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An adaptive wireless passive human detection via fine-grained physical layer information

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ABSTRACT

Wireless device-free passive human detection is a key enabler for a range of indoor location-based services such as asset security, emergency responses, privacy-preserving children and elderly monitoring, etc. Since the feature of received signal varies with different multipath propagation conditions, an labor-intensive on-site calibration procedure is almost indispensable to decide the optimal scenario-specific threshold for human detection. Such overhead, however, impedes readily and fast deployment of wireless device-free human detection systems in practical indoor environments. In this work, we explore PHY layer multipath profiling information to extract a novel quantitative metric K_s as an indicator for link sensitivity, and further exploit a linear detection threshold prediction model. We design an adaptive device-free human detection scheme that automatically predicts the detection threshold according to the richness of multipath propagation within monitored areas. We implement our scheme with commodity WiFi infrastructure and evaluate it in typical office environments. Extensive experimental results show that our scheme yields comparative performance with the state-of-the-art, yet requires no on-site threshold calibration.

1. Introduction

Indoor location-based service (LBS) is fast permeating into ordinary people's daily life due to convenience, production and recreation. The ability to perceive the presence of users within the area of interests by LBS providers is crucial to deliver numerous context-aware services such as navigation and location-based advertisements [1]. Recent advances in wireless technology and the pervasive deployment of wireless infrastructure have raised increasing research interests to leveraging the ubiquitous wireless signals to fulfill this task in a *device-free* manner [2]. In principle, wireless-based device-free human detection works by extracting and analyzing radio shadowing and reflection induced by human motions from wireless monitors deployed in advance, while the target users carry no wireless devices [3–6]. Such device-free human detection mode is especially advantageous in asset security, emergency responses, privacy-preserving elderly monitoring, etc.

A typical wireless device-free human detection system consists of one or multiple transmitter-receiver (TX-RX) links [4,7]. Each TX-RX link operates in two steps: on-site calibration and online monitoring. During the on-site calibration stage, a receiver measures and stores signal features when no one exists within a monitored area, and builds up

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a *normal profile*. It also collects the signal features with human moving within the monitored area, and decides a detection threshold to distinguish the two cases. Afterwards the receiver turns into the online monitoring stage by comparing the measured signal features with the normal profile. Once the deviation from the normal profile exceeds or is below the pre-calibrated threshold, the receiver announces an abnormal event. Such calibration overhead significantly hampers the fast deployment of wireless human detection systems for a new environment, especially in indoor environments.

Although Received Signal Strength Indicator (RSSI)-basd passive human detection [5,8] explores to realize lightweight human detection, only by employing a single normal profile without calibration, it suffers serious performance degradation due to indoor multipath effect. In indoor environments, it is common for wireless signals to transmit to the receiver via multiple paths, which is called the multipath effect. Multipath fading can cause constructive or destructive interference. Different multipath superposition status can lead to diverse link behaviors in reaction to human motions [8] and varied detection coverage shapes [9]. For RSSI-based passive human detection, when a person disturbs a radio link, the RSSI of the link may decrease, increase, or even remain unchanged. Channel state information (CSI), as a fine-grained signal feature [10], characterizes the multipath effect at the granularity of OFDM subcarrier in the frequency domain [11]. It is employed for indoor passive human detection in a revolutionary way and shows good performance. However, existing CSI-base passive human detection systems [7,12,13] more rely on stationary signal patterns, and are *blind* to the propagation conditions where a TX-RX link is deployed and the sensitivity of receivers in dynamic states. The calibration overhead is indispensable if systems were to achieve optimal detection performance under a new multipath propagation environment.

In this work, we raise the question from a unique perspective: instead of blindly relying on on-site calibration or stationary signal patterns to determine the optimal threshold, can we predict the optimal threshold based on assessment of the current multipath propagation conditions without incurring dramatic performance degradation? The key insight is that the threshold to distinguish static and dynamic is closely related to the *sensitivity* of a TX-RX link to human motions. Based on extensive measurements, we observe that such difference in sensitivity to human motions is a result of different multipath propagation conditions. Thus given a quantitative characterization of the multipath propagation conditions, we may predict a threshold without calibration for a new environment. To achieve this goal, we need to address multiple challenges. (1) *How to derive a quantitative metric associated with sensitivity to human motions?* (2) *How to measure the sensitivity metric on commodity wireless devices?* (3) *How to predict the threshold for CSI-based passive human detection based on the sensitivity metric?*

To tackle these challenges, we leverage the recently exposed PHY layer Channel State Information (CSI) on standard IEEE 802.11a/g/n Network Interface Cards (NICs). We take a measurement-driven approach to extract from CSIs an indicator for link sensitivity to human motions. We demonstrate that the metric depicts the abundance of multipath propagation, and is directly measurable using CSI data sampled when there is no human in the area of interests. In addition, we put forward a novel decision model where the proposed metric is harnessed to predict the optimal threshold without on-site calibration for a new environment. To validate the effectiveness of our model, we implement a passive human detection system using off-the-shelf WiFi infrastructure. Extensive experiments conducted in two academic buildings show that the proposed metric can act as a proxy for link sensitivity levels. Compared with the state-of-the-art PHY layer CSI based human motion detection systems [7], our threshold prediction scheme achieves competitive detection performance, while requiring no cumbersome on-site threshold calibration.

Our main contributions are summarized as follows.

- We harness PHY layer frequency-diversity information on commodity WLAN infrastructure to characterize the richness of multipath propagation, and derive an innovative metric to quantitatively evaluate the link sensitivity to environment changes.
- We design an adaptive passive human detection scheme that automatically predicts the detection threshold according to the richness of multipath propagation within a monitored area. It relies on not only stationary signal patterns but also receiver sensitivities in dynamic states. It requires minimal calibration efforts while retaining high detection rates and is helpful to fast deployment of detection systems and avoid frequent system re-calibrations.
- We prototype our scheme on off-the-shelf WiFi devices. Extensive evaluations in typical office environments demonstrate that compared with the state-of-the-art, our scheme achieves comparable detection performance even without on-site calibration for a new environment, which enables fast and lightweight deployment of wireless device-free intruder detection systems in practical indoor environments.

In the remaining of this paper, we provide a preliminary in Section 2, followed by measurements on detection sensitivity in Section 3. We detail the threshold prediction scheme in Section 4.2, and present the performance evaluation in Section 5, followed by brief discussions in Section 6. Section 7 reviews the related work, and Section 8 concludes this work.

2. Preliminary

Wireless passive human detection identifies a person by analyzing the impact of human motions on received signals, while the intruder does not carry any wireless-enabled device [3]. Such motion-induced impact usually leads to dramatic changes in certain received signal features, where Received Signal Strength Indicator (RSSI) acts as the most prevalent signal feature due to its easy access [3,4,14–16]. Recent advances in wireless techniques have also raised increasing interest in utilizing the PHY layer Channel State Information (CSI) on commodity WiFi NICs for finer-grained human motion detection [7,17]. In this section, we review the general framework of wireless passive intruder detection systems, and point out the challenges for fast deployment in practical multipath-dense environments. Then We provide a brief introduction on CSI. Finally, we expound a specific CSI-based human detection scheme with calibration.