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(54) **INDOOR LOCALIZATION USING COMMERCIAL FREQUENCY-MODULATED SIGNALS**

(71) Applicant: **Microsoft Technology Licensing, LLC**, Redmond, WA (US)

(72) Inventors: **Dimitrios Lymberopoulos**, Bellevue, WA (US); **Jie Liu**, Medina, WA (US); **Nissanka Arachchige Bodhi Priyantha**, Redmond, WA (US); **Yin Chen**, Baltimore, MD (US)

(73) Assignee: **Microsoft Technology Licensing, LLC**, Redmond, WA (US)

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CPC ***H04W 4/04*** (2013.01); ***G01S 5/0252*** (2013.01); ***H04W 4/003*** (2013.01); ***H04W 4/043*** (2013.01); ***H04W 64/00*** (2013.01)

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CPC G01S 5/0252; H04W 4/003; H04W 4/04; H04W 4/043; H04W 64/00
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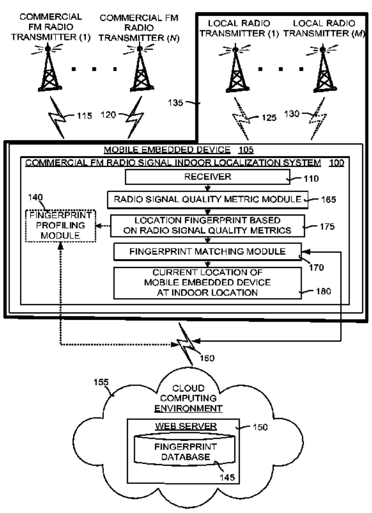
Primary Examiner — Mong-Thuy Tran
(74) *Attorney, Agent, or Firm* — Steve Wight; Sandy Swain; Micky Minhas

(57) **ABSTRACT**

A commercial frequency-modulated (FM) radio signal indoor localization system and method for finding a location of a mobile embedded device (such as a smartphone) within a building. Indoor localization is performed by receiving commercial FM radio signals on the device, analyzing the signals using signal quality metrics, and generating signal quality vectors for each signal and signal quality metric used for the signal. The signal quality metric can be any physical signal quality indicator. The signal quality vectors are added to obtain a current location fingerprint. The current location fingerprint is compared to fingerprints stored in a fingerprint database. The location associated with the stored fingerprint that is the closest match to the current fingerprint location is designated as the current location in the building of the mobile embedded device. Locally generated radio signals can be used in conjunction with the commercial FM radio signals to improve localization accuracy.

20 Claims, 3 Drawing Sheets



(51) **Int. Cl.**

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G01S 5/02	(2010.01)
H04W 64/00	(2009.01)

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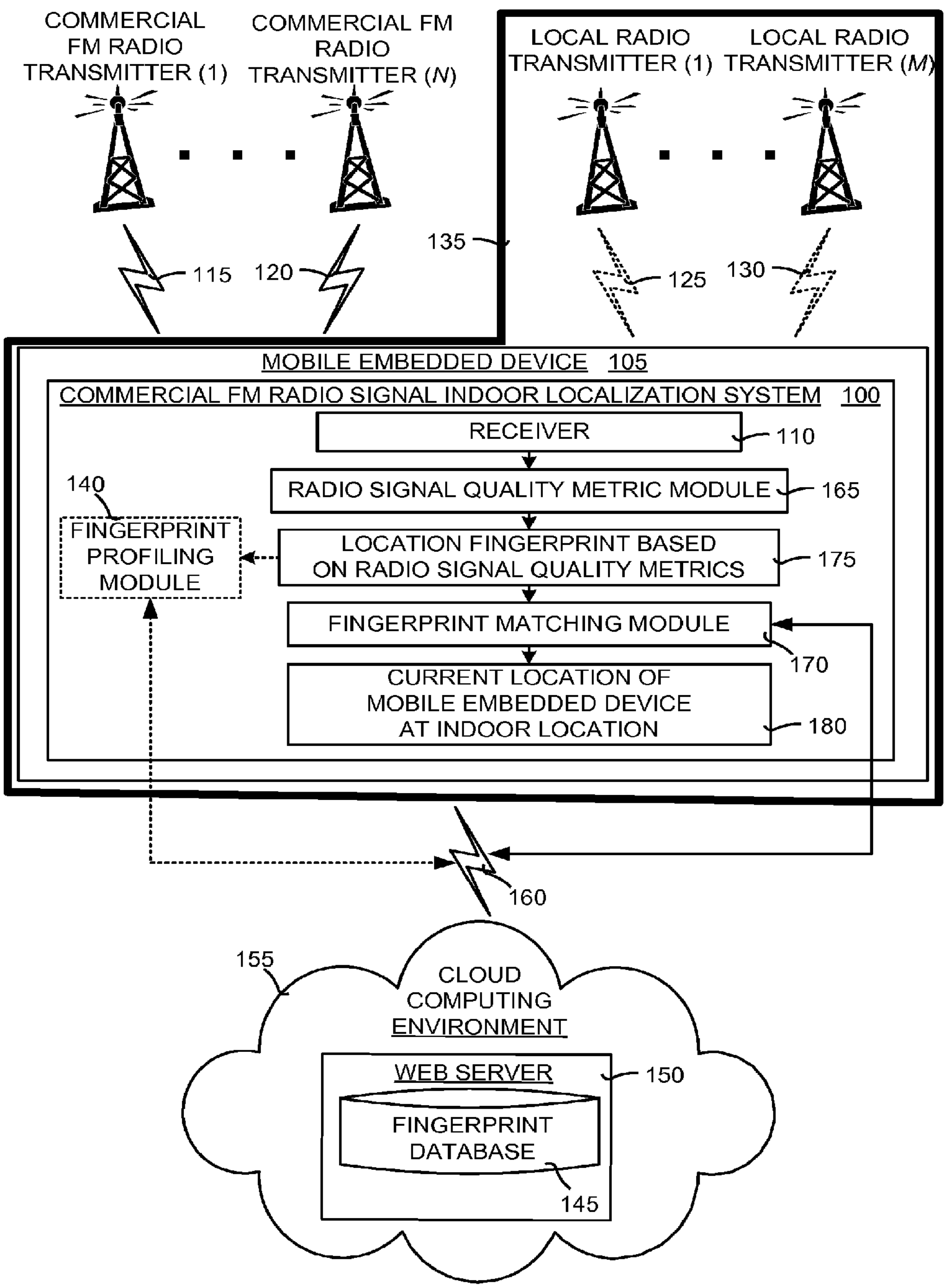
COMMERCIAL FM RADIO TRANSMITTER (1)
COMMERCIAL FM RADIO TRANSMITTER (N)
LOCAL RADIO TRANSMITTER (1)
LOCAL RADIO TRANSMITTER (M)
135
115
120
125
130
MOBILE EMBEDDED DEVICE 105
COMMERCIAL FM RADIO SIGNAL INDOOR LOCALIZATION SYSTEM 100
RECEIVER
110
RADIO SIGNAL QUALITY METRIC MODULE
165
140
FINGERPRINT PROFILING MODULE
LOCATION FINGERPRINT BASED ON RADIO SIGNAL QUALITY METRICS
175
FINGERPRINT MATCHING MODULE
170
CURRENT LOCATION OF MOBILE EMBEDDED DEVICE AT INDOOR LOCATION
180
160
155
CLOUD COMPUTING ENVIRONMENT
WEB SERVER
150
FINGERPRINT DATABASE
145

FIG. 1

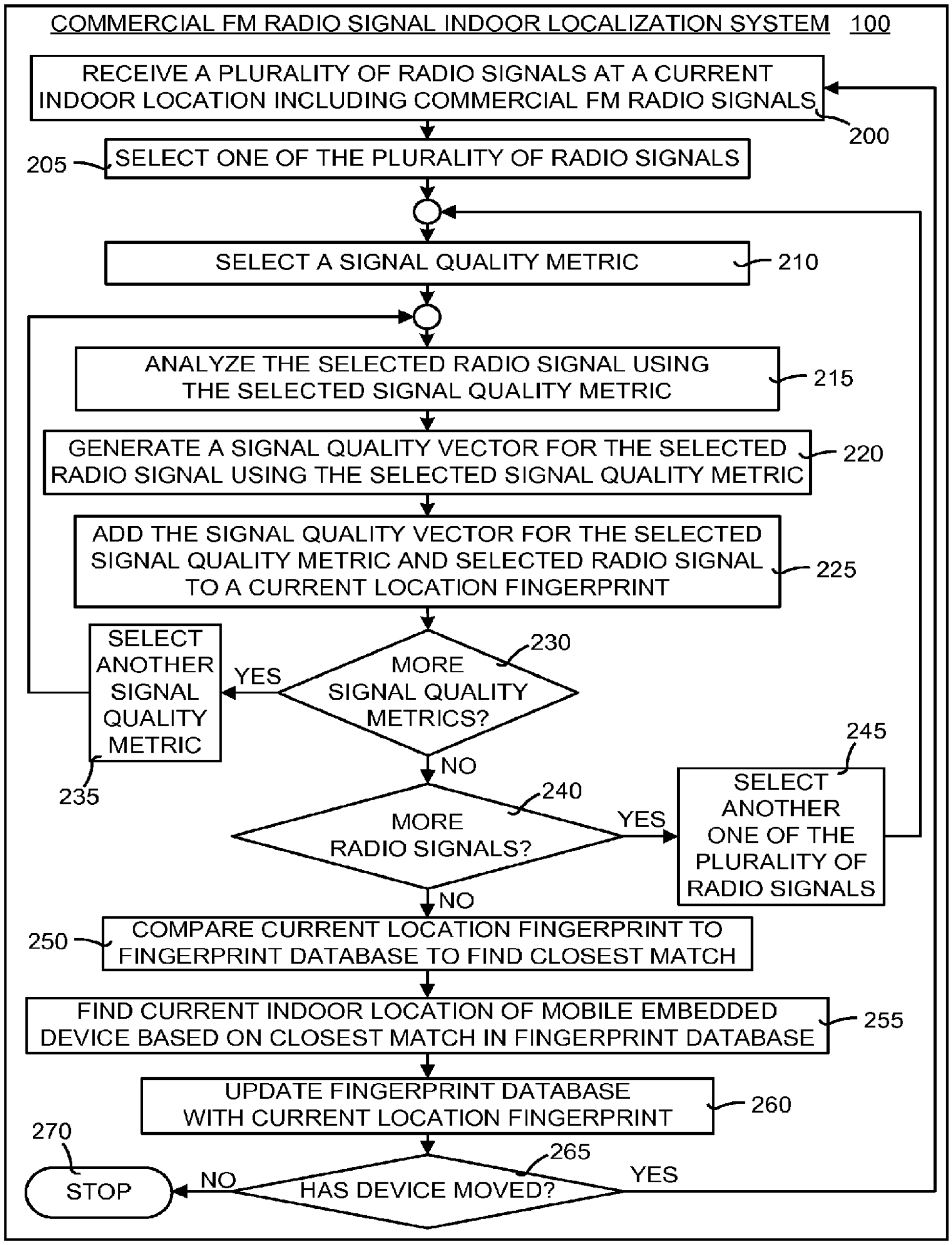
COMMERCIAL FM RADIO SIGNAL INDOOR LOCALIZATION SYSTEM 100
RECEIVE A PLURALITY OF RADIO SIGNALS AT A CURRENT INDOOR LOCATION INCLUDING COMMERCIAL FM RADIO SIGNALS
200
205
SELECT ONE OF THE PLURALITY OF RADIO SIGNALS
SELECT A SIGNAL QUALITY METRIC
210
ANALYZE THE SELECTED RADIO SIGNAL USING THE SELECTED SIGNAL QUALITY METRIC
215
GENERATE A SIGNAL QUALITY VECTOR FOR THE SELECTED RADIO SIGNAL USING THE SELECTED SIGNAL QUALITY METRIC
220
ADD THE SIGNAL QUALITY VECTOR FOR THE SELECTED SIGNAL QUALITY METRIC AND SELECTED RADIO SIGNAL TO A CURRENT LOCATION FINGERPRINT
225
SELECT ANOTHER SIGNAL QUALITY METRIC
235
YES
230
MORE SIGNAL QUALITY METRICS?
NO
245
240
MORE RADIO SIGNALS?
YES
SELECT ANOTHER ONE OF THE PLURALITY OF RADIO SIGNALS
NO
250
COMPARE CURRENT LOCATION FINGERPRINT TO FINGERPRINT DATABASE TO FIND CLOSEST MATCH
FIND CURRENT INDOOR LOCATION OF MOBILE EMBEDDED DEVICE BASED ON CLOSEST MATCH IN FINGERPRINT DATABASE
255
UPDATE FINGERPRINT DATABASE WITH CURRENT LOCATION FINGERPRINT
260
270
265
STOP
NO
HAS DEVICE MOVED?
YES

FIG. 2

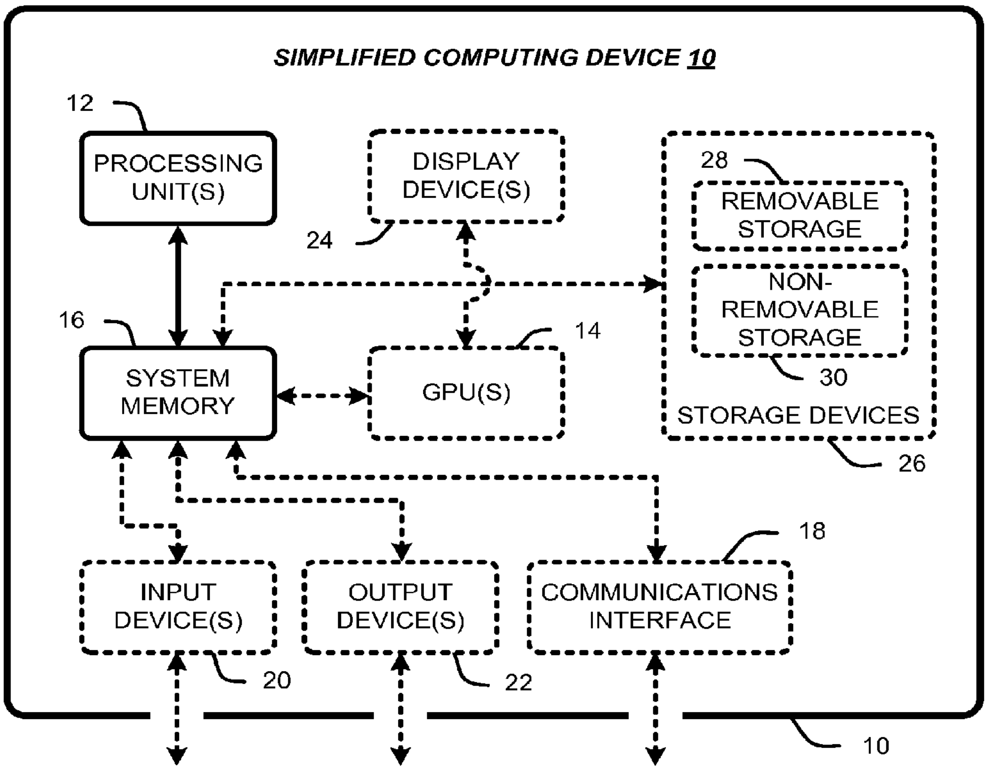
SIMPLIFIED COMPUTING DEVICE 10
12
PROCESSING UNIT(S)
DISPLAY DEVICE(S)
24
28
REMOVABLE STORAGE
NON-REMOVABLE STORAGE
30
STORAGE DEVICES
26
16
SYSTEM MEMORY
GPU(S)
14
18
INPUT DEVICE(S)
20
OUTPUT DEVICE(S)
22
COMMUNICATIONS INTERFACE
10

FIG. 3

INDOOR LOCALIZATION USING COMMERCIAL FREQUENCY-MODULATED SIGNALS

CROSS-REFERENCE TO RELATED APPLICATIONS

This patent application is a continuation of, and claims priority to, U.S. patent application Ser. No. 13/328,613, filed on Dec. 16, 2011, which is incorporated herein by reference in its entirety.

BACKGROUND

Accurately determining the location of mobile embedded devices (such as smartphones) in indoor environments can be difficult. A global positioning systems (GPS) cannot be used because the needed satellite signals are hard to receive indoors because they are blocked by the walls of the building.

There are a number of existing approaches to indoor localization. One approach is a WiFi®-based indoor localization (WiFi® is a registered trademark of the WiFi Alliance in Austin, Tex.). In general, this type of approach records the signal strength from WiFi® access points in the immediate vicinity. Given the location of the WiFi® access points, the location of the mobile device can be calculated. Similar approaches have also been used where FM radio transmitters deployed in the building are used instead of WiFi® signals.

Another approach is proximity-based indoor localization. This type of approach uses a large number of low-power radios (such as RFIDs, low-power Bluetooth® devices (Bluetooth® is a registered trademark of the Bluetooth® Special Interest Group in Kirkland, Wash.), FM radio transmitters) that are deployed in every room or location that needs to be localized. The mobile embedded device detects proximity to and obtains its location from the nearest low-power radio source or sources.

Each of these approaches measure a signal strength between the mobile embedded device and the transmitter. The indoor space of the building then is profiled by creating a map of the signal strength. For example, this profiling may occur by measuring the signal strength along every meter of the indoor space and recording each of the record wireless access points that can be connected to at each location. This collection (or vector) of signal strengths becomes the "fingerprint" of that indoor location. This is performed for a large numbers of locations within the building to create a fingerprint database that consists of pairs of ground truth locations and signal strength vectors.

Once the fingerprint database is obtained, any user can enter the building with his mobile embedded device and localize the device. The mobile embedded device will determine which local radio transmitters are within the range of the device, and will record the signal strength from these individual transmitters at the user's current location in the building. The fingerprint of the mobile embedded device at the location in the building is compared to the fingerprint database to find the closest match. The position that is associated to the closest fingerprint match in the database is assumed to be the location of the mobile embedded device in the building.

One problem, however, with using local radio transmitters (such as WiFi®) is that it operates at the 2.4 GHz range, which means that its signal strength is susceptible to human presence, device orientation, and presence of small objects in a room. Additionally, these parameters change over time, further impacting the signal strength of WiFi® signals, and leading to additional errors in the indoor localization.

SUMMARY

This Summary is provided to introduce a selection of concepts in a simplified form that are further described below in the Detailed Description. This Summary is not intended to identify key features or essential features of the claimed subject matter, nor is it intended to be used to limit the scope of the claimed subject matter.

Embodiments of the commercial FM radio signal indoor localization system and method enable indoor localization of mobile embedded devices (such as smartphones) using commercial frequency-modulated (FM) radio signals. In other words, embodiments of the system and method use commercial FM radio signal broadcasts to find which room in a building the device is located. Embodiments of the system and method use the commercial FM radio signals either alone or in combination with one or more other types of locally-generated radio signals. These are radio signals that are generated locally in the close vicinity or within the building. These other types of locally-generated radio signals include WiFi®, Bluetooth®, and local FM signals.

Commercial FM radio signals are used by embodiments of the system and method because there is an existing and large infrastructure of commercial FM radio stations throughout the country. This is especially true in urban areas. Moreover, because of the low frequency at which these signals operate, they achieve improved penetration through structures, walls and furniture over WiFi®, Bluetooth®, or most other radio signals. In addition, because of the wavelength, FM radio signals have improved resilience to small objects, human presence, and to multipath and fading effects. Further, a WiFi® receiver generally uses more power on a mobile embedded device that an FM radio receiver.

Embodiments of the system and method first build a database of commercial FM radio signal quality vectors that are used for the indoor localization. These signal quality vectors are used to generate a fingerprint at a specific location within the building. The building is profiled by measuring the radio signals at set locations in the building and obtaining fingerprints for the locations. These fingerprints then are stored in a fingerprint database along with the location at which they were recorded.

Later, when a user carries his mobile embedded device into a mapped building, embodiments of the system and method use the receiver in the device to automatically synchronize to the different available commercial FM radio stations. In some embodiments, other types of radio signals are also used. Next, one or more signal quality metrics are applied to each of the radio signals in order to construct a signal quality vector. There is a signal quality vector for each signal quality metric associated with a particular radio signal. Several different types of signal quality metrics of each type of radio signal may be used, including received signals strength indication (RSSI), signal-to-noise ratio (SNR), multipath indicators, and frequency offset indicators. The same process can be repeated for other available wireless signals, such as WiFi® signals, and the resulting signal vectors from each type of wireless signal can be combined to form a single signature.

Embodiments of the system and method then construct a fingerprint for the current location in the building using the signal quality vectors. This current location fingerprint is compared to the fingerprints in the fingerprint database. The closest match is found between the current location fingerprint and a fingerprints in the fingerprint database. The stored fingerprint in the database that is the closest match to the current location fingerprint is designated as the current location in the building of the mobile embedded device.

It should be noted that alternative embodiments are possible, and steps and elements discussed herein may be changed, added, or eliminated, depending on the particular embodiment. These alternative embodiments include alternative steps and alternative elements that may be used, and structural changes that may be made, without departing from the scope of the invention.

DRAWINGS DESCRIPTION

Referring now to the drawings in which like reference numbers represent corresponding parts throughout:

FIG. **1** is a block diagram illustrating a general overview of embodiments of the commercial FM radio signal indoor localization system and method implemented in a computing environment.

FIG. **2** is a flow diagram illustrating the detailed operation of embodiments of the commercial FM radio signal indoor localization system and method shown in FIG. **1**.

FIG. **3** illustrates a simplified example of a general-purpose computer system on which various embodiments and elements of the commercial FM radio signal indoor localization system and method, as described herein and shown in FIGS. **1-2**, may be implemented.

DETAILED DESCRIPTION

In the following description of embodiments of a commercial FM radio signal indoor localization system and method reference is made to the accompanying drawings, which form a part thereof, and in which is shown by way of illustration a specific example whereby embodiments of the commercial FM radio signal indoor localization system and method may be practiced. It is to be understood that other embodiments may be utilized and structural changes may be made without departing from the scope of the claimed subject matter.

I. Commercial Frequency-Modulated (FM) Radio Signals

Embodiments of the commercial FM radio signal indoor localization system and method make use of commercial FM radio signals, such as those used by commercial FM radio stations. Currently, the FM band occupies 87.8-108 MHz, a total of 20.2 MHz and 101 channels. There are usually multiple FM radio stations available at a given location. In addition, some transmission towers are shared by several FM stations.

Commercial FM broadcasting is usually strong enough for outdoor reception. In addition, the indoor penetration of commercial FM radio signal is also high. The wavelength of the FM radio signals is about 3 meters. Thus indoor propagation is less sensitive to the smaller objects, but is more determined by large obstacles such as walls. For the same reason, FM signals are less susceptible to human presence and orientation. This means that FM radio signals are typically more stable in an indoor environment than radio signals of shorter wavelength, such as WiFi® and Bluetooth®.

Moreover, FM receivers are widely available in mobile embedded devices (such as smartphones) due to their small footprint and low cost. As compared to Wi-Fi®, FM receivers also consume much less energy (about 15 mW versus 300 mW). Thus, compared to other types of radio signals (such as Wi-Fi®), commercial FM radio signals require less power, are less susceptible to human presence and small objects, and have improved penetration.

II. System Overview

Embodiments of the commercial FM radio signal indoor localization system and method leverage commercial FM radio signals transmitted by already deployed FM radio towers to profile indoor locations and perform signature-based indoor localization of a mobile embedded device. FIG. **1** is a block diagram illustrating a general overview of embodiments of the commercial FM radio signal indoor localization system **100** and method implemented in a computing environment. In particular, embodiments of the commercial FM radio signal indoor localization system **100** and method are shown implemented on an mobile embedded device **105** (such as a smartphone).

Embodiments of the commercial FM radio signal indoor localization system **100** and method include a receiver **110** that is capable of receiving radio signals. These radio signals may be a variety of types of radio signals. However, in each embodiment of the system **100** and method the receiver **110** is capable of receiving commercial FM radio signals broadcasted by FM radio transmitters. These FM radio transmitters include N number of commercial FM radio transmitters. As shown in FIG. **1**, the N number of commercial FM radio transmitters include commercial FM radio transmitter (1) to commercial FM radio transmitter (N), where N can be any positive integer from 1 or more.

It should be noted that the term "commercial" is used to denote that the commercial FM radio transmitters (1) to (N) broadcast their FM radio signals over a wide area. These FM radio signals are broadcast wirelessly over the airwaves, as denoted by the first communication link **115** from commercial FM radio transmitter (1) to the mobile embedded device **105** and the second communication link **120** from commercial FM radio transmitter (N) to the mobile embedded device **105**. Typically, the commercial FM radio transmitters (1) to (N) will be associated with one or more commercial FM radio stations. Moreover, these transmitters typically will broadcast their FM radio signals over a wide area involving several square miles, such as tens or hundreds of square miles.

Moreover, a commercial FM radio signal is not dedicated only to the indoor localization process, unlike most existing techniques. In fact, the commercial FM radio signal's primary intent is not for indoor localization but for carrying radio broadcasts. Using commercial FM radio signals does not require the deployment of any device in any building. This also limits the cost associated with large-scale deployment of transmitters throughout a building.

Some embodiments of the commercial FM radio signal indoor localization system **100** and method also include using local radio transmitters. It should be noted the term "local" is used to indicate that the radio signals are broadcast over a short geographic range, such as less than a half mile or so. Typically, these local radio transmitters are designed to transmit within a building, such as with a WiFi® network.

As shown in FIG. **1**, these optional local radio transmitters include local radio transmitter (1) to local radio transmitter (M), where M is some positive integer that is 1 or greater. These local radio signals are broadcast wirelessly locally over the airwaves, as denoted by the third communication link **125** from local radio transmitter (**1**) to the mobile embedded device **105** and the fourth communication link **130** from local radio transmitter (M) to the mobile embedded device **105**. The local radio transmitter (1) to (M) are optional, as denoted by the dotted third communication link **125** and the dotted fourth communication link **130**. The local radio transmitters (1) to (M) may be any type of radio signal, such as a WiFi®, Bluetooth®, or even a local non-commercial FM radio signal.

These local radio transmitters (1) to (M) typically have a short geographic range, such as within an enclosed building or structure. FIG. **1** illustrates this building **135** (or structure) as a heavy solid line. Note that the mobile embedded device **105** and the optional local radio transmitters (**1**) to (M) are located within the building **135**.

Embodiments of the commercial FM radio signal indoor localization system **100** and method include an optional fingerprint profiling module **140**. The optionality of the module **140** is shown by the dotted lines around the module **140**. The module **140** is used during a profiling stage of the method to profile the radio signal fingerprints at various location in the building **135**. These fingerprints are stored in a fingerprint database **145**. In some embodiments, the fingerprint database resides on a web server **150** in a cloud computing environment **155**. The cloud computing environment is in communication with the mobile embedded device **105** over a fifth communications link **160**.

The two-way communication between the fingerprint profiling module **140** and the fifth communications link **160** is shown as a dotted two-way arrow to indicate that this the profiling is an optional process. In reality, the profiling is done at least once in order to populate the fingerprint database **145**. However, the fingerprint profiling module **140** does not have to be performed on the mobile embedded device **105** and may be performed with any other type of devices capable of receiving the radio signals and generating the associated fingerprints. Fingerprints can also be automatically crowd-sourced by real users as they check-in to different business from their mobile devices. Every time a check-in is taking place, the signal vectors are recorded on the mobile device, annotated with the location of the business the user checked in and uploaded to the fingerprint database.

Once the fingerprint database **145** is populated and the building **135** is profiled, any mobile embedded device containing embodiments of the system **100** and method can be determine a location of the device **105** within the building **135**, even without the optional fingerprint profiling module **140**. In FIG. **1**, the optional fingerprint profiling module **140** is shown on the mobile embedded device **105** merely for ease of describing embodiments of the system **100** and method.

Embodiments of the commercial FM radio signal indoor localization system **100** and method include a radio signal quality metric module **165** and a fingerprint matching module **170**. In order to find a location of the mobile embedded device **105** once the fingerprint database **145** has been populated, embodiments of the system **100** and method receive radio signals on the receiver **110** and process these radio signals using the radio signal quality metric module **165**. Embodiments of the module **165** use one or more signal quality metrics to measure a signal quality of the incoming radio signals.

The signal quality of the incoming signals is used to generate a location fingerprint **175** based on the signal quality metrics. This location fingerprint **175** is used to update the fingerprint database **145**. In addition, the location fingerprint **175** is process by the fingerprint matching module **170** in order to determine a current location **180** of the mobile embedded device **105** at the indoor location. This process is explained in more detail below.

II.A. Fingerprint Profiling Module

Some embodiments of the commercial FM radio signal indoor localization system **100** and method include the fingerprint profiling module **140**. The module **140** is used during a profiling stage of the method to profile the radio signal fingerprints in the building **135**. Specifically, at a given location inside the building **135**, the desired signal quality metrics are recorded using the receiver **110** and the radio signal quality metric module **165**. This is performed at the given location for every radio signal frequency (or radio station) that the mobile embedded device **105** can receive.

This collection of radio signal quality metric information across each of the plurality of radio signals becomes a "signature" or fingerprint for the given location in the building **135**. Whenever a user is in an unknown location in the building **135**, the mobile embedded device **105** uses a current location fingerprint generated from the plurality of radio signals to and compares it against the fingerprint database **145** of already collected fingerprints. As explained in detail below, the closest fingerprint from the fingerprint database **145** is selected and its corresponding location is assumed to be the current location of the user.

In some embodiments of the commercial FM radio signal indoor localization system **100** and method the fingerprint profiling module **140** is not used. Instead, the GPS location of the mobile embedded device **105** can be associated with signal quality vectors (described below). This avoids the need to profile the entire building **135**. As the user checks into a business in the building **135** the map of the business will be known to the mobile embedded device **105**. This means that the GPS location of the mobile embedded device **105** can be associated with the signal quality vectors and the fingerprint database for the business in the building. In this case, there is longer a need to manually fingerprint the entire building. In many cases the user's consent will be obtained prior to releasing any user data (such as the user's location).

III. Operational Details

FIG. **2** is a flow diagram illustrating the detailed operation of embodiments of the commercial FM radio signal indoor localization system **100** and method shown in FIG. **1**. As shown in FIG. **2**, the operation of embodiments of the commercial FM radio signal indoor localization method begins by using the mobile embedded device **105** to receive a plurality of radio signals at a current indoor location (box **200**). The plurality of radio signals includes at least one commercial FM radio signal.

In some embodiments, only commercial FM radio signals are used for the indoor localization of the mobile embedded device **105**. In other embodiments, the commercial FM radio signal and other types of local radio signals are used. These two general embodiments will now be discussed in further detail.

III.A. Commercial FM Radio Signals for Indoor Localization

Some embodiments of the commercial FM radio signal indoor localization system **100** and method use only commercial FM radio signals for the plurality of radio signals to perform indoor localization. In these embodiments no other types of radio signals are used. Although a single commercial FM radio signal may be used for the indoor localization, improved results are obtained when using a plurality of commercial FM radio signals.

One advantage to commercial FM radio signals is that they are more robust than WiFi® radio signals. The receiver **110** on the mobile embedded device **105** is used to collect individual commercial FM radio signals. As explained below, the each commercial FM radio signal received is analyzed using a signal quality metric to obtain a signal quality vector. These vectors together constitute a fingerprint that defines the indoor location of the mobile embedded device **105**.

The strength of the commercial FM radio signals does vary over the course of the day. Moreover, there is some variation of signal quality metrics over different receivers. However, it has been shown that the variation is not that high to prevent embodiments of the commercial FM radio signal indoor localization system **100** and method from performing the indoor localization.

III.B. Combined Commercial FM Radio Signals and Local Radio Signals

Some embodiments of the commercial FM radio signal indoor localization system **100** and method pair the commercial FM radio signals with additional local (or locally-generated) radio signals. This allows these embodiments of the system **100** and method to exhibit a marked improvement in indoor localization over techniques that use the local radio signals alone.

In these combined embodiments, the plurality of radio signals includes the commercial FM radio signals along with the local radio signals. These local radio signals can include WiFi® radio signals, Bluetooth® radio signals, or even local FM radio signals from local FM radio transmitters. These embodiments can include virtually any combination or type of radio signals, as long as the commercial FM radio signals are included.

In addition, signal quality metrics are used to analyze each type of radio signal in the plurality of radio signals. Because these embodiments have a plurality of different types of radio signals, the fingerprints in the fingerprint database **145** have a longer fingerprint that includes both the commercial FM radio signal fingerprint and fingerprint from the other types of radio signals.

These combined embodiments typically provide a higher indoor localization accuracy that using just the local radio signals or commercial FM radio signals alone. This means that the error is complementary of the error that is obtained using just the local radio signals along. Combined, the indoor localization becomes more accurate.

Referring again to FIG. **2**, one of the plurality of radio signals is selected (box **205**). Embodiments of the method then select a signal quality metric (box **210**). These signal quality metrics include the received signals strength indication (RSSI), signal-to-noise ratio (SNR), multipath indicators, and the offset indicators. Each of these signal quality metrics will be discussed below. However, it should be noted that any physical layer signal quality indicator (or metric) can be used, besides the four listed above. Moreover, all, one, or any combination of the signal quality metrics may be used to analyze the plurality of radio signals.

III.C. Received Signal Strength Indication

The received signal strength indication (RSSI) is a signal quality metric that existing receivers report. However, one problem with the RSSI is that it is a high-level indication signal that because it is high level it contains more noise that low-level signals. More noise means more localization error.

It is desirable to use more low-level signal indicators in place of or to augment a signal quality vector. By using more indicators at the physical layer, we can generate more discriminative signatures can be generated, which improves indoor localization accuracy. Thus, instead of using only RSSI as the signal quality metric for a selected radio signal, embodiments of the system **100** and method can use other signal quality metrics in place of or in addition to the RSSI signal quality metric. These additional signal quality metrics include signal-to-noise ratio, multipath indicators, and frequency offset of signal indicators.

III.D. Signal-to-Noise Ratio

Another type of signal quality metric that can be used by embodiments of the system **100** and method is the signal-to-noise ratio (SNR). The SNR uses the fact that no wireless radio signal has a perfect incoming signal. There is some noise because it is a wireless transmission. The SNR measures the perturbation of the incoming radio signal by indicating how strong the actual signal is compared to the noise of the input signal. The higher the noise as denoted by the SNR, then the lower the confidence in the quality of the signal.

III.E. Multipath Indicators

Yet another type of signal quality metric that can be used by embodiments of the system **100** and method is multipath indicators. Whenever a wireless signal is transmitted, it is reflected when it meets metallic or other types of objects. This causes the receiver **110** to receive the original signal and a plurality of reflected signals. The receiver **110** rarely receives a single signal. It is usually receiving the original signal and its reflected signals.

The multipath indicators indicate how many of these reflected signals have been received. This is a valuable signal quality metric because it can characterize the physical space in which the person is occupying. This is because depending on the space in which the person is occupying (including the walls and furniture setup), the multipath indicators can be used to characterize the room and therefore find the indoor location.

III.F. Frequency Offset of Signal

Still another type of signal quality metric that can be used by embodiments of the system **100** and method is indicators of the frequency offset of the signal. The receiver **110** receives multiple signals at virtually the same time. These multiple signals, because they travel different distances, usually have some delay that is translated into frequency offset. This can be used as a signal quality metric of the incoming signal.

Referring again to FIG. **2**, once the signal quality metric is selected, embodiments of the method then analyze the selected radio signal using the selected signal quality metric (box **215**). A signal quality vector for the selected radio signal then is generated using the selected signal quality metric (box **220**). This signal quality metric corresponding to the selected signal quality metric and the selected radio signal is added to a current location fingerprint (box **225**).

A determination then is made as to whether there are additional signal quality metrics that will be used on the selected radio signal (box **230**). If so, then embodiments of the method select another signal quality metric (box **235**). This newly selected signal quality metric then is used to analyze the selected radio signal (box **215**) and generate a signal quality vector (box **220**). This signal quality vector for the newly selected signal quality metric is added to the current location fingerprint (box **225**).

If there are no additional signal quality metrics to be processed for the selected radio signal, then a determination is made as to whether there are additional radio signals to process (box **240**). If so, then embodiments of the method select another one of the plurality of radio signal (box **245**).

Embodiments of the method then process this selected radio signal as described above in connection with boxes **210**, **215**, **220**, **225**, **230**, and **235**.

If there are no more radio signals to process, then embodiments of the method compare the current location fingerprint to fingerprints in the fingerprint database **145** (box **250**). The fingerprint in the fingerprint database **145** that most closely matches the current location fingerprint is found. This "closest match" means that the signal quality vectors of the current location fingerprint and the fingerprint in the fingerprint database **145** that is the closest match have values that are nearest each other, as compared to the other fingerprints in the fingerprint database **145**.

Embodiments of the system **100** and method can use any one of a variety of techniques to find the closest match between fingerprints. In general, these techniques basically are given a fingerprint to be localized and the fingerprint database **145**, and then find which entry in the fingerprint database **145** is the closest to the given fingerprint. These techniques include distance metric techniques that match the given fingerprints with the fingerprint database **145**. In addition, any type of metric, and any type of smoothing on top of the metric can be used to compare the signal quality vectors obtained from the mobile embedded device **105** to the fingerprint database **145**.

Referring again to FIG. **2**, embodiments of the method then find a current indoor location of the mobile embedded device **105** based on the closest match in the fingerprint database **145** (box **255**). In other words, the location corresponding to the fingerprint in the fingerprint database **145** that is the closest match to the current location fingerprint is designated as the current indoor location of the mobile embedded device **105**.

The fingerprint database **145** then is updated with the current location fingerprint (box **260**). This ensures that the fingerprint database **145** contains current fingerprint information about locations within the building **135**. A determination then is made as to whether the mobile embedded device **105** has moved within the building **135** (box **265**). If so, then the process described above is repeated for the plurality of radio signals to obtain an updated indoor location of the mobile embedded device **105**. Otherwise, the process is completed **270** until the mobile embedded device **105** is moved again.

IV. Exemplary Operating Environment

Embodiments of the commercial FM radio signal indoor localization system **100** and method described herein are operational within numerous types of general purpose or special purpose computing system environments or configurations. FIG. **3** illustrates a simplified example of a general-purpose computer system on which various embodiments and elements of the commercial FM radio signal indoor localization system and method, as described herein and shown in FIGS. **1-2**, may be implemented. It should be noted that any boxes that are represented by broken or dashed lines in FIG. **3** represent alternate embodiments of the simplified computing device, and that any or all of these alternate embodiments, as described below, may be used in combination with other alternate embodiments that are described throughout this document.

For example, FIG. **3** shows a general system diagram showing a simplified computing device **10**. Such computing devices can be typically be found in devices having at least some minimum computational capability, including, but not limited to, personal computers, server computers, hand-held computing devices, laptop or mobile computers, communications devices such as cell phones and PDA's, multiprocessor systems, microprocessor-based systems, set top boxes, programmable consumer electronics, network PCs, minicomputers, mainframe computers, audio or video media players, etc.

To allow a device to implement embodiments of the commercial FM radio signal indoor localization system **100** and method described herein, the device should have a sufficient computational capability and system memory to enable basic computational operations. In particular, as illustrated by FIG. **3**, the computational capability is generally illustrated by one or more processing unit(s) **12**, and may also include one or more GPUs **14**, either or both in communication with system memory **16**. Note that that the processing unit(s) **12** of the general computing device of may be specialized microprocessors, such as a DSP, a VLIW, or other micro-controller, or can be conventional CPUs having one or more processing cores, including specialized GPU-based cores in a multi-core CPU.

In addition, the simplified computing device of FIG. **3** may also include other components, such as, for example, a communications interface **18**. The simplified computing device of FIG. **3** may also include one or more conventional computer input devices **20** (e.g., pointing devices, keyboards, audio input devices, video input devices, haptic input devices, devices for receiving wired or wireless data transmissions, etc.). The simplified computing device of FIG. **3** may also include other optional components, such as, for example, one or more conventional computer output devices **22** (e.g., display device(s) **24**, audio output devices, video output devices, devices for transmitting wired or wireless data transmissions, etc.). Note that typical communications interfaces **18**, input devices **20**, output devices **22**, and storage devices **26** for general-purpose computers are well known to those skilled in the art, and will not be described in detail herein.

The simplified computing device of FIG. **3** may also include a variety of computer readable media. Computer readable media can be any available media that can be accessed by computer **10** via storage devices **26** and includes both volatile and nonvolatile media that is either removable **28** and/or non-removable **30**, for storage of information such as computer-readable or computer-executable instructions, data structures, program modules, or other data. By way of example, and not limitation, computer readable media may comprise computer storage media and communication media. Computer storage media includes, but is not limited to, computer or machine readable media or storage devices such as DVD's, CD's, floppy disks, tape drives, hard drives, optical drives, solid state memory devices, RAM, ROM, EEPROM, flash memory or other memory technology, magnetic cassettes, magnetic tapes, magnetic disk storage, or other magnetic storage devices, or any other device which can be used to store the desired information and which can be accessed by one or more computing devices.

Retention of information such as computer-readable or computer-executable instructions, data structures, program modules, etc., can also be accomplished by using any of a variety of the aforementioned communication media to encode one or more modulated data signals or carrier waves, or other transport mechanisms or communications protocols, and includes any wired or wireless information delivery mechanism. Note that the terms "modulated data signal" or "carrier wave" generally refer to a signal that has one or more of its characteristics set or changed in such a manner as to encode information in the signal. For example, communication media includes wired media such as a wired network or direct-wired connection carrying one or more modulated data signals, and wireless media such as acoustic, RF, infrared, laser, and other wireless media for transmitting and/or receiving one or more modulated data signals or carrier waves. Combinations of the any of the above should also be included within the scope of communication media.

Further, software, programs, and/or computer program products embodying the some or all of the various embodiments of the commercial FM radio signal indoor localization system **100** and method described herein, or portions thereof, may be stored, received, transmitted, or read from any desired combination of computer or machine readable media or storage devices and communication media in the form of computer executable instructions or other data structures.

Finally, embodiments of the commercial FM radio signal indoor localization system **100** and method described herein may be further described in the general context of computer-executable instructions, such as program modules, being executed by a computing device. Generally, program modules include routines, programs, objects, components, data structures, etc., that perform particular tasks or implement particular abstract data types. The embodiments described herein may also be practiced in distributed computing environments where tasks are performed by one or more remote processing devices, or within a cloud of one or more devices, that are linked through one or more communications networks. In a distributed computing environment, program modules may be located in both local and remote computer storage media including media storage devices. Still further, the aforementioned instructions may be implemented, in part or in whole, as hardware logic circuits, which may or may not include a processor.

Moreover, although the subject matter has been described in language specific to structural features and/or methodological acts, it is to be understood that the subject matter defined in the appended claims is not necessarily limited to the specific features or acts described above. Rather, the specific features and acts described above are disclosed as example forms of implementing the claims.

What is claimed is:

1. A computer system comprising:

one or more processing units; and

one or more computer storage media storing computer-executable instructions which, when executed by the one or more processing units, cause the one or more processing units to:

obtain multiple different signal indicators for a frequency-modulated signal, the multiple different signal indicators characterizing the frequency-modulated signal as received by a mobile device and comprising at least:

a detected frequency offset signal indicator that indicates a frequency offset characteristic of the frequency-modulated signal as detected by the mobile device, and

another detected signal indicator that indicates another characteristic of the frequency-modulated signal as detected by the mobile device; and

compare the detected frequency offset signal indicator and the another detected signal indicator to a database to obtain a current location of the mobile device, the database having prerecorded frequency offset signal indicators that indicate the frequency offset characteristic of the frequency-modulated signal as detected by other mobile devices at various locations and prerecorded other signal indicators that indicate the another characteristic of the frequency-modulated signal as detected by the other mobile devices at the various locations.

2. The computer system of claim **1**, embodied as the mobile device.

3. The computer system of claim **1**, wherein the frequency-modulated signal is a commercial frequency-modulated signal.

4. The computer system of claim **3**, wherein the another detected signal indicator is a received signal strength indicator of the commercial frequency-modulated signal.

5. The computer system of claim **3**, wherein the commercial frequency-modulated signal is transmitted by a radio station at a frequency between 87.8 megahertz and 108 megahertz.

6. The computer system of claim **1**, wherein the frequency-modulated signal is a locally-generated frequency-modulated signal.

7. The computer system of claim **1**, wherein the another detected signal indicator is a multipath indicator of the frequency-modulated signal.

8. The computer system of claim **1**, wherein the computer-executable instructions, when executed by the one or more processing units, cause the one or more processing units to:

obtain the multiple different signal indicators for another frequency-modulated signal;

include the multiple different signal indicators for the frequency-modulated signal and the another frequency-modulated signal into a location fingerprint of the mobile device; and

obtain the current location of the mobile device by comparing the location fingerprint to other fingerprints stored in the database.

9. The computer system of claim **8**, wherein both the frequency-modulated signal and the another frequency-modulated signal are both commercial radio signals.

10. A method for determining a location of a mobile device, the method comprising:

obtaining multiple different signal indicators for a frequency-modulated signal, the multiple different signal indicators characterizing the frequency-modulated signal as received by the mobile device and comprising at least:

a detected frequency offset signal indicator that indicates a frequency offset characteristic of the frequency-modulated signal as detected by the mobile device, and

another detected signal indicator that indicates another characteristic of the frequency-modulated signal as detected by the mobile device; and

comparing the detected frequency offset signal indicator and the another detected signal indicator to a database to obtain the location of the mobile device, the database having prerecorded frequency offset signal indicators that indicate the frequency offset characteristic of the frequency-modulated signal as detected by other mobile devices at various locations and prerecorded other signal indicators that indicate the another characteristic of the frequency-modulated signal as detected by the other mobile devices at the various locations.

11. The method of claim **10** performed by the mobile device.

12. The method of claim **10**, wherein the frequency-modulated signal is a commercial frequency-modulated radio signal.

13. The method of claim **12**, wherein the comparing comprises matching a location fingerprint comprising the detected frequency offset signal indicator and the another detected signal indicator to a matching fingerprint stored in the database, wherein the database is located remotely from the mobile device.

14. The method of claim **13**, further comprising:

obtaining the prerecorded frequency offset indicators and the prerecorded other signal indicators from the other mobile devices.

15. The method of claim **14**, wherein:

the location fingerprint includes a received signal strength indicator that indicates a signal strength characteristic of the frequency-modulated signal that is received by the mobile device,

the location fingerprint includes a detected multipath indicator that indicates a multipath characteristic of the frequency-modulated signal that is received by the mobile device, and

the comparing comprises comparing the location fingerprint to prerecorded signal strength indicators and prerecorded multipath indicators detected by the other mobile devices at the various locations.

16. The method of claim **14**, wherein:

the location fingerprint includes a received signal strength indicator that indicates a signal strength of the frequency-modulated signal that is received by the mobile device, and

the comparing comprises comparing the location fingerprint to prerecorded received signal strength indicators detected by the other mobile devices at the various locations.

17. The method of claim **14**, wherein:

the location fingerprint includes a detected multipath indicator that indicates a multipath characteristic of the frequency-modulated signal that is received by the mobile device, and

the comparing comprises comparing the location fingerprint to prerecorded multipath indicators detected by the other mobile devices at the various locations.

18. A system comprising:

a radio signal quality metric module;

a fingerprint matching module; and

one or more processing units configured to execute the radio signal quality metric module and the fingerprint matching module,

wherein the radio signal quality metric module is configured to obtain multiple different signal indicators for a frequency-modulated signal, the multiple different signal indicators characterizing the frequency-modulated signal as received by a mobile device and comprising at least:

a detected frequency offset signal indicator that indicates a frequency offset characteristic of the frequency-modulated signal as detected by the mobile device, and

another detected signal indicator that indicates another characteristic of the frequency-modulated signal as detected by the mobile device; and

wherein the fingerprint matching module is configured to compare the detected frequency offset signal indicator and the another detected signal indicator to a database to obtain a location of the mobile device, the database having prerecorded frequency offset signal indicators that indicate the frequency offset characteristic of the frequency-modulated signal as detected by other mobile devices at various locations and prerecorded other signal indicators that indicate the another characteristic of the frequency-modulated signal as detected by the other mobile devices at the various locations.

19. The system of claim **18**, embodied as the mobile device.

20. The system of claim **19**, further comprising a receiver of the mobile device, wherein the receiver is configured to receive the frequency-modulated signal.

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