RADAR: An In-Building RF-based User Location and Tracking System

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The Problem Definition:

With the increase in wireless and computing devices, the demand & interest in location-based services has increased. Although, a significant amount of research & development is being done currently in this area, to develop efficient location-based services. However, less attention is paid to the problem of locating non-static (mobile) users. The current research done in this area – of tracking non-static (mobile) users, take infrared (IR) wireless networks as a possible solution for location tracking but due to the limited range of IR networks, the coverage remains a challenge. Some other work done in this field use wide-area cellular networks (based on RF) and Global Positioning systems (GPS) but both of these systems are found to be more promising in outdoor environments rather than indoors. This paper tries to fill the gap and presents the idea of RADAR, a radio frequency (RF) based system for the user location as well as tracking inside the building.

Key Idea:

The key idea is to use RF to determine user location (both static and mobile) within the building. RADAR uses triangulation on the signal strength (SS) received from multiple receivers (set up in the testbed) to determine the user's location. The key to this approach is effective data collection from multiple base stations for which signal strength is recorded as a function of the user's location. The data collection and processing are considered critical steps of this analysis. The signal strength is determined in two ways empirically as well as theoretically (radio signal propagation model). It is observed that although the accuracy via the empirical approach is slightly better than the signal propagation approach, signal propagation is recommended for real-time analysis of the mobile user considering factors like setup overhead required in the empirical approach and flexibility in the case of base station migration.

Important Details:

It is discovered that the user's orientation also impacts signal strength (SS) significantly. The few other factors that impact the signal strength and hence the accuracy of the resulting user location but are ignored (for simplification) are Multipath due to reflection & refraction of the signals from the obstacles, movement of other people in the building, and wall attenuation. For the analysis in the paper, the author has taken 70 distant points on the testbed and then using NNSS (Nearest Neighbor in the Search Space) algorithm for some k distinct nearest neighbors, to reduce the error distance and increase the location accuracy.

My Thoughts and Criticism:

The analysis mentioned in the paper is well supported with relevant numbers and proofs but at some point, certain assumptions are made, or certain factors are ignored (for simplification), which I believe could be gaps:

1. The SS (Signal Strength) and Signal to Noise Ratio (SNR) can be highly impacted if any new signal of varied frequency (like Wi-Fi or microwave) is introduced into the space. This factor is not considered in the analysis.
2. In a real-life scenario, the user can have any possible orientations in the given space and not the standard 4 directions (i.e North, south, east, and west). Considering direction is one of the parameters in the tuples collected for empirical data (in the paper), this can highly impact the accuracy of the user location.
3. It is mentioned in the paper that the human body can be an obstacle and in a real-life situation, the indoor space/building can have multiple human beings, with everyone acting as the mobile user and transmitting beacons can lead to overlapping k nearest neighbors thereby impacting the accuracy of each mobile user's location. But the paper lacks the analysis of this scalability situation.
4. The paper relies a lot on the empirical solution but for mobile users, the collection of real-time (on-spot) data will require a lot of setup cost, especially when considering the model on the scale.
5. If multiple mobile/static users need to be identified, then there should be some identity bit stored for each user's data set.
6. When observed for mobile users it is considered that the mobile user is moving at a constant speed, which will not be the case in real life. This can lead to huge *error distance* and hence require computation logic that can be faster and more accurate than the one mentioned in the paper. Due to this variable speed of the mobile user and latency in real-time computation can lead to an increase in the error distance thereby making the current determined accuracy of 2-4 meters (which is ~ the size of a typical room) a questionable number. Hence more accurate estimation method should be introduced to avoid such ambiguities.
7. The Wall attenuation factor in the set-up is claimed to be similar among all the base stations, which I believe in reality would not be the case as each base station will have different physical placement and obstructions around. This can impact the accuracy of the determined user location.
8. Multipath is mentioned as one of the key factors which impact the accuracy of the location determination or tracking. But the solution to this obstruction is less talked about in this paper.

9. Empirical data collection would require large data set as building size increases because as building size increases the setup cost of the RADAR would increase, with base stations on each floor.