Final Project Report

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1 Introduction & Background

Wireless communications are strongly influenced by antenna radiation characteristics and the environments. In practical, multi-path propagation due to reflections strongly affects the received signal. Therefore, understanding these effects is essential for the design and analysis of reliable communication systems, especially in complex environments.

In this project, we use a well-known directional antenna, the Yagi–Uda antenna, to analysis reflections in the environment and the multi-path phenomenon. Moreover, based on the observed interference behavior, we develop the model to estimate distance using received power, connecting physical propagation with localization.

2 Experimental Results & Analysis

Github link
Demo video

2.1 Different angles of Rx

To demonstrate the directional radiation characteristics of a Yagi–Uda antenna in comparison with a regular antenna, we rotated the relative angle between the transmitting and receiving antennas and recorded the received power. As shown in Fig. 1, **the Yagi–Uda antenna exhibits strong directivity**. Moreover, the received energy distribution in the environment is symmetric with respect to the antenna orientation.

To further observe the multipath effect, a reflecting surface made of aluminum foil was introduced into the original environment. The corresponding result is shown in Fig. 2. With the presence of the reflector, the peak of the received power shifts toward the direction of the reflected path, and the average received power increases due to the additional reflected component.

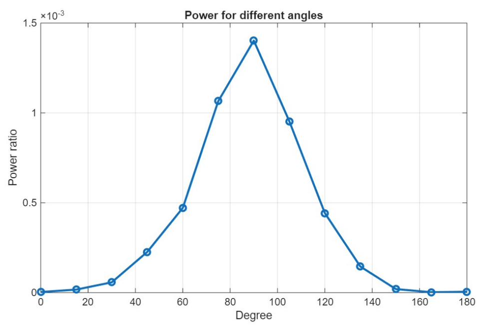

Fig.1: Power v.s Rx angle(without reflector)

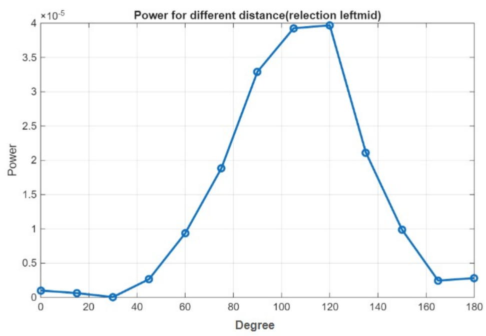

Fig. 2: Power v.s Rx angle(with reflector)

2.2 Different angles and horizontal position of reflector

We placed the reflector at three different horizontal positions and changed it argument from $0°$ to $180°$ at each position. As shown in Fig.3 $\sim$ 5, the measured power exhibited a clear M-shaped pattern across positions. This observation suggested the presence of constructive and destructive interference, which motivated the following experiments to further investigate the interference behavior under controlled conditions.

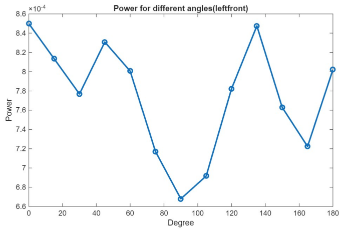

Fig.3: Nearest to Tx

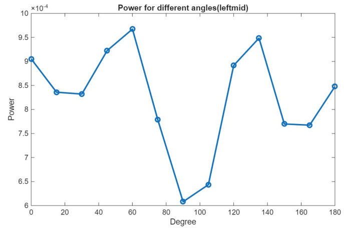

Fig.4: Middle

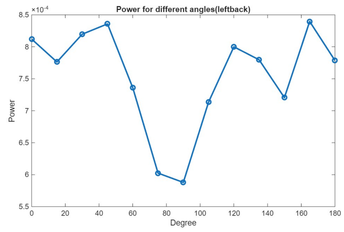

Fig.5: Farthest to Tx

2.3 Distance estimation by interference analysis

To observe the interference effect more clearly, we fix the horizontal position of the reflector and gradually move it away from the device in the vertical direction. This vertical displacement changes the reflection path length, which in turn alters how the reflected signal interferes with the direct signal, resulting in constructive or destructive interference. The schematic diagram of this setup is shown in Fig. 6. The received power as a function of the vertical position can be modeled as

$$P(y) = \frac{A^2}{L^2} + \frac{A^2|\Gamma|^2}{r_r^2(y)} + \frac{A^2|\Gamma|}{L \cdot r_r(y)} \cos(k(r_r(y) - L) + \phi)$$

where

$$r_r(y) = 2\sqrt{y^2 + (L/2)^2}$$

A, k, ϕ are the unknown constants, and Γ is the reflection coefficient of reflector.

From this equation, $P(y)$ can be viewed as the sum of a constant term and a periodic term. The periodic component is a cosine function whose amplitude and period both vary with the vertical distance y.

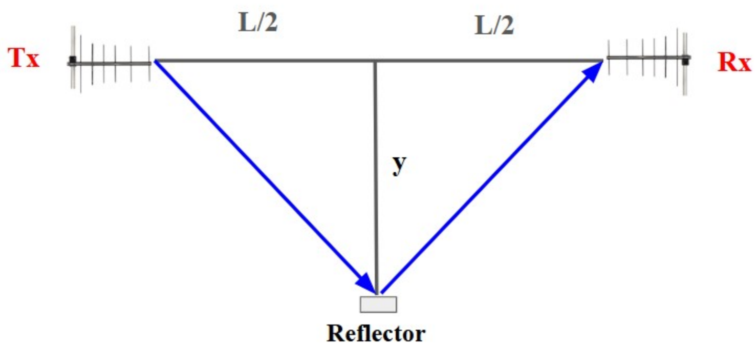

Fig.6: Schematic diagram of multipath

2.3.1 Different vertical position of reflector

In Fig.7, as the distance increases, the period of the power variation becomes shorter. The amplitude of the received power also decreases, and at large distances, the measured power gradually converges to the case without a reflecting surface.

In Fig.8, when compared with the mathematical model, the experimental results exhibit the same characteristics, although the reflection coefficient Γ of the reflector is unknown.

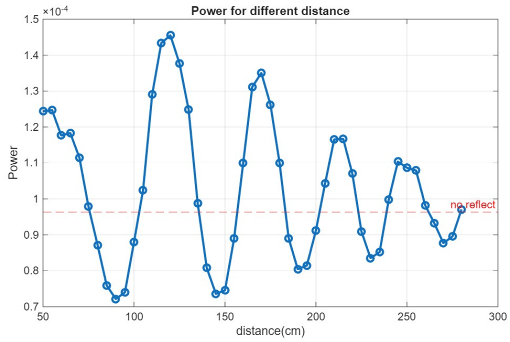

Fig.7: Power v.s vertical distance

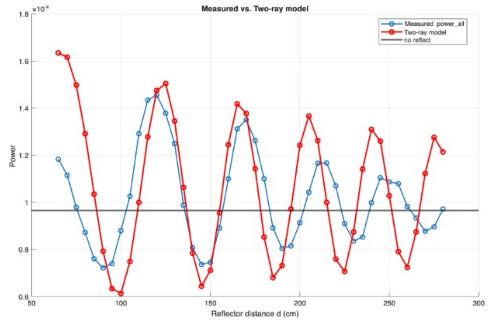

Fig.8: Compared with mathematical model

2.3.2 Different types of reflector

To investigate whether the type of reflector significantly affects the observed results, we replaced the original reflecting surface with **(1) a smaller reflecting surface** and **(2) a corner reflector**, and measured the received power as a function of distance.

As shown in Fig.9, the original reflector produces a larger received amplitude due to its larger effective reflecting area. In addition, different reflecting surfaces introduce different equivalent reflection phase shifts. However, all the cases matches the above model, which implies that type of reflector does not affect the result of our distance estimation.

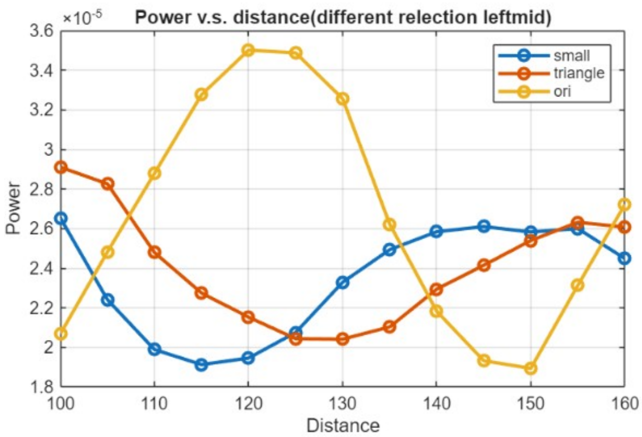

Fig.9: Power vs vertical distance among different reflectors

2.3.3 Distance estimation algorithm

Based on the previous results, we can conclude that the received power varies periodically with distance due to interference effects. In addition, the period becomes shorter as the distance increases, which directly comes from geometry relation. Therefore, it is possible to roughly estimate the distance using a reflecting surface. The distance estimation procedure is described as follows.

We start from an unknown point whose vertical distance is to be estimated. The reflector is then moved along the vertical direction with a fixed step size in each iteration. This process continues until a peak and a trough are observed in the received power. The average of the possible extreme-value candidates is then taken to reduce measurement uncertainty. Next, the following equations are used:

$$\begin{cases} \sqrt{(L/2)^2 + x^2} - \sqrt{(L/2)^2 + y^2} = \lambda/4 \\ x - y = \text{distance between peak and trough} \end{cases}$$

to determine the position of the first peak (or trough). Where y denotes the vertical position of the first peak(trough), x denotes vertical position of the second trough(or peak). In our experiment, $L = 150cm, \lambda = \frac{c}{f_c} = \frac{3\times10^{10}cm/s}{500MHz} = 60cm$. Finally, the vertical position of the starting point is obtained by adding the measured distance between the starting point and the first peak based on the recorded data.

The recording process is shown in Fig. 10. We stop recording after a peak and a trough are observed. From the figure, the peak is not clearly distinguishable, hence it is essential for taking the average of the possible peak candidates. As a result, this method can approach around an ±10cm error.(ground truth: 138cm, estimated: 124cm).

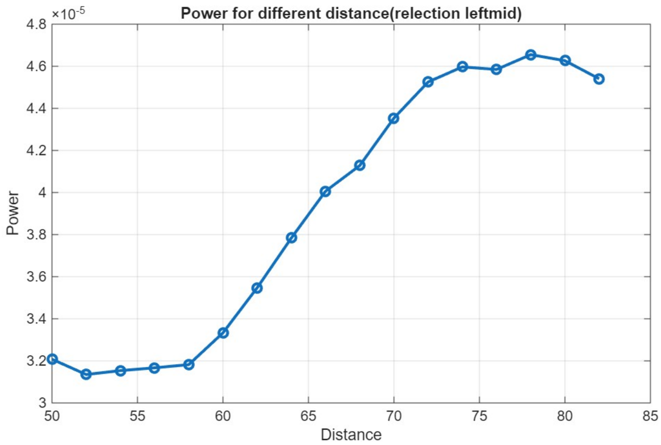

Fig.10: Power v.s distance of the process of distance estimation

3 Conclusion

In this project, we studied the radiation behavior of a Yagi–Uda antenna and the effect of multi-path propagation. The strong directivity of the Yagi–Uda antenna and the effect of reflector were confirmed through measurements. Then we changed the position and the argument of reflector. The measured power showed an M-shaped pattern. Based on this, we proposed the hypothesis that it was due to constructive and destructive interference.

To further verification, vertical displacement of the reflector was introduced. The measured results matched well with the theoretical interference model. Using the peak and trough locations in the power profile, we can estimate distance with an error of about ±10 cm. Overall, this project demonstrates how multi-path interference can be identified and analyzed through simple experiments.

References

1. Two-ray ground-reflection model
2. Multipath propagation