SpotOn: Indoor localization using commercial off-the-shelf WiFi NICs

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ABSTRACT

We describe SpotOn, an accurate indoor localization system that works using existing WiFi access point infrastructure. SpotOn does not require any software or hardware modifications at the access points or the radio that needs to be located. Thus, SpotOn presents a case for widely deployable indoor localization system. SpotOn requires just a WiFi radio to be present on the target device to be located and can accurately localize even when the target device is stationary. This expands the application scenarios of SpotOn indoor localization system beyond localizing mobile devices carried by humans. SpotOn achieves localization using Channel State Information (CSI) calculated for each packet during regular WiFi OFDM communication. SpotOn owes its accuracy to its super-resolution algorithms to estimate the direction of the target device and novel triangulation algorithms which combine measurements from different WiFi access points to estimate the location of the transmitter.

We implemented SpotOn using commercial off-the-shelf Intel 5300 WiFi NICs. SpotOn achieves localization accuracy of 0.6 m when the target device has significant number of access points in line-of-sight. Over all the locations in our test runs, SpotOn achieves localization accuracy of 1.5 m.

1. INTRODUCTION

Indoor localization using WiFi radios has attractive properties like providing localization service using already existing infrastructure for communication purposes. However, existing WiFi based indoor localization systems either suffer from poor localization accuracy, or require extensive calibration, or require special WiFi access points with hardware/software modifications. SpotOn uses Channel State Information (CSI) calculated as part of regular OFDM communication to accurately localize the target devices using commerical off-the-shelf WiFi NICs.

To realize localization using commercial off-the-shelf WiFi radios, the system has to overcome multiple challenges. First, the receiver receives multiple copies of the transmitted signal due to reflections from multiple surfaces in typical indoor environments. This multipath is pronounced in radio wave frequencies used by WiFi radios. So, we cannot apply methods used by visible light and infrared based localization systems as these systems do not experience significant multipath. Second, the bandwidth available for WiFi communications is small (atmost 40 MHz in 802.11n WiFi radios). Hence we cannot use methods similar to the ones used by systems based on ultra wide bandwidth (UWB) signals where they identify the direction of the transmitter by resolving all the reflections. Bandwidth of 40 MHz implies that we cannot separate two reflections that are closer than 25 ns in their time of flight from the transmitter to the receiver. Physically, this translates to the fact that we cannot resolve two reflections closer than 7.5 m in their propagation path length which is large for typical indoor environments. Third, the number of antennas in standard WiFi deployments is limited. Hence we cannot use antenna array based localization techniques, which although very accurate compared to RSSI and fingerprinting based approaches, require large antenna arrays. Fourth, the CSI obtained is quantized. For example, each of the real and imaginary parts of the CSI provided by Intel 5300 WiFi NIC [1] is represented by just 8 bits.

SpotOn overcomes the challenges of WiFi based localization by using super-resolution techniques that accurately estimate the direction of the transmitter from each access point, inspite of limited bandwidth and small number of antennas, and by using novel localization algorithm that combines these estimates from multiple access points to localize the target. Specifically, SpotOn adapts MUSIC [2] algorithm to work with CSI obtained from regular WiFi communication. We then combine these estimates of the direction of the target and RSSI (Received Signal Strength Indicator) measurements from different access points to estimate the location of the target device using novel localization algorithms.

2. HARDWARE SETUP

We built SpotOn using commercial off-the-shelf Intel 5300 WiFi NICs embedded in Intel NUC devices. We constructed a three antenna array at each WiFi access point as displayed in Figure 1. The WiFi NICs operate in 5 GHz WiFi spectrum with 40 MHz bandwidth. The distance between successively placed antennas in the antenna array is 2.6 cm, which is approximately equal to half the wavelength at 5 GHz WiFi spectrum frequencies. We employed Linux CSI tool [1] to obtain the PHY layer CSI for each packet. The Linux CSI tool provides CSI for 30 subcarriers at each of the three antennas. SpotOn assumes the knowledge of the locations of the access points. The locations of the access points are measured accurately by using laser range measuring devices and architectural drawings of the buildings where we deployed SpotOn. This is a one time exercise as the access point locations are not changed frequently in a typical deployment scenario. The access points overhear WiFi transmissions and obtain the CSI information for each of the packets transmitted by the target whose location is of interest. The access points export the CSI, along with a timestamp at which CSI is obtained, to a central server. The server processes the CSI information from multiple access points to determine the location of the transmitter. This setup can be easily replicated for implementation of SpotOn because it is built from off-the-shelf components with no hardware or software modifications.

Figure 1: Access point with three antennas using Intel 5300 WiFi NIC embedded into Intel NUC (placed below the antenna array).

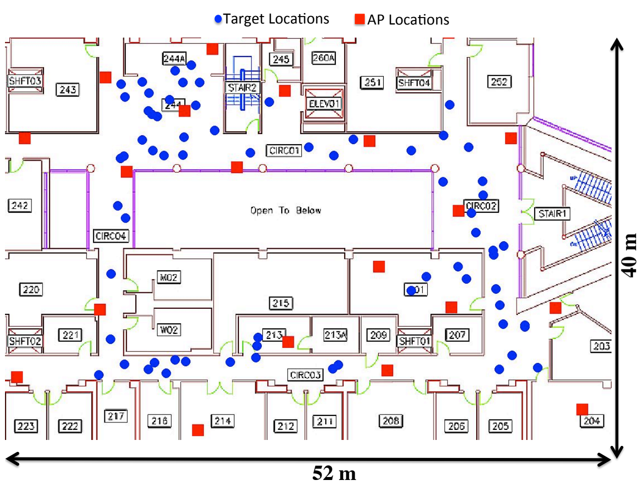

Figure 2: Floor plan showing the testbed, locations of access points and the target locations used to test the performance of SpotOn. The access point locations are represented by red squares and the target locations by blue circles.

3. EVALUATION

Method: Environments where localization system has potential applications include office buildings, shopping complexes, grocery stores, and airports. The diversity of these environments demands that SpotOn performs well in different physical environments. We deployed SpotOn in different locations of our building. Specifically, we deployed SpotOn in our lab which resembles a typical office space with lots of monitors, furniture, and cubicles. We deployed SpotOn in the cafe of our building with tables, chairs, and people. We deployed SpotOn with access points along the corridors of our building and the target moving along the corridor, as may be the case for wayfinding applications inside buildings.

Locations of WiFi APs and 72 target locations are depicted in Figure 2. For each location, we consider the CSI collected by six access points with highest RSSI.

Results: SpotOn achieves median localization error of 1.49 m over all the target locations in different environments. When the environment in which target is placed is such that more than three access points are in Line of Sight from the target, then SpotOn achieves median localization accuracy of 0.6 m.

4. REFERENCES

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[2] R. O. Schmidt. Multiple emitter location and signal parameter estimation. *Antennas and Propagation, IEEE Transactions on*, 34(3):276–280, 1986.