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Radio Interference Resistant Determination of a Geolocation Using a Multi-Frequency Global Navigation Satellite System Receiver

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Abstract:

This publication describes systems and techniques directed to the radio interference resistant determination of geolocation using a multi-frequency global navigation satellite system (GNSS) receiver. The described systems and techniques include user equipment (UE) having a multi-frequency GNSS receiver and a geolocation manager application. The geolocation manager application, when executed by a processor of the UE, directs the UE to perform multiple operations that include determining one or more radio interference conditions that may be caused by subsystems of the UE. Based on the determined radio interference conditions, the processor of the UE uses an algorithm of the geolocation manager application to determine the best estimation of the UE's geolocation. Determining the best estimation of the UE's geolocation includes constructing a cost function and applying an optimization model to signaling received through the multi-frequency GNSS receiver.

Keywords:

multi-frequency global navigation satellite system (GNSS) receiver, radio interference, geolocation computing, geolocation algorithm, geolocation interference, GNSS signaling interference, global positioning system (GPS) algorithm, weight

Background:

Today, global navigation satellite system (GNSS) data that is usable to compute geolocation can be transmitted by different satellite constellations using different radio frequencies. For example, one satellite constellation may transmit GNSS data using an "L1" radio frequency (*e.g.*, 1575.42 Megahertz (MHz)), another satellite constellation may transmit GNSS data using an "L2" radio frequency (*e.g.*, 1227.60 MHz), and yet another satellite constellation may transmit GNSS data using an "L5" radio frequency (1176.45 MHz). Types of GNSS data include ephemeris and almanac data.

A user device, such as a smartphone, is often equipped with a multi-frequency GNSS receiver to accommodate the different radio frequencies. In some instances, the user device may use multiple sets of GNSS signaling, transmitted by different satellite constellations using different radio frequencies, to compute its geolocation.

Such a user device, however, is also often equipped with one or more subsystems that can cause radio interference with signaling that is transmitted using one or more of the different radio frequencies. For example, a display operating on the user device may generate electromagnetic waves that interfere with the L1 radio frequency and distort the reception of GNSS signals being received from a satellite constellation using the L1 radio frequency. Similarly, a microphone operating on the user device may generate electromagnetic waves that interfere with the L2 radio frequency and distort the reception of GNSS signals being received from a satellite constellation using the L2 radio frequency. Such distortions can compromise the user device's ability to compute an accurate geolocation.

Description:

This publication describes systems and techniques directed to the radio-resistant determination of geolocation using a multi-frequency global navigation satellite system (GNSS) receiver. The described systems and techniques include user equipment (UE) having a multi-frequency GNSS receiver and a geolocation manager application. The geolocation manager application, when executed by a processor of the UE, directs the UE to perform multiple operations that include determining one or more radio interference conditions that may be caused by subsystems of the UE. Based on the determined radio interference conditions, the processor of the UE uses an algorithm of the geolocation manager application to determine the best estimation of the UE's geolocation. Determining the best estimation of the UE's geolocation includes constructing a cost function and applying an optimization model to signaling received through the multi-frequency GNSS receiver.

Figure 1, below, illustrates an example environment in accordance with one or more aspects. Although the example environment includes user equipment (UE) that is a smartphone, the UE can be any computing device with a multi-frequency GNSS transceiver, such as an automobile navigation system, a range-finder, a gaming device, and so on.

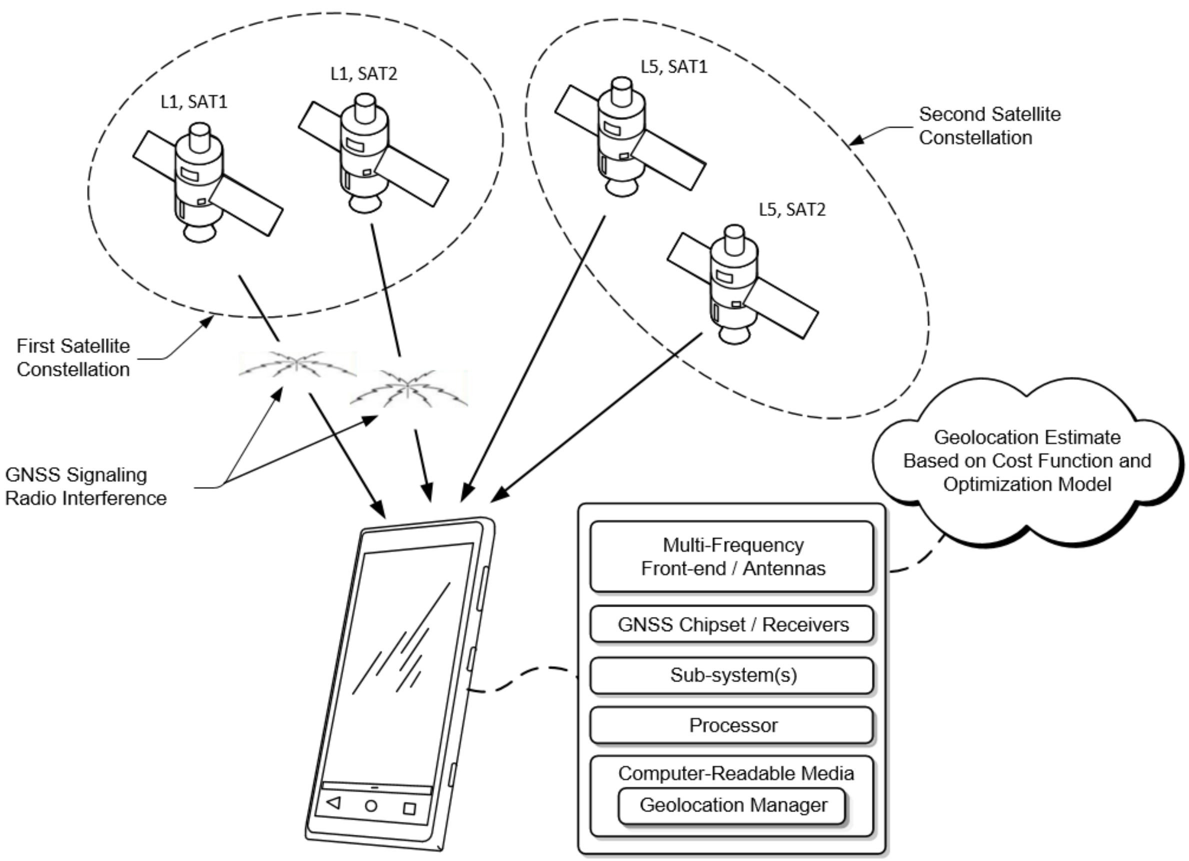


Figure 1

As illustrated, a first satellite constellation (*e.g.*, L1, SAT1 and L1, SAT2) is transmitting GNSS signaling to the UE using an L1 radio frequency. Also, as illustrated, a second satellite constellation (*e.g.*, L5, SAT1 and L5, SAT2) is transmitting GNSS signaling to the UE using an L2 radio frequency.

The UE includes multi-frequency hardware (*e.g.*, multi-frequency front-end circuitry, multi-frequency antennas, a GNSS chipset) for receiving signaling from the first and second satellite constellations. The multi-frequency antennas may be shared across radio access technologies (RATs) using a diplexer or triplexer and may be designed for receiving in-band waveforms (*e.g.*, use impedance tuning and/or frequency-selective filtering to attenuate out-of-band noise and interferences). The GNSS chipset may include multiple receivers tuned for respective radio frequencies (*e.g.*, the L1 radio frequency, the L5 radio frequency), a digital signal processor (DSP) core, and one or more measurement engines that can provide code phase, carrier phase, timing information, and decoded navigation message information about ephemeris and almanac data received through the GNSS signaling from the first satellite constellation and the second satellite constellation.

The UE also includes one or more subsystems (*e.g.*, a display, a microphone, a speaker) that, when operating, generate radio interference with the GNSS signaling transmitted by the first satellite constellation.

The UE includes a processor and a computer-readable media storing executable instructions of a geolocation manager application. The processor executes the instructions of the geolocation manager application to perform computations that determine the best estimation of geolocation of the UE. The instructions, in general, include algorithms to construct a cost function and apply an optimization model to the GNSS signaling received through the UE's multi-frequency hardware.

The geolocation manager application may also include a lookup table that stores RF interference characteristics of the one or more subsystems. The RF interference characteristics may be empirically determined during a product development state of the UE and quantify degrees of radio interference with GNSS signaling radio frequencies (*e.g.*, the L1 radio frequency, the L5 radio frequency) for each of the one or more sub-systems during states of operation. Example RF characteristics include noise/spurs frequency, magnitude, and waveform patterns.

In the example of Figure 1, and while the UE is performing the computations that determine the best estimation of the geolocation of the UE, the geolocation manager application may reference the lookup table that stores the RF interference characteristics of the one or more subsystems. The computations, in effect, place more weight on GNSS signaling from the second satellite constellation (*e.g.*, the L5 radio frequency GNSS signaling) and de-weight GNSS signaling from the first satellite constellation (*e.g.*, the L1 radio frequency GNSS signaling).

Formula 1, below, illustrates an example error function that can be used as part of the algorithm contained in the geolocation manager application. Computing the error function may be performed by the UE (*e.g.*, the processor executing the algorithm).

$$
\begin{aligned}
ERR_{Sat1}^{L1} &= [(X_{ue}^{est} - X_{Sat1})^2 + (Y_{ue}^{est} - Y_{Sat1})^2 + (Z_{ue}^{est} - Z_{Sat1})^2 - (R_{Sat1}^{L1})^2] \times W_{Sat1}^{L1} \\
ERR_{Sat1}^{L5} &= [(X_{ue}^{est} - X_{Sat1})^2 + (Y_{ue}^{est} - Y_{Sat1})^2 + (Z_{ue}^{est} - Z_{Sat1})^2 - (R_{Sat1}^{L5})^2] \times W_{Sat1}^{L5} \\
ERR_{Sat2}^{L1} &= [(X_{ue}^{est} - X_{Sat2})^2 + (Y_{ue}^{est} - Y_{Sat2})^2 + (Z_{ue}^{est} - Z_{Sat2})^2 - (R_{Sat2}^{L1})^2] \times W_{Sat2}^{L1} \\
ERR_{Sat2}^{L5} &= [(X_{ue}^{est} - X_{Sat2})^2 + (Y_{ue}^{est} - Y_{Sat2})^2 + (Z_{ue}^{est} - Z_{Sat2})^2 - (R_{Sat2}^{L5})^2] \times W_{Sat2}^{L5} \\
&\ldots\ldots \\
ERR_{SatN}^{L1} &= [(X_{ue}^{est} - X_{SatN})^2 + (Y_{ue}^{est} - Y_{SatN})^2 + (Z_{ue}^{est} - Z_{SatN})^2 - (R_{SatN}^{L1})^2] \times W_{SatN}^{L1} \\
ERR_{SatN}^{L5} &= [(X_{ue}^{est} - X_{SatN})^2 + (Y_{ue}^{est} - Y_{SatN})^2 + (Z_{ue}^{est} - Z_{SatN})^2 - (R_{SatN}^{L5})^2] \times W_{SatN}^{L5}
\end{aligned}
$$

Formula 1

For example, and as illustrated in Formula 1, ERR_{Sat1}^{L1} is the error function for satellite 1 at the L1 radio frequency (*e.g.*, L1, SAT1 of Figure 1). The error function calculations include a UE geolocation estimation (X_{ue}^{est}, Y_{ue}^{est}, Z_{ue}^{est}) a ranging measurement with uncertainty R_{Sat1}^{L1}, and a weighting factor $W_{Sat\ 1}^{L1}$.

Formula 2, below, illustrates an example costing function that can be used as part of the algorithm contained in the geolocation manager application. Computing the costing function may be performed by the UE (*e.g.*, the processor executing the algorithm).

$$F_{cost}(X_{ue}^{est}, Y_{ue}^{est}, Z_{ue}^{est}) = \sum_{i=1}^{N} (ERR_{Sati}^{L1} + ERR_{Sati}^{L5})$$

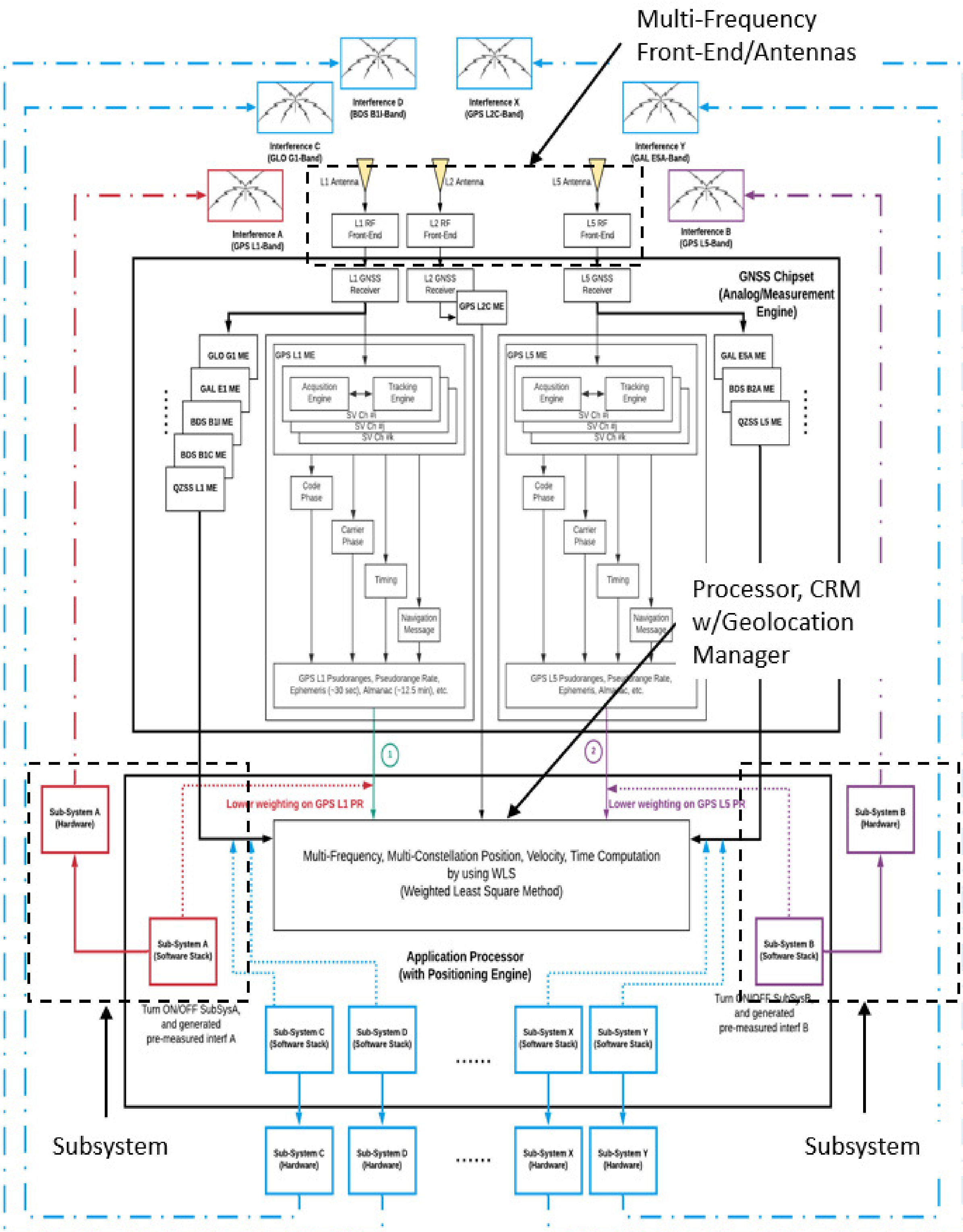
Formula 2

Formula 3, below, illustrates an example optimization function that can be used as part of the algorithm contained in the geolocation manager application. The example optimization function can use one or more different optimization algorithms, such as a Nelder-Mead algorithm, a modified Power algorithm, or a Newton-Conjugate Gradient Algorithm.

$$min\,F_{cost}(X_{ue}^{est}, Y_{ue}^{est}, Z_{ue}^{est})$$

Formula 3

Figure 2, below, illustrates an example hardware and software system implemented in accordance with one or more aspects. The example hardware and software system of Figure 2 includes elements of the UE as illustrated in Figure 1.



Multi-Frequency Front-End/Antennas
Interference D (BDS B1I-Band)
Interference X (GPS L2C-Band)
Interference C (GLO G1-Band)
Interference Y (GAL E5A-Band)
Interference A (GPS L1-Band)
Interference B (GPS L5-Band)
L1 Antenna
L2 Antenna
L5 Antenna
L1 RF Front-End
L2 RF Front-End
L5 RF Front-End
L1 GNSS Receiver
L2 GNSS Receiver
L5 GNSS Receiver
GPS L2C ME
GNSS Chipset (Analog/Measurement Engine)
GLO G1 ME
GAL E1 ME
BDS B1I ME
BDS B1C ME
QZSS L1 ME
GAL E5A ME
BDS B2A ME
QZSS L5 ME
GPS L1 ME
GPS L5 ME
Acqusition Engine
Tracking Engine
SV Ch #i
SV Ch #j
SV Ch #k
Code Phase
Carrier Phase
Timing
Navigation Message
GPS L1 Psudoranges, Pseudorange Rate, Ephemeris (~30 sec), Almanac (~12.5 min), etc.
GPS L5 Psudoranges, Pseudorange Rate, Ephemeris, Almanac, etc.
Processor, CRM w/Geolocation Manager
1
2
Lower weighting on GPS L1 PR
Lower weighting on GPS L5 PR
Sub-System A (Hardware)
Sub-System B (Hardware)
Multi-Frequency, Multi-Constellation Position, Velocity, Time Computation by using WLS (Weighted Least Square Method)
Sub-System A (Software Stack)
Sub-System B (Software Stack)
Application Processor (with Positioning Engine)
Turn ON/OFF SubSysA, and generated pre-measured interf A
Turn ON/OFF SubSysB, and generated pre-measured interf B
Sub-System C (Software Stack)
Sub-System D (Software Stack)
Sub-System X (Software Stack)
Sub-System Y (Software Stack)
Subsystem
Subsystem
Sub-System C (Hardware)
Sub-System D (Hardware)
Sub-System X (Hardware)
Sub-System Y (Hardware)

Figure 2

In the example hardware and software system of Figure 2, multi-frequency hardware includes multi-frequency front-end circuitry, multi-frequency antennas, and GNSS chipset to support three GNSS signaling radio frequencies (*e.g.*, the L1 radio frequency, the L2 radio frequency, the L5 radio frequency). The example hardware and software system of Figure 2 also includes subsystems that generate electromagnetic waves that interfere with GNSS signaling frequencies, as well as an application processor for computing parameters needed to estimate a best geolocation of the UE (in this example, the processor may be included on a system-on-chip that includes a computer-readable media with a geolocation manager application).

There are many variations applicable to the above-described examples. As a first example variation, and as opposed to referencing a lookup table for RF interference characteristics of the one or more subsystems, the UE may include spectrum scanning hardware such that the UE may perform a real-time spectrum scan to detect noise spurs and de-weight a satellite, radio frequency, and/or constellation. As a second example variation, the geolocation manager application may include algorithms to distinguish and weight GNSS signaling radio frequencies having different pseudo-ranges with different uncertainties (*e.g.*, an L1 radio frequency may have a pseudo-range with an uncertainty of five to ten meters, whereas an L5 radio frequency may have a pseudo-range with an uncertainty of less than one meter).

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