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Infrastructure-less Intelligent RF Spatial Positioning

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Abstract- Previous indoor localization approaches usually rely on extensively deploying extra positioning infrastructure such as Bluetooth beacons or proprietary 'anchor' stations to function accurately. Such infrastructure-based approaches tend to induce extra provisioning and maintenance costs, and are naturally infrastructure disturbance-prone. Worse, positioning-only infrastructure always faces the risk of obsolescence due to the contending from evolving, wireless communication standards in both the frequency spectrum and the business aspects. Some alternatives resort to scene analysis including fingerprinting on received signal strength (RSS) of e.g. Wi-Fi signals to avoid extra infrastructure deployment overheads. However, most previous fingerprint-based approaches only utilizing a small fraction of the available signals, resulting in unsatisfactory positioning accuracy.

In this study we propose a novel infrastructure-less, AIoT (AI+IoT) based spatial positioning solution incorporating massive data analysis of available RF signals to overcome the aforementioned obstacles. Unlike previous approaches, our solution leverages existing massive wireless communication infrastructure such as IEEE 802-11 (Wi-Fi) and cellular base stations especially proliferative in the metropolitan areas, by harvesting the abundant information contained in the existing RF signals for intelligent processing. Note that, our solution can be augmented to accommodate futuristic wireless standards such as 802.11ax (Wi-Fi 6) and/or millimeter wave based 5G networks, to name a few. Specifically, various characteristics of each perceived RF signal source at a location-of-interest, including (but not limited to) the received signal strength (RSS) and round-trip delay time (RTT) etc., are digitized to extract its information entropy as the basis of further processing. The digitized readings are collectively treated as the fingerprint at that location-of-interest. The local information gains of all perceivable RF signals, as well as the collective global information gain of the fingerprint at that location-of-interest are thus calculated to filter and select the most influential signal sources. The filtered fingerprints will then be fed into a deep-learning based ensemble framework of multiple positioning algorithm modules to match and obtain the most likely spatial position. The spatial models in the positioning algorithm ensembles are trained by a series of spatially calibrated reference fingerprints in an offline manner. To fulfill the demand of such a computationally intensive positioning task, elastic cloud computing services are employed instead of burdening the limited resources on the devices under targeting (DUTs), effectively enlarged the application scope of our solution as more and more smaller, inexpensive IoT devices can be used as DUTs.

To validate our proposed positioning solution in the real world, we designed and implemented a prototype positioning system equipped with the ensemble of both conventional positioning algorithms including Weighted K-nearest neighbors (WKNN) and supporting vector machines (SVM), as well as various deep neural networks (DNN). We conducted a series of experiments on our prototype using Ming-Da Building at National Taiwan University, a 7-story, 12,500m2 RC concrete educational building completed in 2007, as our test site, with no less than 500 residential W-Fi perceivable signal sources. Our prototype, built upon the scalable Google Kubernetes (k8s) containerization framework, has been operational on a 3-node, 10Gb Ethernet-connected private Linux cluster with dual 64-bit Intel Xeon processors with totally 8 physical cores, 64GB RAM, 6TB mass storage space, and a single NVIDIA Quadro P1000 GPU on each server node. The prototype's complement of ROBOTIS TurtleBot3-based robots with enhanced Lidar and attended SLAM capability are responsible to gather authenticate reference fingerprints for training and updating the spatial models of the algorithm ensembles in the prototype. Preliminary experimental results of simultaneously positioning a mixture of multiple Raspberry Pis and Google Pixel 4 phones showed that, our prototype can achieve within 2.1m (7 ft.) accuracy within 90% cumulative distribution by solely utilizing 802.11ac (Wi-Fi 5) RSS fingerprints, and within 1.2m (4 ft.) accuracy within 90% cumulative distribution by incorporating Wi-Fi RTT information.

Index terms: Spatial positioning, Infrastructure-less, artificial intelligence, RF signal fingerprinting, information entropy, scalability, containerization.