Leveraging Machine Learning for Access Point Localization Using RSS Data and Wi-Fi Scanning

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Summary of Related Works

- **Content**: Eyiara Oladipo (20%), Ethan Scheys (50%), Osama Najeeb (30%)
- **Formatting**: Eyiara Oladipo (80%), Ethan Scheys (20%)
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- **Summary Table**: Eyiara Oladipo (50%), Osama Najeeb (50%)

Paper Summaries

We each chose papers either to be the main readers or to be the main proofreaders and we still made sure to look over each other's papers and verify the information:

- **Localization Algorithm of Indoor Wi-Fi Access Points Based on Signal Strength Relative Relationship and Region Division**
    - Main Reader / Proofreader: Ethan Scheys / Eyiara Oladipo
- **Access Point Localization Using Local Signal Strength Gradient**
    - Main Reader / Proofreader: Eyiara Oladipo / Osama Najeeb
- **Enhancing WiFi Access Point Localization With AI-Based Filtering**
    - Main Reader / Proofreader: Ethan Scheys / Osama Najeeb
- **Efficient Wi-Fi AP Localization through Channel Feature Fusion and Anomaly Detection**
    - Main Reader / Proofreader: Ethan Scheys / Eyiara Oladipo
- **EasyAPPos: Positioning Wi-Fi Access Points by Using a Mobile Phone**
    - Main Reader / Proofreader: Ethan Scheys / Eyiara Oladipo
- **An Efficient Indoor Wi-Fi Positioning Method Using Virtual Location of AP**
    - Main Reader / Proofreader: Osama Najeeb / Ethan Scheys

Summary of Related Works

Overview

Access point localization seeks to estimate the physical positions of Wi-Fi APs using network scan data (typically RSSI measurements) collected from known locations. Unlike traditional indoor localization for mobile devices, here the challenge is to determine where the APs are installed—even when their locations aren't explicitly recorded. This is valuable for network planning, maintenance, and even for creating databases (like WiGLE) that map AP distributions. We found various papers that approach the problem of AP localization in different methods, and we split them into four main groups: Signal strength analysis-based methods, Machine learning methods, Virtual-AP methods, and Crowdsourcing methods; However, we will only be focusing on the first three methods for the rest of the literature review, as they are most applicable to our use-case and dataset.

Signal Strength Analysis:

These methods rely on the relationship between signal strength and distance, using techniques such as trilateration, signal strength gradients, and relative strength comparisons to guess the position of the access point

Papers:

1. Localization Algorithm of Indoor Wi-Fi Access Points Based on Signal Strength Relative Relationship and Region Division (https://cdn.techscience.cn/files/cmc/2018/v55n1/cmc.2018.055.071.pdf)
2. Access Point Localization Using Local Signal Strength Gradient (https://www.cs.cmu.edu/~dga/papers/han-pam2009.pdf)

Strengths: Uses widely available RSSI data, which is easily obtained from standard Wi-Fi scans without requiring additional hardware**.** Can also be used in various indoor and outdoor settings without requiring major infrastructure modifications.

Weaknesses: It is highly sensitive to environmental factors: Walls, furniture, and human movement cause signal attenuation and can reduce localization accuracy. Signal strength can also vary due to interference, hardware differences, and time-dependent factors (e.g., network congestion), making it less reliable for precise localization.

Machine Learning Based:

These papers made use of machine-learning-based approaches to enhance Wifi AP-localisation, using tools and approaches like anomaly detection, predictive analysis, and so on. They can provide better accuracy, as they adapt and learn patterns from signal data.

Papers:

1. Enhancing WiFi Access Point Localization With AI-Based Filtering (https://ieeexplore.ieee.org/abstract/document/10478650)
2. Efficient Wi-Fi AP Localization through Channel Feature Fusion and Anomaly Detection (https://ieeexplore.ieee.org/abstract/document/10571086)

Strengths: Machine learning-based approaches can adapt to different environments, filter out noise, and handle signal fluctuations better than traditional methods. They generalize well across deployment scenarios and improve accuracy by leveraging pattern recognition and anomaly detection.

Weaknesses: These methods require large, high-quality datasets for training and may struggle with generalization in unseen environments. They can also be computationally expensive, making real-time processing challenging in some cases.

Virtual AP–Based Methods:

These are based on estimating the "virtual" location of an AP by using signal strength ratios and Apollonius Circle theory. This approach eliminates the need to know the exact attenuation parameters for access point localization.

Papers:

1. EasyAPPos: Positioning Wi-Fi Access Points by Using a Mobile Phone (https://ieeexplore.ieee.org/abstract/document/10087321)
2. An Efficient Indoor Wi-Fi Positioning Method Using Virtual Location of AP (https://www.mdpi.com/2220-9964/9/4/261)

- **Strengths:** More robust to signal fluctuations and environmental obstacles; often achieves lower localization errors.
- **Weaknesses:** Require dense fingerprint data and careful selection of nearby reference points to ensure the assumption of similar propagation conditions holds.

Crowdsourced Data Aggregation:

Systems like WiGLE aggregate millions of GPS-tagged Wi-Fi scans from user devices to infer AP locations.

Papers:

1. Crowdsourced Wi-Fi Access Point Localization using Vertical Movement Detection (https://ieeexplore.ieee.org/abstract/document/10332484)
2. Detect Rogue AP with Crowd Wisdom (https://ieeexplore.ieee.org/document/7980190)

- **Strengths:** Can build large-scale databases covering extensive areas without dedicated site surveys.

- **Weaknesses:** Accuracy is variable, as the quality of crowdsourced data depends on the devices, user behavior, and GPS errors, which may be problematic in indoor or urban canyon environments.

Similarities/Differences

Virtual AP-based methods, Crowdsourced data aggregation, and signal strength analysis all rely on Wi-Fi signal measurements to estimate access point (AP) locations but differ in their approach and robustness. Virtual AP-based methods use signal strength ratios and tools like Apollonius Circle, to estimate an AP's virtual location, without needing precise parameters, making them more resilient to signal fluctuations and environment obstacles, provided dense data and careful calibration are available. Signal strength analysis, however, typically uses direct RSSI-to-distance relationships, such as trilateration or gradient analysis, and is more susceptible to errors from environmental factors like interference and multipath fading. Crowd-sourced data aggregation, unlike the other two methods, relies on user-collected, GPS-tagged scans to map AP locations. This makes them more scalable but can often produce worse results in accuracy due to GPS errors and lack of standardization in devices. On the other hand, machine learning-based approaches can help improve these approaches by using learning patterns from signal data, and being able to use those patterns to reduce noise and adapt to different environments, which can help make the models more robust and applicable to real-world cases.

Discussions

We find the machine-learning-based approaches to be the most effective because they can dynamically adapt to different environments, reducing the impact of signal fluctuations and interference, which is a big issue when collecting RSSI data. Also, unlike the other methods that rely on fixed models or assumptions, ML-based techniques continuously learn from data, allowing for improved accuracy even in complex or unpredictable conditions.

Summary Table

Paper Title	Year	Machine Learning Method Used	Dataset Used	Key Contributions	Evaluation Metrics	Main Findings
Enhancing WiFi Access Point Localization With AI-Based Filtering	2024	Using Neural Networks in a Binary Classification Problem	They used simulated data of an indoor office using Wireless Insite + an indoor corridor at the National Sun Yat-sen University.	They used machine learning to enhance AP positioning accuracy while reducing localization time complexity	Signal-to-noise ratio and angle error	The proposed AI-based filter significantly improved AP positioning accuracy
Efficient Wi-Fi AP Localization through Channel Feature Fusion and Anomaly Detection	2024	AI-based anomaly detection (AD) system, with an LSTM encoder-decoder network	The researchers used simulations in an indoor office environment with Wireless Insite to generate their dataset.	The proposed approach significantly improved LoS-AoA (Line of sight - Angle of arrival) estimations, even under challenging indoor scenarios	Improvement in LoS-AoA estimations. They also monitored the reduction in positioning error	Their method was shown to have improvements in accuracy in AP localization compared to older/more traditional methods
Localization Algorithm of Indoor Wi-Fi Access Points Based on Signal Strength Relative Relationship and Region Division	2018	Mainly rule-based structure - using a hierarchical region division and RSS comparison	In-house location fingerprint database	Instead of relying on raw Received Signal Strength values (which are often unreliable due to interference and obstacles), the method compares relative RSS values to determine location.	Localization accuracy (Error distance)	Their method achieved an average localization error of 0.30m and a minimum error of 0.16m, which is better than existing indoor Wi-Fi localization techniques.
Access Point Localization Using	2009	They used a gradient algorithm for AP location	They made use of an in-house database (they	They introduced the new gradient algorithm, which	Localization error - the distance between	Their algorithm performed well in simulations and

Local Signal Strength Gradient		estimation - the algorithm estimates the direction of the AP from each measurement point by calculating the direction of the strongest signal in the neighboring area	collected their own data)	improved accuracy by 12% compared to the state-of-the-art algorithm at that time	the estimated and actual AP location	was able to localize access points within 1 meter
EasyAPPos: Positioning Wi-Fi Access Points by Using a Mobile Phone	2023	Channel-based SLAM	They use both simulations and real-world data	They used a new SLAM algorithm that transforms CSI information from phones into AP coordinates	AP localization accuracy - they could achieve an accuracy of 0.5m	They found that AP positioning depends not only on the precision of measurements but also from the angles that were scanned
An Efficient Indoor Wi-Fi Positioning Method Using Virtual Location of AP	2020	Weighted K Nearest Neighboring (WKNN).	They conducted their evaluation in a laboratory building	They mainly focused on building on the idea of Virtual AP's and used Apollonius Circle theory to improve their model's accuracy	AP localization accuracy (in meters)	Their approach improved the accuracy and robustness of Wifi fingerprinting techniques

Paper Summaries

1. Localization algorithm of indoor Wi-Fi access points based on signal strength relative relationship and region division.

Access Link: https://cdn.techscience.cn/files/cmc/2018/v55n1/cmc.2018.055.071.pdf

Authors: Wenyan Liu, Xiangyang Luo, Yimin Liu, Jianqiang Liu, Minghao Liu and Yun Q. Shi

Type: Journal

Publication Date: 2018

Citations: 37

Contributors: Ethan Scheys

What is the main purpose of the paper?

The main purpose of this paper is to propose a more accurate and reliable method for indoor Wi-Fi access point (AP) localization by overcoming the limitations of traditional RSS-based approaches.

What key question(s) does the paper address?

1. How can the accuracy of indoor Wi-Fi access point (AP) localization be improved despite the interference of environmental factors like multipath propagation and non-line-of-sight (NLOS) conditions?
2. Can the limitations of traditional RSS-based localization methods, which struggle with precise signal measurement, be overcome to achieve higher localization accuracy?
3. Is it possible to develop a method that progressively refines the estimated location of a Wi-Fi AP using relative RSS values and region division techniques, resulting in more reliable indoor localization?

What are the key contributions of the paper?

Instead of relying on raw Received Signal Strength values (which are often unreliable due to interference and obstacles), their proposed method compares relative RSS values to determine location, this results in the achievement of a high localization accuracy, with an average error of 0.30 meters and a minimum error of 0.16 meters.

Technical Details

Methods Used: The methodology involves dividing the room hierarchically and measuring the Received Signal Strength (RSS) at reference points in various directions. The relative RSS values are then compared to identify the next candidate region. This process is repeated iteratively, refining the candidate region with each step, until the region's size falls below a predefined accuracy threshold. The final localization result is determined by the center point of the smallest candidate region.

Dataset Used: They used an in-house dataset, created from conducting 360 experiments using 8 different types of WiFi APs.

Number of Samples: 360 experiments were carried out, but the specific number of samples is not mentioned.

Number of Features: The primary feature is the Received Signal Strength (RSS) from the target Wi-Fi access point.

Evaluation Metrics: Average localization error, minimum localization error, and the percentage of results within certain error thresholds.

Main Findings/Conclusion

They found their method to produce a significant improvement in AP localization. They achieved an average localization error of 0.30m and a minimum error of 0.16m, which exceeds the results produced by existing indoor Wi-Fi localization techniques. The proposed algorithm is less affected by factors like room structure, AP type, and number of APs compared to existing RSS-based localization methods. The authors describe their future work as focusing on understanding the impact of indoor environmental factors on WiFi AP localization and the relationship between RSS and distance.

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2. Efficient Wi-Fi AP Localization through Channel Feature Fusion and Anomaly Detection

Access Link: https://ieeexplore.ieee.org/abstract/document/10571086

Authors: Yan Li, Jie Yang, Shang-Ling Shih, Wan-Ting Shih, Chao-Kai Wen, Shi Jin

Type: Conference Proceeding

Publication Date: July 2024

Citations: 0

Contributors: Ethan Scheys

What is the main purpose of the paper?

This paper proposes an AI-driven technique that combines channel state information from nearby trajectory points to improve the accuracy of line-of-sight (LoS) angle of arrival (AoA) estimation for Wi-Fi access point (AP) localization. It also introduces an AI-based anomaly detection system to filter out unreliable measurements, which significantly enhances AP positioning accuracy even in challenging indoor scenarios.

What key question(s) does the paper address?

1. How can channel state information (CSI) from multiple adjacent trajectory points be integrated using AI to improve the accuracy of LoS-AoA estimation for WiFi AP localization?
2. How can an AI-based anomaly detection (AD) system be used to filter out unreliable LoS-AoA estimates, especially in complex multipath environments?
3. Can the proposed techniques be applied to untrained APs, in order to make the approach more widely applicable?

What are the key contributions of the paper?

This paper contributes multiple things that add to the world of AP localization. First, it contributes an AI-driven feature fusion approach that integrates channel state information from multiple adjacent trajectory points to enable more accurate LoS-AoA estimation. Second, it contributes an anomaly detection scheme tailored to communication signals that can pinpoint and filter out potentially inaccurate LoS-AoA estimates, especially in complex multipath environments. Additionally, the paper demonstrates that the method is robust and can be applied to untrained access points, broadening its potential for real-world applications compared to existing models that rely on trained access points.

Technical Details

Methods Used: Used WiFi beacon frames to determine AP locations, modeled channel frequency response (CFR) and extracted location-embedded parameters (path gain, time of arrival, and angle of arrival), Applied an AI-based feature fusion approach to enhance the accuracy of LoS-AoA estimation, and finally integrated an AD scheme to filter out inaccurate LoS-AoA estimates.

Dataset Used: The dataset used in the study was a simulated indoor office environment with 10 APs and a UE moving along a grid of points.

Number of Samples: The paper does not explicitly mention the number of samples.

Number of Features: 4 (path gain, time of arrival, angle of arrival, and sine/cosine components).

Evaluation Metrics: Trajectory length (5 points per trajectory), number of multipath signals extracted per point, reconstruction error threshold from the AD net, number of randomly generated trajectories for analysis, and LoS-AoA estimation errors.

Main Findings/Conclusion

The paper introduces an AI-based anomaly detection system to filter out unreliable measurements, and an AI-optimized LoS-AoA network to accurately estimate the LoS-AoA. The proposed approach significantly improves LoS-AoA estimation and AP positioning accuracy, even in challenging indoor environments, outperforming top benchmarks. The approach can achieve consistent LoS-AoA estimation accuracy across different indoor scenarios by filtering out anomalous sequences using the anomaly detection system.

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3. Enhancing WiFi Access Point Localization With AI-Based Filtering.

Access Link: https://ieeexplore.ieee.org/document/10478650

Authors: Cheng-Yu Yang, Wan-Ting Shih, Chao-Kai Wen, Shang-Ho Tsai, Chau Yuen

Title: Enhancing WiFi Access Point Localization With AI-Based Filtering

Type: Journal

Publication Date: June, 2024

Citations: 1

Contributors: Ethan Scheys

What is the main purpose of the paper?

The main purpose of this paper is to propose an Artificial Intelligence (AI)-based filter, called EasyAPPos.

What key question(s) does the paper address?

1. When under the limitation of bandwidth, over a Wifi connection, is it possible to more accurately estimate the location of access points?
2. How can Artificial Intelligence be leveraged in combination with existing localization methods to improve the accuracy of location estimation of access points?

3. Is it possible to utilize and/or expand upon existing technologies and methodologies to navigate the limitations caused by lack of timing synchronization, limited antenna array size, and limited antenna elements and bandwidth?

What are the key contributions of the paper?

To address issues with inaccurate measurements, an AI-driven filtering method known as EasyAPPos was introduced. This technique not only resolves challenges associated with fluctuating confidence levels but also enhances the efficiency of localization by reducing its time complexity. According to the authors, EasyAPPos leads to a significantly improved user experience, making it a valuable solution for tackling both measurement and performance-related issues.

Technical Details

Methods Used: The authors integrate AI-based filtering into the EasyAPPos system for WiFi AP positioning. It collects channel state information (CSI) from smartphones, extracting parameters like angle of arrival (AOA) and time of arrival (TOA). A neural network (NN) classifies and filters these parameters, adapting to the AP's localization precision.

Dataset Used: They made use of simulated data of an indoor office environment, using Wireless Insite, which is a ray tracing-based simulator. They also made use of real-world data collected from their experiments at an indoor corridor at the National Sun Yat-sen University.

Number of Samples: For the simulated data, there were 6,890 user positions and 10 access points. For the real-world data, 100 rounds of measurements were collected from 5 access points.

Number of Features: The features that are mentioned in the paper for both the real-world and simulated data are Received Signal Strength Indicator, Time of Arrival, and Angle of Arrival.

Evaluation Metrics: Accuracy, Root Mean Squared Error, Cumulative Distribution Function (CDF), and Mean Absolute Error.

Main Findings/Conclusion

They found that their AI filtering method significantly improved the accuracy of AP localization using Wifi beacon signals. With a CDF of 0.68, the position error improved from 6.1 to 0.2. Additionally, with a CDF of 0.95, the position error was improved from 8.1 to 0.3.

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4. Access Point Localization Using Local Signal Strength Gradient

Access Link: https://www.cs.cmu.edu/~dga/papers/han-pam2009.pdf

Authors: Dongsu Han, David G. Andersen, Michael Kaminsky, Konstantina Papagiannaki, and Srinivasan Seshan

Type: Conference

Publication Date: 2009

Citations: 147

Contributors: Eyiara Oladipo

What is the main purpose of the paper?

The main purpose of the paper is to introduce a new "gradient algorithm" that localizes APs using only RSSI measurements.

What key question(s) does the paper address?

1. How can AP localization be improved using only received signal strength (RSS) measurements from standard data?
2. Can local signal strength gradients provide more accurate directional estimates than global signal patterns?
3. How does the proposed gradient algorithm compare to existing state-of-the-art localization techniques in terms of accuracy and robustness?

What are the key contributions of the paper?

The key contribution involves creating a gradient approach that estimates the direction of an AP from each measurement point by analyzing local signal strength variations, then combining those directional estimates from multiple vantage points to determine the AP's location

Technical Details

Methods Used: Gradient Algorithm

Dataset Used: The paper used real-world data collected through wardriving - which involves driving around and passively monitoring 802.11 frames to record RSS and location information.

Number of Samples: They used varying numbers of measuring points from 10 to 50, and in the experiments, they used 200 points.

Number of Features: They used location (x, y) coordinates and RSS as features

Evaluation Metrics: Mean localization error, maximum error, and the standard deviation of errors

Main Findings/Conclusion

They found that the gradient algorithm improves accuracy by 12% compared to the state-of-the-art algorithms at the time the paper was released. Their algorithm also reduces the maximum error and standard deviation of errors by more than 33%.

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5. EasyAPPos: Positioning Wi-Fi Access Points by Using a Mobile Phone

Access Link: https://ieeexplore.ieee.org/abstract/document/10087321

Authors: Wan-Ting Shih, Chao-Kai Wen, Shang-Ho Tsai, Ran Lio, and Chau Yuen

Type: Journal

Publication Date: March 2023

Citations: 7

Contributors: Ethan Scheys

What is the main purpose of the paper?

The main purpose of this paper is to introduce EasyAPPos, a lightweight and user-friendly solution for localizing WiFi APs using only widely available smartphones, without the need for additional hardware or infrastructure.

What key question(s) does the paper address?

1. How to determine the location of WiFi APs using only widely available smartphones, without the need for additional hardware or specialized equipment?
2. How to develop a lightweight, user-friendly solution for AP positioning that eliminates the need for additional costs and simplifies the process.

What are the key contributions of the paper?

This paper proposes a lightweight, user-centric AP positioning solution called EasyAPPos that utilizes widely available mobile phones without requiring additional hardware or infrastructure. It addresses three key challenges in AP positioning: limited angular range, absence of timing synchronization, and coarse measurements from mobile phones. They validated EasyAPPos through simulations and experiments, demonstrating decimeter-level positioning accuracy even under harsh conditions.

Technical Details

Methods Used: Proposes a lightweight, user-centric AP positioning solution (EasyAPPos) that utilizes widely available mobile phones and WiFi beacon signals, addresses the challenges of limited angular range, absence of timing synchronization, and coarse measurements by redesigning the SLAM and leveraging the natural rotation of humans to overcome the limitations of commercial smartphones with patch arrays.

Dataset Used: This paper does not mention the use of any specific dataset.

Number of Samples: This paper does not mention the number of samples.

Number of Features: This paper does not mention the number of features.

Evaluation Metrics: Percentage of measured AoA errors, scanning angle, positioning errors, variance of the estimated AP, and AoA errors.

Main Findings/Conclusion

The proposed system, EasyAPPos can locate WiFi APs within 0.5 m accuracy using only WiFi beacon signals and a smartphone. Additionally, EasyAPPos addresses the challenges of limited angular range, lack of time synchronization, and coarse measurements in smartphone-based AP localization by modifying the SLAM algorithm and leveraging the natural rotation of users.

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6. An Efficient Indoor Wi-Fi Positioning Method Using Virtual Location of AP

Access Link: https://www.mdpi.com/2220-9964/9/4/261

Authors: Xu, F., Hu, X., Luo, S., & Shang

Type: Journal

Publication Date: April, 2020

Citations: 10

Contributors: Osama Najeeb

What is the main purpose of the paper?

The study recommends using Virtual Access Points (VAPs) to enhance indoor Wi-Fi placement. It seeks to improve Wi-Fi fingerprinting's accuracy and resilience, as it frequently experiences signal fluctuations.

What key question(s) does the paper address?

1. How can Wi-Fi fingerprinting accuracy be increased in intricate indoor settings?
2. Can signal variations be mitigated using Virtual Access Points (VAPs) to improve positioning robustness?
3. How can the accuracy of conventional Log-Normal Shadowing Models be improved by removing the attenuation factor?

What are the key contributions of the paper?

By building Apollonius circles using signal strength ratios, the study does away with the need for the attenuation parameter, resulting in more precise virtual AP positioning. An innovative approach that combines fingerprints and virtual access points to increase accuracy and resilience. The technique lowers the inaccuracies in location estimation brought on by signal variations. In three distinct interior contexts, the suggested solution performs better than conventional techniques like RADAR (fingerprinting), Iterative Positioning Algorithm (IPA, ranging-based), and PD-WKNN (virtual AP-based).

Technical Details

Method Used: Offline Phase (Data Collection & Virtual AP Estimation) and Online Phase (Localization)

Dataset Used: The dataset was collected in a laboratory building (fourth floor) at China University of Geosciences.

Number of Samples: Not mentioned

Number of Features: Wi-Fi RSSI values from multiple APs, Reference point coordinates (X, Y)

Evaluation Metrics: Mean Error (meters), Median Error (meters)

Main Findings/Conclusion

The Apollonius Circle technique and virtual APs are used in this study to propose a new, reliable, and effective indoor positioning method. It improves accuracy in difficult indoor situations by successfully doing away with the requirement for attenuation parameters. In order to prevent local optima and enhance error handling in initial location estimation, future research will focus on improving the least squares approach.