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FM Based Localization: A Proposed Improvement

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Abstract:
Localization is an essential issue in pervasive computing application. FM performs worse in some indoor environment when its structure is same to some extent the outdoor environment like shopping mall. Furthermore, FM signal are less varied over time, low power consumption and less effected by human and small object presence when it compared to Wi-Fi. Consequently, this paper focuses on FM radio signal technique and its characteristics that make it suitable to be used for indoor localization, its benefits, areas of applications and limitations.

Keywords: Indoor localization; FM localization; fingerprinting.

Introduction:

Localization is the process of determining the location of an object or a mobile user relative to their environment. The indoor positioning techniques can be affected by the structure of the building, the size and position of the furniture. Global Positioning System (GPS) cannot be used for indoor positioning due to signal low intensity [1].

Wi-Fi or WLAN or IEEE 802.11 are wireless standard of data transmission [2] [3] at short range signal (2,4 GHz and 5 GHz). RFID (Radio Frequency Identification) is a short range signal used for tracking persons or objects [4]. For indoor localization in very large buildings, the system imposes an intensive infrastructure of tags/readers which means a very high number of RFID to be used and preregistered location information [5].

Bluetooth is used for Indoor positioning systems. The project in [6] designed an indoor Bluetooth positioning system integrated with Global Positioning Module (GPM) software. This integration allows the user of mobile or any device which contains Bluetooth to estimate the location. The positioning accuracy achieved by the system is about 50% with approximately 1.5 m of the actual position when the user is not moving and this accuracy decreased when the user moves [6].

Long range signals as GSM and FM are also used for indoor positioning [7]. In [7], the authors develop WLAN positioning system based on RSS fingerprint and then develop a positioning system based on RSS fingerprint in GSM in same indoor environments.

FM is less attenuated by building material and this make the signal easily penetrate walls compared to Wi-Fi and GSM and also lead to a wide availability of these signals for indoor positioning [8], [9]. The radio signals are less susceptible to zone condition such as woods, tree leaves movement while GSM and Wi-Fi signal proliferation is affected by the leaves movement [1], [2]. FM receivers are embedded in mobile devices; they consume low power and do not overlap with other devices or wireless technologies [1], [8] and [9] [10].

In [11] the proposed hybrid approach used the Wi-Fi infrastructure and number of Bluetooth hotspots with radio coverage range varies from one meter to ten meters. The two technologies are deployed in different way in order to improve the accuracy of the indoor positions. Wi-Fi is deployed as the main infrastructure.

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The contributions of this comparison study paper may be short listed as follows:

- Exploitation of FM radio signal in the indoor localization environment.
- High localization accuracies achieved by combining FM positioning technology with Wi-Fi.
- Low power consumption FM-based localization.

FM RADIO PROPAGATION

Radio waves are part of the electromagnetic spectrum. Radio wave propagation is the study of the transmitted or propagated radio waves behavior from one point to another, on the earth or into the parts of atmosphere. These waves are affected by many phenomena as reflection, refraction, absorption, scattering, diffraction and polarization.

Radio signals may travel in multiple paths from the transmitter to the receiver. These multiple paths depend on the frequency, the type and the height of the antenna and atmospheric environment. The radio signals are affected by the ionosphere because of the different frequencies of the radio waves that range from (2-100) MHz. The ionosphere may act as a reflector, or an absorber, or a scattering, and for frequencies above 30 MHz, the radio waves penetrate the ionosphere [12]. The transmission of radio wave may travel in two ways from the transmitter to the receiver. The ground waves which are the radio waves that propagated along the earth, i.e. all radio waves have some ground waves. The sky waves which are the radio waves that reflected from the ionosphere back to the earth [13].

To transfer the energy of the emitted radio wave from the transmitter to the receiver, the paths of this wave may consist of one or more of the transmission media which are the free space, earth atmosphere, ground surface and surrounding medium, ocean and sea water and inside earth [12], [14] these media is characterized by three parameter which are permittivity, permeability, conductivity.

In the free space, the radio waves emitted from isotropic antenna will be radiated in all direction and do not suffer from energy absorption [14]. Vegetation impact on the waves propagation is varies seasonally. To predict the field strength, curves are developed by measuring values at different time to specify the service area of stations; these curves predict the strength field for different antennas height, distance and frequencies [12].

POSITIONING APPROACHES AND TECHNIQUES

Different approaches are used for the localization information detection depending on the applications. The general approaches for indoor are: time based (Multilateration) and angulation approach [15].

- ***Angulation Approach***

The approach is based on measuring the angle of the signal transmitted from the client mobile to multiple measuring points. At least two known measuring points and two measured angles θ_1, θ_2 used to determine the object location; the location can be determined by the intersection of pairs of angle direction lines [15] as shown in Figure-1.

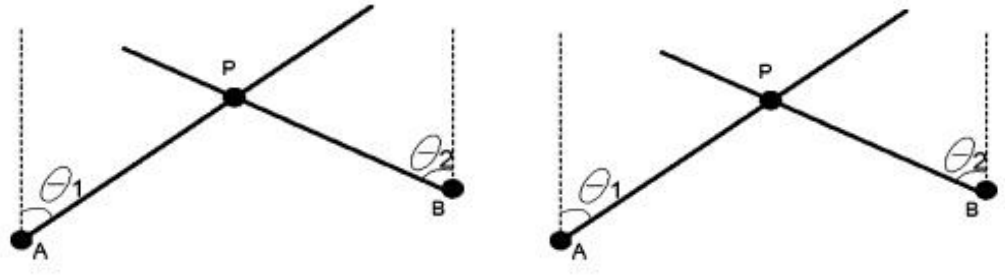

Figure 1-positioning based on AOA measurements

A.2. Time-Based (Multilateration) Approach:

Multilateration may be applied to find the location of target object by calculating the distance from multiple reference point. Also by measuring the attenuation of the signal strength, roundtrip time of flight (RTOF) are used in some systems.

A.2.1. Time of Arrival (TOA):

The distance from the target to the measuring unit is relative to the proliferation time. The TOA depends on the sending signal time and the time of receiving that signal. Precise synchronization between all the transmitters and the receivers is required [17]. The signal should also contain time information to know the distance that the signal traveled [16].

A.2.2 Time Difference of Arrival (TDOA)

This approach based on the calculation of the difference in time at which the signal received by many reference points instead of calculation the absolute time of the arrival TOA [16]. To have TDOA calculation, the time difference should define a hyperbolic line, i.e. the transmitters must lie on hyperboloid [15] as shown in Fig.2. Time synchronization is required between the transmitters only. This method and the previous one have disadvantages that the multipath effects have impact on the time and the angle which leads to decrease the positioning accuracy.

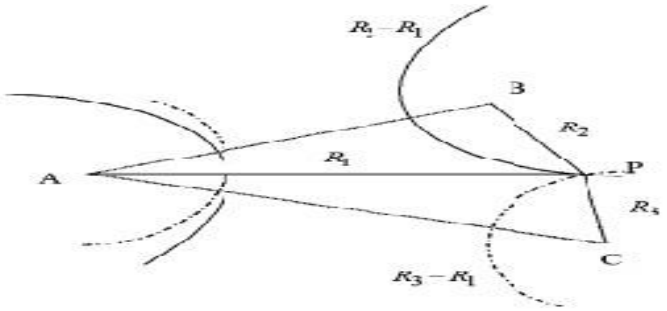

Figure 2-positioning based on TDOA measurements

A.2.3. Signal Attenuation

This approach based on exploiting the features of the received signal itself. These features include many properties such as signal phase, signal-to noise ratio (SNR) and signal strength. The most exploiting property is the RSS. In this method the path loss of the attenuated signal strength is measured and these measurements are used to determine the position of mobile object from many reference points [15].

A.2.4. Roundtrip time to flight

In this method the total time of sending a signal from the transmitter and receiving it by the measuring unit and back is measured. TOA and RTOF have the same range measurements. The measuring unit has a difficulty in knowing the exact delay time caused by the responder [16].

B. Positioning techniques

Propagation modelling and fingerprinting techniques are general approaches used for localization that rely on the measurements of received signal strength indication [2].

B.1. Propagation model:

Radio waves in an indoor location are susceptible to reflection, diffraction and scattering by the inner layout of the building. The transmitted signal reaches via multipath causing inconstancy in the received signal phase and this make the prediction of signal strength difficult. The propagation model takes into account the structure of the building to measure the distance between the transmitter and receiver. The positioning accuracy provided by the propagation model is dependent on the complexity of the model and on the weather condition [2].

In RADAR [18], the authors suggested a propagation model called Wall Attenuation Factor (WAF), which is adopted from floor attenuation factor propagation model. This model regarded the

walls between the transmitter and the receiver as the main obstacle and predicted the signal propagation behavior.

There are three types of propagation model using the RSSI which are:

B.1.1. Free space model

This model is applicable when there are no barriers between the senders and the receivers of signals [19], [20] and the travelled distance is greater than the beacon size and the wave carrier [19].

B.1.2. 2-Ray ground model

It is used when the travelling distance is not so large and the height of the sender's beacon or receiver's beacon is more than 50 meter [19]. This model receives two rays, the direct ray and reflected ray [20].

B.1.3 Normal-log shadowing model (NLSM)

The model can be derived using empirical and analytical methods [20]. The localization accuracy achieved by this model is generally worse than the localization accuracy provided by fingerprint approach [2].

B.2. Fingerprinting

Fingerprinting is an economic technique since it doesn't require any additional hardware or infrastructure, time independent and it makes use of the multipath phenomena when it compared to the approaches that depend on the distance in positioning [3].

Fingerprinting consists of two steps: first step is calibration or training step and the second step is the localization or the positioning step [3]. During the first step, the construction of fingerprint database is done by collecting received signal strength for set of base stations. In the second step the unknown position is estimated by comparing the observed signal strength and the previously collected fingerprint database [9], by using a sufficient algorithm like deterministic and probabilistic or classification and regression. The mostly used algorithms for location fingerprints positioning using pattern recognition are probabilistic and k-nearest neighbor.

In the probabilistic method the position is regarded as a classification problem, where there are n position nominees P_1, P_2… P_n, and s is the observed signal strength vector during the first step of fingerprinting. K-nearest-neighbor classifier (kNN) is a simple classification method based on fingerprint [8]. The classification is done by given fingerprint and the algorithm reform the distance to the fingerprint in the training set, and the k closest ones are chosen to estimate the location [8]. The algorithm can be work with any distance measurements. The algorithm has only one parameter k which represents the number of regarded neighbors [8], [19]. By using leave-one-out cross validation, the optimal values of k are set [8].

EXAMPLES OF EXPERIMENTS USING FM RADIO FOR LOCALIZATION

The frequency modulated (FM) radio is regarded good approach for indoor positioning due to its advantages over other positioning technologies for example as a comparison to Wi-Fi , the installation of Wi-Fi localization system requires additional hardware in spite of the availability of Wi-Fi infrastructure [18], while the FM transmitters are inexpensive and available in electronics shops. FM is less power consumption when it compared to Wi-Fi.

In FINDR (FM INDooR) [20] the authors proposed an approach which explores the applicability of short range FM radio signal in indoor positioning. To determine the relative position of the user, the angle between the antennas, the signal propagation time and RSSI are used, and for FM positioning three features are used which are: RSSI, SNR and stereo channel separation (SCR).

An empirical calculation is used to evaluate FINDR. The room dimension where the experiment is done was 12x6 m with office furniture. Three transmitters, Nokia N800 internet tablet was used as receiving device, a standard N800 headset as an antenna, König mp3 player with built in FM transmitter as a transmitting device and a 1.8meter audio cable connected to the transmitter to increase its range and it is powered by USB power adapter to avoid the battery degradation.

As a summery FINDR, is a low-cost positioning system since it consists of an inexpensive transmitters and an embedded FM receiver in a client device like smart phone or PDA, the median accuracy that it shows is 1.3m and 4.5m at 95% confidence level.

The audio features of FM radio signal like SNR and SCS are less used for indoor localization as shown in [21]. The audio features quality depend on the received radio frequency signal quality that encoded by a modulation manners, this signal degrades with the distance and the SNR and SCS are

affected by the noise that pass through the audio part. The same transmitter that used in [20] is used to show whether the SNR is a suitable feature for positioning by setting it to broadcast a continuous dual-tone multi frequency (DTMF) signal which is composed of 1209Hz and 697 Hz sine wave.
Result in Fig. 3 shown that SNR feature, there is no clear dependency on distance where the mean value of SNR is gradually change and after distance of 4.5 m it rapidly noised [18] which means that SNR is a suitable feature for positioning at long distance where RSSI value is low [21]. Two reasons are considered when choosing SCS feature to measure the distance, which are: the noise sensitivity of the stereophonic signal is more than of the monophonic and the left and right radio channel are less RF noise sensitivity, the other reason; the quality of stereo signal is impact by the subcarrier deformation. The value of SCS is estimated by calculating the difference between the component frequencies 697 Hz and 1209 Hz of the DTMF that broadcasted from the transmitter on the right channel and the left channel respectively. SCS degrades whenever the distance increases, reaching its minimum value and stay constant afterward [21]. The accuracy provided by SCS is (2.1m). SCS has some limitation that it used for positioning at small distance and a known stereo signal should be broadcasted by the transmitter.

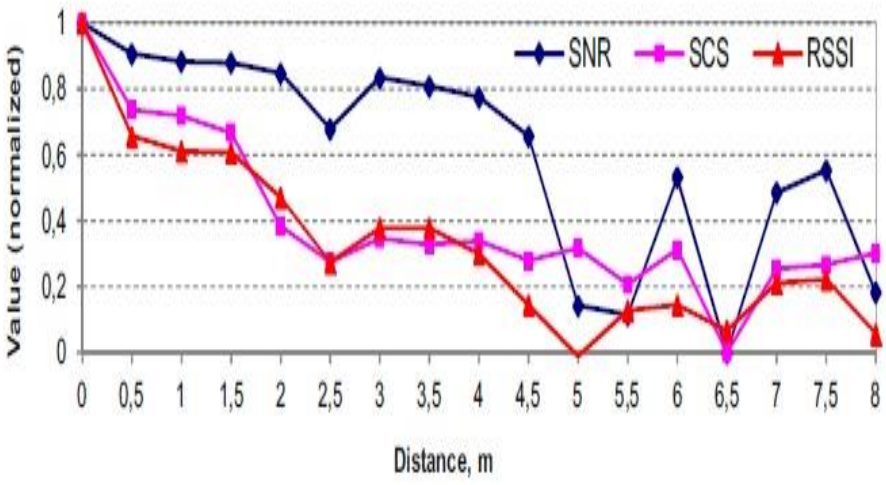

Figure 3-Dependency of SNR, SCS and RSSI on distance

Authors in [2] produce an improved FINDR system which has the ability to spontaneously recalibrate as a responding to signal degradation, this system is based on fingerprints and combined advantages of FM and Wi-Fi positioning system.

To determine the user position, matching between the observed RSSI and the prerecorded fingerprint data base defined by the training process is required. The location is regarded as a classification and regression problem so both K-nearest neighbors and Gaussian process methods are used to determine location based on RSSI. The localization accuracy for both FM signal and Wi-Fi is estimated using leave-one-out evaluation method with different grid sizes during the training. Firstly a test is done with a grid size 1m and then with 0.5 grid size and the result show that the median error is 30 cm lower in the second case. A grid of 0.5m is used during the training when only Gaussian process is applied.

A combination of the existing Wi-Fi fingerprint with the fingerprint of FM radio system is used to increase the positioning accuracy in the work presented in [2]. Each fingerprint has 6 RSSI values, 3 for Wi-Fi and 3 for FM. Using this combination of positioning techniques improves the positioning accuracy about 22% (0.85 m at 95^{th} percentile for KNN) while for GP the difference is not so high. This combination has some advantages like lessen the cost by install more FM transmitters instead of installing a high cost Wi-Fi access points, find position in areas not well covered by Wi-Fi, enhancing battery life because FM transmitters less power consuming.
SI-4735 FM receiver from Silicon Lab is used in the experiment for reasons like: it is wide used by different consumers and its ability to provide the low level signal information like SNR, multipath (MULTIPATH) and frequency offset (FREQOFF) to the application layer besides the RSSI values.

The FM signature is collected as a combination of RSSI, SNR, MULTIPATH and FREQOFF while the Wi-Fi signatures collected using 802.11/a/b/g/n compatible Wi-Fi link and consist of RSSI only. Wi-Fi and FM signatures are collected for three random points for each room of the experiments' rooms. Both Wi-Fi and FM receiver connected to a Lenovo T61 laptop to record their fingerprints.
In the room-level localization accuracy of the office building, RSSI of both Wi-Fi and FM are used alone at the beginning and it shows that both support high localization accuracy near to 90%, which is a slightly higher when using Manhattan distance as shown in Table-1 [10].

Despite both Wi-Fi and FM show approximately same accuracies, the localization errors in Wi-Fi case are lower than the FM case as shown in Fig. 4, and the explanation for this is; the Wi-Fi access points are visible for parts of the buildings' rooms and this leads to decrease the search space and makes the localization error low, in contrast to the FM case. the signals are able to penetrate the building and this increases the localization error and makes every room in the building a candidate location.

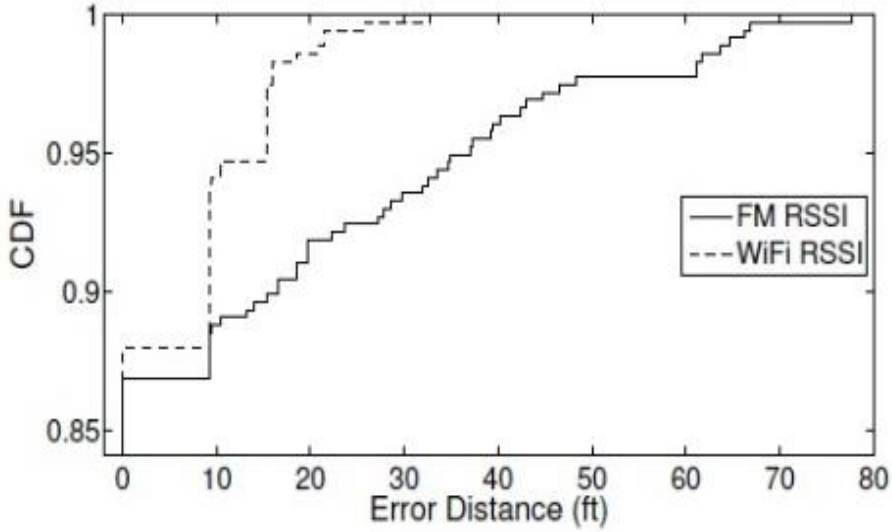

Figure 4-Distribution of localization errors for FM and Wi-Fi RSSI using Manhattan distance between RSSI vectors

When other FM signal information indicators (SNR, MULTIPATH and FREQOFF) are used, the localization accuracy increased because these indicators provide detail information about signal reception and how it is affected by room layout and position inside the building. They can be used individually or in combination to represent a signal signature. The calculation of the distance between the combinations of signal indicators is a bit difficult because all of these indicators have different range of value and the calculation may be biased by the high values, therefore each signal indicator is normalized by using the standard deviation. Using the standard deviation limits the error when the location prediction goes wrong besides the improving the accuracy

Combining FM and Wi-Fi signal indicators decrease the location errors and improve the accuracy to 98%. The experiment results show that the FM localization errors are not related to those that generated by Wi-Fi signatures and also show that both FM signals and Wi-Fi are affected over time by the presence of the objects like doors, chairs and the human movement. However FM is less affected when it compared to Wi-Fi. Table-1 [10]; shows the localization accuracy when combining Wi-Fi signatures with FM signatures.

Table 1-Localization accuracy for office building of 3 floors and 119 Room

Localization Accuracy	Signature type	Distance Metric	
		Euclidean	Manhattan
RSSI of FM & Wi-FI	FM RSSI	85%	87%
	Wi-Fi RSSI	76%	88%
localization accuracy with different signature types	FM All	81%	91%
	FM All Normalized	90%	93%
	Wi-Fi RSSI	76%	88%
	FM & Wi-Fi All	93%	98%
	FM & Wi-Fi All Normalized	94%	98%

For the shopping mall, the second building where the experiment is done, results that achieved in the office building; result shows that the FM signature performs worse when it compared to the office building due to its structure (high ceilings, big and sparse rooms) that make it similar to the outdoor environment, while the Wi-Fi signature performance is much significant but still the combination of FM and Wi-Fi signal indicators achieve a high localization accuracy.

In the residential building, results show that both Wi-Fi and FM signatures achieve localization accuracy more than 90% and using FM RSSI individually achieves a perfect positioning accuracy. Comparing these results with ones achieved in the office and mall buildings indicate that the localization accuracy is independent on the building type. FM can be applied in different locations with different broadcast infrastructure. A comparison of FM approaches can be summarized as shown in Table-3.

Table 3-Comparison of FM Approaches

Approaches	**Localization accuracy**
FINDR	1.3m and 4.5m at 95% confidence level
Audio Features (SNR & SCS)	- SNR: good for long distance with low RSSI values. - SCS: 2.1 m (short distance with high RSSI values)
spontaneously recalibration approach	0.93m median error and 0.85 when FM combined with Wi-Fi
All FM signal indicators (RSSI, SNR, MULTIPATH, FREQOFF)	- FM RSSI: (80% - 100) -All FM indicators: (72-91) -All FM indicators and Wi-Fi: (98%)

CONCLUSIONS

This paper discusses the exploitation of FM radio signal in the indoor localization environment. High localization accuracies can be achieved when using a combination of FM information indicators and these accuracies are enhanced by using a combination of FM positioning technology with Wi-Fi. The future study of this comparison paper is to seek the implementation options in ASIC or reconfigurable [22-25] platform of the available FM localization methods.

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