenna towards the signal source, a strong peak was observed, while rotating it 180 degrees nearly eliminated the signal. The study also examines signal behavior at different distances and angles, measuring reception at multiple points on each side of the collapsed buildings. The findings and details of these analyses are presented, specifically when evaluating the impact of antenna type, frequency, and receiver positioning on signal detection and localization.

Keywords – Attenuation, Radio Communications, Building Penetration, Earthquake Rubble Characterization, Emergency Responders, Direction of Arrival.

I. INTRODUCTION

Natural disasters such as earthquakes, landslides, and explosions often cause severe structural collapses, trapping survivors under rubble. Search-and-rescue teams rely on various detection methods, including sound sensors, thermal imaging, and trained rescue dogs, to locate survivors. However, these conventional methods are often limited by noise interference, environmental conditions, and accessibility challenges [1], making it difficult to detect individuals trapped beneath debris. In recent years, radio frequency (RF) signals have been explored as a potential tool for detecting survivors under collapsed structures. RF signals can penetrate materials, allowing for signal transmission and reception through rubble [2]. By analyzing received signal strength and direction, emergency responders can estimate the location of a hidden signal source. This method has significant advantages, particularly in environments where conventional search techniques fail [3].

Previous research has investigated signal propagation through obstacles, focusing on factors such as frequency-dependent attenuation, antenna type, and directional signal reception [4]. Studies have demonstrated that directional antennas improve signal localization, while omnidirectional antennas allow for broad initial detection [5]. However, there is a need for a systematic approach combining both antenna types to efficiently detect and pinpoint signals in large-scale disaster scenarios. It has also shown in the literature that higher frequencies mostly experience higher attenuation [3].

In this context, this study employs real-world experimentation in an earthquake-affected area to understand RF signal behaviour under actual disaster conditions. For this purpose, 500-2000 MHz radio signal propagation through real collapsed structures were assessed using both omnidirectional and directional antennas. Specifically, the research focuses on determining the suitability of antennas for detecting radio signals under debris and analyzing signal attenuation and directionality across multiple measurement points where structural locations are unknown by first identifying signals with a dipole antenna and then pinpointing the approximate location using a directional LOG-Periodic antenna. The experiment was conducted in Tall Rifat, a disaster-affected area where entire neighborhoods were destroyed, making it difficult to determine exact building locations. The dipole antenna was used first to detect any potential signals across a wide area, while the LOG-Periodic antenna was then used to precisely locate the transmitter's position by measuring signal strength at multiple points on each side of the rubble. In addition to these direction-of-arrival estimation analyzes, the frequency variations of rubble attenuation were also evaluated for different debris conditions. The findings of this research will contribute to more effective RF-based disaster response strategies, enhancing survivor detection capabilities for emergency teams.

II. MATERIALS AND METHOD

The field experiments were conducted in Tall Rifat, Syria, a region severely impacted by an earthquake where entire neighborhoods were destroyed as shown in Fig.1. Due to the extent of destruction, the exact locations of collapsed buildings were unknown, creating a realistic scenario for large-area signal scanning and survivor localization. The terrain included rubble, reinforced concrete, and debris, serving as natural obstacles to radio signal propagation. Since different building materials can affect RF penetration, previous studies have analyzed attenuation patterns in various environments [4]. The experimental conditions in this study closely resemble real-life emergency scenarios, ensuring that the findings are practically applicable.

Fig. 1. The collapsing of entire neighborhoods.

A. Measurement System

The measurement system involved the use of a Software-Defined Radio (SDR) transceiver, HackRF One which served as both the transmitter and receiver (see Fig. 2). HackRF One operates within a broad frequency range of 1 MHz to 6 GHz [6, 7], making it suitable for analyzing signal behavior over multiple frequency bands. Two types of antennas were used in the study: a dipole antenna which provides omnidirectional radiation, and a LOG-Periodic antenna [8], which is directional and allows focused signal reception.

Fig. 2. Measurement materials: Left: HackRF One transceiver, Middle: Original HackRF dipole antenna Right: Log-periodic (HyperLOG) directional antenna.

B. Method

The transmitter was placed under the rubble and continuously transmitted signals in the 500 MHz to 2000 MHz range, with frequency steps of 100 MHz. The measurement process involved placing the transmitter in two distinct locations—one at the center of a collapsed building and another at a corner of a collapsed structure—allowing for a comparative analysis of signal attenuation and reception patterns based on the transmitter's position relative to the receiver (see Fig. 3.)

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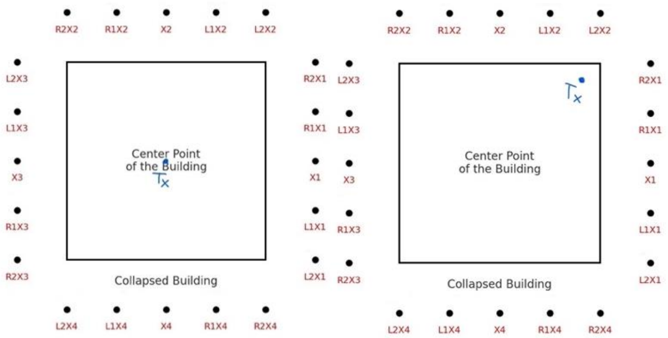
(a) (b)

Fig. 3. (a) 1st where Tx located at the center of the collapsed building, (b) 2nd site where Tx located at a corner of the collapsed building.



(a) (b)

Fig. 4. (a) 1st site where Tx at the center of the collapsed building with multiple receiving points & sides, (b) 2nd site where Tx at a corner of the collapsed building with multiple receiving points & sides.

To accurately assess signal propagation, the receiver was systematically positioned at multiple points around the rubble. Measurements were taken on all four sides of the collapsed buildings, with five evenly spaced points on each side as shown in Fig. 4. A laser meter was used to ensure consistent positioning across all measurement points. The reception process followed a structured two-step approach to optimize detection efficiency. Initially, the dipole antenna was connected to the receiver to perform broad-area scanning, ensuring that no signals were overlooked. This method was necessary given the widespread destruction of Tall Rifat seen in Fig. 1, where the locations of individual buildings were not clearly identifiable. By detecting signals in all directions, the dipole antenna enabled the identification of emitting RF signals. Once a signal was detected, the dipole antenna was replaced with the LOG-Periodic antenna to accurately determine the transmitter's position Fig. 3. The directional nature of the LOG-Periodic antenna allowed for a refined search process by gradually rotating the antenna until the maximum signal strength was observed, thereby indicating the precise direction of the signal source. A 180-degree rotation test was performed, demonstrating that when the LOG-Periodic antenna was aimed directly at the transmitter, the received signal strength peaked, whereas when turned completely away from the source, the signal nearly disappeared.

Signal strength was recorded at each receiver position and frequency step, providing data for further analysis. The received power was evaluated using the standard path loss equation [4]

$$Pr = Pt + Gt + Gr - PL \tag{1}$$

where Pr represents the received power, Pt is the transmitted power, Gt and Gr denote the gains of the transmitting and receiving antennas, PL refers to the path loss. By analyzing variations in received power at different measurement points, the study examined the impact of frequency, distance, and antenna type on signal detection accuracy. The results of these analyses are further discussed in the following section, focusing on attenuation patterns, directionality effects, and the feasibility of RF-based search-and-rescue applications.

III. RESULTS

The results are presented systematically, focusing on the received signal strength measurements at various frequencies, different antenna types, and different transmitter positions. Measurements were taken along all four sides of two collapsed buildings, with the receiver positioned at multiple points spaced evenly at 2-meter intervals. The objective of the measurements was to characterize how signal attenuation varied under different conditions and to evaluate the ability of each antenna to detect and localize the transmitter's position beneath the rubble. Sample results of these measurements were presented in the following.

A. Frequency Variation of Attenuation

As a first analysis, variation of attenuation with frequency was investigated by using the results of 1st site given in Table. 1. These measured data, also plotted in Fig. 5 and Fig. 6, demonstrate that as frequency increases, the received signal strength decreases across all measurement points. This trend is expected, as higher frequencies generally experience greater attenuation due to material penetration losses and environmental obstructions. Both the dipole and LOG-Periodic antennas exhibited this pattern, with the LOG-Periodic antenna consistently achieving stronger reception, particularly at higher frequencies, due to its directional gain (see Fig. 5 and Fig. 6).

B. Effect of Direction-of-Arrival

Another important observation is that when considering a single frequency levels, such as 500 MHz (see Table 2 and Fig. 7), the highest received signal strength was recorded when the receiver was positioned perpendicular to the transmitter. Since the receiver measurement points were evenly spaced on all four sides of both buildings, this confirms that the strongest reception is achieved when the receiver is aligned directly with the transmitter. This effect was consistent across both test scenarios but was more uniform in the first building compared to the second.

Table 1. Frequency measurement results for the 1st site.

MHz	Received values at center point of the building perpendicular on Tx: DIRECTIONAL "Peak (dB)"	Received values at center point of the building perpendicular on Tx: DIPOLE "Peak (dB)"	Received Values, SHIFT 2m RIGHT: DIRECTIONAL "Peak (dB)"	Received Values, SHIFT 2m RIGHT: DIPOLE "Peak (dB)"
500	- 52.1	- 54.0	- 53.7	- 56.9
600	- 53.6	- 55.5	- 55.1	- 58.0
700	- 55.4	- 57.8	- 57.0	- 59.1
800	- 57.9	- 60.0	- 59.1	- 62.7
900	- 58.7	- 62.4	- 60.6	- 64.4
1000	- 60.0	- 63.6	- 62.3	- 66.2
1100	- 62.7	- 65.5	- 64.8	- 68.5
1200	- 63.9	- 67.4	- 66.0	- 70.3

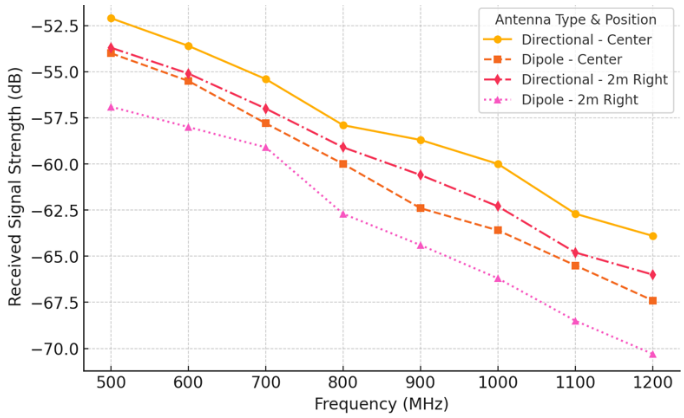


Fig. 5. Plots of the received signal strength values given in Table 1.

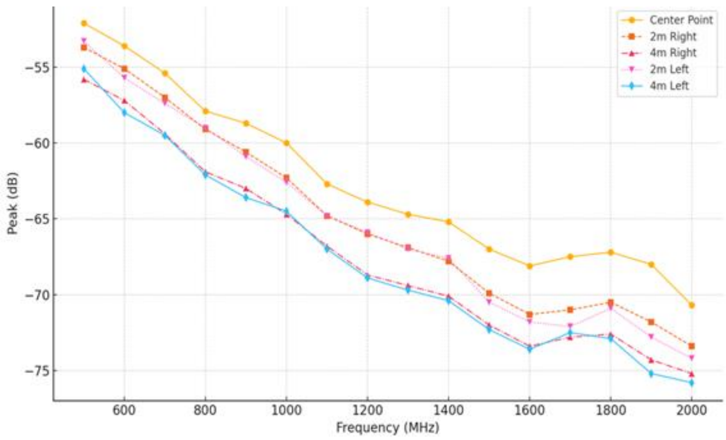


Fig. 6. Received signal strength values for the LOG-periodic directional antenna (TX in center of the site).

Table 2. Received signal strength at 500 MHz for the 1st site.

No.	RX Position	Side 1 (dB)	Side 2 (dB)	Side 3 (dB)	Side 4 (dB)
1	4m Left Shift	- 52.1	- 55.1	- 49.8	- 55.0
2	2m Left Shift	- 50.3	- 53.3	- 46.3	- 52.1
3	Perpendicular	- 48.1	- 52.1	- 45.3	- 49.0
4	2m Right Shift	- 49.7	- 53.7	- 47.5	- 52.9
5	4m Right Shift	- 51.8	- 55.8	- 50.6	- 56.6

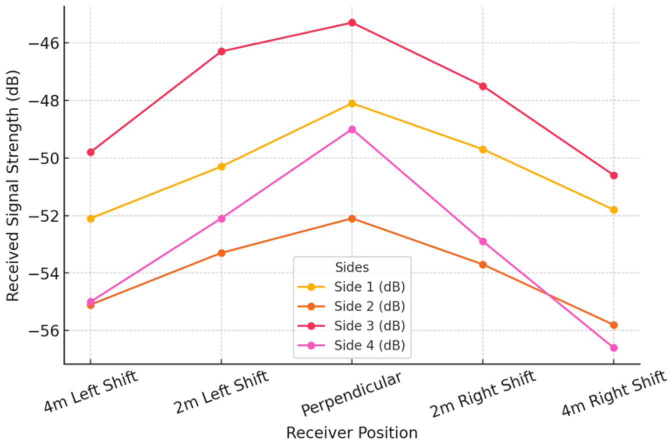


Fig. 7. Plots of the received signal strength values given in Table 2.

C. Average Results for the 1st site

In the first building, where the transmitter was placed at the center, the received signal strength was relatively uniform across all four sides. The attenuation values were nearly identical, indicating that the distance from the transmitter to each side was equal at 25 meters. The symmetry in signal behavior (see Table 3) confirms that when the transmitter is centrally located, the received power levels remain stable across the surrounding area.

Table 3. Average signal attenuation across all sides of the 1st site.

No.	RX Position	Average Attenuation
1	4m Left Shift	- 53.000
2	2m Left Shift	- 50.499
3	Perpendicular	- 48.625
4	2m Right Shift	- 50.950
5	4m Right Shift	- 53.699

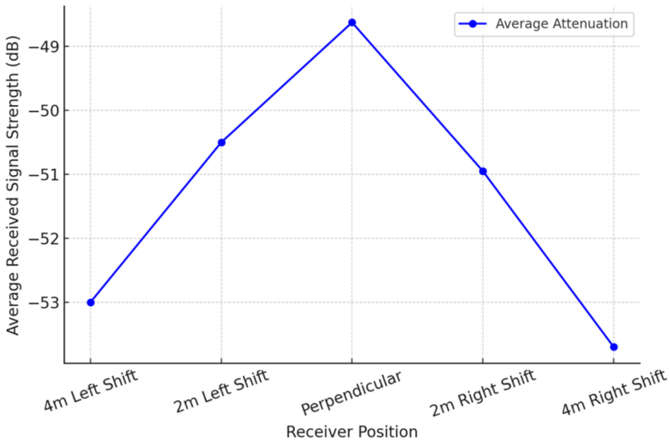


Fig. 8. Plots of the average signal attenuation values given in Table 2.

D. Average Results for the 2nd site

In contrast, in the second building, where the transmitter was placed at one of the corners, the received signal strength varied significantly across different sides as shown in Table 4 and Fig. 9. The measurements showed that the two adjacent sides closest to the transmitter received stronger signals, while the opposite two sides experienced greater attenuation. This indicates that the distance between the transmitter and receiver was no longer uniform, leading to noticeable variations in signal reception depending on the receiver's position. These results suggest that by analyzing variations in signal attenuation, it is possible to infer the approximate location of a transmitter within a collapsed structure. The changes in received power across different measurement points allowed for a clear identification that the transmitter was positioned in a corner rather than at the center of the structure (see Fig. 9 and compare it with Fig. 4b).

Table 4. Received signal strength at 500 MHz for the 2nd site.

No.	**RX Position**	**Side 1 (dB)**	**Side 2 (dB)**	**Side 3 (dB)**	**Side 4 (dB)**
1	4m Left Shift	- 57.9	- 50.2	- 57.1	- 68.6
2	2m Left Shift	- 54.0	- 53.1	- 59.5	- 65.3
3	Not Perpendicular	- 53.4	- 56.9	- 61.8	- 63.4
4	2m Right Shift	- 51.3	- 58.4	- 64.0	- 60.0
5	4m Right Shift	- 48.6	- 62.6	- 67.9	- 57.7

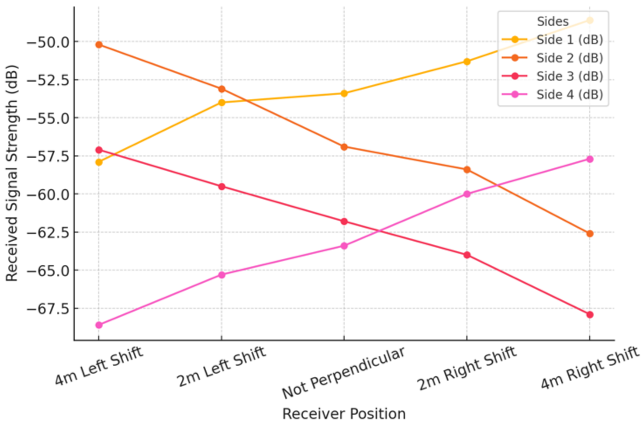


Fig. 9. Plots of the received signal strength values given in Table 4.

E. Comparison of Antenna Types

The comparison between the dipole and LOG-Periodic antennas further highlights their respective roles in search-and-rescue applications. The LOG-Periodic antenna consistently demonstrated higher received power levels, particularly at higher frequencies, due to its directional gain. However, the dipole antenna proved to be an essential tool for initial detection, as its omnidirectional radiation pattern enabled a broad scan of the disaster area without requiring prior knowledge of the transmitter's location. The LOG-Periodic antenna was then used to refine the localization process, as its directionality allowed for precise identification of the transmitter’s position (see Fig. 10).

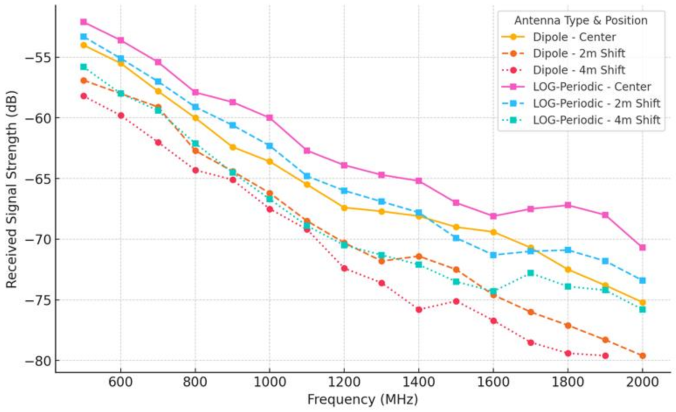


Fig. 10. Comparison of dipole vs LOG-Periodic antenna performance.

IV. DISCUSSION

These findings confirm that RF signal behavior can be effectively used to determine the location of a hidden transmitter under rubble. The measured data supports the approach of using a dipole antenna for initial detection to scan large disaster zones, followed by a LOG-Periodic antenna for accurate localization. The variations in received power based on transmitter positioning demonstrate that signal strength measurements can provide search-and-rescue teams with valuable information for identifying the exact location of survivors or radio emitters trapped beneath collapsed buildings.

The experimental findings demonstrated that dipole antennas were highly effective in the initial phase of signal detection, allowing for broad scanning in large disaster-affected areas where the exact location of collapsed buildings was unknown. Once a signal was detected, the LOG-Periodic antenna provided precise localization capabilities, significantly improving direction-of-arrival (DoA) analysis by focusing on the strongest received signal. Measurements conducted at various positions and frequency levels confirmed that signal attenuation increased with distance and frequency, and the directional antenna exhibited superior performance in pinpointing the source of transmission.

The results further highlighted a key distinction between transmitters placed at the center versus at the corner of a collapsed building. When the transmitter was centrally located, received signal strength was relatively uniform across all four sides, whereas a transmitter positioned at a corner produced variations in reception due to differing distances from the receiver. This observation provided valuable insights into how signal patterns can be analyzed to estimate the approximate location of a buried transmitter, an approach that could be directly applied to real-world rescue missions.

V. CONCLUSION

This study investigated the propagation of radio signals through collapsed buildings to aid search-and-rescue operations in post-earthquake environments. The research was centered on determining the effectiveness of different antennas in detecting and localizing hidden transmitters under rubble. The main research question focused on whether a combination of omnidirectional and directional antennas could enhance signal detection accuracy for emergency response teams. The selection of the dipole antenna for initial scanning was justified by its ability to detect signals over a large area without requiring prior knowledge of transmitter locations. This ensured that emergency responders could quickly identify the presence of any signal before transitioning to a more refined localization process. The LOG-Periodic antenna was subsequently used to enhance accuracy by focusing on the detected signal's direction and pinpointing its precise location. The multi-point measurement strategy across all sides of the collapsed buildings provided a robust dataset for evaluating signal behavior under different environmental conditions. Furthermore, the controlled frequency steps from 500 MHz to 2000 MHz allowed for a detailed analysis of frequency-dependent attenuation, ensuring that the findings were applicable across various communication bands used in emergency response systems by integrating a structured measurement approach with real-world disaster conditions.

The obtained findings have several important implications. First, they support the use of RF-based detection techniques as a complementary tool for search-and-rescue operations, particularly in scenarios where conventional methods such as thermal imaging or sound detection may fail. Second, the study validates the practicality of a two-stage antenna approach, where an omnidirectional dipole is used for initial detection, followed by a directional LOG-Periodic antenna for precise localization. Finally, the methodology outlined in this research can be adapted to other disaster scenarios, improving the efficiency of survivor detection efforts.

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