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ArrayTrack: A Fine-Grained Indoor Location System

The Global Positioning System (GPS) provides accurate location services which are employed by millions of people for their daily tasks. However, these GPS signals fade in indoor environments due to low signal strength. This paper aims to resolve this issue by using Multiple input, Multiple output (MIMO) techniques in order to increase the number of antennas inside a building and thereby increasing the signal strength. Precise indoor location system have many uses such as building navigation (as we saw previously in IoT Review 3), social networking, marketing, etc. The available technologies can be classified into two parts :

1. **Not accurate enough** (WiFi)
2. **Require dedicated infrastructure** (ultrasound)
3. **Require good light conditions/cameras** (vision)

However, regarding WiFi, by increasing the number of antennas on an access point (AP), improves the capacity and coverage. Also, WiFi is ubiquitous and densely deployed on airplanes, subways and buses.

The authors in the paper provide a basic overview of their approach as follows:

- The APs overhear a client's transmission.
- The AP uses multiple antennas to generate physical angles of arrival (**AoA**) of a client's signals
- With multiple APs, central server synthesizes AoA spectra to obtain a location estimate for the client

However, the main challenge that the paper looks to address is multipath reflections.

Problem #1: Strong multipath reflections are seen indoors.

Problem #2: Direct path attenuated/completely blocked. Thus, the direct path signal may not be the strongest.

ArrayTrack tries to advance the art of localization by using the following three points : (**Point #1**) MPSA algorithm which effectively remove the reflection paths between clients and APs.

Multipath suppression algorithm (**MPSA**) : Direct path bearing is more stable than the reflection path bearings when the client moves slightly. The MPSA can be explained as follows :

1. For a given AoA spectra from two nearby locations, find the peak bearings in each AoA spectrum.
2. Discard any peak not paired with a peak in the other AoA spectrum.

(**Point #2**) Upon detecting a frame, an ArrayTrack AP quickly switches between sets of antennas, synthesizing new AoA information from each. This is called Diversity synthesis.

Step 1 : Detection & Recording : Content of the packet and the type of modulation do not matter. It works with any part of a packet (ArrayTrack utilized the most robust **preamble part**). A small sample of a packet is needed for the process (ex: at 40 MHz sampling rate, one sample is 25 ns). In the absence of noise, a single sample works well while, in the case of noise, the authors propose using multiple samples for averaging to remove noise.

Diversity synthesis : This consists of recording 10 samples from the first preamble half and another 10 samples from the second preamble half from two different antennas.

(**Point #3**) ArrayTrack's system architecture centers around parallel processing in hardware, at APs, and in software, at the database backend, for fast location estimates

Step 2 : AoA spectrum generation : The authors discuss related work for AoA spectrum estimation such as **(a) MUltiple SIgnal Classification** (**MUSIC**) which analyzes the Rcvd. phase from source to each antenna but performs poorly for phase-synchronized signals and **(b) Spatial Smoothing** (**SS**) [Shan et al, 1985] which looks at the average of the incoming signals across groups of antennas and reduces correlation.

Step 3 : AoA spectra synthesis : "N" APs generate "N" AoA spectra as follows : $P_1(\theta)$, $P_2(\theta)$, … , $P_N(\theta)$

Thus, for a random position "X", the likelihood of being at X = $L(X) = \prod_{i=1}^{N} P_i(\theta_i)$, where i = all AP's. This is then evaluated at each point by using a 10cm x 10cm grid.

Step 4: search for highest probability position

ArrayTrack is implemented on the Rice WARP FPGA platform and evaluated in a 41-node network deployed over one floor of a busy office space.

For the implementation, the authors use the following :

1. AP which consists of 2 Rice WARP FPGAs, each with 4 radio boards (8 antennas). Custom FPGA design using Xilinx System Generator for packet synchronization, diversity synthesis, RF oscillator synchronization and 4-16 antennas placed linearly, spaced at $\lambda/2$.
2. The client consists of Soekris boxes with 802.11 radios.
3. The backend location server has been implemented on Matlab - the server **has a knowledge of each AP's location.**

Key results : The authors show that (and it is expected) that a bigger number of AP's help in better localization (**6 is optimal**).

1. MUSIC + SS achieves an accuracy of 26cms which is fairly good (first in the world to achieve sub half metre localization accuracy).
2. MPSA achieves a median value of 23cms - slight improvement (using ArrayTrack + 6 AP's) and 100cm (1m) with 3 AP's.
3. The method achieves a high accuracy despite there being an AP-client height difference.
4. With more antennas at each AP, more accurate the AoA spectrum. Thus, better localization accuracy (expected).

However, there were a few points that needed more clarity :

Questions :

1. Why did the authors not try increasing the separation between antennas in an antenna array? By increasing the separation, the resolution of the AoA beam is increased.
2. A 3D tracking system is something that can be looked at in the future since an indoor environment can have multiple floors and the current work is based on a single floor (2D space).

More details about the paper

Xiong, J., & Jamieson, K. (2013). Arraytrack: A fine-grained indoor location system. In Presented as part of the 10th {USENIX} Symposium on Networked Systems Design and Implementation ({NSDI} 13) (pp. 71-84).