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Performing GNSS Shadow Matching for User Equipment with Varied Carrying Positions

Abstract:

This publication describes apparatuses, methods, and techniques for performing Global Navigation Satellite System (GNSS) shadow matching for user equipment (*e.g.*, smartphones) with varied carrying positions, such as in a user's hand, pocket, purse, backpack, and so forth. To do so, the smartphone utilizes an Urban Canyon Positioning Algorithm to find line-of-sight (LOS) signals of satellites of the GNSS. Then, the Urban Canyon Positioning Algorithm estimates a signal-strength degradation of the LOS signals due to the carrying position, such as when the user puts their smartphone in their pocket. After estimating the signal-strength degradation of the LOS signals, the Urban Canyon Positioning Algorithm adjusts LOS signals and non-line-of-sight (NLOS) signals with the estimated signal-strength degradation of the LOS signals. Finally, the Urban Canyon Positioning Algorithm computes GNSS shadow matching by adjusting parameters (*e.g.*, the median and the standard deviation) of the signal strength of all the signals (LOS and NLOS) received by the smartphone.

Keywords:

Global Navigation Satellite System, GNSS, Global Positioning Satellite, GPS, shadow matching, GNSS shadow, GPS shadow, urban canyon, satellite signal, line-of-sight signal, LOS, non-line-of-sight signal, NLOS, geolocation.

Background:

User equipment (UE), such as smartphones, often utilize accelerometers, gyroscopes, magnetometers, barometers, Global Navigation Satellite System (GNSS) technology (*e.g.*, Global Positioning System (GPS), Galileo, BeiDou, GLONASS, Indian Regional Navigation Satellite System (IRNSS), Quasi-Zenith Satellite System (QZSS)), proximity sensors, ambient light sensors (ALS), touchscreen sensors, radar technology, cameras, microphones, and various other sensors that are embedded in or on the smartphone, which enhance the user experience and can play a role in the functionality of many application software (applications).

Many applications installed on a UE, such as navigation applications, social media applications, business locator applications, and so forth, depend on accurate user location. To this end, UE manufacturers and operating system (OS) developers can use algorithms that leverage different technologies to increase the user location accuracy, as is illustrated in Figure 1.

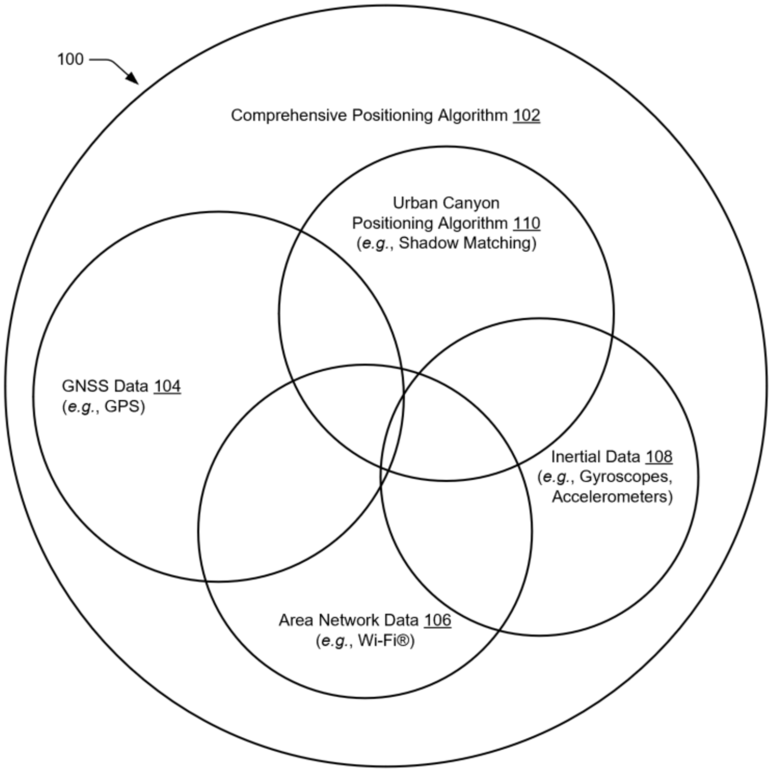

Figure 1

Figure 1 illustrates a Venn diagram 100 illustrating a comprehensive positioning algorithm 102. The comprehensive positioning algorithm 102 can utilize GNSS data 104 (*e.g.*, GPS), area network data 106 (*e.g.*, Wi-Fi® hot spots), inertial data 108 (*e.g.*, gyroscopes, accelerometers), and an Urban Canyon Positioning Algorithm 110 to determine user location, when a user is standing still, walking, running, or driving. The Urban Canyon Positioning Algorithm 110 augments the GNSS data 104 that the smartphone receives from signals sent from a "constellation" of satellites of the GNSS. Further, the Urban Canyon Positioning Algorithm 110 is useful when the user is in an urban environment.

When the user is in an urban environment, the user's smartphone can receive line-of-sight (LOS) signals and/or non-line-of-sight (NLOS) signals of satellites of the GNSS. NLOS signals have various excess path lengths and can distort the estimated user location, as is illustrated in Figure 2.

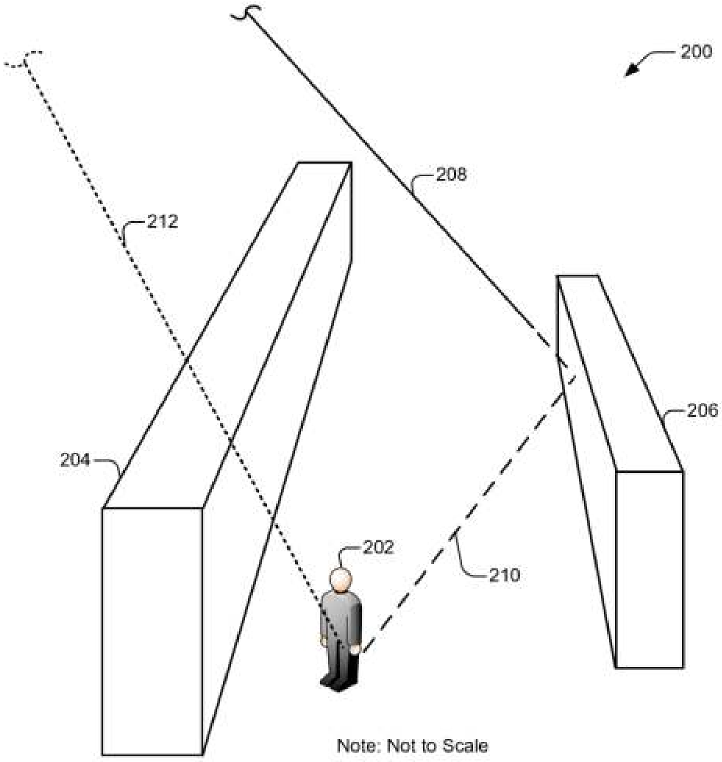

Figure 2

Figure 2 is an example urban environment 200, in which a user 202 is located between building 204 and building 206. The user 202 is carrying their smartphone on their hand, but the smartphone is not in line of sight of a satellite (the satellite is not illustrated in Figure 2) of the GNSS. Instead, the smartphone receives a reflected signal (an NLOS signal) of the satellite. In Figure 2, the solid line represents the direction of a signal 208 of the satellite of the GNSS, the dashed line represents an excess path length 210, and the dotted line represents the distance 212 of the user to the satellite of the GNSS. If the smartphone cannot differentiate an LOS signal of a satellite from an NLOS signal of the satellite, the smartphone may falsely report the user as being farther from their location by a distance equal to the illustrated excess path length 210.

The NLOS received signals reflected off physical features (*e.g.*, buildings) in a dense urban environment are often weaker than LOS signals. As such, in many cases, the smartphone can differentiate an LOS signal from an NLOS signal by measuring a carrier-to-noise density (signal strength), C/N_0, of a received signal. The signal strength is measured in decibels per Hertz (dB/Hz). This technique, however, is useful with a presumption that the user carries their smartphone on their hand. In practice, the user may put their smartphone in their pocket, purse, backpack, and so forth. Depending on the carrying position of the smartphone, the smartphone can measure a different signal strength from a same satellite signal, making the differentiation between LOS and NLOS signals difficult. Therefore, it is desirable to have a technological solution that can accurately report the user position in an urban environment regardless of the carrying position of the smartphone.

Description:

This publication describes techniques that can increase user location accuracy in an urban environment regardless of the carrying position of the smartphone. In one aspect, the techniques involve performing accurate GNSS shadow matching when the user holds their smartphone on their hand, carries their smartphone in their pocket, purse, backpack, and so forth.

GNSS Shadow Matching

Physical features (*e.g.*, buildings, bridges, tunnels) in the urban environment can block LOS signals from one or more satellites in the constellation of satellites of the GNSS, as is illustrated in Figure 3.

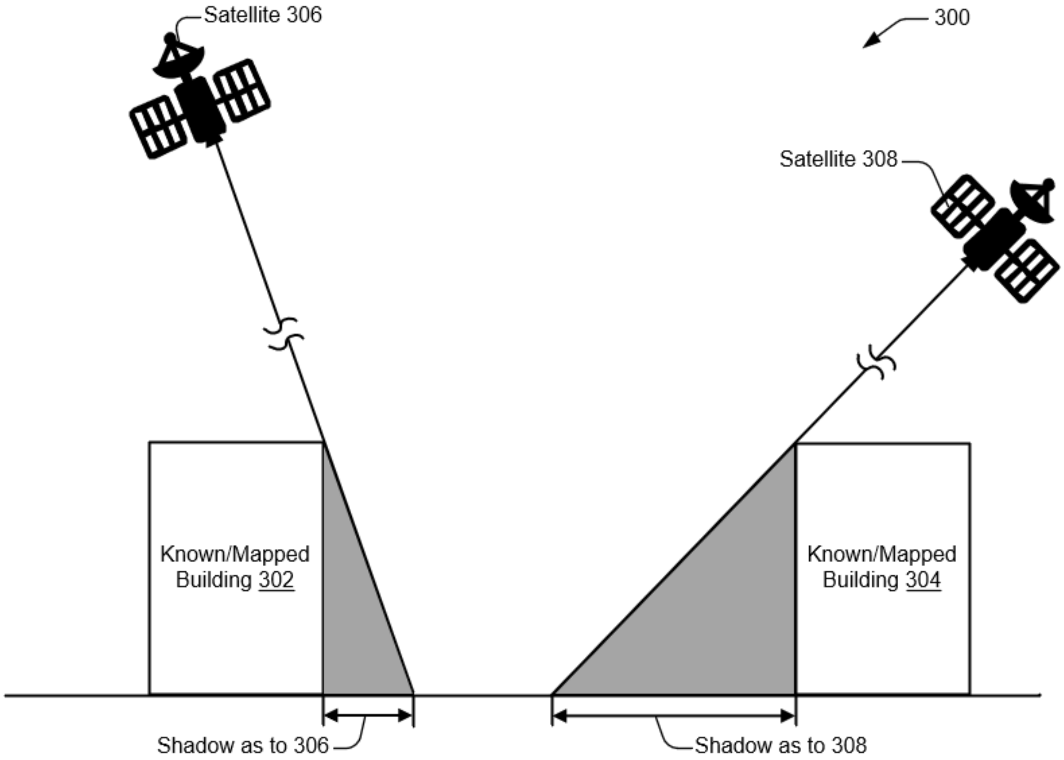

Figure 3

Figure 3 illustrates a portion of an urban environment 300, which includes building 302 and building 304. The smartphone of the user receives LOS and/or NLOS signals from satellites

306 and 308, which are part of the constellation of satellites of the GNSS. Locations that do not receive LOS signals may be considered to be shadow locations. Similar to light from a light source (*e.g.*, the Sun, a streetlight) leaving shadows when the light shines on a physical feature (*e.g.*, a building), physical features can block LOS signals from one or more satellites of the GNSS, leaving invisible "shadows." Consequently, when the smartphone does not have a line of sight to a satellite, the smartphone is in a shadow. Figure 3 illustrates a shadow near the building 302, where the building 302 blocks LOS signals of the satellite 306 (illustrated as "shadow as to 306"). Also, Figure 3 illustrates a shadow near the building 304, where the building 304 blocks LOS signals of the satellite 308 (illustrated as "shadow as to 308"). In the shadow as to 306, the smartphone often detects a weaker signal (lower C/N_0) of the satellite 306. Similarly, in the shadow as to 308, the smartphone often detects a weaker signal of the satellite 308.

As is illustrated in Figure 3, in the shadow as to 306, the smartphone can receive NLOS signals of satellite 306. Still, in the shadow as to 306, the smartphone can receive LOS signals from the satellite 308. Similarly, in the shadow as to 308, the smartphone can receive NLOS signals of the satellite 308. Still, in the shadow as to 308, the smartphone can receive an LOS signal of the satellite 306. When the user is located between the buildings 302 and 304 and between the illustrated shadows, the smartphone can receive LOS and NLOS signals of both satellites (306 and 308). Alternatively, although not illustrated as such in Figure 3, the user may only receive NLOS signals when the user is located in an urban environment, because the user may not be in a line of sight of any satellite of the GNSS (*e.g.*, the user may be under a bridge). Note that an increased number of satellites in the constellation of satellites of the GNSS can increase user location accuracy.

In one aspect, to achieve GNSS shadow matching, OS developers may create a two-dimensional (2D) building map of an urban environment, as is illustrated in Figure 4.

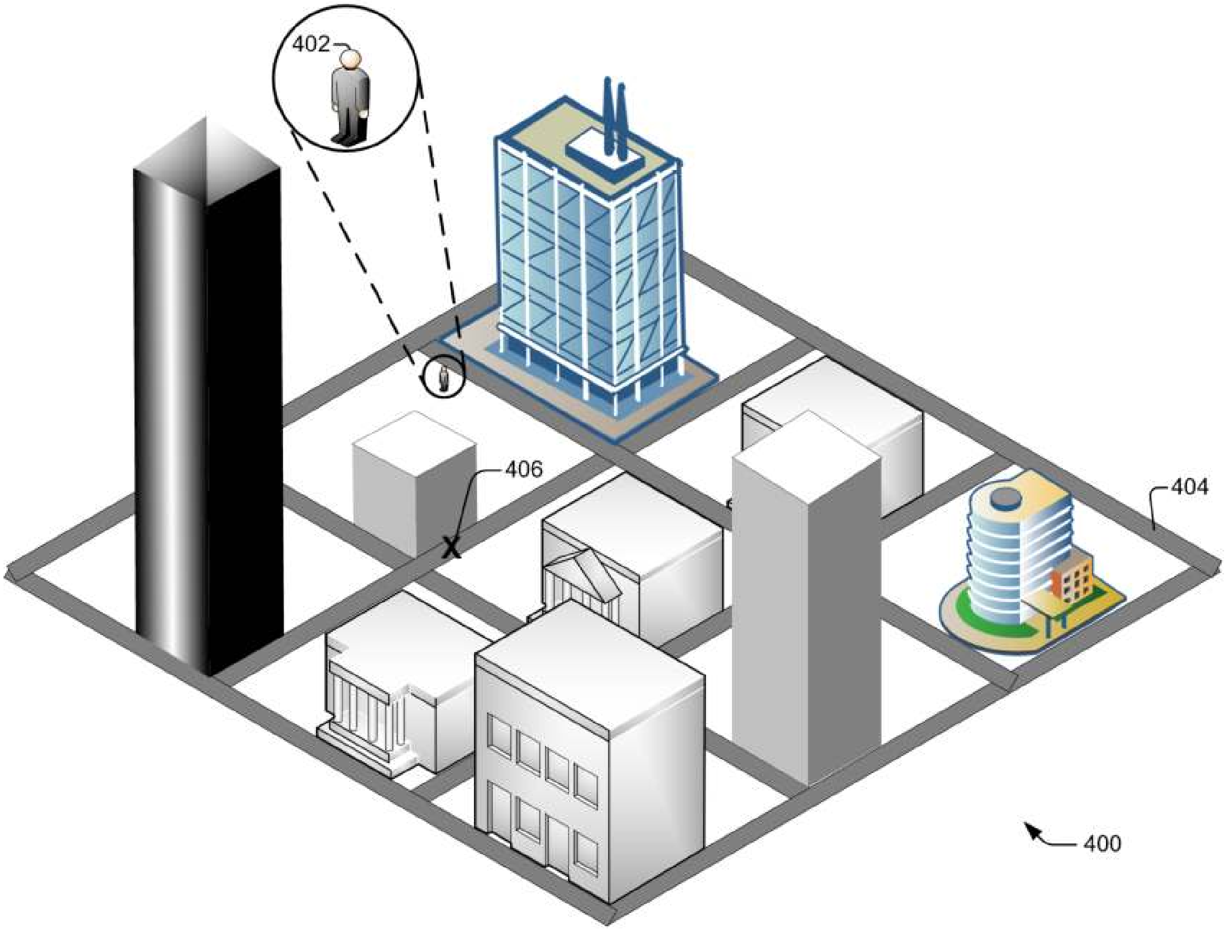

Figure 4

Figure 4 is an example urban environment 400, illustrating a user 402 and a 2D building map 404 (illustrated as grey pathways). To establish the 2D building map 404, the OS developer may use an inertial measurement unit (IMU) to map the various locations of the urban environment 400 accurately. Then, the OS developer may employ several users (surveyors) carrying smartphones of multiple makes and models, which utilize navigation applications and have the capability to measure and report the signal strength, C/N_0, of the received signals. In a sense, shadow matching refers to the reported user location, using a smartphone, and matching the 2D building map 404. In a dense urban environment, however, GNSS shadow matching may be challenging to achieve. Hence, at times, the smartphone of the user 402 can report an inaccurate location 406, which can be on a different street from the location of the user 402.

In one aspect, the OS developer may tabulate signal-strength data of signals received by the smartphones of the surveyors. The signal-strength data may include the parameters:

- C/N_0—the carrier-to-noise density (signal strength) of the signals;
- μ—the median of the C/N_0; and
- σ—the standard deviation of the C/N_0.

Then, offline (*e.g.*, at a server), the OS developer may collect and analyze the signal-strength parameters measured and reported by the smartphones of the surveyors. For example, using various statistical methods, the OS developer may correlate the reported location of the surveyors, the type of their smartphones (*e.g.*, make and model), the 2D building map, the measured signal strength (C/N_0), and calculated parameters, such as μ, σ, 2σ, 3σ, and so forth, of the C/N_0. Hence, the OS developer may increase the accuracy of the GNSS shadow matching between the 2D building map 404 and the location of surveyors carrying the multiple smartphones. To eliminate a carrying position variable, the surveyors may carry the multiple smartphones on their hands, instead of in their pockets, purses, backpacks, and so forth.

Nevertheless, an everyday user (a passive user instead of a surveyor) may carry their smartphone on their hand, put their smartphone in their pocket, purse, backpack, and so forth. Thus, the passive user injects other variables, such as the carrying position, which is challenging to consider when the OS developer implementing the Urban Canyon Positioning Algorithm 110 performs the GNSS shadow matching. For example, when the passive user puts their smartphone in their pocket, their smartphone can measure a weaker signal (*e.g.*, with signal loss of 5 dB/Hz).

As another example, when the passive user places their smartphone in their backpack, their smartphone can measure a far weaker signal (*e.g.*, with signal loss of 15 dB/Hz). Even when using other sensors of the smartphone, such as a camera or an ambient light sensor (ALS), the smartphone cannot distinguish whether the passive user has simply covered the camera or the ALS with their palm, placed their smartphone in their pocket, or placed their smartphone in their backpack.

Note that a passive user may be provided with controls allowing the user to make an election as to both if and when systems, programs, or features described herein may enable collection of user information (*e.g.*, information about a passive user's social network, social actions, social activities, profession, a passive user's preferences, or a passive user's current location), and if the passive user is sent content or communications from a server. In addition, certain data may be treated in one or more ways before it is stored or used, so that personally identifiable information is removed. For example, a passive user's identity may be treated so that no personally identifiable information can be determined for the passive user. Thus, the passive user may have control over what information is collected about the passive user, how that information is used, and what information is provided to the passive user. The passive user can also disable the Urban Canyon Positioning Algorithm 110 and may choose to rely only on GNSS data (*e.g.*, GPS) when utilizing applications that rely on user location (*e.g.*, navigation applications).

Adjustment for Carrying Positions

To account for the varied carrying positions, a smartphone utilizing the Urban Canyon Positioning Algorithm 110 can perform the following steps to increase user location accuracy:

1. Find LOS signals of the GNSS;

2. Estimate signal-strength degradation for the LOS signals in Step 1;
3. Adjust all signals (LOS and NLOS) with the estimated signal-strength degradation in Step 2; and
4. Compute GNSS shadow matching with the adjusted values in Step 3.

Finding LOS Signals

As is illustrated in Figure 4, when the user 402 is in the example urban environment 400, the Urban Canyon Positioning Algorithm 110 cannot determine with a high degree of accuracy the user location. Further, in the example of Figure 4, the Urban Canyon Positioning Algorithm 110 cannot determine whether the smartphone of the user 402 receives LOS, NLOS, or LOS and NLOS signals. Nevertheless, the Urban Canyon Positioning Algorithm 110 can determine an approximate user location (*e.g.*, within two blocks in the example urban environment 400). In that case, the Urban Canyon Positioning Algorithm 110 can determine a wide LOS area for one or more satellites in which the smartphone receives LOS signals, as is illustrated in FIG. 5.

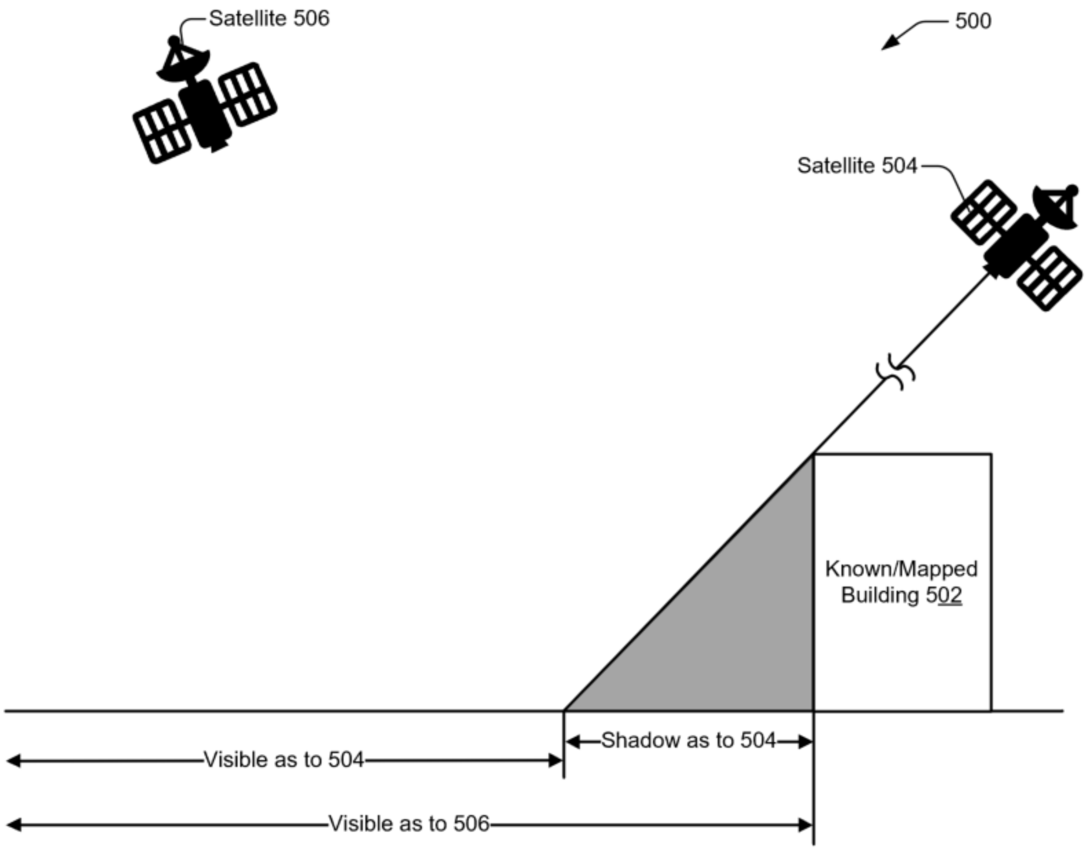

Figure 5

Figure 5 is a portion of an urban environment 500, which includes building 502. The smartphone of the user can receive LOS and NLOS signals from satellites 504 and 506, which are part of the constellation of satellites of the GNSS. Assume the smartphone of the user cannot correctly determine whether the user is in a shadow as to the satellite 504 or not, due to the building 502. The Urban Canyon Positioning Algorithm 110, however, can determine whether the user is in a line of sight as to the satellite 506 because the user is in a wide area where there are no known (or mapped) buildings that can block LOS signals of the satellite 506. Note, as is illustrated in Figure 5, the area where the smartphone of the user can receive LOS signals of the satellite 506 is wider than the area where the smartphone is in a shadow as to the satellite 504 (in Figure 5, compare “Visible as to 506” to “Shadow as to 504”).

Estimating Signal-Strength Degradation of LOS Signals

Figure 5 illustrates one aspect used by the user's smartphone with the Urban Canyon Positioning Algorithm 110 to determine whether the received signals by the smartphone are LOS or NLOS signals. Further, the Urban Canyon Positioning Algorithm 110 can determine the make and model of the smartphone, can measure the signal strength, C/N_0, of the received LOS signals, and can calculate a degradation of the signal strength of the received LOS signals using Equation 1.

$$\frac{C}{N_0}_{degradation} = \frac{C}{N_0}_{expected} - \frac{C}{N_0}_{measured} \qquad \textbf{(Equation 1)}$$

In Equation 1, the various parameters are defined as follows:

- $\frac{C}{N_0}_{measured}$ represents the signal strength of the LOS signals that are received and measured by the smartphone of the user;
- $\frac{C}{N_0}_{expected}$ represents an expected signal strength of the LOS signals, which is determined by data collected, compiled, and tabulated, from surveyors holding smartphones of the same make and model in their hands; and
- $\frac{C}{N_0}_{degradation}$ represents the degradation of the signal strength of the LOS signals that are received by the smartphone of the user, wherein the degradation is due to the carrying position (*e.g.*, the smartphone may be in the user's pocket).

Similar to the received LOS signals of the satellite 506 in Figure 5, the Urban Canyon Positioning Algorithm 110 computes a median degradation of the signal strength from all LOS signals in the vicinity of the user from the constellation of satellites of the GNSS. Also, the Urban Canyon Positioning Algorithm 110 can use a filtering method, such as Kalman filtering, to determine the degradation of the signal strengths of the received LOS signals over time. Note that the filtering method increases the likelihood that the computed degradation of the signal strength of the received LOS signals is genuine and persistent. In a sense, the filtering method is a weighted average of the calculated degradation of the signal strength, $\frac{C}{N_{0}}_{degradation}$, of the received LOS signals.

Adjusting All Signals (LOS and NLOS) with the Degradation of the Signal Strength

The Urban Canyon Positioning Algorithm 110 initially calculates the degradation of the signal strength, $\frac{C}{N_{0}}_{degradation}$, of LOS signals (instead of NLOS signals) to minimize the effect of excess path length 210, as is illustrated in Figure 2. Further, in general, LOS signals have higher signal strengths than NLOS signals, increasing the accuracy of the computed degradation of the signal strength, $\frac{C}{N_{0}}_{degradation}$, due to the carrying position. Nevertheless, accurate shadow matching utilizes data from LOS and NLOS signals. Therefore, the Urban Canyon Positioning Algorithm 110 adjusts all signals (LOS and NLOS) with the degradation of the signal strength using Equation 2:

$$\forall signals\colon \frac{C}{N_0} \pm \frac{C}{N_{0}}_{degradation} \qquad \textbf{Equation 2}$$

where, in mathematics, ∀ denotes “for all” and ± denotes “add/subtract the following value.” Differently stated, using Equation 2, the Urban Canyon Positioning Algorithm 110 adjusts the signal strength, C/N_0, for all the signals (LOS and NLOS) received by the smartphone using the degradation of the signal strength, $\frac{C}{N_{0}}_{degradation}$, of the LOS signals.

Computing GNSS Shadow Matching

The calculated parameters, such as μ, σ, 2σ, 3σ, and so forth, of the C/N_0 from the surveyors, who carry their smartphones in their hands, may no longer be valid for determining an accurate GNSS shadow matching when the smartphone of the passive user receives degraded LOS and NLOS signals. In that case, the Urban Canyon Positioning Algorithm 110 may increase the standard deviation, σ, of the adjusted signal strengths. Also, the Urban Canyon Positioning Algorithm 110 may ignore all adjusted signal-strength values that fall outside two standard deviations, 2σ. Further, the Urban Canyon Positioning Algorithm 110 may adjust the calculated parameters depending on the location of the passive user, the degree of the degradation of the signal strength, the make and model of the smartphone, the number of satellites that are in a line of sight, and/or other variables.

Conclusion

This disclosure describes apparatuses, methods, and techniques for performing GNSS shadow matching for smartphones with varied carrying positions. To do so, the smartphone utilizes an Urban Canyon Positioning Algorithm to find LOS signals of satellites of the GNSS. The Urban Canyon Positioning Algorithm estimates the degradation of the signal strength of the LOS signals due to the carrying position. Then, the Urban Canyon Positioning Algorithm adjusts all signals (LOS and NLOS) with the degradation of the signal strength of the LOS signals. Finally, the Urban Canyon Positioning Algorithm computes GNSS shadow matching by adjusting parameters, such as μ, σ, 2σ, 3σ, and so forth, of the carrier-to-noise density, C/N_0, of the adjusted signal strength of all received signals (LOS and NLOS).

References:

[1] Patent Publication: US20170131409A1. System and method for localization and tracking using GNSS location estimates, satellite SNR data and 3D maps. Priority Date: July 17, 2015.

[2] Patent Publication: US20190107630A1. Localization and Tracking Using Location, Signal Strength, and Pseudorange Data. Priority Date: September 14, 2016.