UbiTrack: Enabling Scalable & Low-Cost Device Localization with Onboard WiFi

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ABSTRACT

Wireless sensing and the Internet of Things support real-time monitoring and data-driven control of the built environment, enabling more sustainable and responsive infrastructure. As buildings and physical structures tend to be large and complex, instrumenting them to support a wide range of applications often requires numerous sensors distributed over a large area. One impediment to this type of large-scale sensing is simply tracking where exactly devices are over time, as the physical infrastructure is updated and interacted with over time. Having low-cost but accurate localization for devices (instead of users) would enable scalable IoT network management, but current localization approaches do not provide a suitable tradeoff in terms of cost, energy, and accuracy for low power devices in unknown environments.

We propose UbiTrack, a low-cost indoor positioning system that enables accurate tracking for single antenna commodity WiFi devices, without the need for a complex antenna array. UbiTrack leverages two-way channel state information (CSI) across all WiFi channels to measure the distance between nodes, and uses a new probabilistic localization algorithm based on Bayesian estimation to locate each device. We demonstrate the system on commodity $4.00 ESP32 WiFi chips and realize 1-meter level position accuracy in an indoor environment. This approach provides localization for everyday IoT devices, enabling more scalable deployments and new IoT applications.

CCS CONCEPTS

• **Computer systems organization → Embedded and cyber-physical systems**.

KEYWORDS

Indoor localization, smart IoT devices, WiFi channel state information (CSI), Bayesian estimation

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1 INTRODUCTION

New sensors, more computing power, reliable mobile connectivity, and easier production is enabling growth in the number of deployed Internet of Things (IoT) devices. In turn, this availability and cost-effectiveness will continue to make new sensor applications possible, including large-scale monitoring and detection. Many applications will require high density deployment of IoT devices, creating a new challenge to determine and track the location of every deployed device. Overcoming this challenge will require automatic localization for devices. Automatic device localization will also simplify device installation, enable smart building deployments to adapt to changes in building use and physical structure over time, and unlock the potential for numerous location-based applications. However, many of today's IoT nodes do not include any indoor localization capabilities, and thus require periodic manual location checks and label updates. This limits the scalability of the smart IoT system in buildings.

Despite significant progress in the general field of localizing people, accurately localizing small commodity IoT devices presents a different challenge. Many approaches have a significant drawback, either providing low accuracy with multiple meter error, requiring uncommon onboard hardware or radios, or requiring significant infrastructure to be present. Yet, enabling accurate location-based services for small IoT devices could have many benefits. For example, hospitals could easily keep track of their mobile and shared equipment to more effectively manage resources, networks in homes could identify and block malicious devices accessing the network outside building walls, and small items like keys could be easily found when lost.

Enabling localization services for many resource-constrained devices on a large scale, rather than localization for human users or on an ad-hoc basis presents several design challenges that must be considered: (1) The additional cost for localization must be minimized. Using expensive hardware limits the scalability of the system. The design should leverage existing hardware components and avoid adding extra hardware. (2) Many IoT devices have a restricted energy budget. The localization approach cannot require a large number of measurements. (3) The localization accuracy must be sufficient. As devices and sensors have contextual clues (e.g. a door sensor is likely on a door) or are attached to physical objects (e.g. a chair monitoring sensor), centimeter-scale accuracy is not required, however, meter-level accuracy is needed to resolve ambiguities and track devices inside of a building.

There exist various works for providing indoor localization for devices [16, 22, 29, 33]. However, they either do not consider hardware limitations, are too energy-expensive, or do not meet the accuracy requirements, making them unsuitable for a dense indoor IoT network. Specifically, some works use ultra-wideband (UWB)