Received Signal Strength Indicator and Its Analysis in a Typical WLAN System (Short Paper)

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***Abstract*—Received signal strength based fingerprinting approaches have been widely exploited for localization. The received signal strength (RSS) plays a very crucial role in determining the nature and characteristics of location fingerprints stored in a radio-map. The received signal strength is a function of distance between the transmitter and receiving device, which varies due to various in-path interferences. A detailed analysis of factors affecting the received signal for indoor localization is presented in this paper. The paper discusses the effect of factors such as spatial, temporal, environmental, hardware and human presence on the received signal strength through extensive measurements in a typical IEEE 802.11b/g/n network. It also presents the statistical analysis of the measured data that defines the reliability of RSS-based location fingerprints for indoor localization.**

I. Introduction

Historically, received signal strength indicator (RSSI) based fingerprinting has been playing a key role in numerous indoor positioning systems. Typical location fingerprinting algorithms consist of two phases: an off-line/training phase and an on-line/positioning phase. The training phase consists of collection of RSSI at known distinct locations called as Reference Points (RPs). These RPs are stored as a fingerprint in a radio-map. In the positioning phase, real-time data is collected at an unknown location called as a Test Point (TP). The localization algorithm uses the radio-map to derive the location of a TP by calculating the Euclidean distance between a TP and each RP fingerprint. The fingerprint consists of N RSS values for each cited Beacon/Access Point (AP) in a wireless network. Furthermore, localization algorithm uses either probabilistic or deterministic methods for positioning [1] [2]. RSS as a fingerprint forms a basis in creating a radio-map for fingerprinting algorithms.

RSS at a given location is average of the signal received through different paths (multipath effects). Therefore, it becomes crucial to determine the factors that affect RSS. In this paper, we attempt to answer the question, whether RSSI can be used for creating the reliable location fingerprints? The main objective of our experiment is to study the characteristics of the RSS, to figure out the parameters and its effect on the RSS at a particular location and instant of time. We investigate the effects of hardware orientation, location, time and duration of measurement, interference and user's presence on the RSS.

II. Related Work

The data analysis of localization algorithm has been presented in [1]- [3]. Bahl et al. presents the effect of user's orientation on the mean value of RSS [1]. The study shows that RSS at a location can deviate by 5 dBm maximum depending on user's orientation. Based on the observations, researchers have suggested to exploit the orientational database for fingerprinting to improve the accuracy of localization. In [3] authors have pointed out that the factors such as hardware quality and number of received samples from APs affects the localization. But the study have not presented any investigations regarding the effect of these factors on localization. Ahmad et al. presented the analysis of the temporal variations on RSS samples [4]. The study indicates that the absence of samples from APs due to degradation of radio channels may adversely affect the indoor localization. This can degrade the performance and scalability of the localization algorithm with more computations. In [5] author has presented the detailed analysis of RSSI measurement and investigated the effect of wireless local area network (WLAN) card, time and duration of measurement, interference and building environment (corridor, small office or large hall). Make of WLAN card affects RSS significantly due to different quantization bins. However, the effect of user's presence and device orientation on RSSI is not considered. Further the study considers the antenna of WLAN card to be omni-directional. The analysis in carried out in 3 different building environment using limited (maximum 6) APs.

All these studies raised some serious concerns on reliability of the RSSI in fingerprinting. In our studies, we show empirically that the RSSI is significantly affected by hardware orientation and several other factors. Therefore, RSSI when used to create location signatures are unreliable when multiple devices from different vendors and physical constraints are being used. However it may be possible to use RSSI for fingerprinting using a single device with fixed hardware configuration to provide the reliable location fingerprints.

III. Experiment Setup

The RSSI measurements were carried out using a laptop in a typical IEEE 802.11 b/g network and using available APs in a real-time work environment. A Dell Latitude E5400 laptop

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with Intel(R) WiFi Link 5100 AGN (NDIS 6 Native WiFi) card is placed at a fixed and undisturbed location to record the RSSI for the wireless AP infrastructure. Results from the fixed positioned APs are presented and signals from mobile APs (laptop, smartphone) are not considered for analysis in our paper. The NetSurveyor [6] surveying software is used to capture the wireless signal strength. The data is logged for four different orientations of the laptop namely east, west, north and south over a duration of day and/or a week. The log file provides the scan time of each sample and stores all the RSSI values along with the AP index. Further it details the AP characteristics such as BSSID, Service Set Identifier (SSID), operating Channel, radio-type and encryption if any. The sampling rate of the data is approximately 1400 samples/hour, thus recorded 33600 samples over 24 hours. The experiment is carried out on the 4th floor in a 5-floor building consisting of various meeting rooms and cubicles and seminar rooms. RSS measurements are taken from 13 APs in a typical office environment. Each deployed AP transmit signals with 3 distinct Basic Service Set Identifiers (BSSIDs) as test_secure, test_wireless and test_visitor operating in 2.4 and 5 GHz channels.

In our experiment, measurements are carried out using a laptop by rotating it into 4 directions. Measurements at the AP side is not collected. The analysis using a single WLAN card is presented. We have considered samples with -100 dBm and 0 dBm values reported by Network Interface Card (NIC) as the weaker samples and absent samples respectively and are treated as invalid samples for statistical analysis. Furthermore, various data statistics such as minimum, maximum, range, mean, mode, median and standard deviation are calculated based on valid samples. In this paper, the terms RSS and RSSI are referred interchangeably.

IV. Data Analysis

In this section, we present the details regarding our measurements, figure out the various contributing factors responsible for RSS variation and discuss the statistical properties of the measured data.

A. Measurement data summary

The summary of logged data is shown in Table I.

Location	Orientation	Factors		
		Duration (days)	Total Samples	Observed BSSIDs
Location 1	East	2	66630	84
	West	1	33594	63
	North	1	33590	79
	South	1	33786	63
Location 2	East	3	99866	129
	West	7	207864	162
	North	2	67452	118
	South	3	88677	231

TABLE I: Data Summary

We have collected data in each orientation for at least 24 hours to provide the uniformity in the analysis.

B. Causes of RSS variations

To analyse the RSSI variation, we divide the cause of variation as follows

1) Hardware: Orientation, directionality and type of antenna (WLAN card)
2) Spatial: Distance between receiver and transmitter (AP)
3) Temporal: Time and period of measurement
4) Interference: RF interference due to nearby devices operating is same/different radio channel
5) Human: User's presence/absence, orientation, mobility
6) Environment: Building types, materials

1) Hardware: The orientation of the receiving device is exploited to investigate the effect of antenna directionality of the wireless card. To analyse the RSS variation for different orientations of the laptop, RSS data is collected for 4 directions such as east, west, north and south over 24 hours at a fixed location. Figure 1 shows the RSSI variation of a AP for a day.

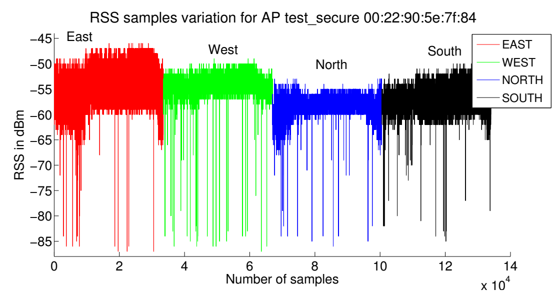

Fig. 1: RSSI for different orientations

The statistics for each direction is calculated and presented in the Table II.

TABLE II: Statistics at location 1 for 4 directions

Orientation	Min	Max	Range	Mean	Mode	Median	Std. Dev.
East	-86	-47	39	-54.49	-54	-57	4.74
West	-86	-50	36	-54.09	-54	-52	2.09
North	-85	-54	31	-58.49	-59	-59	2.07
South	-84	-50	34	-56.69	-57	-58	2.91

From the Table II, range variation of at least 3 dBm is observed for different orientations. The mean for east and west direction is equal but varies by 4 and 2 dBm for north and south direction respectively. Also the standard deviation of samples for east direction is almost double than other directions. This variation can be due to the directionality of the antenna of the WLAN card. The directionality of the antenna (bidirectional, omni-directional etc.) defines the signal transmit/receive capability. Thus, it can be noted that the orientation of the received device i.e. directionality of the antenna affects the RSSI.

2) Spatial: RSS varies as a function of distance between transmitter and receiver. The measurements at two locations L1 and L2 separated by 1 meter are used to analyse the spatial properties of RSS. We have considered a AP observed at both locations and its regularity of the samples is compared. At L2, device captured more weaker samples than L1. Table III indicates the RSS statistics for the same AP at two locations L1 and L2. The range difference at two locations is 12 dBm.

TABLE III: Statistics for Location 1 and Location 2

Location	Min	Max	Range	Mean	Std. Dev.	% valid samples
L1	-88	-46	-42	-54.51	4.84	100
L2	-100	-46	-54	-60.46	5.10	99.26

Also, the mean RSS fluctuation of 6 dBm is observed between two locations. Thus the location granularity of 1 meter shows considerable difference in terms of RSS range and mean.

3) Temporal: Location signature captured at a location during the day time may not be same during night time. This difference in location signature may affect the localization accuracy, since it uses pre-stored radio-map. Therefore, it is important to determine the temporal variations of RSS. We analyse the time-variant nature of RSS in terms of its variation, distribution, nature and number of samples over time.

Time-variance: RSS from a signal source varies over time due to factors such as moving people, interferences, degradation of radio channel and many more. To figure out the extent of temporal RSS fluctuations, we have plotted the RSS values against captured time for 2 consecutive days for east direction at location 1 as shown in Figure 2.

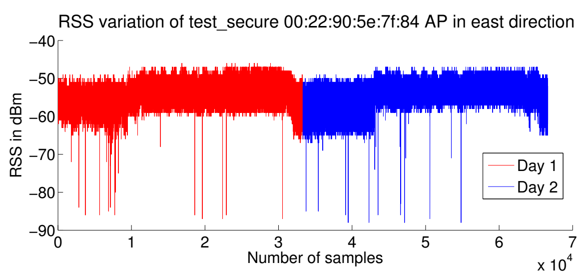

Fig. 2: RSSI variation over 2 consecutive days

It is clearly seen that the minimum and maximum of RSSI variation were lower during working hours (0-10000 samples) than rest of the day(10000-33500 samples). Also, a similar pattern of variation is observed for the second day.

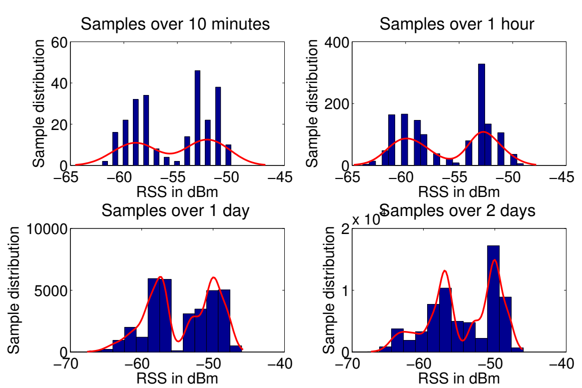

Fig. 3: RSSI distribution different durations

RSS distribution & Skewness: Due to the irregular nature of samples from each AP, the number of samples required to form a fingerprint have to be evaluated. Figure 3 shows the RSSI samples distribution collected for various time duration.

The normalized histogram clearly shows bi-modal distribution for the samples collected for 10 min, 1 hour, a day and 2 days.

A set of 15 APs visibility is observed for 4 orientations at Location 1. The skewness of each of the 15 AP for each direction is shown in Figure 4. Skewness defines the degree of asymmetry of a distribution.

It is noted that, except for 1st and 15th AP, all other APs show either positive or negative skewness, but their amount of skewness varies considerably for different orientations.

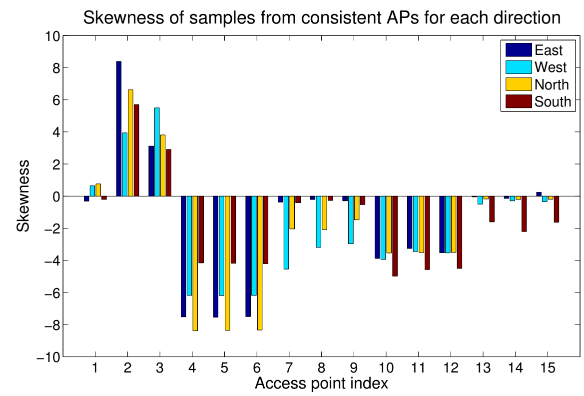

Fig. 4: Skewness of 15 consistent APs for 4 directions at Location 1

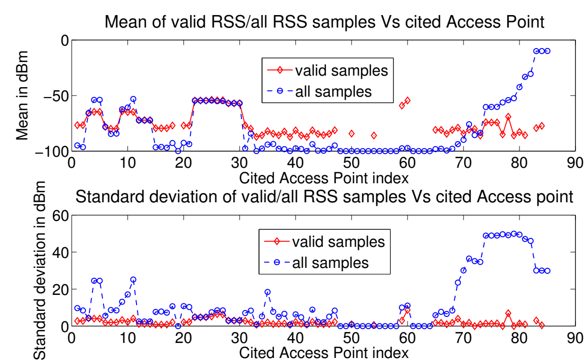

Fig. 5: Mean and standard deviation of all the APs for east direction using valid and all samples

Nature and number of samples: As mentioned in Section III, data collected from various APs varies from 0 to -100 dB. This is due to absence of signals from AP (due to channel degradation over time) or weaker signal due to distance and interference or moving people. It affects the location fingerprint used for indoor positioning. For further investigation, we consider these signals as invalid samples. Figure 5 shows the effect of invalid samples such as mean and standard deviation for each cited BSSID.

The calculated mean of RSS for each AP using valid samples have higher value than using all the samples. Also the standard deviation is lower for APs with higher valid samples.

Thus, mean and standard deviation of samples from a AP is directly proportional to regularity and irregularity of samples respectively.

To explore the effect of number of RSS samples further, we have calculated the statistics for varying number of samples for a consistent AP at location 1 for east direction and is presented in Table IV.

TABLE IV: RSS Statistics for varying number of samples

No. of samples	10	100	500	1000	10000	33000
Range	7	12	12	15	39	41
Mean	-55	-54.48	-55.48	-55.81	-56.39	-54.45
Std. Dev.	3.06	3.56	3.63	3.77	4.57	4.72
Variance	9.33	12.7	13.16	14.24	20.85	22.25
Skewness	-0.39	-0.68	-0.11	-0.17	-0.56	-0.37
Std. Error	0.97	0.36	0.16	0.12	0.05	0.03
Confidence Level 95%	1.89	0.70	0.32	0.23	0.09	0.05

From the measurements, it is seen that for standard error of 0.1, the number of samples of around 1000 may provide good fingerprinting data. This number of samples further might be reduced by applying some pre-processing techniques.

4) Interference: The dependence and interference of the radio devices (multiple APs) operating in same or other channels can be determined by evaluating the correlation coefficient of the samples at a particular location in a given time. For evaluation of correlation of samples, we have chosen, 3 BSSIDs (from AP1) operating in channel 1 (2.4 GHz) and 3 BSSIDs (from AP2) operating in channel 149 (5 GHz). BSSIDs operating in same channel found to have low or trivial correlation, whereas BSSIDs operating in different channels are seen with correlation coefficient less than 0.1. This results indicates that very small correlation exists between the samples from APs operating in same or nearby radio channel.

5) Human presence: Presence and movement of people affects the RSSI, because human body that contains more than 50% water, absorbs the radio signals. To analyse the effect, data is captured over 3 days, where a person collecting the data was present on the first day during working hours and rest of the first day and other days, the person was absent. The effect of user presence is shown in Figure 6. Samples

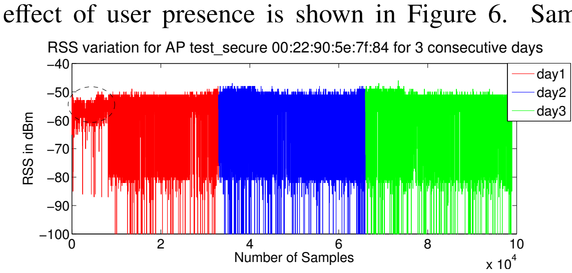

Fig. 6: RSSI variation over 3 consecutive days

from 0-8500 denotes 10-6pm, when user was present. It is evident that human body tend to affect the RSSI.

6) Environment: During data collection, a varying number of APs were observed and the samples from corresponding APs were noticed to be fluctuating. Also, certain APs were observed for particular interval in a day. For example, some APs were found to be visible during working hours whereas some APs were cited during night time. On the other hand, some APs were observed during entire day with either frequent samples or occasional samples. This irregularity of the samples from APs may be due to environment such as switching on/off of the modems from residential areas and more interference during working hours than night. Also, presence of user and particular orientation may lead to invisibility of signal during measurements. This behaviour of visibility of APs may affect the on-line location estimation phase while matching the RSSI fingerprint in a pre-stored radio-map.

V. Conclusion

In this paper, we have investigated the factors affecting RSS including orientation of the receiver, distance between transmitter and receiver, time and duration of measurement, interference due to other radio devices, presence of human and building environment on the RSSI. We had shown empirically that the RSSI fluctuations are quite significant even for a single hardware. In the case of multiple devices from different vendors are used, this variations will be amplified even further due to different sampling rates and quantization bins. Our experiment shows that diferent orientation of a single device results in at least 2 dBm mean deviation whereas location granularity of 1 meter leads to upto 6 dBm mean fluctuation. Further, time and duration of the measurement for determining the required number of samples to form a location fingerprint varies due to irregularity of samples, its distribution and skewness. From our analysis, it is evident that multiple orientations at a fixed location with user's presence can provide various radio signatures that can be incorporated in the radio-map for location fingeprinting. We intend to explore the possibility of exploiting aggregated information from different types of devices, to determine the correlation between different devices that results in RSSI variation. This will help in normalizing the hardware dependency to provide more robust location fingerprinting using RSS signatures.

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