Source Localization Using Time Reversal in Urban Environments: A Ray Tracing Approach

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***Abstract*—The source localization using time reversal in urban environments is studied for single and array receive antennas. Ray tracing is used for simulation of the EM wave propagation because full wave methods (e.g., the FDTD method) are not able to deal with the large size of the environments.**

I. INTRODUCTION

Time reversal has been used in acoustics [1,2] and later in electromagnetics [3-7] for source detection and communications. There are two implementation schemes for time reversal: single antenna [8] and array antenna in the receiving side. Single antenna works only in a multipath environment which provides different 'perspectives' of the source. Equivalently, when we trace back along these multipaths, we will arrive at the source where all the multipaths converge. In [5,6], we examined the focusing effect using single receive antennas in an indoor environment. The finite-difference time-domain (FDTD) method was used to simulate the radio wave propagation in a small block of an office building. It was found that scatterers such as desks, bookshelves, computer monitors, and other furniture pieces can enhance the spatial focusing and time compression by providing more multipaths.

In this paper we explore the focusing effect of time reversal in urban environments. The richness of the multipaths in urban environments is directly dependent on the distribution of the buildings, thus affecting the time reversal focusing for single and array antenna receiving systems. Since the physical and electrical sizes of the environments can be large, it is difficult to use full wave simulation tools such as FDTD for the study of the focusing effect as we did in [5,6]. Because of this issue, a ray tracing method is employed for the simulation of wave propagation.

II. FORMULATION OF TIME REVERSAL

The ray tracing method we employed is in frequency domain [9]. It has the capability of frequency sweep: when the rays from a source point (Tx) to an observation point (Rx) are determined, the field can be calculated for each of the frequencies. This frequency sweep is fast because the ray paths are not dependent on the frequencies. The following is the procedure for the time reversal implementation.

First, we send rays from Tx and find the rays arriving at Rx. The field at Rx is calculated for all the frequency components in a certain band. The obtained field can be Fourier transformed to give a time domain result. This time domain response at Rx is time reversed and is set as the source at the Rx location for focusing at Tx. To get the frequency domain representation of this time reversed source, we can simply conjugate the frequency domain field obtained at Rx.

Second, we set the Rx location as the new source location and the time reversed field as the source. The fields at Tx and in a neighborhood around Tx are then calculated using ray tracing.

If there are several Rx locations, the received field at these locations due to the source at Tx will be calculated first. Then these Rx locations will serve as source points with respective time reversed fields as the sources. The fields at Tx and in a neighborhood around Tx can then be calculated. Fig. 1 is an illustration of the procedure.

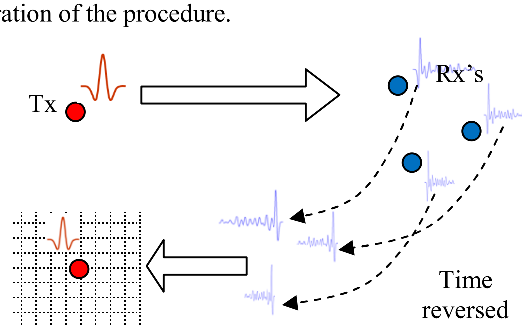

Fig. 1. The procedure of time reversal focusing.

III. RESULTS

A realistic urban environment is used for the study. A block of the city is shown in Fig. 2 where typical rays from a source (Tx) and to an observation point (Rx) are shown. It can be seen in the area, that there are quite many multipaths. The frequency band is 1 GHz to 10 GHz (center frequency 5.5 GHz).

First, we consider the case of a single receive antenna. The locations of Tx and Rx are shown in Fig. 2. (The red and green dots represent Tx and Rx, respectively.) The field in a square neighborhood of Tx is shown in Fig. 3 with Tx located at the center. This square has a size of 5 x 5 wavelengths at the center frequency (5.5 GHz). It can be seen that the time reversed field focuses at the Tx location, although not ideal.

Second, we consider an array antenna at the receive side. Two more antennas are added to the previous one to form a linear array with inter-element distance of 0.5 wavelength (at the center frequency). The result is similar to the first case and no significant improvement is observed.

Finally, instead of making a linear array for the receive antenna, the two extra antennas are located away from the original Rx location with large distances, as indicated by the two white dots shown in Fig. 2. This scenario simulates communications with cooperative capabilities. The result is shown in Fig. 4. It can be seen from the figure that the focusing is improved in a way that the focusing spot is more circular and sharper.

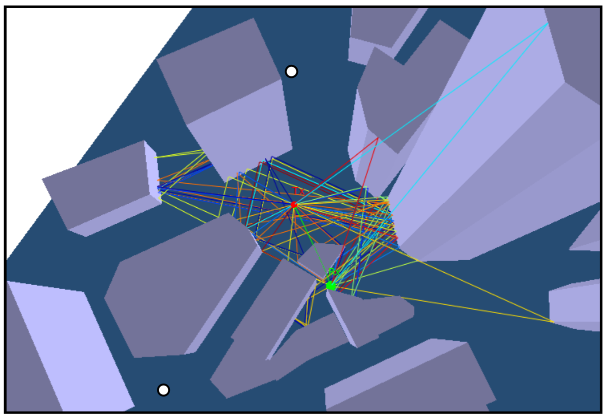

Fig. 2. A block of an urban area studied in this paper.

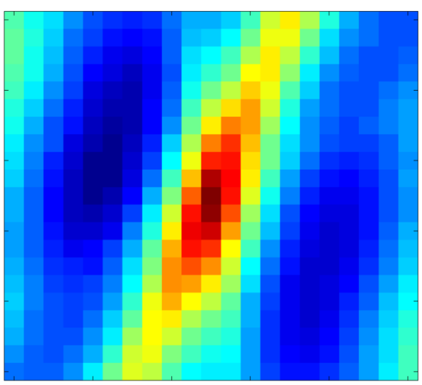

Fig. 3. The time-reversal field in the neighborhood of Tx: Single receive antenna.

IV. Conclusion

Ray tracing is successfully employed in the study of source detection and localization using time reversal with single and multiple receive antennas. The rich multipath environment makes it possible for single receive antenna time reversal focusing. Multiple receive antennas help the focusing resolution, especially when the distance between these antennas is large. More comprehensive results will be presented in the conference.

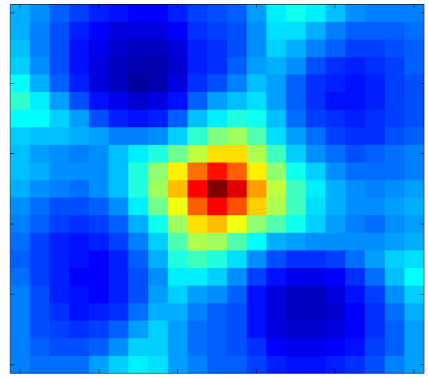

Fig. 4. The time-reversal field in the neighborhood of Tx: Triple receive antennas.

Acknowledgement

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