CSCI 5273 - Paper Review #1
Kevin Hallock
2020-10-30

Paper information:
Title: RADAR: An In-Building RF-based User Location and Tracking System
Authors: Victor Bahl, Venkat Padmanabhan
Publish date: March 2000
URL:
https://www.microsoft.com/en-us/research/publication/radar-an-in-building-rf-based-user-location-and-tracking-system/

Paper Summary:

This paper investigates using signal strength of a wireless client with respect to multiple wireless access points to triangulate the client's location within a building. The authors construct a basic model (referred to as the “empirical model”) that tracks signal strength to each of 3 access points at 70 different locations in their office building and at 4 orientations (N, S, E, W) at each point, which are then used with a nearest neighbor algorithm to approximate a client's location based on the signal strength to each of the base stations at a particular point. This model proved to be quite accurate, achieving 25th and 50th percentile distance errors of 1.92 and 2.94 meters, respectively. However, it is costly to implement and not scalable due to the need to collect new readings at each existing dataset location when a new access point is added.

The authors then investigated an alternative “radio propagation” model that does not rely on a pre-existing dataset of signal strength samples at known locations, but rather approximates the signal strength at a given location based on propagation characteristics of the network related to the physical distance and number of walls between the client and the base station. This model requires basic testing and configuration in order to determine reasonable values for "wall attenuation factor" and "maximum number of walls up to which the attenuation factor makes a difference", but these can be generalized for use across a site; this means that new base stations could be added to the network seamlessly. The propagation model achieves a higher accuracy than the empirical model at the 25th percentile, 1.86 meters, but drops off quickly to a 50th percentile distance error of 4.3 meters.

Strengths:

- This paper addresses the existing need for a positioning system that works indoors (without GPS) and at a hyper-localized scale (on the order of meters).
- The idea of piggybacking on pre-existing WiFi network deployments is an incredibly novel and prescient concept for a paper published 2000, when WiFi technology was nowhere near as prevalent as it is in 2020. Leveraging infrastructure that already exists is critical for implementing a tracking system like this at any remotely feasible cost.
- The proposed “propagation model” system is scalable and allows new access points to be added to the network with minimal effort.

Weaknesses:

- The “propagation” model makes an assumption that the coverage space is fairly homogeneous in composition (building materials, room contents, etc).
- The topics of signal strength and signal-to-noise, specifically in regard to the underlying math and physics, was hard to follow as someone who is not already familiar with the subject matter.

What I learned from this paper:

I learned that there is a desire for location-based networking services on a smaller scale than I had previously considered. One proposed application of this technology from the paper that stuck with me is the idea of being able to print a document to the nearest printer; while there are certainly some real-world practical concerns (what if the person whose office the printer is hosting a meeting or locked their door while out to lunch?), the “just works” simplicity of this idea is very appealing and made the desire/need for hyper-localized location-based services make much more sense to me.

What are the avenues for future work that you think are important? If you are asked to work on the problem studied in this paper, what will you do differently?

The authors of the paper discuss this in their own future work section; I agree with them and I think it would be particularly beneficial to have some sort of current conditions or environmental factor that can help to accommodate the varying number of people in an office space. In particular, I think that it might be useful to add a temporal component to this dataset; presumably an office building has fairly predictable hours during which it is populated, so this is one route forward towards the idea of factoring in the current conditions.

I would also be curious to see what the impact of using more than 3 wireless access points would be on the accuracy of the triangulation. Obviously every office space is different, but I believe that modern wireless infrastructure is much more dense than it used to be (to accommodate more users, to deal with the faster drop off of 5 GHz signals, etc) and I anticipate that this would yield a more accurate triangulation location.

I would also like to investigate the feasibility of using the “propagation” model in a multi-floor office space environment. While this clearly complicates the problem being discussed, it seems unlikely that all potential use cases for this model are truly located on a single floor.

Finally, I would be curious if machine learning techniques could be used to enhance this propagation model. I am not personally an expert on the topic of machine learning, but it seems to me that the linear regression analysis used in building the “propagation” model could be significantly enhanced with modern techniques.

Detailed comments:

I like the methods used to create/train a model with many signal strength samples and the subsequent testing of the model in real time. I thought it was particularly interesting that using only the highest signal of each of the four orientations at each point was clever, as it allowed them to use multiple nearest neighbors without muddying the results by reusing the same point with different orientations.

The “propagation” model that was implemented seems to work very well in a somewhat “simple” office environment -- the P_{d0} and n parameters used for the model are the mean of the three values for each of the base stations, which were all reasonably close in the first place. However, I am skeptical that this model would prove to be useful in a more heterogeneous environment. For example, the University of Colorado Engineering Center is a conglomerate of several buildings, with a variety of different building materials used throughout the building; additionally, the variety of lab equipment and experiments going on in the building could significantly impact the reliability of this system. Overall the project is quite promising, but the first building on the CU campus that came to mind in which to implement it makes me question its viability in real-world practice.