# Full-wave Analysis of Time of Arrival Based Localization with Polarization Diversity


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***Abstract*—We investigate a time of arrival based localization technique for nodes deployed in complex GPS-challenged environments. The proposed technique exploits spatial and polarization diversity via anchors equipped with polarization diversity antennas operating at low frequencies. Empirically derived effective dielectric constants are used for penetration delay compensation. Our full-wave simulations of a complex scene suggest that sub-meter localization error can be achieved, with low-power transmission at upper HF and lower VHF bands.**


## I. Introduction

Accurate localization of mobile nodes in GPS-challenged scenarios has various civilian and military applications including navigation of robotic platforms deployed in complex infrastructure-poor environments for situational awareness as well as search and rescue missions. Conventional techniques that operate at microwave frequency bands either have poor accuracies or require extensive training and/or site specific measurement database and often assume the availability of infrastructure [1]-[2]. For near-ground nodes deployed in such environments, recent studies suggest that lower frequencies (20-120 MHz) offer significant advantages due to the presence of a dominant line-of-sight (LoS) like path even when there are a multitude of scatterers between the nodes. This is due to the improved penetration and reduced multipath levels [3]. The presence of a dominant direct path makes the near-ground low frequency channel a good candidate to improve the accuracy of time of arrival (ToA) and array based localization techniques. However, the presence of electrically large conductive scatterers creates signal components that will introduce significant errors. The strength of the scattered components is a function of the electrical size, material charateristics, frequency, range and polarization. For example, a vertically oriented metallic cylinder will reflect a vertically polarized wave, but minimally affects horizontally polarized field, and vice versa. This suggests that, depending on the orientation of nearby scatterers, one polarization may be preferred to minimize scattering and preserve a dominant LoS-like channel. Another important factor is phase aberration due to penetration delays through obstacles, that can significanlty bias the ToA based range estimate, resulting in a biased localization estimate. In this paper, we report our initial investigation of a ToA based localization technique that exploits polarization diversity and empirical penetration delay compensation.

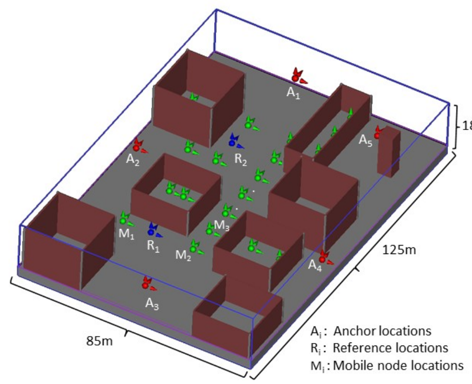


Fig. 1. An indoor-outdoor scenario consisting of dielectric and metallic scatterers with 5 anchors, 2 reference locations and 29 mobile node locations.

## II. ToA based Localization with polarization Diversity

We consider a ToA based localization technique that leverages the low frequency near-ground channel in conjunction with polarization diversity and penetration delay compensation to significantly reduce ranging and localization errors. A typical scenario of interest consists of a minimum of three anchors with known locations as well as a mobile node deployed in an indoor or urban scenario. We assume all nodes are equipped with co-located polarization diversity antennas and the anchors transmit known Gaussian pulses in all three antenna orientations. The mobile node captures the three components of the signal from the various anchors. We assume orthogonal transmission among the anchors, e.g. using code division multiple access. As alluded to in the previous section, although the near-ground low frequency channel has a LoS-like dominant component due to better penetration and reduced multipath [3], the presence of electrically large scatterers near the antennas can cause some polarizations to experience significant multipath depending on the orientation of the dominant obstacle.

For a given location of the mobile node, the received signal from each anchor will have three components corresponding to the three orientations of the antennas. The receiver employs a matched filter for each polarization, matched to the Gaussian

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pulse. Three different ToA estimates are then computed by taking the difference between receive pulse time for each polarization and reference transmit time. We then choose the smallest ToA as our estimate. This ensures that the polarization that experienced the least multipath is selected as the ToA estimate for that anchor.

In the presence of multiple layers of large scatterers, even if there is a dominant direct path, the spatially varying penetration delay through multiple layers of scatterers could be significant. To combat this, an empirically estimated anchor-dependent effective dielectric constant is applied to improve the accuracy of the ToA estimates. For example, the effective dielectric constant for the scene shown in Figure 1 is approximated based on the ToA from each anchor to known reference locations ($R_1$ and $R_2$). For each anchor $i$, the ToA to the known reference location $j$ is calculated from full-wave simulations (call it $t_f^{i,j}$). Then, the dielectric constant is computed as $\epsilon_r^{i,j} = [t_f^{i,j}/t_e^{i,j}]^2$, where $t_e^{i,j}$ is the exact ToA computed from the known locations of the anchors and reference locations. The effective dielectric constant for the whole scene is then approximated by taking the average of the estimates from multiple reference locations (2 reference locations are used in this paper). The corrected ToA from anchor $i$ to unknown location $k$ is then computed as $t_c^{i,k} = t_f^{i,k}/[\epsilon_r^i]^{0.5}$.

From the ToA estimates, the ranges from each anchor to the mobile node are computed. We then estimate the location of the mobile node using a weighted squared range least squares (WSR-LS) approach described in [4] which provides an exact solution for the coordinate vector of the mobile node from the range estimates. It has been shown through numerical simulations that the WSR-LS approach is more accurate than existing approximations such as the unconstrained squared range-based LS estimate (USR-LS).

## III. Full wave Simulation Results

We investigate the proposed approach via a full-wave simulation of a realistic indoor/outdoor scenario. The scene shown in Figure 1 consists of several buildings where both LoS and NLoS channels are considered. Concrete building walls modeled as lossy dielectric layers and steel reinforcement are included in the simulations. The antenna height on the mobile and reference nodes is 0.5m and the antenna height for the anchors is 7.5m. The simulations are performed using a finite difference time domain (FDTD) solver at center frequencies of 20MHz and 40MHz. The results shown use 5 anchors and 2 reference locations to estimate 29 unknown locations. Figures 2 and 3 show the absolute value of the ranging error and a 2D map of the location estimates. The mean error without correcting for penetration delays with the effective dielectric constant is 1.23m. The mean error for the 29 locations of the mobile node goes down to 0.89m when the correction is applied. It should be noted that the FDTD solver introduces some error due to dispersion. The range error comparison among various antenna orientations given in Figure 2 shows the advantage of polarization diversity.

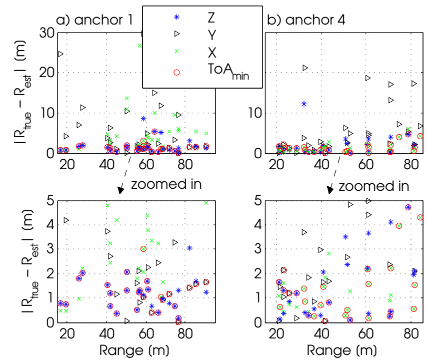


Fig. 2. The ranging errors based on ToA estimated from each polarization pairs are shown for anchors 1 and 4. The final estimate (denoted by $ToA_{min}$) is computed by taking the smallest ToA estimate based on all 3 polarizations; note that the final choice varies with node location.

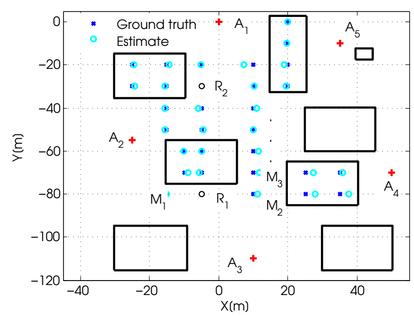


Fig. 3. The estimated and true location of the mobile node are plotted along with the anchor locations on the building map schematic.

## IV. Conclusion

The potential of utilizing polarization diversity to improve ToA based ranging and localization in harsh propagation scenarios leveraging the low frequency near-ground channel is investigated via full-wave simulations. The proposed technique exploits spatial and polarization diversity via multiple anchors co-located polarization diversity antennas. By applying a penetration delay compensation via an empirically derived effective dielectric constant, we show that the mean localization error can be reduced to 0.89m, a 28% improvement in accuracy compared to the result without correction. We are currently planning experiments to validate the proposed approach.

## References

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