## Abstract:

We present ARIEL, a room localization system that automatically learns room fingerprints based on occupants’ indoor movements. ARIEL consists of (1) a zone-based clustering algorithm that accurately identifies in-room occupancy “hotspot(s)” using Wi-Fi signatures; (2) a motion-based clustering algorithm to identify inter-zone correlation, thereby distinguishing different rooms; and (3) an energy-efficient motion detection algorithm to minimize the noise of Wi-Fi signatures. ARIEL has been implemented and deployed for real-world testing with 21 users over a 10-month period. Our studies show that it supports room localization with higher than 95% accuracy without requiring labor-intensive manual annotation.

This article describes ARIEL, an automatic room localization system using Wi-Fi based room fingerprint analysis based on personal mobile phones carried by occupants. **Designing an indoor room localization system that learns room fingerprints without manual annotation is challenging.** First, due to signal reflection, refraction, diffraction, and absorption, indoor Wi-Fi signals are noisy. Such noise obscures the unique relation- ship between Wi-Fi fingerprints and individual rooms. Second, occupant-specific indoor activities directly affect the room fingerprinting process. For instance, in-room occupancy “hotspot(s)” are unevenly distributed both spatially and temporally. With such distribution, clustering algorithms may learn multiple fingerprints for a room. Third, as a collaborative voluntary effort, the overhead, e.g., energy consumption, imposed on personal mobile phones must be low. In response to these challenges, we have developed the following algorithms:

• A zone-based clustering algorithm that accurately and automatically identifies in-room occupancy hotspot(s) using Wi-Fi signature;

• A motion-based clustering algorithm to identify inter- zone correlation, thereby distinguishing different rooms; and

• An energy-efficient motion detection algorithm to minimize the noise of Wi-Fi signature.

ARIEL demonstrates excellent accuracy for room localization over a wide range of building environments, and offers comparable accuracy (95%) to existing supervised learning techniques requiring time-consuming manual annotation.

## 2 System Overview

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ARIEL supports automatic indoor room fingerprinting and room localization using collaborative Wi-Fi signature analysis based on personal mobile phones carried by occupants. Figure 1 illustrates the overall system architecture, which is comprised of components on the mobile phone side and server side.

On the mobile phone side, ARIEL performs the following operations.

• The run-time Wi-Fi signal vectors observed by each mobile phone are collected and delivered to the server to support room fingerprinting and room localization.

• The Wi-Fi signal vector stream is further annotated with motion data from build-in accelerometer, i.e., either collected when the occupant is in motion or stationary. Such information is also delivered to the server to improve Wi-Fi fingerprint identification of in-room occupancy hotspot(s) and inter-hotspot correlation.

• Each mobile phone also maintains a local database storing the fingerprints1 of the rooms that the user has visited before, which serves as a local cache, enabling run-time on-device room localization without engaging the server.

• A system software module provides room localization APIs to support high-level applications & services.

On the server side, ARIEL performs room fingerprinting and localization through an incremental process.

• Given the streams of Wi-Fi signal vectors and the corresponding motion information collected from mobile phones, ARIEL uses the zone-based clustering algorithm to incrementally identify in-room occupancy hotspot(s), or zone(s). Meanwhile, inter-zone correla- tions are identified by the motion-based clustering algorithm, then zones belonging to the same room are merged into a new cluster. Each cluster is assigned a room ID and the Wi-Fi signal vectors in the cluster form the room fingerprint.

• Using the n-gram augmented Bayesian room localization method, run-time room localization services are then offered to the occupants. A room fingerprint database maintains room IDs, room fingerprints, and the converted room fingerprints (n-gram AP subsequences and corresponding probabilities). The converted room fingerprints are selectively synchronized to each user’s mobile phone based on the user’s room visit history and predicted room visits in the future.

### Conclusion

ARIEL has been implemented and deployed for a 10-month study with 21 participants. The evaluation results demonstrate that our automated clustering algorithm generates clusters that are high representative of individual rooms and achieves high accuracy (95%) for room localization. The accuracy is comparable to existing techniques that require labor-intensive manual annotation.

The cluster identities generated by ARIEL can serve as room identification and are sufficient for most applications that do not require semantic name/label for each room. If room names are required, ARIEL can rely on users’ feedback [13] to provide this information. The advantage of our system is that there are much fewer clusters than Wi-Fi fingerprints, significantly reduced annotation effort. With unique identities, we can easily identify different rooms with the same name, learn how people name the same room differently, and identify commonly used names for a room.