Systems and Methods For Calibration-On-Demand of Wi-Fi Indoor Positioning System using Smartphones

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I. Application Domian

The proposed system and methods are expected to increase the reliability and reduce the maintenance cost of Wi-Fi Indoor Positioning System (IPS). Detection, consumption and reaction of Radio map Anomalous Events (RAEs) streams help detect system anomalies, threads and opportunities and thus enhance the operational intelligence.

II. Problem Definition

Wi-Fi fingerprinting approaches perform calibration by constructing a radio map database during the offline phase. Re-calibrations are required from time to time to compensate the shift of signal baseline caused by the changing indoor environment. However, radio map calibration is expensive and time-consuming.

Many researchers have proposed crowdsourcing based calibration approaches using user-contributed data to alleviate the pain of calibration. However, these methods assume user active participation. Also, fingerprinting data from untrained personnel tend to be erroneous [1].

One of the best strategies for radio map management is to reduce the amount of re-calibration to a necessity-based level that we only recalibrate when the system degrades. We observe that the performance of Wi-Fi IPS plummets only when its radio map undergoes substantial and long-term deviation from the original state. Such deviations are mainly infrastructural or environmental abnormity, which are caused by natural processes and malicious or unintended behavior of users. In this research, we define such processes that contaminate radio map as Radio map Anomalous Events (RAEs).

Conventionally, detection of these events is untimely and expensive due to the demand of professional on-site management and hardware installations for data collection. Fortunately, advance in mobile computing technologies provides an additional source of sensing data. The availability of user-generated data relaxes the reliance on professional staffs for radio map management. Previous works [2][3] on Wi-Fi indoor positioning systems fault detection have focused on the detection of malicious attack and have ignored other negative effects caused by routine operation of the indoor environment. Such routine operations induce repeating events with recognizable patterns that could aid in reducing the number of false alarms. These works also lack the ability to detect the nodes correspondent for the system anomaly.

III. Overall Aim and Objectives

This research course aims at developing an online Radio map Anomalous Events Detection System (RAEDS) for Wi-Fi indoor positioning systems diagnostics by detecting the occurrence of radio map anomalous events using smartphone data.

Objectives of this research are as follows:

- Study and define the characteristics of RAEs.
- Design systems for RAEs detection and evaluate their performance through experiments.
- Conduct long-time and pilot-scale experiments to evaluate of the detection rate, false alarm rate and latency of the proposed system in RAEs detection.

IV. Methodologies

A. *An Overview of the RAEDS system*

RAEDS is mainly consisted of two modules: outlier detector and event discriminator. The architecture of RAEDS is outlined in Fig. 1. The outlier detector identifies outliers that do not conform to historical measurement patterns. A time series outlier stream is generated and then fed into the event discriminator to determine the probability of an event. An event will be declared if its probability is beyond the controlling threshold.

B. *Algorihms of the Outlier Detector*

1) Outlier Detection by time-series Wi-Fi Received Signal Strength.

This algorithm identifies abnormal Wi-Fi signal by comparing the correlation of real time Received Signal Strength (RSS) to historical background RSS in a given time window to the predefined outlier controlling threshold. However, the background RSS is difficult to be modeled due to the non-stationarity of Wi-Fi signals. Certain state estimate approaches are needed to tolerate the variation of RSS data in time series.

The first state estimate technique is the Auto-Regressive Prediction Filter (ARPF). ARPF uses an autoregressive model [4] that estimates current value of a time series as a weighted sum of past value. Another state estimation technique, the Multi-Variate Nearest Neighbor (MVNN) [5], provides a measure of similarity of the new data with P previously measured samples contained in the history window.

2) Outlier Detection by Correlations of Wi-Fi Received Signal Strength, Other Ambient signals and Users' Motions.

This algorithm assumes the spatial correlations of Wi-Fi signals, users' dominant activities and other ambient signals of Bluetooth receivers, GSM receivers, magnetometers and other sensors on a smartphone. Motion Landmarks (*ML*) is built using a Least-Square Support Vector Machine [6]. Unsupervised clustering approaches such as DBSCAN [7] is used to identify Wi-Fi Landmarks (*WL*) and Ambient Landmarks (*AL*).

During the online operation, we compute the WL_i with the *WL* classifier using real-time Wi-Fi RSS data as input and the WL_j, which is inferred using the Bayesian Theorem given the occurrence of *ML* and *AL*. If the WL_j is different from WL_i, the outlier detector declares an outlier data.

3) Outlier Detection by the computed trajectories of mobile users.

An intuition is that users' trajectory in indoor environment (especially feature-rich environment) demonstrates a repetitive pattern under normal circumstances. Upon the occurrence of RAEs, the Wi-Fi IPS degrades and results in abnormal user trajectory estimation.

During the offline phase, we build the patterns of user trajectory using sequences of previously visited locations. During the online phase, the user movement scenario can be modeled with techniques like Neural Networks [8] and Markov predictor [9]. An outlier is confirmed if the predicted location L_i is significantly distant from L_j, which is computed by the Wi-Fi IPS.

C. *The Event Discriminator*

Binomial Event Discriminator (BED) [10], which is based on the assumption of the Bernoulli Process, is deployed to calculates the accumulated probability according to the distribution density of outliers within a given time window.

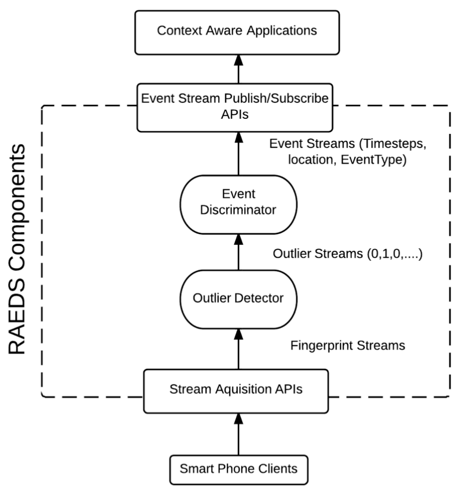

Fig 1. The architecture of RAEDS.

V. PROGRESS AND FUTURE PLAN

The RAEDS system using the time-series Wi-Fi RSS for outlier detection has been tested with both simulated and experimental data. Initial results show that the state estimate algorithms are able to accurately model the background RSS with an average deviation of 0.4 sigma and to adapt to varying Wi-Fi sensing characteristics of different phones. The system is able to detect over 92% of simulated events and 87.5% of real world events with a low false alarm rate.

However, the applicability of current version of RAEDS is limited by the assumption of the availability of mobile data feed. Collaborative and global event detection based on data of distributed nodes will be further studied.

In the future, other algorithms for outlier detection mentioned in IV.B will be built into RAEDS and evaluated by experiments. The completion of these two parts may take up to 6 to 9 months considering the possible change of plan. The potential of coupling these three outlier detection algorithms in serial or parallel manner will also be investigated.

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BIOGRAPHY

Dezhi Zhang is a second-year PhD candidate supervised by Prof. Guoping Qiu of the University of Nottingham, Ningbo, China. His research is dedicated to indoor positioning and mapping technologies, especially technologies for Wi-Fi indoor positioning system diagnostics. Mr. Zhang has devised various systems to detect radio map anomalous events with crowdsourcing data. The expected graduation time is June 201