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Proximity Enhanced Location Query

Abstract

Embodiments described herein enable proximity enhancements for a location query performed for a target wireless device. One embodiment provides for a method to determine a range and direction to a target wireless device using one our more wireless ranging operations when the wireless communication device is within a threshold range of the target wireless device, generate an augmented reality view that includes a target position estimate for the wireless device, and present the augmented reality view that includes the target position estimate for the wireless device

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Background/Summary

CROSS-REFERENCE [0001] This application is a continuation of U.S. patent application Ser. No. 17/603,580, filed Oct. 13, 2021, entitled "Proximity Enhanced Location Query," which is a U.S. National Phase Application under 35 U.S.C. § 371 of International Application No. PCT/US2020/028326, filed Apr. 15, 2020, entitled "Finding a Target Device for Using Augmented Reality," which claims priority to U.S. Provisional Application Ser. No. 62/835,494, filed on Apr. 17, 2019, and U.S. Provisional Application Ser. No. 62/855,963 filed on Jun. 1, 2019, each of which are hereby incorporated herein by reference.

FIELD
[0002] Embodiments described herein relate generally to a system and method of locating wireless devices and accessories. More specifically, embodiments relate to an infrastructure to enable proximity enhancement to the user experience of device locator applications.

BACKGROUND OF THE DESCRIPTION
[0003] Current security features in handheld and portable products allow the location of the product to be identified when requested by the user, such as in instances where the product is lost or stolen. If the wireless device includes positioning technology, the device can be configured to report its last location to the server computer, which is displayed by the service on a map presented to the user. Often wireless devices are used with wireless accessory devices that cannot determine their location and cannot communicate with a remote tracking services over a wide area network. These accessory devices can include, for example, wireless earbuds, headphones, headsets and other wearable devices (e.g., smartwatches, fitness bands, optical head-mounted displays) that communicate directly with the wireless device using peer-to-peer communications. For wireless accessory devices that cannot determine their location and cannot communicate with the remote tracking service, those devices cannot be tracked by the service when lost or stolen.

SUMMARY OF THE DESCRIPTION
[0004] Embodiments described herein provide systems and methods to enable proximity enhancements for a location query performed for a target wireless device.

[0005] One embodiment provides for a non-transitory machine-readable medium storing instructions to cause one or more processors of a wireless communication device to perform operations comprising determining a range and direction to a target wireless device using one our more wireless ranging operations when within a threshold range of the target wireless device, determining a pose of the wireless communication device via sensor data received from an inertial measurement unit within the wireless communication device; determining a target position estimate of the target wireless device relative to the wireless communication device based on the range, direction, and pose, generating an augmented reality view that includes the target position estimate of the wireless device, and presenting the augmented reality view via a display of the wireless communication device.

[0006] One embodiment provides for an electronic device comprising a wireless controller including a ranging sensor and a communications radio, a display device, memory to store instructions, and one or more processors to execute the instructions. The instructions cause the one or more processors to scan for a beacon advertisement via the communications radio of the wireless controller and in response to detection of a beacon advertisement of a target wireless device,

transmitting a command to the target wireless device to initiate a bi-directional ranging operation with the electronic device. The one or more processors can additionally determine a range and direction to the target wireless device via the ranging sensor of the wireless controller during the bi-directional ranging operation, determine a target position estimate for the target wireless device relative to the electronic device based on the range and direction to the target wireless device, generate an augmented reality view that includes the target position estimate for the wireless device, and present the augmented reality view via the display device.

[0007] One embodiment provides for a method comprising, on a wireless communication device including one or more processors, determining a range and direction to a target wireless device using one our more wireless ranging operations when the wireless communication device is within a threshold range of the target wireless device. The method additionally includes determining a pose of the wireless communication device via sensor data received from an inertial measurement unit within the wireless communication device, determining a target position estimate for the target wireless device relative to the wireless communication device based on the range and direction to the target wireless device and the pose of the wireless communication device, and generating an augmented reality view that includes the target position estimate for the wireless device. The method additionally includes presenting the augmented reality view via a display of the wireless communication device.

[0008] The above summary does not include an exhaustive list of all embodiments in this disclosure. All systems and methods can be practiced from all suitable combinations of the various aspects and embodiments summarized above, and also those disclosed in the Detailed Description below.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] The present invention is illustrated by way of example and not limitation in the figures of the accompanying drawings in which like references indicate similar elements, and in which:

[0010] FIG. **1** is a block diagram of a network operating environment for mobile devices, according to an embodiment;

[0011] FIG. **2** illustrates a system to locate a wireless accessory that lacks access to a wide area network, according to an embodiment;

[0012] FIG. **3** illustrates a system for pairing and locating a wireless accessory, according to embodiments described herein;

[0013] FIG. **4**A-**4**C are flow diagrams illustrating methods for use with the device locator systems described herein;

[0014] FIG. **5** is a flow diagram illustrating a method of broadcasting a signal beacon at a wireless accessory, according to an embodiment;

[0015] FIG. **6**A-**6**B illustrate operations of a method that can be performed by a finder device, according to embodiments described herein;

[0016] FIG. **7** illustrates the gathering of signal and ranging data by a finder device, according to an embodiment;

[0017] FIG. **8** illustrates a networked system for locating devices and wireless accessories, according to an embodiment;

[0018] FIG. **9**A-**9**C illustrate a device locator user interface, according to an embodiment;

[0019] FIG. **10** illustrates an accessory pairing user interface that is displayed when attempting to pair with a lost wireless accessory, according to an embodiment;

[0020] FIG. **11** is a block diagram illustrating an exemplary API architecture, which may be used in some embodiments of the invention;

[0021] FIG. **12** is a block diagram of a device architecture for a mobile or embedded device, according to an embodiment;

[0022] FIG. **13** is a block diagram of a computing system, according to an embodiment;

[0023] FIG. **14** illustrates a system in which proximity enhancements can be enabled for a location query application;

[0024] FIG. **15**A-**15**C illustrate a location query application user interfaces with proximity enhancements, according to an embodiment;

[0025] FIG. **16**A-**16**E illustrate additional location query application user interfaces with proximity enhancements, according to an embodiment;

[0026] FIG. **17** illustrates a system architecture that enables proximity enhancements for a location query application, according to an embodiment;

[0027] FIG. **18** illustrates a system to enable the fusion of ranging and pose estimates to generate a target position estimate of a target item, according to an embodiment;

[0028] FIG. **19** illustrates a method to enable proximity enhanced user interfaces for a location query application;

[0029] FIG. **20** illustrates a flow diagram of a method performed by a target wireless device to signal a motion status, according to an embodiment; and

[0030] FIG. **21** illustrates a flow diagram of a method performed on a mobile device to indicate determine a device locator UI view, according to an embodiment.

DETAILED DESCRIPTION

[0031] Embodiments described herein provide techniques to enable secure crowdsourced locator services for lost or misplaced devices that cannot communicate with a wide area network. Various embodiments and aspects will be described with reference to details discussed below, and the accompanying drawings will illustrate the various embodiments. The following description and drawings are illustrative and are not to be construed as limiting. Numerous specific details are described to provide a thorough understanding of various embodiments. However, in certain instances, well-known or conventional details are not described in order to provide a concise discussion of embodiments.

[0032] The terminology used in this description is for the purpose of describing particular embodiments only and is not intended to be limiting of the invention. As used in the description of the invention and the appended claims, the singular forms "a", "an" and "the" are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will also be understood that the term "and/or" as used herein refers to and encompasses any and all possible combinations of one or more of the associated listed items. It will be further understood that the terms "comprises" and/or "comprising," when used in this specification, specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof.

[0033] In the discussion that follows, a computing device that includes a touch-sensitive display is described. It should be understood, however, that the computing device may include one or more other physical user-interface devices. The various applications that may be executed on the device may use at least one common physical user-interface device, such as the touch-sensitive surface. One or more functions of the touch-sensitive surface as well as corresponding information displayed on the device may be adjusted and/or varied from one application to the next and/or within a respective application. In this way, a common physical architecture (such as the touch-sensitive surface) of the device may support the variety of applications with user interfaces that are intuitive and transparent.

[0034] Some processes are described below in terms of some sequential operations. However, it should be appreciated that some of the operations described may be performed in a different order. Moreover, some operations may be performed in parallel rather than sequentially.

[0035] FIG. **1** is a block diagram of a network operating environment **100** for mobile devices, according to an embodiment. The network operating environment **100** includes multiple mobile devices, such as mobile device **102**A and mobile device **102**B. The mobile devices **102**A-**102**B can each be any electronic device capable of communicating with a wireless network and one or more wireless accessory devices. Some example mobile devices include but are not limited to a smartphone, a tablet computer, a notebook computer, a wearable computer (e.g., smartwatch or other wearable computing accessory), a mobile media player, a personal digital assistant, and other similar devices. Each of mobile device **102**A and mobile device **102**B include a user interface, such as user interface **104** of mobile device **102**B. Mobile device **102**A and mobile device **102**B can communicate over one or more wired and/or wireless networks **110** to perform data communication. For example, a wireless network **112** (e.g., cellular network, Wi-Fi network) can communicate with a wide area network **114**, such as the Internet, by use of a gateway **116**. Likewise, an access device **118**, such as a mobile hotspot wireless access device, can provide communication access to the wide area network **114**. The gateway **116** and access device **118** can then communicate with the wide area network **114** over a combination of wired and/or wireless networks.

[0036] In some implementations, both voice and data communications can be established over the wireless network **112** and/or the access device **118**. For example, mobile device **102**A can place and receive phone calls (e.g., using VoTP protocols), send and receive e-mail messages (e.g., using POP3 protocol), and retrieve electronic documents and/or streams, such as web pages, photographs, and videos, over the wireless network **112**, gateway **116**, and wide area network **114** (e.g., using TCP/IP or UDP). In some implementations, mobile device **102**A can place and receive phone calls, send and receive e-mail messages, and retrieve electronic documents over the access device **118** and the wide area network **114**. In some implementations, mobile device **102**A or mobile device **102**B can be physically connected to the access device **118** using one or more cables, for example, where the access device **118** is a personal computer. In this configuration, mobile device **102**A or mobile device **102**B can be referred to as a "tethered" device. In one embodiment, mobile device **102**A can communicate with mobile device **102**B via a wireless peer-to-peer connection **120**. The wireless peer-to-peer connection **120** can be used to synchronize data between the devices.

[0037] Mobile device **102**A or mobile device **102**B can communicate with a service provider **115** that provides or enables one or more services. Exemplary services include a telephony service **130**, a messaging service **140**, a media service **150**, a storage service **160**, and a device locator service **170** over the one or more wired and/or wireless networks **110**. For example, the telephony service **130** can enable telephonic communication between mobile device **102**A and mobile device **102**B, or between a mobile device and a wired telephonic device. The telephony service **130** can route voice over IP (VoIP) calls over the wide area network **114** or can access a cellular voice network (e.g., wireless network **112**). The messaging service **140** can, for example, provide e-mail and/or other messaging services. The media service **150** can, for example, provide access to media files, such as song files, audio books, movie files, video clips, and other media data. The storage service **160** can provide network storage capabilities to mobile device **102**A and mobile device **102**B to store documents and media files. The device locator service **170** can enable a user to locate a lost or misplaced device that was, at least at some point, connected to the one or more wired and/or wireless networks **110**. For example, mobile device **102**A can perform a location query for mobile device **102**B. The device locator service **170** can also enable location queries for devices that do not have a network connection via the use of a network of finder devices, as shown below in FIG. **2-3**. Other services can also be provided, including a software update service to update operating system software or client software on the mobile devices. In one embodiment, the messaging service **140**, media service **150**, storage service **160**, and device locator service **170** can each be associated with a cloud service provider, where the various services are facilitated via a cloud services account associated with the mobile devices **102**A-**102**B.

[0038] FIG. **2** illustrates a system **200** to locate a wireless accessory **201** that lacks access to a wide area network, according to an embodiment. The system **200** can also be used to locate a device that is unable to access a WAN or LAN, and thus cannot transmit the device location. In one embodiment, the wireless accessory **201** includes one or more wireless transceivers and can communicate, either directly or indirectly (e.g., through another device or computer) with a companion device (e.g., mobile device **102**) over a wireless network or peer-to-peer communication link. Some examples of wireless accessory devices include but are not limited to wireless earbuds, headphones, headsets and other wearable devices (e.g., smartwatches, fitness bands, optical head-mounted displays). The wireless accessory **201** can also include other wireless devices such as game controllers or remote controls. The wireless accessory **201**, in one embodiment, also includes smartphones, tablet computers, laptop computers, smart speaker devices, televisions, or television set top boxes that at least temporarily are unable to access a wide area network, such as the Internet (e.g., wide area network **114** as in FIG. **1**). The wireless accessory can also be any other wireless device, including beacon or locator tags that can be attached to other devices to enable the tracking or locating of those devices. In one embodiment, the wireless accessory **201** can be paired with the mobile device **102** using a wireless technology standard, such as but not limited to Bluetooth. The wireless accessory **201** can also communicate with the mobile device **102** over wireless technologies such as Wi-Fi direct, Zigbee, or similar technologies. While the companion device to which the wireless accessory **201** is paired is generally referred to as a mobile device **102**, companion devices are not limited to mobile devices. Companion devices, in some embodiments, can also include laptop or desktop devices and can additionally include some wearable accessories, such as but not limited to a smart watch device or a wearable display.

[0039] In one embodiment, the wireless accessory **201** can periodically transmit a wireless beacon signal. The wireless accessory **201** can transmit the beacon signal using one of a variety of wireless technologies described herein (e.g., Bluetooth, Wi-Fi, etc.) and in one embodiment can also beacon using an ultra-wideband (UWB) radio technology. The beacon signal can be transmitted using a single wireless technology, one of multiple selectable wireless technologies, or multiple simultaneous wireless technologies. The beacon signal can transmit a beacon identifier that includes information to specifically identify the wireless accessory **201**. In one embodiment, the beacon identifier is a public encryption key associated with the device.

[0040] The beacon signal can also convey information about the wireless accessory **201**, such as a beacon type, device classification, battery level. In one embodiment the beacon signal can also convey device status, such as a lost status, alarm status, or a near-owner status. The beacon signal can also include information that specifies battery life, charging status, and/or other status information. The lost status can indicate that the wireless accessory **201** has determined itself to be lost or has been placed into a lost state by the owner of the device. The alarm status can indicate that the wireless accessory **201** was placed in a state that the device should trigger an alarm if moved from a current location. The near-owner status can indicate that the wireless accessory **201** has detected the nearby presence of the mobile device **102** associated with the owner of the accessory.

[0041] The beacon signal can be detected by a finder device **202**, which is locally proximate to the wireless accessory **201**. The finder device **202** can be a similar device as the mobile device **102** and can receive and transmitting data over a wide area network **114** and receiving and transmitting using similar wireless technologies as the wireless accessory **201** (e.g., Bluetooth, etc.). Particularly, the finder device **202** can receive data using the wireless protocol over which the beacon signal is transmitted. The finder device **202** can determine a location using one or more location and/or positioning services including, but not limited to a satellite positioning service **206** or a terrestrial positioning system using RF signals received from wireless base stations **205** such as Wi-Fi access points or cell tower transmitters of a cellular telephone network. In an embodiment,

the finder device **202** periodically stores its location as determined based on the one or more location and/or positioning services. The stored location can be associated with a timestamp for which the location was determined. When the finder device **202** receives a beacon signal from the wireless accessory **201**, the finder device **202** can transmit a location for the finder device over the wide area network **114** to a device locator server **203**. The timestamp for a determined location for the finder device **202** can be correlated with a timestamp for which a beacon signal was received to associate a geographic location with a received beacon signal.

[0042] Where the wireless accessory **201** provides a public key within the beacon signal, the finder device **202** can encrypt the determined location data and transmit the encrypted location data to the device locator server **203** over the wide area network **114**. In one embodiment, additional data can either be encrypted and transmitted along with the location data or transmitted unencrypted to the device locator server **203**. For example, a received signal strength indicator (RSSI) for the beacon signal can be transmitted along with the location data. The RSSI data can then be used to determine the distance of the wireless accessory **201** from the finder device **202** and assist in triangulation on the owner device. Where the RSSI data is transmitted in an unencrypted state, in one embodiment the server can use RSSI information to reduce noise by discarding very weak signals if other, stronger signals are present. In one embodiment, UWB ranging data can also be provided, where such data is available.

[0043] In one embodiment, the finder device **202** can behave differently upon receiving a beacon signal from a wireless accessory **201** depending upon a device status conveyed by the wireless accessory **201**. For standard beacon signals, the finder device **202** can place encrypted location data into a queue and transmit the location data to the device locator server **203** during a periodic transmission window. However, if the wireless accessory **201** is indicating an alarm state, the finder device **202** can transmit the location data to the device locator server **203** immediately. Additionally, the finder device **202** may not transmit the location data to the device locator server **203** if the beacon signal of the wireless accessory **201** indicates that the accessory is near the owner of the accessory. Alternatively, the finder device **202** may delay transmission of encrypted location data.

[0044] If the owner of the wireless accessory **201** wishes to locate the wireless accessory, the owner can access a device locator user interface **204** on the mobile device **102**. The device locator user interface **204** can be associated with a device locator application that is used to locate electronic devices and accessories that are registered with an online account of the user, such as a cloud services account or another type of online account. The device owner, using the device locator UI **204**, can query the device locator server **203** for location data that may have been transmitted to the device locator server by a finder device **202** of the wireless accessory **201**. In one embodiment, the mobile device **102** can transmit the public encryption key associated with the wireless accessory **201** to the device locator server **203**. The device locator server **203** can then return any stored location data that corresponds with the public encryption key. The location data returned to the mobile device **102** can be encrypted data that is encrypted by the finder device **202** using the public encryption key. The mobile device **102** can use an associated private key to decrypt the encrypted location data. The decrypted location data can then be processed by the mobile device **102** to determine a most probable location for the wireless accessory **201**. In various embodiments, the most probable location for the wireless accessory **201** can be determined by triangulation from multiple received locations and using other data, such as a beacon signal RSSI associated with each location and timestamp or UWB ranging data included within the location data.

[0045] FIG. **3** illustrates a system **300** for pairing and locating a wireless accessory, according to embodiments described herein. In one embodiment a mobile device **102** of a user of the wireless accessory **201** can present an accessory pairing UI **302** by which the user can pair the mobile device **102** with the wireless accessory **201**. During an initial pairing (**305**) between the mobile

device 102 and the wireless accessory, a public key exchange (310) can be performed between the mobile device and the wireless accessory. In one embodiment, during the public key exchange (310) the mobile device 102 and the wireless accessory 201 exchange public keys of public key pairs generated by the device and the accessory. In one embodiment the public key exchange (310) is a one-way transfer, in which the mobile device 102 transmits a public key of a public/private key pair to the wireless accessory 201. Alternatively, or additionally, the public key exchange (310) may be a Diffie-Hellman key exchange in which the device and the accessory establish a shared secret between two parties. In one embodiment, the public key exchange (310) additionally uses elliptic curve cryptography to establish the shared secret. For example, Elliptic-curve Diffie-Hellman (ECDH) can be used to enable the establishment of a public key pair and one or more shared secrets. In one embodiment, the one or more shared secrets include an anti-tracking secret, which can be used by the wireless accessory 201 to periodically derive additional public keys. In one embodiment, instead of using public key cryptography with a broadcasted public key, the wireless accessory can advertise a temporary identity and subsequently use identity-based encryption. With identity-based encryption, the public key is, or is derived from, some unique element of information about the identity of the user, such as an e-mail address. The entity that is to decrypt the encrypted information can obtain the decryption key from a trusted central authority.

[0046] After the wireless accessory 201 has been paired with the mobile device 102, the wireless accessory 201 can periodically broadcast a beacon signal 301 that includes device status information and a beacon identifier. In one embodiment the beacon identifier is a public key derived from a shared secret that is established during the public key exchange (310). Additionally, the wireless accessory 201 can periodically perform a public key derivation (315) to generate a new public key and begin broadcasting the new public key as the beacon identifier. The public key is a K-byte key, with a new K-byte key generated every M minutes. The value K and M can vary between embodiments. In one embodiment, a K value of 28 bytes is used. In one embodiment, a K value of 27 bytes is used. The value K can be determined at least in part based on the beacon length associated with the wireless protocol used to transmit the beacon signal 301. In one embodiment, the beacon signal can transmit a variant of beacon advertisement packet associated with a low-energy radio protocol, such as Bluetooth Low Energy.

[0047] The value M, in one embodiment, is 15 minutes, such that a new K-byte key is generated every 15 minutes. The public key can be derived deterministically based on a timestamp and an anti-tracking secret generated during the public key exchange 310. The public key derivation (315) process enables the wireless accessory 201 to use different keys over time, preventing the long-term association with a specific key with a specific device. The key can be derived based on an anti-tracking secret known only to the mobile device 102 and the wireless accessory 201, allowing the mobile device 102, and only the mobile device, to determine which public key will be broadcast by the wireless accessory 201 at any given timestamp. The anti-tracking secret can be generated along with an ECDH public key and transferred to the wireless accessory 201. The anti-tracking secret can then be used to enable the wireless accessory 201 to generate a sequence of public keys P_i. In one embodiment, the sequence of public keys $P_i = \lambda_i . \mathrm{Math} . P$, which defines a group operation between a scalar or exponent value λ_i and group elements, such as, for example, Elliptic Curve points P. The scalar or exponent value $\lambda = KDF(AT, i)$, where KDF is a key derivation function, AT is the anti-tracking secret, and i is a counter or timestamp.

[0048] In one embodiment, backtracking resistance can be enabled to protect the anti-tracking secret in the event the wireless accessory 201 is compromised. When backtracking resistance is enabled, the anti-tracking secret is transferred to the wireless accessory 201 but is not retained by the wireless accessory. Instead, the accessory computes a value $\lambda_{i+1} = H(\lambda_i \| time)$, with $\lambda_0 = AT$ and H being a cryptographic hash function. The wireless accessory 201 then stores λ_i for a given time period i. If the wireless accessory 201 is compromised, only λ_i for current and future values of i is exposed, without exposing the anti-tracking secret AT. In one

embodiment, backtracking resistance is performed by periodically writing λ.sub.i to non-volatile memory of the wireless accessory **201**.

[0049] In one embodiment the wireless accessory **201** can transmit the beacon signal **301** every two seconds, although other beacon rates can be used, and the beacon rate can vary under certain circumstances. For example, the wireless accessory **201** can decrease a beacon rate when in a near-owner state. Beacon rate can also vary based on accelerometer triggered events. For example, the wireless accessory **201** can increase the beacon rate when in an alarm state, which can be triggered by the accelerometer on the wireless accessory **201**.

[0050] The wireless accessory **201** can enter the near-owner state if, after transmitting the beacon signal **301**, the wireless accessory **201** receives a reply from the mobile device **102** associated with the user of the accessory, which indicates that the mobile device **102** is within range of the wireless accessory. Additionally, while the wireless accessory is in the near-owner state, the amount of data transmitted by the beacon signal **301** may be reduced. In one embodiment, the rate at which new public keys are generated can also be reduced while the wireless accessory is in the near-owner state.

[0051] The wireless accessory **201** can enter an alarm state upon receiving a message from the mobile device **102** that indicates that the wireless accessory **201** should enter the alarm state. When in the alarm state, the wireless accessory can initially enter an armed state in which the wireless accessory **201** can reduce or cease the transmission of locator beacon signals, although other types of wireless signaling can persist. The wireless accessory **201** can remain in the armed state until the state is deactivated by the mobile device **102** or alarm is triggered. The alarm can be triggered, in one embodiment, upon detection of movement, for example, via an accelerometer within the wireless accessory **201**. The alarm can also be triggered, in one embodiment, upon detection that the wireless accessory has moved out of range of the mobile device and is no longer in the near-owner state. When the alarm is triggered, the rate at which the beacon signal **301** can be increased, to increase the speed by which the wireless accessory **201** can be located.

[0052] The beacon signal **301** transmitted by the wireless accessory **201** can be detected by a set of finder devices **303**, which are other electronic devices that can receive the beacon signal transmitted by the wireless accessory and are transmit location and other data associated with the beacon signal **301** to the device locator server **203** via the wide area network **114**. In one embodiment the set of finder devices **303** include variants of the mobile device **102** or can be other types of electronic devices. The set of finder devices **303** can include a variant of the finder device **202** of FIG. **2** and can determine similar location determination techniques. For example, the set of finder devices can perform operations (**320**) to correlate the beacon signal **301** received from the wireless accessory **201** with a device location associated with the finder device. As described with respect to FIG. **2**, the device location can be determined via a satellite positioning service or a terrestrial positioning system that uses RF signals received from wireless base stations (e.g., Wi-Fi access points or cell tower transmitters). In one embodiment the set of finder devices **303** can also include stationary devices such as smart speaker devices, televisions, or television set top boxes that can receive the beacon signal **301**.

[0053] The set of finder devices **303** can encrypt the location data with the beacon identifier (e.g., public key) received within the beacon signal **301** and send the location data (**325**) to the device locator server **203**. The data sent by the set of finder devices **303** is sent anonymously and no identifying information for the finder devices is stored with the data sent by the finder devices.

[0054] The device locator server **203** can store encrypted location data in a data store **304**, which in one embodiment can be a distributed database having multiple nodes. Hashes of the beacon identifier/public key of an accessory can be sent along with encrypted location data. The encrypted location data can be stored to a database node based on a hash of the beacon identifier. The encrypted location data can be indexed by the device locator server **203** using the hash of the beacon identifier, which prevents the storage of the full beacon identifier to the server. Other

information can also be sent and stored with the location data, either in an encrypted or unencrypted state. The other information can include timestamps for when the beacon signal **301** was received, RSSI information for the received beacon, and/or ranging information determined, for example, via UWB ranging.

[0055] When the user or owner of the wireless accessory **201** wishes to locate the accessory, the user or owner can access the device locator UI **204** on the mobile device **102**. The device locator UI **204** can be associated with a device locator application or feature of the mobile device **102**. The device locator UI **204** may also have a web-based interface that can be accessed from the mobile device **102** or another type of electronic device, such as a laptop or desktop device. The mobile device **102**, upon loading the device locator UI **204**, can send a request (**330**) for location data to the device locator server **203**. The request **330** can include a set of public key hashes, which can be used to locate the encrypted location data for the device. The mobile device **102** can generate the set of public key hashes based on the secret information held by the mobile device **102** and the wireless accessory **201** and the timestamps over which the mobile device **102** wishes to receive location data. In one embodiment the set of public key hashes is based on the sequence of public keys P.sub.i that are generated based on the anti-tracking secret. The sequence of public keys P.sub.i corresponds to a matching sequence of private keys d.sub.i. The mobile device **102** can generate the sequence of public keys, as well as the corresponding sequence of public keys d.sub.i, where i is a counter or timestamp. In one embodiment, the mobile device **102** can generate and send the previous 24 hours of public keys within the request **330**. If no data is found for 24 hours of public keys, the mobile device **102** can send generate keys for an earlier period, back to a pre-determined location data retention limit.

[0056] In one embodiment, the wireless accessory **201** can be placed in a light lost mode. In the light lost mode, a set of future public keys can be generated for the wireless accessory and transmitted to the device locator server **203**. The device locator server **203** can then notify the mobile device **102** if any location data is received that correspond with a key in the set of future public keys. In one embodiment, a finder device that sends a location for a wireless accessory that is in the light lost mode can be directed by the device locator server **203** to relay a message to the wireless accessory **201** that notifies the wireless accessory that it is in the light lost mode. A similar mechanism can be used to relay a message to the wireless accessory **201** that places the accessory in an explicit lost mode. The explicit lost mode can be enabled by the user via the device locator UI **204**. In the explicit lost mode, the wireless accessory **201** cannot be paired with another device unless unlocked by the owner.

[0057] FIG. **4**A-**4**C are flow diagrams illustrating methods for use with the device locator systems described herein. FIG. **4**A illustrates a method **400** to pair a mobile device with a wireless accessory. FIG. **4**B illustrates a method **410** to determine a location for a wireless accessory via a device locator server. FIG. **4**C illustrates an additional method **420** to determine a location for a wireless accessory via a device locator server. Aspects of method **400**, **410**, and **420** are also illustrated in FIG. **2** and FIG. **3**, as described above. For example, the description of the operations below refers to the mobile device **102**, wireless accessory **201** and device locator server **203**.

[0058] As shown in FIG. **4**A, method **400** includes an operation (block **401**) that performs an initial pairing with a wireless accessory. The initial pairing can be a Bluetooth pairing or another type of pairing using other wireless radio technologies. During the initial pairing, the mobile device and the wireless accessory can exchange identifiers, passkeys, or other credentials that enables a wireless data exchange to be performed between a mobile or another electronic device and the wireless accessory. On one embodiment the initial paring with the wireless accessory can include the exchange of credentials associated with the wireless protocol for which the pairing is performed, allowing all data exchanged wirelessly to have at least a first layer of encryption.

[0059] The mobile device can then generate a public/private key pair and one or more additional shared secrets (block **402**). The device can then send the public key and one or more additional

shared secrets to the wireless accessory (block **403**). A variety of key generation techniques can be used. In one embodiment, a variant of ECDH is used to generate a public key pair for encryption. In one embodiment, the one or more additional shared secrets can include an anti-tracking secret that enables the wireless accessory to derive a new public key based on an existing public key.

[0060] After generating the public/private keypair and one or more additional shared secrets, the mobile device can store public/private key pair to keystore (block **404**). In one embodiment the keystore is a cloud-based keystore that can be synchronized with other devices associated with the same cloud services account, or family of cloud services accounts, to which the mobile device and wireless accessory are associated. The cloud-based keystore allows the wireless accessory to be located by other synchronized devices. The mobile device can then register the wireless accessory with a device management server (block **405**). Registering the wireless accessory with the device management server can form an association between the wireless accessory and the cloud services account to which the mobile device is associated. The device management server can be associated with other cloud-based servers that are used to facilitate cloud-based services accessible to the mobile device, such as the device locator server **203** of FIG. **2** and FIG. **3**.

[0061] As shown in FIG. **4**B, method **410** includes an operation in which an electronic device launches a device locator UI (block **411**). In response to launching the device locator UI, the electronic device, which can be a mobile device as described herein, or another electronic device associated with the same cloud services account as the mobile electronic device, can perform an operation to generate a set of public keys that were included within a beacon signal broadcast by a wireless accessory during a first period (block **412**). The first period can be, for example, a previous 24 hours. The electronic device is aware of how often the wireless accessory is to generate or rotate to new public keys and, using a shared secret generated with the wireless accessory, can generate a set of public keys that correspond with the keys that were generated by the wireless accessory over the first period. The electronic device can then send the set of public keys within a request for the device locator server to send location data that corresponds with the set of public keys (block **413**). In one embodiment, location data sent by the server in response to the request will be encrypted using the public key transmitted as the beacon identifier of the wireless accessory. The electronic device can decrypt the encrypted location data received by the server using the private key generated during the initial pairing with the wireless accessory (block **414**). The electronic device can then process the location data to determine the highest probability location for the wireless accessory (block **415**).

[0062] Processing the location data can include a variety of different operations. In one embodiment the location data includes latitude and longitude information along with a timestamp for which the location was determined. The electronic device can triangulate based on the timestamps and remove noise or outlier locations. In one embodiment the location data specifies the location of the finder device that detected the beacon. The location data can additionally include UWB ranging information and/or RSSI information for the beacon detected by the finder device. The electronic device can analyze the UWB ranging information and/or RSSI information in context with the device locations to develop a more accurate location for the wireless accessory. Data that can be transmitted by a finder device and used for location processing is shown in FIG. **10** and described below.

[0063] As shown in FIG. **4**C, method **420** includes operations that can be performed if the device locator server does not have location data to provide to the electronic device in response to a request. The electronic device can generate a first set of public keys that were included within a beacon signal broadcast by wireless accessory during a first period (block **421**). The first period can be, for example, 24 hours, although other initial search periods can be used. The electronic device can perform a subsequent operation to request the device locator server to send location data that corresponds with first set of public keys (block **422**). If the data is returned by the server (block **423**, "yes"), the electronic device can decrypt the location data received from the server using the

private key that corresponds with the set of public keys (block **429**).

[0064] If data is not returned by the server (block **423**, "no") the electronic device can generate a second set of public keys that were included within a beacon signal broadcast by the wireless accessory during a second period (block **424**). The second period can be the **24**, **48**, or another number of hours before the first period. The electronic device can then request for the device locator server to send data that corresponds with the second set of public keys (block **425**). If, in response to the request, data is returned by the server (block **426**, "yes"), method **420** can proceed to block **429**, in which the electronic device decrypts the received data. If data is not returned by the server (block **426**, "no"), or the server sends a reply that indicates data is not available, method **420** includes for the electronic device can widen the search time by requesting successively older time periods until the max period is reached (block **427**).

[0065] FIG. **5** is a flow diagram illustrating a method **500** of broadcasting a signal beacon at a wireless accessory, according to an embodiment. Aspects of method **500** are also illustrated in FIG. **2** and FIG. **3**. Method **500** includes for the wireless accessory to derive a public key (block **502**). The public key can be derived based on a shared secret and a timestamp determined based on a clock or time keeping device of the wireless accessory. The wireless accessory can then transmit a beacon signal at a first transmission interval, where the beacon signal includes the public key (block **503**). The first transmission interval can vary, and in one embodiment is one beacon every two seconds.

[0066] After transmitting a beacon signal, the wireless accessory can listen for a response from the owner device. If the wireless signal receives a response from the owner device (block **504**, "yes"), the wireless accessory can enter a near owner state (block **505**) and begin to transmit the beacon signal at a second, slower transmission interval (block **507**). If the wireless accessory does not receive a response from the owner device (block **504**, "no"), the wireless accessory can continue beaconing at the first transmission interval (block **506**).

[0067] Method **500** additionally includes for the wireless device, while beaconing, to rotate the public key every M minutes, where the value of M can vary across embodiments and/or based on the device state. Based on a timer expiration, counter, or another mechanism, the wireless accessory can determine whether the accessory has entered a new key period (block **508**). While the wireless accessory has not entered a new key period (block **508**, "no"), the accessory can continue beaconing using the current public key (block **510**). When the wireless accessory detects that it has entered a new key period (block **508**, "yes") the accessory can derive a new public key using the current timestamp (block **509**). In one embodiment the new public key can be derived using an existing public key, a timestamp, and an anti-tracking secret.

[0068] FIG. **6**A-**6**B illustrate operations of a method **600** that can be performed by a finder device, according to embodiments described herein. Aspects of method **600** are also illustrated in FIG. **2** and FIG. **3**.

[0069] As shown in FIG. **6**A, method **600** includes for the finder device to perform a periodic beacon scan using a wireless baseband processor while an application processor of the finder device is in a low power mode (block **601**). While the beacon scan can also be performed when the application processor is active, beacon scans can be performed by the wireless processor and a wireless radio receiver as a low power operation while the finder device is idle, inactive, or otherwise in a low power state. The finder device can store a timestamp and a beacon identifier to a beacon scan buffer for any beacon data received by the finder device (block **602**). The beacon identifier, in one embodiment, is a public key that is generated by the wireless device based on a timestamp and a shared secret generated with the mobile device of the owner.

[0070] Method **600** additionally includes for the finder device to perform periodic Wi-Fi scans using the wireless processor while application processor is in a low power mode (block **603**). While the Wi-Fi scans can also be performed when the application processor is active, Wi-Fi scans can be performed by the wireless processor and a wireless radio receiver as a low power operation while

the finder device is idle, inactive, or otherwise in a low power state. The finder device can then store Wi-Fi service set identifiers (SSIDs) and scan timestamps to a Wi-Fi scan buffer on the finder device (block **604**).

[0071] In one embodiment, the Wi-Fi scan buffer is a rolling buffer that stores the most recently detected SSIDs, while overwriting older detected SSIDs. In one embodiment the beacon scan buffer can be a fixed-size buffer having space for a pre-determined number of entries. The finder device can wake the application processor when the beacon scan buffer becomes full (block **605**) and correlate those beacon scan with the most recently detected SSIDs in the Wi-Fi scan buffer. That correlation can enable the finder device to determine a set of device locations that correspond with received beacons based on Wi-Fi scan buffer data (block **606**).

[0072] Method **600** continues in FIG. **6**B and includes for the finder device to correlate device locations from the Wi-Fi scan buffer data with other location data if other location data is available (block **607**), to generate refined device locations. If refined device locations are generated, the finder device can optionally combine the beacon data with refined device locations (block **608**). The finder device can also add signal strength (RSSI) or ranging data to the location data (block **609**). The signal strength and ranging data (e.g., UWB ranging data) can be gathered when the beacon signal is received by the finder device. The finder device can then encrypt the location data with one or more public keys received within the beacon data (block **610**). The signal and ranging data may be encrypted along with the location data or can be send unencrypted along with the encrypted location data. The finder device can enqueue encrypted location data for transmission to the device locator server (block **611**). The device locator server can be one of multiple cloud services servers to which communication is generally performed in a batched and throttled manner. A batch of encrypted data can be gathered and placed in the transmission queue until a transmit interval arrives, during which the finder device can transmit data to the cloud services servers (block **612**). The encrypted data can be sent along with hashes of the beacon identifiers that correspond with the encrypted locations and the server will store the encrypted locations indexed by the hash of the beacon identifier.

[0073] FIG. **7** illustrates the gathering of signal and ranging data by a finder device, according to an embodiment. In one embodiment, the finder device **202** can gather signal strength information (e.g., RSSI **704**A-**704**N) for a beacon signal **301** received from the wireless accessory **201** across multiple locations **702**A-**702**N. The finder device **202** can also represent multiple finder devices, such as the set of finder devices **303** in FIG. **3**, where each finder device detects the beacon signal at a different location. Each finder device **202** can send different locations and signal strengths and the location and signal strength data received from the multiple finder devices will be aggregated by the device locator server. In one embodiment, where a finder device and the wireless device each include UWB radios, UWB ranging **706** can be performed if the finder device and the wireless device are within range of UWB transmissions. UWB ranging and signal strength data can be transmitted along with location data for the finder devices to the device locator server.

[0074] The owner device can retrieve the RSSI or UWB information from the device locator server along with location data, which in one embodiment is provided the form of latitude and longitude information, along with timestamps for which the locations were determined. The owner device can then use the location data, timestamps, and signal information to triangulate a most probable location for the wireless accessory **201**.

[0075] FIG. **8** illustrates a networked system **800** for locating devices and wireless accessories, according to an embodiment. The system **800** also illustrates an exemplary server architecture for the device locator server **203**, according to an embodiment. In one embodiment the device locator server **203** is a cluster of interconnected server devices, which may be physical or virtual servers within a single datacenter or distributed across multiple datacenters and/or geographic locations. As described above, the device locator server **203** can communicate with a mobile device **102** of an accessory owner or user and the set of finder devices **303** over a wide area network **114**. The

mobile device **102** includes a UI provided by a local or web application that enables the location of a wireless accessory and the finder devices **303** receive beacon signals from wireless accessories and transmits location data associated with the received signals to the device locator server **203**.

[0076] In one embodiment the device locator server **203** includes a locator service front-end **803**, an account database **825**, a database cluster manager **813**, and a set of database cluster nodes **823**A-**823**C. The locator service front-end **803** is a front-end interface to which the mobile device **102** and the set of finder devices **303** can communicate. The account database **825** stores account profile data for accounts of a cloud service provider to which the mobile device **102** and the finder devices **303** are associated. The database cluster manager **813** can configure the database cluster nodes **823**A-**823**C as a distributed location database that can store location, signal, and ranging data in association with beacon identifiers for signal beacons received by the set of finder devices **303**.

[0077] In one embodiment, the account database **825** can contain a list of devices that are associated with each cloud services account. In response to a request to locate a given device, including a wireless accessory as described herein, the account database **825** can verify that the request is coming from a device that is authorized to request the location of the given device. In one embodiment, when a user launches a device locator UI and communicates with the locator service front-end **803**, the locator service front-end can communicate with the account database **825** and provide a current or last known location for each device that is associated with a requesting user, including devices and/or wireless accessories associated with other users that are in a family of accounts associated with the requesting user.

[0078] In one embodiment, the database cluster manager **813** can select a database cluster node **823**A-**823**C to which beacon data is to be stored based on the hash of the beacon ID associated with a set of location data. Each database cluster node **823**A-**823**C can be associated with a range of hash values. The database cluster manager can then store location data to the cluster node that corresponds with the range of hash values associated with the hash of a given beacon ID, with the location data indexed based on the hash of the beacon ID. Although three database cluster nodes are illustrated, embodiments are not limited to any specific number of nodes and greater or fewer nodes may be used.

[0079] FIG. **9**A-**9**C illustrate a device locator UI **204**, according to an embodiment. FIG. **9**A shows a first graphical user interface of the device locator UI **204**, according to an embodiment, which shows a location for various electronic devices and wireless accessories of a user. FIG. **9**B shows a second graphical user interface of the device locator UI **204**, according to an embodiment, which enables a wireless accessory to be set to an alarm mode. FIG. **9**C shows a third graphical user interface of the device locator UI **204**, according to an embodiment, which enables a wireless accessory to be set to a lost mode.

[0080] As shown in FIG. **9**A, the device locator UI **204** can be displayed on an electronic device **900**, which can be a mobile device, or any other type of electronic device described herein. The device locator UI **204** can present a unified graphical interface through which multiple different types of devices and accessories can be located, including wireless devices with network or cellular access and wireless accessories without current or native network access. The device locator UI **204** can include a map **901** with a marker **902** that shows the current or last known location of a wireless device or accessory. The marker **902** can be an icon, image, graphic or any other user interface element that identifies the accessory and conveys a location for the accessory. A selectable element **903** in the device locator UI can present a description or name of the wireless device or accessory and can show an estimated distance between the wireless device or accessory and the current location of the electronic device **900**.

[0081] As shown in FIG. **9**B, the device locator UI **204** can present a second user interface that enables a wireless accessory to be set to an alarm mode. The second user interface can be displayed, in one embodiment, in response to the selection of the selectable element **903** shown in FIG. **9**A. The second user interface can present a user interface element **904** that represents and/or

describes the wireless accessory in question, as well as the map **901** and marker **902** that show the current or last known location of the wireless accessory. In one embodiment, the device locator UI **204** can present a selectable element **905**, such as a button or another user interface element, that allows a user of the device locator UI **204** to place a selected wireless accessory into an alarm mode. While in the alarm mode, the wireless accessory can be configured to trigger a notification to the user if the wireless accessory is moved from its current location.

[0082] In one embodiment the wireless accessory can detect movement via an accelerometer or another type of motion sensor within the wireless accessory. The notification can be initiated by the wireless accessory by setting a flag in the data packet transmitted by the beacon signal of the wireless accessory that indicates the wireless accessory alarm has been triggered. In various embodiments, other trigger or notification modes can be used. In one embodiment, the alarm can optionally be triggered by the mobile device upon detection that the wireless accessory has moved out of range of the mobile device and is no longer in the near-owner state. In one embodiment, the alarm can optionally be triggered when the wireless accessory is out of range of, or otherwise cannot be located by, any of the devices associated with the account or family of user accounts to which the wireless accessory is associated.

[0083] As shown in FIG. **9**C, the device locator UI **204** can present a third graphical user interface that enables a wireless accessory to be set to a lost mode. In one embodiment, when a wireless accessory cannot be located via the device locator UI **204**, the map **901** will not display a marker that indicates a location for the accessory. The device locator UI **204** can present the user interface element **904** that represents and/or describes the wireless accessory in question and a set of selectable user interface elements. One selectable user interface element **906** can present the option to notify the user when the accessory is found. When notify when found is enabled, in one embodiment the wireless accessory can be placed into a light lost mode. The electronic device associated with the device locator UI **204** can generate a set of public keys that the wireless accessory will broadcast with the beacon signal during a future time period (e.g., next 24 hours, next 48 hours, etc.). If a signal is detected by a finder device using one of the future keys, the device locator server can notify one or more electronic devices associated with the user.

[0084] Another selectable user interface element **907** can place the wireless accessory into an explicit lost mode. When explicitly placed into lost mode, the wireless accessory will be unable to be paired with other devices until the accessory is unlocked by the user or owner that places the device into lost mode. When sending a request to place a wireless accessory into lost mode, the requesting user can be required to enter authenticating information to ensure that the requesting user is authorized to request that lost mode be initiated on the lost accessory. The authenticating information can include a username or password associated with an account of a user, such as a cloud services account to which the user, electronic device, and wireless accessory are associated. The authenticating information can also include biometric information, such as a fingerprint or facial recognition data.

[0085] In one embodiment, a message and contact information provided by the requesting user can be displayed on the user device to alert a person who finds the lost wireless accessory on how to contact the requesting user. In one embodiment, the message and contact information can be displayed when another user attempts to pair another electronic device with the lost accessory.

[0086] FIG. **10** illustrates an accessory pairing UI **302** that is displayed when attempting to pair with a lost wireless accessory, according to an embodiment. In one embodiment, when an electronic device **1000** that is different from the electronic device **900** of FIG. **9**A and is not associated with the registered user or owner of a wireless accessory attempts to pair with a lost wireless accessory, the accessory pairing UI of the electronic device can be displayed as shown in FIG. **10**. In one embodiment, the accessory pairing UI **302** can display a name or description **1001** associated with the wireless accessory, as well as a message **1002** entered by the user of the accessory upon placing the accessory into lost mode. Contact information **1004** can also be

displayed, along with a user interface element **1006**, such as a button, that enables the electronic device **1000** to contact the requesting user by using the provided contact information **1004**.

[0087] Embodiments described herein include one or more application programming interfaces (APIs) in an environment in which calling program code interacts with other program code that is called through one or more programming interfaces. Various function calls, messages, or other types of invocations, which further may include various kinds of parameters, can be transferred via the APIs between the calling program and the code being called. In addition, an API may provide the calling program code the ability to use data types or classes defined in the API and implemented in the called program code.

[0088] An API allows a developer of an API-calling component (which may be a third-party developer) to leverage specified features provided by an API-implementing component. There may be one API-calling component or there may be more than one such component. An API can be a source code interface that a computer system or program library provides to support requests for services from an application. An operating system (OS) can have multiple APIs to allow applications running on the OS to call one or more of those APIs, and a service (such as a program library) can have multiple APIs to allow an application that uses the service to call one or more of those APIs. An API can be specified in terms of a programming language that can be interpreted or compiled when an application is built.

[0089] In some embodiments, the API-implementing component may provide more than one API, each providing a different view of or with different aspects that access different aspects of the functionality implemented by the API-implementing component. For example, one API of an API-implementing component can provide a first set of functions and can be exposed to third party developers, and another API of the API-implementing component can be hidden (not exposed) and provide a subset of the first set of functions and also provide another set of functions, such as testing or debugging functions which are not in the first set of functions. In other embodiments, the API-implementing component may itself call one or more other components via an underlying API and thus be both an API-calling component and an API-implementing component.

[0090] An API defines the language and parameters that API-calling components use when accessing and using specified features of the API-implementing component. For example, an API-calling component accesses the specified features of the API-implementing component through one or more API calls or invocations (embodied for example by function or method calls) exposed by the API and passes data and control information using parameters via the API calls or invocations. The API-implementing component may return a value through the API in response to an API call from an API-calling component. While the API defines the syntax and result of an API call (e.g., how to invoke the API call and what the API call does), the API may not reveal how the API call accomplishes the function specified by the API call. Various API calls are transferred via the one or more application programming interfaces between the calling (API-calling component) and an API-implementing component. Transferring the API calls may include issuing, initiating, invoking, calling, receiving, returning, or responding to the function calls or messages; in other words, transferring can describe actions by either of the API-calling component or the API-implementing component. The function calls or other invocations of the API may send or receive one or more parameters through a parameter list or other structure. A parameter can be a constant, key, data structure, object, object class, variable, data type, pointer, array, list or a pointer to a function or method or another way to reference a data or other item to be passed via the API.

[0091] Furthermore, data types or classes may be provided by the API and implemented by the API-implementing component. Thus, the API-calling component may declare variables, use pointers to, use or instantiate constant values of such types or classes by using definitions provided in the API.

[0092] Generally, an API can be used to access a service or data provided by the API-implementing component or to initiate performance of an operation or computation provided by the API-

implementing component. By way of example, the API-implementing component and the API-calling component may each be any one of an operating system, a library, a device driver, an API, an application program, or other module (it should be understood that the API-implementing component and the API-calling component may be the same or different type of module from each other). API-implementing components may in some cases be embodied at least in part in firmware, microcode, or other hardware logic. In some embodiments, an API may allow a client program to use the services provided by a Software Development Kit (SDK) library. In other embodiments, an application or other client program may use an API provided by an Application Framework. In these embodiments, the application or client program may incorporate calls to functions or methods provided by the SDK and provided by the API or use data types or objects defined in the SDK and provided by the API. An Application Framework may in these embodiments provide a main event loop for a program that responds to various events defined by the Framework. The API allows the application to specify the events and the responses to the events using the Application Framework. In some implementations, an API call can report to an application the capabilities or state of a hardware device, including those related to aspects such as input capabilities and state, output capabilities and state, processing capability, power state, storage capacity and state, communications capability, etc., and the API may be implemented in part by firmware, microcode, or other low-level logic that executes in part on the hardware component.

[0093] The API-calling component may be a local component (i.e., on the same data processing system as the API-implementing component) or a remote component (i.e., on a different data processing system from the API-implementing component) that communicates with the API-implementing component through the API over a network. It should be understood that an API-implementing component may also act as an API-calling component (i.e., it may make API calls to an API exposed by a different API-implementing component) and an API-calling component may also act as an API-implementing component by implementing an API that is exposed to a different API-calling component.

[0094] The API may allow multiple API-calling components written in different programming languages to communicate with the API-implementing component (thus the API may include features for translating calls and returns between the API-implementing component and the API-calling component); however, the API may be implemented in terms of a specific programming language. An API-calling component can, in one embedment, call APIs from different providers such as a set of APIs from an OS provider and another set of APIs from a plug-in provider and another set of APIs from another provider (e.g., the provider of a software library) or creator of the other set of APIs.

[0095] FIG. **11** is a block diagram illustrating an exemplary API architecture, which may be used in some embodiments of the invention. As shown in FIG. **11**, the API architecture **1100** includes the API-implementing component **1110** (e.g., an operating system, a library, a device driver, an API, an application program, software or other module) that implements the API **1120**. The API **1120** specifies one or more functions, methods, classes, objects, protocols, data structures, formats and/or other features of the API-implementing component that may be used by the API-calling component **1130**. The API **1120** can specify at least one calling convention that specifies how a function in the API-implementing component receives parameters from the API-calling component and how the function returns a result to the API-calling component. The API-calling component **1130** (e.g., an operating system, a library, a device driver, an API, an application program, software or other module), makes API calls through the API **1120** to access and use the features of the API-implementing component **1110** that are specified by the API **1120**. The API-implementing component **1110** may return a value through the API **1120** to the API-calling component **1130** in response to an API call.

[0096] It will be appreciated that the API-implementing component **1110** may include additional functions, methods, classes, data structures, and/or other features that are not specified through the

API **1120** and are not available to the API-calling component **1130**. It should be understood that the API-calling component **1130** may be on the same system as the API-implementing component **1110** or may be located remotely and accesses the API-implementing component **1110** using the API **1120** over a network. While FIG. **11** illustrates an API-calling component **1130** interacting with the API **1120**, it should be understood that other API-calling components, which may be written in different languages (or the same language) than the API-calling component **1130**, may use the API **1120**.

[0097] The API-implementing component **1110**, the API **1120**, and the API-calling component **1130** may be stored in a machine-readable medium, which includes any mechanism for storing information in a form readable by a machine (e.g., a computer or other data processing system). For example, a machine-readable medium includes magnetic disks, optical disks, random-access memory; read only memory, flash memory devices, etc.

[0098] FIG. **12** is a block diagram of a device architecture **1200** for a mobile or embedded device, according to an embodiment. The device architecture **1200** includes a memory interface **1202**, one or more processors **1204** (e.g., data processors, image processors and/or graphics processors), and a peripherals interface **1206**. The various components can be coupled by one or more communication buses or signal lines. The various components can be separate logical components or devices or can be integrated in one or more integrated circuits, such as in a system on a chip integrated circuit.

[0099] The memory interface **1202** can be coupled to memory **1250**, which can include high-speed random-access memory such as static random-access memory (SRAM) or dynamic random-access memory (DRAM) and/or non-volatile memory, such as but not limited to flash memory (e.g., NAND flash, NOR flash, etc.).

[0100] Sensors, devices, and subsystems can be coupled to the peripherals interface **1206** to facilitate multiple functionalities. For example, a set of sensors **1210** including a motion sensor **1211**, a light sensor **1212**, and a proximity sensor **1214** can be coupled to the peripherals interface **1206** to facilitate the mobile device functionality. One or more biometric sensor(s) **1215** may also be present, such as a fingerprint scanner for fingerprint recognition or an image sensor for facial recognition. Other sensors **1216** can also be connected to the peripherals interface **1206**, such as a positioning system (e.g., GPS receiver), a temperature sensor, or other sensing device, to facilitate related functionalities.

[0101] The device architecture **1200** additionally includes an audio/video system **1220**. A camera subsystem **1221** and an optical sensor **1222**, e.g., a charged coupled device (CCD) or a complementary metal-oxide semiconductor (CMOS) optical sensor, can be utilized to facilitate camera functions, such as recording photographs and video clips. An audio subsystem **1226** can be coupled to a speaker **1228** and a microphone **1230** to facilitate voice-enabled functions, such as voice recognition, voice replication, digital recording, and telephony functions. In smart media devices described herein, the audio subsystem **1226** can be a high-quality audio system including support for virtual surround sound.

[0102] Communication functions can be facilitated through one or more wireless communication subsystems **1224**, which can include radio frequency receivers and transmitters and/or optical (e.g., infrared) receivers and transmitters. The specific design and implementation of the wireless communication subsystems **1224** can depend on the communication network(s) over which a mobile device is intended to operate. For example, a mobile device including the illustrated device architecture **1200** can include wireless communication subsystems **1224** designed to operate over a GSM network, a CDMA network, an LTE network, a Wi-Fi network, a Bluetooth network, or any other wireless network. In particular, the wireless communication subsystems **1224** can provide a communications mechanism over which a media playback application can retrieve resources from a remote media server or scheduled events from a remote calendar or event server.

[0103] The I/O subsystem **1240** can include a touchscreen controller **1242** and/or other input controller(s) **1245**. For computing devices including a display device, the touchscreen controller

1242 can be coupled to a touch sensitive display system **1246** (e.g., touchscreen). The touch sensitive display system **1246** and touchscreen controller **1242** can, for example, detect contact and movement and/or pressure using any of a plurality of touch and pressure sensing technologies, including but not limited to capacitive, resistive, infrared, and surface acoustic wave technologies, as well as other proximity sensor arrays or other elements for determining one or more points of contact with a touch sensitive display system **1246**. Display output for the touch sensitive display system **1246** can be generated by a display controller **1243**. In one embodiment, the display controller **1243** can provide frame data to the touch sensitive display system **1246** at a variable frame rate.

[0104] In one embodiment, a sensor controller **1244** is included to monitor, control, and/or processes data received from one or more of the motion sensor **1211**, light sensor **1212**, proximity sensor **1214**, or other sensors **1216**. The sensor controller **1244** can include logic to interpret sensor data to determine the occurrence of one of more motion events or activities by analysis of the sensor data from the sensors.

[0105] In one embodiment, the I/O subsystem **1240** includes other input controller(s) **1245** that can be coupled to other input/control devices **1248**, such as one or more buttons, rocker switches, thumb-wheel, infrared port, USB port, and/or a pointer device such as a stylus, or control devices such as an up/down button for volume control of the speaker **1228** and/or the microphone **1230**.

[0106] In one embodiment, the memory **1250** coupled to the memory interface **1202** can store instructions for an operating system **1252**, including portable operating system interface (POSIX) compliant and non-compliant operating system or an embedded operating system. The operating system **1252** may include instructions for handling basic system services and for performing hardware dependent tasks. In some implementations, the operating system **1252** can be a kernel.

[0107] The memory **1250** can also store communication instructions **1254** to facilitate communicating with one or more additional devices, one or more computers and/or one or more servers, for example, to retrieve web resources from remote web servers. The memory **1250** can also include user interface instructions **1256**, including graphical user interface instructions to facilitate graphic user interface processing.

[0108] Additionally, the memory **1250** can store sensor processing instructions **1258** to facilitate sensor-related processing and functions; telephony instructions **1260** to facilitate telephone-related processes and functions; messaging instructions **1262** to facilitate electronic-messaging related processes and functions; web browser instructions **1264** to facilitate web browsing-related processes and functions; media processing instructions **1266** to facilitate media processing-related processes and functions; location services instructions including GPS and/or navigation instructions **1268** and Wi-Fi based location instructions to facilitate location based functionality; camera instructions **1270** to facilitate camera-related processes and functions; and/or other software instructions **1272** to facilitate other processes and functions, e.g., security processes and functions, and processes and functions related to the systems. The memory **1250** may also store other software instructions such as web video instructions to facilitate web video-related processes and functions; and/or web shopping instructions to facilitate web shopping-related processes and functions. In some implementations, the media processing instructions **1266** are divided into audio processing instructions and video processing instructions to facilitate audio processing-related processes and functions and video processing-related processes and functions, respectively. A mobile equipment identifier, such as an International Mobile Equipment Identity (IMEI) **1274** or a similar hardware identifier can also be stored in memory **1250**.

[0109] Each of the above identified instructions and applications can correspond to a set of instructions for performing one or more functions described above. These instructions need not be implemented as separate software programs, procedures, or modules. The memory **1250** can include additional instructions or fewer instructions. Furthermore, various functions may be implemented in hardware and/or in software, including in one or more signal processing and/or

application specific integrated circuits.

[0110] FIG. **13** is a block diagram of a computing system **1300**, according to an embodiment. The illustrated computing system **1300** is intended to represent a range of computing systems (either wired or wireless) including, for example, desktop computer systems, laptop computer systems, tablet computer systems, cellular telephones, personal digital assistants (PDAs) including cellular-enabled PDAs, set top boxes, entertainment systems or other consumer electronic devices, smart appliance devices, or one or more implementations of a smart media playback device. Alternative computing systems may include more, fewer and/or different components. The computing system **1300** can be used to provide the computing device and/or a server device to which the computing device may connect.

[0111] The computing system **1300** includes an interconnect **1335** (e.g., bus, fabric) to enable communication between components of the computing system **1300**. One or more processor(s) **1310** can coupled with the interconnect **1335**. The computing system **1300** further may include memory **1320** in the form of random-access memory (RAM) or other dynamic storage device coupled to the interconnect **1335**. The memory **1320** may store information and instructions that may be executed by processor(s) **1310**. The memory **1320** may also be main memory that is used to store temporary variables or other intermediate information during execution of instructions by the processor(s) **1310**.

[0112] The computing system **1300** may also include read only memory (ROM) **1330** and/or another data storage device **1340** coupled to the interconnect **1335** that may store information and instructions for the processor(s) **1310**. The data storage device **1340** can be or include a variety of storage devices, such as a flash memory device, a magnetic disk, or an optical disc and may be coupled to computing system **1300** via the interconnect **1335** or via a remote peripheral interface.

[0113] The computing system **1300** may also be coupled, via the interconnect **1335**, to a display device **1350** to display information to a user. The computing system **1300** can also include an alphanumeric input device **1360**, including alphanumeric and other keys, which may be coupled to interconnect **1335** to communicate information and command selections to processor(s) **1310**. Another type of user input device includes a cursor control **1370** device, such as a touchpad, a mouse, a trackball, or cursor direction keys to communicate direction information and command selections to processor(s) **1310** and to control cursor movement on the display device **1350**. The computing system **1300** may also receive user input from a remote device that is communicatively coupled via one or more network interface(s) **1380**.

[0114] The computing system **1300** further may include one or more network interface(s) **1380** to provide access to a network, such as a local area network. The network interface(s) **1380** may include, for example, a wireless network interface having antenna **1385**, which may represent one or more antenna(e). The computing system **1300** can include multiple wireless network interfaces such as a combination of Wi-Fi, Bluetooth®, near field communication (NFC), and/or cellular telephony interfaces. The network interface(s) **1380** may also include, for example, a wired network interface to communicate with remote devices via network cable **1387**, which may be, for example, an Ethernet cable, a coaxial cable, a fiber optic cable, a serial cable, or a parallel cable.

[0115] In one embodiment, the network interface(s) **1380** may provide access to a local area network, for example, by conforming to IEEE 802.11 wireless standards and/or the wireless network interface may provide access to a personal area network, for example, by conforming to Bluetooth standards. Other wireless network interfaces and/or protocols can also be supported. In addition to, or instead of, communication via wireless LAN standards, network interface(s) **1380** may provide wireless communications using, for example, Time Division, Multiple Access (TDMA) protocols, Global System for Mobile Communications (GSM) protocols, Code Division, Multiple Access (CDMA) protocols, Long Term Evolution (LTE) protocols, and/or any other type of wireless communications protocol.

[0116] The computing system **1300** can further include one or more power sources **1305** and one or

more energy measurement systems **1345**. Power sources **1305** can include an AC/DC adapter coupled to an external power source, one or more batteries, one or more charge storage devices, a USB charger, or other power source. Energy measurement systems include at least one voltage or amperage measuring device that can measure energy consumed by the computing system **1300** during a predetermined period of time. Additionally, one or more energy measurement systems can be included that measure, e.g., energy consumed by a display device, cooling subsystem, Wi-Fi subsystem, or other frequently used or high-energy consumption subsystem.

Proximity Enhancements for a Location Query Application

[0117] In embodiments described herein, a wireless communication device such as a smartphone, smart watch, or tablet computer device can use one or more measurements, such as but not limited to wireless ranging or radio signal-based distance measurements to locate a proximate object in an environment. The proximate object can be a physical device, such as an electronic device or an electronic peripheral, which can be located via a virtual representation of the device that can be presented via an augmented reality display. The wireless communication device may implement a user-interface technique in which an identifier associated with the object is received wirelessly and one or more measurements are used to wirelessly determine a range of the object from the wireless communication device and/or a direction to the object. The wireless communication device may present information that indicates the range and/or the direction to the proximate object. For example, the wireless communication device may display a map of a proximate area in the environment with an indicator representative of the object on the map. Alternatively, the wireless communication device may display an image of the proximate area (e.g., as captured by a camera of the wireless communication device) with the indicator representative of the object on the image. This user-interface technique can remove the constraints associated with many existing user interfaces improve the user experience when using the wireless communication device, and thus may increase customer satisfaction and retention.

[0118] FIG. **14** illustrates a system **1400** in which proximity enhancements can be enabled for a location query application. One embodiment provides a system **1400** to enhance the functionality of a location query application when in a location environment **1408** that is proximate to an item or device to be located. The location environment **1408** can include a mobile device **1402** (e.g., smartphone, wearable, tablet, etc.). The mobile device **1402** can communicate wirelessly with a wireless device **1420** that includes a radio **1419**. The mobile device **1402** can also include a variant of the radio **1419** in the wireless device **1420**. The mobile device **1402** can be a mobile device **102** as described herein. The wireless device **1420** may also be a mobile device **102** or can be a wireless accessory **201** as described herein.

[0119] The devices can communicate wirelessly via wireless communication signals **1405** by detecting one another by scanning wireless channels, transmitting and receiving beacons or beacon frames on wireless channels, establishing connections (for example, by transmitting connect requests), and/or transmitting and receiving packets or frames (which may include the request and/or additional information, such as data, as payloads). The wireless communication signals **1405** can be carrier signals that conform to wireless communication technologies such as, but not limited to Wi-Fi or Bluetooth. In addition to wireless communication, the mobile device **1402** and the wireless device **1420** perform wireless ranging operations using wireless ranging signals **1406**. The wireless ranging signals can be, for example, ultra-wideband signals that can be used to determine a distance and/or angle between the wireless device **1420** and the mobile device **1402** using techniques described herein. In one embodiment, data provided by the wireless ranging signals **1406** can be correlated with other metrics, such as an RSSI of the wireless communication signals **1405**. In one embodiment, a communications processor of the mobile device **1402** and the wireless device **1420** can fuse multiple types of ranging to provide a unified distance and/or angle estimate based on multiple types of radio data.

[0120] The mobile device **1402** can provide a device locator UI **1404** that presents a map and/or an

augmented reality view of the location environment **1408**. The map and/or augmented reality view can present a virtual representation of the wireless device **1420**. The virtual representation can streamline the process of locating the wireless device **1420** by user of the mobile device **1402**. For example, using a direction indicator that points to a detected location of the wireless device **1420** can simplify the process of finding the approximate location of the wireless device **1420**. The direction indicator can be pared with a map of the location environment **1408**, where the map can include the virtual representation of the wireless device **1420**. When the mobile device **1402** enters proximity with the wireless device, an augmented reality view of the location environment **1408** can be presented, which can allow the user to identify the wireless device **1420** when the wireless is hidden from view.

[0121] In one scenario the wireless device **1420** may be concealed by an item **1418**. The item **1418** may be, for example, a jacket or another article of clothing and the wireless device **1420** may be a smartphone or tablet device that is in a pocket of the item **1418**. The item **1418** and the wireless device **1420** may each be within a container **1410**, such as a backpack, storage chest, item of luggage, or another item that make reduce the efficiency of audio-based location techniques that rely on the wireless device **1420** to play a sound that can be heard by a user.

[0122] In another scenario, the wireless device **1420** may be a beacon peripheral or locator tag that is attached to the item **1418**. To find the item **1418**, the user can use the device locator UI **1404** on the mobile device **1402** to find the wireless device **1420**, enabling the user to locate the item **1418** to which the wireless device **1420** is attached. The proximity enhancements described herein can be used to augment the device locator UI **1404**, allowing the user to quickly determine the location of the item **1418**, via the wireless device **1420**, in scenarios where the item may be concealed by a container **1410** or another physical item.

[0123] In one embodiment the mobile device **1402** can establish a secure wireless communication connection (e.g., a Bluetooth connection) with the wireless device **1420** (e.g., via wireless communication signals **1405**) and command the wireless device **1420** to begin a wireless ranging process, for example, using the wireless ranging signals **1406**, which can be UWB signals. The wireless ranging signals **1406** enable the mobile device **1402** to receive measurements of range and angles to the wireless device **1420**.

[0124] In embodiments described herein, wireless ranging can be performed using any standard or proprietary ranging technique, or any combination of standard and/or proprietary ranging techniques. A wireless ranging operation can be performed to determine a distance between devices (e.g., between an initiator and a responder), a direction between devices, or both. For example, a Time of Flight/Time of Arrival (ToF/ToA) can be determined for one or more messages between the devices, which can be used to establish a measure of distance. The one or more messages can have any format and can be transmitted using any wireless protocol. In some embodiments, ToF/ToA can be determined using a bi-directional exchange of two or more messages. In some embodiments, one or more messages used to perform ranging can be secured, e.g., by encrypting or otherwise protecting at least a portion of the content. Further, in some embodiments, the direction of the source of one or more wireless signals can be determined using a technique such as Angle of Arrival (AoA). For example, AoA estimation can be performed using multiple receive elements (e.g., elements of an antenna array) to measure the different times (TDOA) and/or different phases (PDOA) of arrival of a signal. Additionally, or alternatively, in some embodiments, directionality can be determined by measuring Doppler shifts to establish a frequency difference of arrival (FDOA). Wireless ranging techniques can be applied individually or in combination to perform a single ranging operation. Further, wireless ranging techniques can be applied individually or in combination to perform on-going ranging operations, such as continuous or intermittent ranging, and a history of measurements can be captured and used in performing operations based on range and/or direction.

[0125] The incoming measurements can be processed to reduce measurement noise and stabilize

the estimated location of the lost item. In one embodiment, the mobile device **1402** can use a sensor fusion technique that relies upon multiple streams of measurements to arrive at a best estimate of device location. For example, incoming range and/or angle measurements can be fused with position and orientation measurements of the mobile device **1402**. The position and orientation measurements can be gathered using visual-inertial odometry (VIO), which determines the device location and orientation using an IMU and computer vision using camera data. The VIO data enables software on the mobile device **1402** to be aware of the movement and orientation of the device. Combining the VIO data with the range and/or angle measurements determined via the wireless ranging signals **1406** enables estimation of the most likely position of the wireless device and allows the user to be pointed towards the device. VIO data may be particularly useful in scenarios where one or more of the range or angle measurements may be inaccurate due to multipath signal propagation effects.

[0126] The algorithm for determining the position of a lost item can be accessed via the device locator UI **1404**. When a user intends to locate an item, the user can select the item from a list of registered devices and select a "find" button that is presented via the device locator UI **1404**. In various embodiments, multiple user interfaces may be presented. Some interfaces resemble a two-dimensional compass like view with a two-dimensional arrow guiding the user to the target item or device to be found. Other interfaces are three-dimensional augmented reality view with virtual objects, including a three-dimensional arrow, that can guide a user to and highlight the lost item.

[0127] FIG. **15**A-**15**C illustrate location query application user interfaces that include proximity enhancements, according to an embodiment. As shown in FIG. **15**A, in one embodiment a location query application on a mobile device **1402** can present a device locator UI **1404** that includes a map **1510**. The map **1510** can present an indicator **1516** that shows a location of a target wireless device (e.g., wireless device **1420**) to be located. The device locator UI **1404** may present a range **1512** and direction **1414** that is determined based on the relative position of the location corresponding to the indicator **1516** and a current location determined by the mobile device **1402**. In one embodiment and interface element **1506** can be presented that allows a user to switch to a "find" interface that can present an augmented reality view of the location environment.

[0128] The indicator **1516** can be based on a last observed location of the device associated with the indicator **1516**. The last observed location can be a location observed by the mobile device **1402** or another device of the user account associated with the mobile device **1402**. In one embodiment the location of the indicator **1516** can be initially based on a location provided by a device locator server **203** in response to a location query performed by the location query application. As shown in FIG. **2**, the location provided by the device locator server **203** can be a location determined by one or more finder devices **202** that observed a beacon advertisement of the wireless accessory **201**, where the wireless accessory **201** is the target device associated with the indicator **1516**. As shown in FIG. **7**, the one or more finder devices **202** can enhance the location determination process using signal and ranging data (e.g., RSSI and UWB). The signal and ranging data can be provided to the device locator server **203**, which can further refine the location estimate used for the indicator **1516**.

[0129] As with the finder devices **202** in FIG. **7**, once the mobile device **1402** comes within a proximity of the device to be located, signal and ranging data can be used to enhance the positioning of the indicator **1516** on the map **1510**. The signal and ranging data can also be used to provide an enhanced estimate of the range **1512** to the device and the direction **1414** to the device.

[0130] As shown in FIG. **15**B, the device locator UI **1404** on the mobile device **1402** can also present an augmented reality view **1508** that overlays information that can be used to locate a target wireless device within a video stream that is captured via a camera of the mobile device **1402**. The information can include, for example, an identifier **1504**, such as name assigned to the wireless device or beacon peripheral to be located (e.g., Alan's Keys). The information can also include a direction indicator **1502** that shows a relative direction towards the wireless device to be located.

[0131] As shown in FIG. **15**C, once the beacon attached item or wireless device to be located is visible in the augmented reality view **1508** of the device locator UI **1404**, a virtual representation **1526** of the item or device can be presented that indicates a detected location of the item or device.

[0132] FIG. **16**A-**16**E illustrate additional proximity enhanced user interfaces for a location query application. As shown in FIG. **16**A, the device locator UI **1404** on the mobile device **1402** can present a direction and range view that enhances the ability of a user to locate a beacon attached item or wireless device. A forward direction indicator **1602** can be presented that represents a zero-degree bearing relative to the mobile device **1402**. A virtual indicator **1601** for the beacon attached item or wireless device to be located can be displayed. The user can rotate about a room until the virtual indicator **1601** lines up with the forward direction indicator. At that point, the user will be facing directly towards the item or device to be located. The direction and range view can also present information such as an identifier **1604** for the item to be located, which can be, for example, a name assigned to a beacon peripheral attached to an item (e.g., Gemma's keys). The information can also include location information **1605**, which may be a currently detected location of interest (e.g., home) for the item to be found, a determined range to the item (e.g., 12 ft) and the last time the item was observed (e.g., now). The device locator UI **1404** can also present interface elements to perform actions on the wireless device/beacon peripheral to be located and/or on the mobile device **1402**. In one embodiment, an interface element **1606** is presented to cause the wireless device/beacon peripheral to be located to play a sound that enables a user to locate the device/peripheral. An interface element **1607** can also be presented that enables an illumination mechanism (e.g., flashlight) on the mobile device **1402** for use when the location environment is dark or dimly lit.

[0133] If during direction determination the motion of the target wireless device exceeds a threshold, the specific direction to the target wireless device may be difficult to determine based on instantaneous wireless ranging data. This difficulty may be of particular issue if angle of arrival measurements are inaccurate and cannot be relied upon. In such scenario, the direction to the target wireless device can be determined using a series of range measurements. If while gathering the range measurements to the target device, the motion of the target device exceeds a threshold, a view of the device locator UI **1404** can change to the view presented in FIG. **16**B.

[0134] As shown in FIG. **16**B, the forward direction indicator **1602** may present an indeterminate direction when the uncertainty of the position estimate of the target wireless device exceeds a threshold. A UI element **1620** can be presented with a message to the user that indicates that the target wireless device (or target item) is moving and that the mobile device **1402** is determining a new location for the target wireless device. The new location can be determined by gathering and analyzing a fusion of wireless ranging and augmented reality sensor data to determine a new position estimate for the target wireless device. The UI of FIG. **16**B can be displayed as an initial view when an initial position of the target wireless device is being determined for a target wireless device that is in motion. The UI of FIG. **16**B can also be displayed if an item associated with the target wireless device goes into motion during direction determination. While the forward direction indicator **1602** may indicate an indeterminate location, the location information **1605** can continue to display the determined range based if the accuracy of the range measurement is within an accuracy threshold. When a new location for the target wireless device is determined, the view of the device locator UI **1404** can change, for example, to the view of FIG. **16**A, or an equivalent view in which a direction indication is presented, for example, as in FIG. **15**A-**15**B or as in FIG. **16**D.

[0135] If while gathering the range measurements to the target device, the motion of both the target device and the mobile device **1402** exceeds a threshold, a view of the device locator UI **1404** can change to the view presented in FIG. **16**C.

[0136] As shown in FIG. **16**C, the forward direction indicator **1602** indicates an indeterminate location and a UI element **1620** is presented with a message to the user that indicates that both the mobile device **1402** and the target wireless device (or target item) is moving and that less

movement is required to detect a direction to the item. In some implementations, the UI element **1620** may also present further instructions to the user to stop or slow the movement of the mobile device **1402** so that a new direction and/or position for the target wireless device (or target item) may be determined. While the forward direction indicator **1602** may indicate an indeterminate location, the location information **1605** can continue to display the determined range based if the accuracy of the range measurement is within an accuracy threshold. If the motion of either the target device or the mobile device **1402** falls below the threshold, a view of the device locator UI **1404** may change to the view presented in FIG. **16**B. If the motion of both the target device and the mobile device **1402** falls below the threshold, the view of the device locator UI **1404** can change, for example, to the view of FIG. **16**A, or an equivalent view in which a direction indication is presented, for example, as in FIG. **15**A-**15**B or as in FIG. **16**D.

[0137] As shown in FIG. **16**D, an additional direction and range view can be presented via the device locator UI **1404** of the mobile device **1402**. In one embodiment the direction and range view of FIG. **16**D can be presented once the user is within a threshold range of a wireless device and UWB ranging may be used. The illustrated direction and range view can include the virtual indicator **1601** of the item or device to be located. A direction indicator **1612** can be presented that indicates a current bearing that the user should use to approach the location of the item. A range indicator **1614** can be presented that specifies a current range to the item represented by the virtual indicator **1601**.

[0138] In one embodiment, the direction and range view of FIG. **16**D can be presented while the user of the mobile device **1402** has the mobile device positioned substantially parallel to the ground or floor, such that item/device to be located is not within view of the rear camera of the mobile device **1402**. A text instruction **1616** can be presented to the user that indicates to the user that an augmented reality view can be presented once the user changes the angle (e.g., raises) the mobile device **1402** to bring the item/device within view of the camera.

[0139] As shown in FIG. **16**E, an augmented reality view **1610** can be presented via the device locator UI **1404** of the mobile device **1402** when the item/device to be located comes within view of the rear camera of the mobile device **1402**. The virtual indicator **1601** for the item/device can be presented as an overlay on a video captured via the rear camera of the device. The augmented reality view can also display a range indicator **1614** that shows a current range to the item/device.

[0140] FIG. **17** illustrates a system architecture **1700** that enables proximity enhancements for a location query application, according to an embodiment. In one embodiment the system architecture **1700** includes a host operating system **1702** that executes on one or more application processors of a device (e.g., mobile device **1402**, wireless device **1420**). The system architecture **1700** also includes a wireless controller **1730**, which can couple with a wireless radio and one or more wireless antennas.

[0141] The host operating system **1702** can include a location query application **1710** and a nearby device daemon **1720**. The location query application **1710** can present the device locator UI **1404** described herein. The location query application **1710** can include libraries and resources associated with a sensor fusion framework **1711** and a proximity framework **1712**. The proximity framework **1712** presents program interfaces that enable the location query application to communicate with a nearby device daemon **1720** via inter-process communication (IPC **1715**) messages. The nearby device daemon **1720** includes a controller framework **1722**. The controller framework enables the nearby device daemon **1720** to communicate with the wireless controller **1730** on the device via a real-time operating system (RTOS) firmware interface **1725**. The sensor fusion framework **1711** enables sensor data received from the wireless controller to be fused with augmented reality sensor data.

[0142] In one embodiment the wireless controller **1730** can execute a separate real-time operating system (RTOS **1732**) on one or more processors **1736** of the controller. The one or more processors **1736** of the wireless controller **1730** are separate from the application processor that executes the

host operating system **1702**. In one embodiment the one or more processors **1736** includes secure memory, cryptographic accelerators, and other components that enables the wireless controller **1730** to perform secure ranging operations using a ranging sensor **1734**. For example, the one or more processors **1736** can include a secure processor, such as a secure element processor. In one embodiment the processor **1736** is a secure processor, such as a secure element processor (SEP).

[0143] The ranging sensor **1734** can include an ultra-wideband transceiver that can transmit and receive ultra-wideband radio signals. In one embodiment the wireless controller also includes a wireless communications radio **1738** that enables the wireless controller to facilitate communication with other devices using one or more wireless communication or networking protocols, such as Wi-Fi, Bluetooth, or NFC. Metrics associated with signals received by the wireless communications radio **1738** can also be used as one aspect of the ranging process.

[0144] FIG. **18** illustrates a system **1800** to enable the fusion of ranging and pose estimates to generate a target position estimate of a target item, according to an embodiment. In one embodiment the system **1800** includes a wireless controller **1730**, an IMU **1812**, and a set of frameworks that execute on an application processor of a mobile device as described herein. The set of frameworks can include an augmented reality (AR) framework **1810** and the sensor fusion framework **1711**. The wireless controller **1730** can send range measurements **1801** interpolator logic **1804** within the sensor fusion framework **1711**. The AR framework **1810** can receive sensor measurements **1803** from the IMU **1812** and generate pose estimates **1802** for the mobile device. The pose estimates **1802** can be sent to the interpolator logic **1804** within the sensor fusion framework **1711**. The interpolator logic **1804** can process the range measurements **1801** and pose estimates **1802** to generate a measurement with an aligned pose **1805**. The interpolator logic **1804** can generate the measurement with an aligned pose **1805** by interpolating and aligning range measurements **1801** and pose estimates **1802** based on the times in which the measurements and estimates were determined. The measurement with an aligned pose **1805** can be provided to estimator logic **1806**. The estimator logic **1806** can then generate a three-dimensional target position estimate **1807** for use by the mobile device. This target position estimate can be used by the mobile device to generate a virtual representation or virtual indicator in an augmented reality view of a location environment.

[0145] The interpolator logic **1804** and estimator logic **1806** can include various algorithmic techniques to overcome anomalous data and sensor interference to enhance the precision of the three-dimensional target position estimate **1807**. In one embodiment, the system **1800** can fuse inertial data gathered from the IMU **1812** with images captured via one or more cameras to perform visual inertial odometry (VIO). VIO techniques include the analysis of a sequence of images to estimate camera motion over the sequence of images. Using image-based camera motion estimation and inertial measurements captured over the same period of time, motion of the mobile device through a coordinate system can be estimated, providing software of the system **1800** the ability to estimate both the position of the finder mobile device and the wireless device to be located within a three-dimensional coordinate space.

[0146] In one embodiment, the target location estimate can take the form of a nonlinear least-squares problem that can be solved using a non-linear-least-squares (NLLS) batch filter. For example, given r.sub.−i as a range measurement at time t.sub.i, and p(t.sub.i) as a pose estimate relative to the center of VIO coordinate system at the same time, a target location x=[x y z].sup.T can be determined that minimizes the cost function:

$$[00001] J(\underline{x}) = \tfrac{1}{2} \sum_{i=1}^{N} \frac{(r_i - \| \underline{x} - p(t_i) \|)^2}{\sigma^2_{range,i}}$$

The specific pose estimate used may be based on or relative to the position of the wireless ranging radio antenna on the mobile device. Alternatively, a Kalman Filter or spatial occupancy grid-based approach may be applied.

[0147] In one embodiment, once an initial target position for a wireless device has been determined

within the three-dimensional coordinate space, the relative target position of the wireless device can be updated using augmented reality data even in the absence of updated range measurements between the wireless device and the wireless accessory. In such scenario, the frequency of wireless ranging operations may be throttled to reduce power consumption by the wireless device and mobile device.

Ranging Algorithm Enhancements

[0148] Performance and accuracy of the distance, bearing, and range calculations can be enhanced using various algorithmic approaches. In one scenario, as the device traces out a trajectory through space towards a target, the device may encounter multipath signal propagation effects when ranging to the target. Multipath propagation is a phenomenon that results in radio signals reaching a receiving antenna by two or more paths. Multipath propagation can occur if the line of sight to the target is obscured by obstacles in the environment, the antenna pattern severely attenuates the line of sight signal, or the users themselves block the signal. As the mobile device traces a trajectory through space towards the target, the measured range to the target can evolve over time, along with the distance traveled over the trajectory. During this evolution, anomalies and interference may arise.

[0149] At times the measured range determined from the sensor data may appear to jump more than the distance traveled through space. A sudden jump in the measured range that differs from the distance travelled over a period of time may be used to determine when the multipath conditions have changed. When the change in range is positive and larger than the distance traveled, the bias on the measurement due to multi path may have increased. Similarly, when the change in range is negative and larger in magnitude than the distance traveled, a multi path component likely existed before and has reduced in effect. When multipath propagation is detected to have decreased, the uncertainty of previous measurements can be increased to account for the potential multi interference. In one embodiment, previous measurements that have been deemed as multipath measurements may be removed from the measurement history by setting the weights associated with those measurements to zero. When multipath interference is detected to have increased, the measurements received after the detected increase can similarly be de-weighted or those measurements can be rejected.

[0150] In one embodiment range measurements can be de-weighted due to the passage of time. As range measurements are gathered over the device's trajectory, the solution for the target's position becomes overdetermined. Range measurements can be de-weighted as the measurements age and/or as VIO errors accumulate. In the case of a moving target, analysis of range measurements as a function of time may be particularly important, as a time series of range measurements can be used to determine an angle measurement to the device without relying on angle measurements associated with any one ranging operation. Thus, the weights associated with older measurements may be decayed based on a time function.

[0151] In one embodiment, range measurements can be de-weighted due to the measured and/or estimated distance to target. As measurements indicate further ranges, the possibility of multipath interference increases, and the measurements become less useful. As a solution is formed, the estimated distance to each position where a measurement was formed can be calculated. Based on that distance, the measurement can be reweighed. Additionally, the measurement itself is a range, and can be used to infer a measurement uncertainty.

[0152] In one embodiment, angle of arrival measurements can be used to further refine the target position when a range-only solution indicates the target is in the device's field of view. A position solution for the device can be formed using ranging measurements only (e.g., without angle measurements). Given the position solution, probabilities can be calculated that each of the angle measurements was made from the mobile device when the target was in the device's field of view. If the probability meets a threshold, the angle measurement can be used to form a new position solution. Use of the angle measurement can resolve ambiguities that may be present in the range

solution, especially in the up direction, due to the device trajectory mostly being in a single plane.

[0153] After measurements are used to form the position solution, the measurement errors of individual contributing measurements can be calculated. In an over determined solution, the measurement errors will be non-zero and give some indication of the quality of the position fix. If large errors are seen, the confidence in the position fix can be decreased. A threshold on the confidence can be used to determine if the position should be shown to the user. If all measurements are seen to disagree by small amounts, the errors can be used to increase the uncertainty of the position.

[0154] FIG. **19** illustrates a method **1900** to enable proximity enhanced user interfaces for a location query application. Method **1900** includes operations by which range measurements determined by a wireless controller can be fused with pose estimates determined based on sensor data from an IMU to generate pose aligned measurements and three-dimensional target position estimates. The three-dimensional target position estimates can be used to enable an augmented reality view of a location environment that includes a target device or item to be located. Method **1900** can be performed by a wireless communication device (e.g., mobile device **1402**) as described herein to locate a target wireless device (e.g., wireless device **1420**) or wireless accessory (e.g., wireless accessory **201**) described herein, or an item associated with a wireless accessory, such as an item that is tagged with a beacon or locator tag.

[0155] In one embodiment, method **1900** includes operations to receive, at a wireless communication device, a geographic location of a target wireless device (block **1901**). The geographic location for the target wireless device can be a location determined by the wireless communication device, a device that shares a user account of the wireless communication device, or a location received from a device locator server.

[0156] The wireless communication device can then present an indicator for the target wireless device on an interface of a location query application that is executed by the wireless communication device (block **1902**). The indicator can be a map indicator that shows a location of the target wireless device on a map of the nearby environment. A distance and range measurement to the target wireless device can be presented on the map, along with the map indicator that shows the location of the target wireless device. The user of the wireless communication device can then move towards the location of the target wireless device.

[0157] When the wireless communication device is within a threshold range of the target wireless device, the wireless communication device can determine a range and/or direction to the target wireless device using one our more wireless ranging operations (block **1903**). The one or more ranging operations can include continuous or periodic ultra-wideband ranging operations. The ultra-wideband ranging operations can be performed in conjunction with other range determination techniques, such as RSSI-based distance determinations. In one embodiment the ultra-wideband ranging operations are secure ranging operations in which the ranging packets exchanged are encrypted. In one embodiment, both range and direction determinations can be made based on the one or more ranging operations. In one embodiment, range-only determinations can be made and the direction is determined based on analysis of multiple range measurements. Where both range and angle measurements may be determined based on instantaneous wireless ranging signal analysis, a history of range measurements can be used to increase the accuracy of the determined angle measurements.

[0158] The wireless communication device can then determine a pose of the wireless communication device via sensor data received from an inertial measurement unit within the wireless communication device (block **1904**). The inertial measurement unit data can be processed by the augmented reality system to determine the pose of the wireless communication device. The pose data can be used to further enhance the direction determinations made for the target wireless device based on wireless ranging sensors.

[0159] The wireless communication device can then determine a position estimate of the target

wireless device based on the range, direction, and pose (block **1905**). In one embodiment the specific range, direction, and pose determined for the target wireless device and the wireless communication device is determined based on a fusion of sensor data from the wireless ranging system and the augmented reality system of the wireless communication device. The position estimate may be a position relative to the wireless communication device or an absolute position within a 3D coordinate space. The wireless communication device can then generate and display a device locator UI that includes the position estimate of the wireless device (block **1906**). The device locator UI can be directional view, for example, as shown in FIG. **15**A-**15**B, **16**A or an augmented reality view, for example, as shown in FIGS. **15**C and **16**E. The augmented reality view can include video captured via a camera of the wireless communication device, with the position estimate positioned within the video at the location determined for the target wireless device. If, during a ranging operation, motion of either the target wireless device or wireless communication device prevents a direction determination, a UI as in FIG. **16**B or **16**C can be displayed.

[0160] FIG. **20** illustrates a flow diagram of a method **2000** performed by a target wireless device to signal a motion status, according to an embodiment. Method **2000** can be performed by a target wireless device (e.g., wireless device **1420**) during a wireless ranging session with a wireless communication device (e.g., mobile device **1402**).

[0161] Method **2000** includes operations to establish, at a target wireless device, a wireless ranging session with a wireless communication device (block **2001**). In response to establishing the wireless ranging session, the target wireless device can enable a motion sensor on the target wireless device (block **2002**). The target wireless device can then determine, via the motion sensor, if motion of target wireless device exceeds a motion threshold (block **2003**). If the motion is determined to be over the motion threshold (block **2004**, "yes"), the target wireless device can signal the wireless communication device that the target device motion has exceeded the motion threshold (block **2005**). Otherwise, the target wireless device can continue to monitor its motion via the motion sensor. The target wireless device can monitor its motion via the motion sensor by periodically polling sensor data from the motion sensor. The target wireless device may also enable the motion sensor to trigger an interrupt to a sensor processor when

[0162] In one embodiment the target wireless device determines motion state via an accelerometer within the motion sensor, for example, by tracking changes in device orientation. The accelerometer can be an inertial frame sensor that detects changes in device acceleration, including acceleration resulting from gravity. Movement of the target wireless device will result in at least slight changes in the orientation of the target wireless device, which can be detected via the accelerometer. Data from other types of sensors, such as gyroscopes or magnetometers may also be used to determine device motion, either as alternatives to the accelerometer or in fusion with the accelerometer.

[0163] In one embodiment the target wireless device can signal the wireless communication device that the target device motion has exceeded the motion threshold via, for example, a Bluetooth message. The message can be transmitted over an active Bluetooth link between the target wireless device and the wireless communication device, or via another Bluetooth signaling method, such as, for example, status bits that are includes within a Bluetooth wireless advertisement. Other wireless signaling methods may also be used.

[0164] FIG. **21** illustrates a flow diagram of a method **2100** performed on a mobile device to indicate determine a device locator UI view, according to an embodiment. Method **2100** can be performed by a target wireless device (e.g., wireless device **1420**) during a wireless ranging session with a wireless communication device (e.g., mobile device **1402**).

[0165] Method **2100** includes operations to establish, at a wireless communication device, a wireless ranging session with a target wireless device (block **2101**). The wireless communication device can then determine a motion state for the target wireless device and the wireless communication device (block **2102**). The wireless communication device can determine the motion

state for the target wireless device via wireless data received from the target wireless device. The wireless communication device can determine the motion state for the wireless communication device via sensor data processed by a sensor processor (e.g., sensor controller **1244** as in FIG. **12**). If the wireless communication device determines that both devices are over the motion threshold (block **2103**, "yes"), the wireless communication device can display a message via a user interface that less movement is required to detect the direction to the target wireless device (block **2105**). The wireless communication device can then continue to monitor the motion states (block **2102**). Motion state monitoring for both the wireless communication device and the target wireless device can be performed by periodically polling for motion states or via an interrupt-based mechanism.

[0166] If the motion of both devices is not over the motion threshold (block **2103**, "no"), the wireless communication device can determine a UI view to display based on the motion state of the target wireless device. If the target device motion is over the motion threshold (block **2104**, "yes") the wireless communication device can display a message that the target wireless device is moving and that new location is being determined (block **2106**). The wireless communication device can then continue to monitor the motion states (block **2102**).

[0167] If the motion of the target wireless device is below the motion threshold (block **2104**, "no"), and when the motion of the wireless communication device has been determined to be below the motion threshold (block **2103**, "no"), the wireless communication device can determine a position estimate of the target wireless device relative to the wireless communication device and display a location and/or direction for the target wireless device in device locator UI as described herein (block **2107**).

[0168] Reference herein to "one embodiment" or "an embodiment" means that a particular feature, structure, or characteristic described in conjunction with the embodiment can be included in at least one embodiment of the invention. The appearances of the phrase "in one embodiment" in various places in the specification do not necessarily all refer to the same embodiment. The processes depicted in the figures that follow can be performed by processing logic that comprises hardware (e.g. circuitry, dedicated logic, etc.), software (as instructions on a non-transitory machine-readable storage medium), or a combination of both hardware and software. Reference will be made in detail to various embodiments, examples of which are illustrated in the accompanying drawings. In the following detailed description, numerous specific details are set forth in order to provide a thorough understanding of the present invention. However, it will be apparent to one of ordinary skill in the art that the present invention may be practiced without these specific details. In other instances, well-known methods, procedures, components, circuits, and networks have not been described in detail so as not to unnecessarily obscure aspects of the embodiments.

[0169] It will also be understood that, although the terms first, second, etc. may be used herein to describe various elements, these elements should not be limited by these terms. These terms are only used to distinguish one element from another. For example, a first contact could be termed a second contact, and, similarly, a second contact could be termed a first contact, without departing from the scope of the present invention. The first contact and the second contact are both contacts, but they are not the same contact.

[0170] The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting as to all embodiments. As used in the description of the invention and the appended claims, the singular forms "a", "an" and "the" are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will also be understood that the term "and/or" as used herein refers to and encompasses any and all possible combinations of one or more of the associated listed items. It will be further understood that the terms "comprises" and/or "comprising," when used in this specification, specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof.

[0171] As used herein, the term "if" may be construed to mean "when" or "upon" or "in response

to determining" or "in response to detecting," depending on the context. Similarly, the phrase "if it is determined" or "if [a stated condition or event] is detected" may be construed to mean "upon determining" or "in response to determining" or "upon detecting [the stated condition or event]" or "in response to detecting [the stated condition or event]," depending on the context.

[0172] Computing devices, user interfaces for such devices, and associated processes for using such devices are described herein. In some embodiments, the computing device is a portable communications device such as a mobile telephone that also contains other functions, such as PDA and/or music player functions. In the description and figures of this application, where a wireless device, wireless accessory, or wireless accessory device is described or illustrated, unless stated otherwise the described or illustrated attributes can generally be applied to any type of wireless device, wirelesses accessory, or wireless accessory device that is capable of broadcasting a wireless beacon.

[0173] One embodiment provides for a non-transitory machine-readable medium storing instructions to cause one or more processors of a wireless communication device to perform operations comprising determining a range and direction to a target wireless device using one our more wireless ranging operations when within a threshold range of the target wireless device; determining a pose of the wireless communication device via sensor data received from an inertial measurement unit within the wireless communication device; determining a target position estimate of the target wireless device relative to the wireless communication device based on the range, direction, and pose; generating an augmented reality view that includes the target position estimate of the wireless device; and presenting the augmented reality view via a display of the wireless communication device. The augmented reality view can include video captured via a camera of the wireless communication device. The target position estimate can be positioned within the video at a location determined for the target wireless device.

[0174] In the foregoing description, example embodiments of the disclosure have been described. It will be evident that various modifications can be made thereto without departing from the broader spirit and scope of the disclosure. The specification and drawings are, accordingly, to be regarded in an illustrative sense rather than a restrictive sense. The specifics in the descriptions and examples provided may be used anywhere in one or more embodiments. The various features of the different embodiments or examples may be variously combined with some features included and others excluded to suit a variety of different applications. Examples may include subject matter such as a method, means for performing acts of the method, at least one machine-readable medium including instructions that, when performed by a machine cause the machine to perform acts of the method, or of an apparatus or system according to embodiments and examples described herein. Additionally, various components described herein can be a means for performing the operations or functions described herein.

[0175] One embodiment provides for a non-transitory machine-readable medium storing instructions to cause one or more processors of a wireless communication device to perform operations comprising determining a range and direction to a target wireless device using one our more wireless ranging operations when within a threshold range of the target wireless device, determining a pose of the wireless communication device via sensor data received from an inertial measurement unit within the wireless communication device; determining a target position estimate of the target wireless device relative to the wireless communication device based on the range, direction, and pose, generating an augmented reality view that includes the target position estimate of the wireless device, and presenting the augmented reality view via a display of the wireless communication device.

[0176] One embodiment provides for an electronic device comprising a wireless controller including a ranging sensor and a communications radio, a display device, memory to store instructions, and one or more processors to execute the instructions. The instructions cause the one or more processors to scan for a beacon advertisement via the communications radio of the wireless

controller and in response to detection of a beacon advertisement of a target wireless device, transmitting a command to the target wireless device to initiate a bi-directional ranging operation with the electronic device. The one or more processors can additionally determine a range and direction to the target wireless device via the ranging sensor of the wireless controller during the bi-directional ranging operation, determine a target position estimate for the target wireless device relative to the electronic device based on the range and direction to the target wireless device, generate an augmented reality view that includes the target position estimate for the wireless device, and present the augmented reality view via the display device.

[0177] One embodiment provides for a method comprising, on a wireless communication device including one or more processors, determining a range and direction to a target wireless device using one our more wireless ranging operations when the wireless communication device is within a threshold range of the target wireless device. The method additionally includes determining a pose of the wireless communication device via sensor data received from an inertial measurement unit within the wireless communication device, determining a target position estimate for the target wireless device relative to the wireless communication device based on the range and direction to the target wireless device and the pose of the wireless communication device, and generating an augmented reality view that includes the target position estimate for the wireless device. The method additionally includes presenting the augmented reality view via a display of the wireless communication device.

[0178] One embodiment provides for a method on a target wireless device to signal a paired wireless communication device (e.g., mobile device) that the motion for the target wireless device has exceeded a threshold. In response to establishing a wireless ranging session with the paired communication device, the target wireless device can enable a motion sensor on the target wireless device to determine if motion of the target wireless device exceeds a motion threshold. In response to a determination that the motion is over the motion threshold, the target wireless device can signal the wireless communication device that the target device motion has exceeded the motion threshold via one of a variety of wireless signaling techniques.

[0179] One embodiment provides for a method at a wireless communication device to indicate whether a location for a target wireless device can be determined and displayed. The wireless communication device can determine a motion state for the target wireless device via wireless data received from the target wireless device. The wireless communication device can determine the motion state for the wireless communication device via sensor data processed by a sensor processor of the wireless communication device. If the wireless communication device determines that both devices are over the motion threshold, the wireless communication device can display a message via a user interface that less movement is required to detect the direction to the target wireless device. If the motion of both devices is not over the motion threshold the wireless communication device can determine a UI view to display based on the motion state of the target wireless device, such that if the target device motion is over the motion threshold the wireless communication device can display a message that the target wireless device is moving and that new location is being determined. If the motion of the target wireless device and the wireless communication device is below the motion threshold the wireless communication device can determine a position estimate of the target wireless device and display a device location and/or direction for the target wireless device in the device location UI.

[0180] A system and/or non-transitory machine-readable medium may also be provided that performs the operations of any of the above described methods.

[0181] Those skilled in the art will appreciate from the foregoing description that the broad techniques of the embodiments can be implemented in a variety of forms. Therefore, while the embodiments have been described in connection with particular examples thereof, the true scope of the embodiments should not be so limited since other modifications will become apparent to the skilled practitioner upon a study of the drawings, specification, and following claims.

Claims

1. (canceled)

2. A non-transitory machine-readable medium storing instructions to cause one or more processors of a wireless communication device to perform operations comprising: presenting, at a display of the wireless communication device, a first view of a device locator user interface, the first view comprising a finding option and a map that includes an indicator of a first location of a target wireless device; determining a target position estimate for the target wireless device relative to the wireless communication device based at least in part on (i) a range and a direction to the first location, and (ii) a second location of the wireless communication device; and responsive to a user input that selects the finding option, presenting a second view of the device locator user interface, the second view comprising a direction indicator that identifies a relative direction towards the target position estimate.

3. The non-transitory machine-readable medium of claim 2, further comprising additional instructions to cause the one or more processors to perform additional operations comprising determining the range and the direction to the target wireless device using one or more wireless ranging operations.

4. The non-transitory machine-readable medium of claim 3, wherein the one or more wireless ranging operations comprise a ranging operation performed via an ultra-wideband radio.

5. The non-transitory machine-readable medium of claim 4, wherein the ranging operation performed via the ultra-wideband radio comprises using a time-of-flight measurement.

6. The non-transitory machine-readable medium of claim 2, wherein the first view further comprises an indicator of the range and the direction to the target wireless device.

7. The non-transitory machine-readable medium of claim 2, wherein the first location comprises a last observed location of the target wireless device.

8. The non-transitory machine-readable medium of claim 7, wherein the last observed location comprises a location that has been observed by the wireless communication device, observed a different wireless communication device, or received from a device locator server.

9. An electronic device comprising: a display; memory configured to store instructions; and one or more processors configured to access the memory and execute the instruction to at least: present, at the display of the electronic device, a first view of a device locator user interface, the first view comprising a finding option and a map that includes an indicator of a first location of a target wireless device; determine a target position estimate for the target wireless device relative to the electronic device based at least in part on (i) a range and a direction to the first location, and (ii) a second location of the electronic device; and responsive to a user input that selects the finding option, present a second view of the device locator user interface, the second view comprising a direction indicator that identifies a relative direction towards the target position estimate.

10. The electronic device of claim 9, wherein the memory is configured to store additional instructions, and the one or more processors are configured to access the memory and execute the additional instructions to at least determine the range and the direction to the target wireless device using one or more wireless ranging operations.

11. The electronic device of claim 10, wherein the one or more wireless ranging operations comprise a ranging operation performed via an ultra-wideband radio.

12. The electronic device of claim 11, wherein the ranging operation performed via the ultra-wideband radio comprises using a time-of-flight measurement.

13. The electronic device of claim 9, wherein the first view further comprises an indicator of the range and the direction to the target wireless device.

14. The electronic device of claim 9, wherein the first location comprises a last observed location of the target wireless device.

15. The electronic device of claim 14, wherein the last observed location comprises a location that has been observed by the electronic device, observed a different wireless communication device, or received from a device locator server.

16. A computer-implemented method, comprising: presenting, at a display of a wireless communication device, a first view of a device locator user interface, the first view comprising a finding option and a map that includes an indicator of a first location of a target wireless device; determining a target position estimate for the target wireless device relative to the wireless communication device based at least in part on (i) a range and a direction to the first location, and (ii) a second location of the wireless communication device; and responsive to a user input that selects the finding option, presenting a second view of the device locator user interface, the second view comprising a direction indicator that identifies a relative direction towards the target position estimate.

17. The computer-implemented method of claim 16, further comprising determining the range and the direction to the target wireless device using one or more wireless ranging operations.

18. The computer-implemented method of claim 17, wherein the one or more wireless ranging operations comprise a ranging operation performed via an ultra-wideband radio.

19. The computer-implemented method of claim 18, wherein the ranging operation performed via the ultra-wideband radio comprises using a time-of-flight measurement.

20. The computer-implemented method of claim 16, wherein the first view further comprises an indicator of the range and the direction to the target wireless device.

21. The computer-implemented method of claim 16, wherein the first location comprises a last observed location of the target wireless device.