ArrayTrack: A Fine-Grained Indoor Location System

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The Problem Definition:

With advancements in indoor applications, especially the ones which implement indoor localization, for example, Grocery Stores where the exact location of the item is a key (maybe like Amazon Go stores), libraries that locate books, Asset tracking (mobile phones, laptops, etc.), huge parking spaces, Augmented reality, etc. it has become crucial to have a localization system which is highly accurate (in the indoor environment), has low latency and also required less calibration. Although, a huge amount of impressive research is done in this area- with solutions majority of which use Wi-Fi to detect the location and others like Cricket, Bat (which uses ultrasound), a few others which are based on image processing, crowdsourcing, RADAR, etc. but still most of them either require a lot of calibration, infrastructure setup or are not as accurate as the indoor localization systems should be. Therefore, in this paper, a solution named ArrayTrack is presented, which claims to provide the median accuracy of the object to around 23cms with the use of MIMO-based (multiple-input, multiple-output) techniques.

Key Idea:

As ArrayTrack uses the MIMO-based technique. Therefore, the key idea here is to leverage the evolution of Wi-Fi and the devices (rather indoor devices) with multiple antennas. With the increase in the antennas on the access points, we can create a sharp Angle of Arrival (AoA) Spectrum between the client (or object whose location needs to be tracked) and the Access point (AP). This way with multiple access points (APs) having one or multiple antennas in place, multiple AoA Spectrum can be formed between the client and the APs. The intersection of the probabilities from these multiple APs can be used to obtain the highest probability region (where the client lies) in real time, using the hill climbing algorithm. Thereby providing a more precise location of the client without much calibration overhead or delay. But achieving AoA for multiple paths isn't simple as there are a lot of reflections from multiple obstacles indoors leading to multipath. Moreover, sometimes it becomes difficult to detect the direct path, as due to the presence of obstacles (and of different types) the direct path attenuation can sometimes be more than other reflection paths.

Important Details:

To deal with the multipath challenge, the author is using a Multipath suspension algorithm, based on the assumption that the client will not be 100% static in the indoor space. This algorithm works on the observation that the direct path bearing is stronger & stable than the reflection path bearing. Although experimental observations are also made by ruling out this assumption (that the client is 100% static) and hence without using the Multipath suspension algorithm according to which if we can increase the number of access points, we can achieve the same level of median accuracy as we get when we use the Multipath suspension algorithm. Another technique that is used in this experiment is Diversity Synthesis (DS), which is claimed to be highly useful in cases when the density of the access points is less. For DS the system switches between the set of antennas as soon as it has received the packet samples. This way, say if an access point has two antennas, then after A_1 receives all the sample packets (which in the experiment is N=10) it will switch to A_2 and start receiving packages again. This will repeat for all the Antennas in the Access point. Then in order to get the steeper AoA spectrum, the author proposes the MUSIC algorithm, but as there is more noise and coherent signals in the indoor environment so the paper uses the Spatial Smoothing technique to get the sharper and steeper lobs on the AoA spectrum, which dominates the weaker lobs and helps in attaining more precision.

My Thoughts and Criticism:

The paper indeed presents some great work in the field with relevant observations and proofs (with and without all the assumptions) made while performing the analysis on the setup testbed. The utilization of Access points, which are usually already set in indoor spaces like our homes and offices will reduce the infrastructure setup cost, and since ArrayTrack is an RF-based location system, the reliability on the GPS, light sources in the room, or calibration overhead won't be an issue. Also, the system is proven to be highly robust against antenna orientation, collisions, different antenna heights, and low SNR. However, thinking of a few scenarios made me question the capabilities of the ArrayTrack:

1. ArrayTrack highly relies on the availability of Access points (APs) or rather MIMO, especially Wi-Fi APs. Even today there are a few places that would need indoor localization but miss multiple or advanced modern APs examples of historical places, or places that meet disasters (fire, earthquakes etc). Although the author claims that even if there are fewer APs but multiple antennas in the Access point then, we can achieve the same level of accuracy. But only modern APs come with multiple antennas.
2. Another strong assumption made by the author is for ruling out Multipath, for which they use Multipath Suspension Algorithm. It is assumed that the client is not 100% static. Although the tradeoff of the assumption is we need to have multiple access points in order to attain the same level of accuracy but what if there is a limitation on the number of access points?
3. The testbed has 41 uniformly spaced nodes (as clients) but in an ideal scenario, this won't be the case. It can be a lot of people or clients on one side of the room/office space. In that case, the analysis and observations can be different as there will be a lot of interference/collisions involved.

4. The paper also relies on the observation that direct path bearing is stronger and more stable than the reflection path bearing but I believe this can be different based on the material of the obstacles which come in the path of the signal transmission. Also, if in case the client is in the metal block which completely blocks the signal then ArrayTrack should fail as there will be no direct path in this scenario. This limits the application of ArrayTracker (until improved) for government use against criminal offenses such as human trafficking or rescue zones.
5. As the system relies on the parallel processing in hardware at Access Points (which are technically 3rd party devices), therefore the reliability and system up & running time of ArrayTrack will depend highly on these APs as well as their quality/maintenance.
6. In the analysis, the number of samples taken (as claimed) is significantly less i.e. 10 (and the author also claims that the analysis can be done with even 1 sample, but they use 10 considering the noise factor). Since the noise is a function of multiple factors one of which is the medium of propagation. Therefore, as the medium varies the noise can also vary and the number of samples can also vary which can add to the latency of real-time computation of the resulting location.

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