APPENDIX F

Additional Topics on Radio Positioning

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This appendix comprises additional topics on radio positioning, including details of alternative positioning technologies that could not be accommodated within the main book. Section F.1 describes angular positioning using iterated least squares. Section F.2 describes radio determination satellite services (RDSS). Section F.3 describes landing guidance systems. Section F.4 describes a number of radio tracking systems. Section F.5 describes some phone positioning terminology. Finally, Section F.6 provides additional information on positioning using digital television and radio broadcasts.

F.1 Angular Positioning using Iterated Least Squares

This section describes angular positioning using ILS. It builds on Section 7.1.5, which presents the exact single-epoch horizontal position solution obtained from two azimuth measurements. Where more than two measurements are available, iterated least squares may be used to determine the position. More information on ILS may be found in Section 7.3.3 and Section D.1 of Appendix D on CD. A local-tangent-plane coordinate frame, denoted *l*, is used here.

The first step is to generate a predicted user position, $(\hat{x}_{la}^{l-}, \hat{y}_{la}^{l-})$, from which predicted azimuth measurements, $\hat{\psi}_{lu}^{a1-}, \hat{\psi}_{lu}^{a2-} \ldots \hat{\psi}_{lu}^{am-}$, are calculated using

$$\hat{\psi}_{lu}^{aj-} = \arctan_2\left[\left(y_{lj}^{l} - \hat{y}_{la}^{l-}\right), \left(x_{lj}^{l} - \hat{x}_{la}^{l-}\right)\right] \qquad j \in 1,2...m, \tag{F.1}$$

where (x_{lj}^{l}, y_{lj}^{l}) is the position of the j^{th} transmitter, assumed to be known.

The user position estimate is then updated using

$$\begin{pmatrix} \hat{x}_{la}^{l+} \\ \hat{y}_{la}^{l+} \end{pmatrix} = \begin{pmatrix} \hat{x}_{la}^{l-} \\ \hat{y}_{la}^{l-} \end{pmatrix} + \left(\mathbf{H}_{\psi}^{\mathrm{T}}\mathbf{H}_{\psi}\right)^{-1}\mathbf{H}_{\psi}^{\mathrm{T}} \begin{pmatrix} \tilde{\psi}_{lu}^{a1} - \hat{\psi}_{lu}^{a1-} \\ \tilde{\psi}_{lu}^{a2} - \hat{\psi}_{lu}^{a2-} \\ \vdots \\ \tilde{\psi}_{lu}^{am} - \hat{\psi}_{lu}^{am-} \end{pmatrix}, \tag{F.2}$$

where $\tilde{\psi}_{lu}^{aj}$ is the measured azimuth of transmitter j and the measurement matrix is given by

$$\mathbf{H}_{\psi} = \begin{pmatrix} \dfrac{y_{l1}^{l} - \hat{y}_{la}^{l-}}{\left(x_{l1}^{l} - \hat{x}_{la}^{l-}\right)^2 + \left(y_{l1}^{l} - \hat{y}_{la}^{l-}\right)^2} & -\dfrac{x_{l1}^{l} - \hat{x}_{la}^{l-}}{\left(x_{l1}^{l} - \hat{x}_{la}^{-l}\right)^2 + \left(y_{l1}^{l} - \hat{y}_{la}^{l-}\right)^2} \\ \dfrac{y_{l2}^{l} - \hat{y}_{la}^{l}}{\left(x_{l2}^{l} - \hat{x}_{la}^{l-}\right)^2 + \left(y_{l2}^{l} - \hat{y}_{la}^{l-}\right)^2} & -\dfrac{x_{l2}^{l} - \hat{x}_{la}^{l-}}{\left(x_{l2}^{l} - \hat{x}_{la}^{-l}\right)^2 + \left(y_{l2}^{l} - \hat{y}_{la}^{l-}\right)^2} \\ \vdots & \vdots \\ \dfrac{y_{lm}^{l} - \hat{y}_{la}^{l-}}{\left(x_{lm}^{l} - \hat{x}_{la}^{l-}\right)^2 + \left(y_{lm}^{l} - \hat{y}_{la}^{l-}\right)^2} & -\dfrac{x_{lm}^{l} - \hat{x}_{la}^{l-}}{\left(x_{lm}^{l} - \hat{x}_{la}^{-l}\right)^2 + \left(y_{lm}^{l} - \hat{y}_{la}^{l-}\right)^2} \end{pmatrix}. \tag{F.3}$$

As the measurement matrix is a function of the position states estimated, the least-squares estimate must be iterated. Thus, the above process is repeated with $(\hat{x}_{la}^{l-}, \hat{y}_{la}^{l-})$ reset to $(\hat{x}_{la}^{l+}, \hat{y}_{la}^{l+})$ from the previous iteration. This continues until the solution converges, i.e. the difference between successive position solutions is within the required precision.

Where m elevation measurements are also available, a 3D position may be calculated using

$$\begin{pmatrix} \hat{x}_{la}^{l+} \\ \hat{y}_{la}^{l+} \\ \hat{z}_{la}^{l+} \end{pmatrix} = \begin{pmatrix} \hat{x}_{la}^{l-} \\ \hat{y}_{la}^{l-} \\ \hat{z}_{la}^{l-} \end{pmatrix} + \left(\mathbf{H}_{\psi}^{\mathrm{T}}\mathbf{H}_{\psi} + \mathbf{H}_{\theta}^{\mathrm{T}}\mathbf{H}_{\theta}\right)^{-1} \left[\mathbf{H}_{\psi}^{\mathrm{T}} \begin{pmatrix} \tilde{\psi}_{lu}^{a1} - \hat{\psi}_{lu}^{a1-} \\ \tilde{\psi}_{lu}^{a2} - \hat{\psi}_{lu}^{a2-} \\ \vdots \\ \tilde{\psi}_{lu}^{am} - \hat{\psi}_{lu}^{am} \end{pmatrix} + \mathbf{H}_{\theta}^{\mathrm{T}} \begin{pmatrix} \tilde{\theta}_{lu}^{a1} - \hat{\theta}_{lu}^{a1-} \\ \tilde{\theta}_{lu}^{a2} - \hat{\theta}_{lu}^{a2-} \\ \vdots \\ \tilde{\theta}_{lu}^{am} - \hat{\theta}_{lu}^{am} \end{pmatrix} \right], \tag{F.4}$$

where $\tilde{\theta}_{lu}^{aj}$ is the measured elevation of transmitter j, $\hat{\theta}_{lu}^{aj-}$ is the predicted elevation, given by

$$\hat{\theta}_{lu}^{aj-} = -\arctan\left(\frac{z_{lj}^{l} - \hat{z}_{la}^{l-}}{\sqrt{\left(x_{lj}^{l} - \hat{x}_{la}^{l-}\right)^2 + \left(y_{lj}^{l} - \hat{y}_{la}^{l-}\right)^2}} \right) \qquad j \in 1,2,\ldots m, \tag{F.5}$$

and the elevation measurement matrix is given by

$$\mathbf{H}_{\theta} = \begin{pmatrix} -\dfrac{\left(x_{l1}^{l} - \hat{x}_{la}^{l-}\right)\left(z_{l1}^{l} - \hat{z}_{la}^{l-}\right)}{\left(\Delta_{xyz}^{1}\right)^2 \Delta_{xy}^{1}} & -\dfrac{\left(y_{l1}^{l} - \hat{y}_{la}^{l-}\right)\left(z_{l1}^{l} - \hat{z}_{la}^{l-}\right)}{\left(\Delta_{xyz}^{1}\right)^2 \Delta_{xy}^{1}} & \dfrac{\Delta_{xy}^{1}}{\left(\Delta_{xyz}^{1}\right)^2} \\ -\dfrac{\left(x_{l2}^{l} - \hat{x}_{la}^{l-}\right)\left(z_{l2}^{l} - \hat{z}_{la}^{l-}\right)}{\left(\Delta_{xyz}^{2}\right)^2 \Delta_{xy}^{2}} & -\dfrac{\left(y_{l2}^{l} - \hat{y}_{la}^{l-}\right)\left(z_{l2}^{l} - \hat{z}_{la}^{l-}\right)}{\left(\Delta_{xyz}^{2}\right)^2 \Delta_{xy}^{2}} & \dfrac{\Delta_{xy}^{2}}{\left(\Delta_{xyz}^{2}\right)^2} \\ \vdots & \vdots & \vdots \\ -\dfrac{\left(x_{lm}^{l} - \hat{x}_{la}^{l-}\right)\left(z_{lm}^{l} - \hat{z}_{la}^{l-}\right)}{\left(\Delta_{xyz}^{m}\right)^2 \Delta_{xy}^{m}} & -\dfrac{\left(y_{lm}^{l} - \hat{y}_{la}^{l-}\right)\left(z_{lm}^{l} - \hat{z}_{la}^{l-}\right)}{\left(\Delta_{xyz}^{m}\right)^2 \Delta_{xy}^{m}} & \dfrac{\Delta_{xy}^{m}}{\left(\Delta_{xyz}^{m}\right)^2} \end{pmatrix}. \tag{F.6}$$

where

$$\begin{aligned} \left(\Delta_{xyz}^{j}\right)^2 &= \left(x_{lj}^{l} - \hat{x}_{la}^{l-}\right)^2 + \left(y_{lj}^{l} - \hat{y}_{la}^{l-}\right)^2 + \left(z_{lj}^{l} - \hat{z}_{la}^{l-}\right)^2 \qquad j \in 1,2\ldots m \\ \Delta_{xy}^{j} &= \sqrt{\left(x_{lj}^{l} - \hat{x}_{la}^{l-}\right)^2 + \left(y_{lj}^{l} - \hat{y}_{la}^{l-}\right)^2} \end{aligned}. \tag{F.7}$$

Note that the third column of $\mathbf{H}_{\psi}$ is zeroes.

Bearing measurements made by radio direction finding determine the direction of a transmitter with respect to the sensor body frame. To convert the bearing measurements to measurements of the azimuth (with respect to north), the azimuth of the direction finding system is required. Where this is unknown, a horizontal position solution may still be determined using differenced bearing measurements, provided at least three bearings have been measured.

The user position estimate is updated using

$$\begin{pmatrix} \hat{x}_{la}^{l+} \\ \hat{y}_{la}^{l+} \end{pmatrix} = \begin{pmatrix} \hat{x}_{la}^{l-} \\ \hat{y}_{la}^{l-} \end{pmatrix} + \left(\mathbf{H}_{\psi}^{\Delta\,\mathrm{T}} \mathbf{H}_{\psi}^{\Delta} \right)^{-1} \mathbf{H}_{\psi}^{\Delta\,\mathrm{T}} \begin{pmatrix} \tilde{\psi}_{bu}^{a1} - \tilde{\psi}_{bu}^{ar} - \hat{\psi}_{lu}^{a1-} + \hat{\psi}_{lu}^{ar-} \\ \tilde{\psi}_{bu}^{a2} - \tilde{\psi}_{bu}^{ar} - \hat{\psi}_{lu}^{a2-} + \hat{\psi}_{lu}^{ar-} \\ \vdots \\ \tilde{\psi}_{bu}^{am} - \tilde{\psi}_{bu}^{ar} - \hat{\psi}_{lu}^{am-} + \hat{\psi}_{lu}^{ar-} \end{pmatrix}, \tag{F.8}$$

where r denotes the reference transmitter, $\tilde{\psi}_{bu}^{aj}$ is the measured bearing of transmitter j, and the measurement matrix is given by

$$\mathbf{H}_{\psi}^{\Delta} = \mathbf{H}_{\psi} - \begin{pmatrix} h_x^r & h_y^r \\ h_x^r & h_y^r \\ \vdots & \vdots \\ h_x^r & h_y^r \end{pmatrix}. \tag{F.9}$$

where

$$h_x^r = \frac{y_{lr}^l - \hat{y}_{la}^{l-}}{\left(x_{lr}^l - \hat{x}_{la}^{l-}\right)^2 + \left(y_{lr}^l - \hat{y}_{la}^{l-}\right)^2}, \qquad h_y^r = -\frac{x_{lr}^l - \hat{x}_{la}^{l-}}{\left(x_{lr}^l - \hat{x}_{la}^{-l}\right)^2 + \left(y_{lr}^l - \hat{y}_{la}^{l-}\right)^2}. \tag{F.10}$$

F.2 Radio Determination Satellite Services

A radio determination satellite service can determine a two-dimensional navigation solution using signals from only two satellites in geostationary orbit using two-way ranging (Section 7.1.4.5). The signal geometry from geostationary satellites does not allow height and latitude to be observed separately so the user height is assumed to match that of the terrain or sea as appropriate. There is also a north-south hemisphere ambiguity in the latitude solution, so all users are assumed to be in the northern or southern hemisphere as appropriate.

In an RDSS system, the receiver records a short segment of the navigation signal and then transmits this to the satellite constellation at a fixed lag. This is then relayed to the control center, which computes the position solution and reports it to the user via satellite. The control center uses a terrain height database to obtain the correct latitude and longitude from the ranging measurement [1].

The only RDSS to be established are the Beidou Position Reporting Service and Qualcomm Automatic Satellite Position Reporting System (QASPR). These are summarized in turn, followed by a discussion of uncompleted systems

F.2.1 Beidou Position Reporting Service

The original Beidou (or Compass) navigation system, now referred to as Phase 1 or Beidou 1, used RDSS. The system was intended for road, rail, and maritime applications. Beidou 1 used a constellation of three geostationary satellites at longitudes of 80.2°, 110.4°, and 139.9°. A good signal was available at longitudes between about 70° and 150°, spanning China and neighboring countries. The first satellite was launched in late 2000 and the system became fully operational at the beginning of 2004 [1, 2]. With the advent of an initial regional implementation of a GNSS-based Compass system, known as Phase 2 (see Chapter 8), Beidou 1 was deemed an “experimental system”. The RDSS positioning capability has been retained in Phase 2 as the Position Reporting Service. However, coverage is unlikely to be extended beyond China.

The RDSS navigation signals are broadcast at a carrier frequency of 2,491.75 MHz and the user equipment transmits back at 1,615.68 MHz. The code-chipping rate is 4.08 Mchip s^{-1}. The position accuracy within the area covered by the Beidou calibration station network is 20m (1σ), noting that an accurate latitude solution is only available for users at latitudes above 20°. The system can provide up to 540,000 position fixes per hour [2].

F.2.2 Qualcomm Automatic Satellite Position Reporting System

QASPR is a proprietary long-range positioning system. It is used by the OmniTRACS vehicle tracking and communications system, which primarily serves the road haulage industry. OmniTRACS, has been operating since 1988 and serves many parts of the world, including North America and Europe, where it is known as EutelTRACS. QASPR is accurate to within 300m.

F.2.3 Uncompleted Systems

Geostar and Locstar were proposed RDSS systems, operating on the same two-way ranging principle as Beidou Phase 1 and using the same frequencies. Geostar was to cover North America, while Locstar was to cover Europe, the Middle East and Africa [3]. However, as the systems offered horizontal-only position with a limited update rate and would have charged a monthly subscription fee, they were superseded by GPS before the satellites were launched.

F.3 Landing Guidance Systems

This section describes the Instrument Landing System and Microwave Landing System, both of which are used for guiding aircraft approaches to runways. They thus provide guidance information rather than a position solution to the user. Landing guidance systems based on GNSS, augmented with GBAS, are now being deployed. These will largely supersede the older systems.

F.3.1 Instrument Landing System

Development of ILS started in the 1920s and it was standardized by the ICAO in 1947. Signals are transmitted over a cone, centered about the recommended approach route and extending for 10–20 km from the runway threshold. There are three components, the localizer, the glide slope, and up to three marker beacons, as Figure F.1 illustrates [3–5].

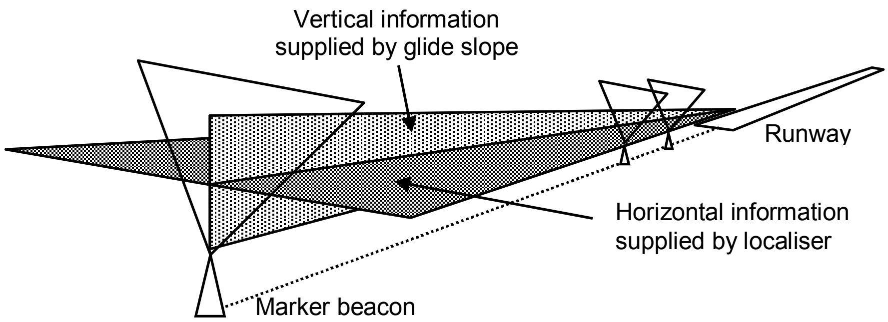

Figure F.1 Instrument Landing System schematic.

The localizer, transmitting in the 108–112 MHz band, extends to at least ±35° either side of the runway centerline. It comprises a carrier, identification, and two amplitude-modulated tones. The received amplitude of one tone is greater when the aircraft is to the left of the centerline, while that of the other is greater when the aircraft is to the right. The difference in depth of modulation (DDM) of the two tones is proportional to the course deviation when the aircraft is within 3°–6° of the centerline. Beyond this, a constant reading is obtained.

The glideslope, transmitted in the 329–335 MHz band, provides the corresponding information in the pitch plane. The DDM is proportional to the path deviation when the elevation of the aircraft path is within a quarter of that recommended, typically 3° . Beyond that, it gives a constant reading, extending to at least 8° above the recommended path.

The marker beacons transmit constant tones at 75 MHz in an upward cone. The first beacon marks the start of the approach, the second is typically located 900−1,000m from the runway threshold, while a third is sometimes located at 300–400m. Marker beacons are often omitted where a DME beacon is co-located with the ILS.

ILS accuracy varies from installation to installation. However, typical values are 0.5° for the localizer and 0.2° for the glideslope [3, 5]. The main limitations of ILS are that only one approach path per runway is supported, multipath interference is a problem at certain sites, and frequency congestion can be a problem in some places as there are only 50 channels. In the long term, ILS is likely to be discontinued in favor of newer technology; however, this will not occur before 2020 [6].

PRMG, a Russian acronym for Approach and Landing Radio Beacon Group System, is a landing aid, similar to ILS. It operates on the same UHF frequencies as RSBN (Section 11.1.2) and has the same user base.

F.3.2 Microwave Landing System

The Microwave Landing System (MLS) was developed in the 1970s and 80s as a replacement for ILS [3, 4]. MLS is currently used by military aircraft and a version was used by NASA for Space Shuttle landing. However, civil aviation use is currently limited to an installation at London Heathrow airport, deployed in 2003 [7].

Each MLS installation uses a single frequency in the 5031.0–5090.7 MHz band, with the azimuth, elevation, and data components time multiplexed. The localizer and glideslope of ILS are replaced by scanning beams about 1° wide. By timing the interval between receiving the maximum signal strength in the to and fro sweeps of the beam, users determine their bearing and elevation relative to the recommended approach route. Accuracy is typically better than 0.1° [3].

Range is provided by a modified form of DME, known as DME/P, which offers higher precision from use of a larger bandwidth, but shorter range, than conventional DME, also known as DME/N. Transponders operate in both DME/P and DME/N modes, switching to precision mode when an aircraft is within about 15 km. The W and Z DME modes are normally used. Accuracy varies from about 10m (1σ) at short range to 50m at the transition to precision mode [3]. There are 200 paired MLS and DME channels.

F.4 Radio Tracking Systems

Tracking systems determine the position of targets, performing the necessary calculations at central control centers rather than onboard the target. Their primary aim is to remotely monitor the location of the target. However, they can be used for navigation if the position and/or guidance instructions are then reported back to the target. This section describes a number of radio tracking systems, comprising the Enhanced Position Location Reporting System (EPLRS), Datatrak, Argos, Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS), and the Deep Space Network (DSN). These systems are all cooperative in that the targets collaborate in the tracking process by transmitting information to the control centers via tracking receivers.

F.4.1 Enhanced Position Location Reporting System

The Enhanced Position Location Reporting System (EPLRS) is a US military situation awareness system used by aircraft, land vehicles, and personnel. Up to 460 mobile users and base stations can be supported over a 300-km square. The original Position Location Reporting System (PLRS) was deployed in the 1970s with EPLRS, incorporating data communication, first deployed in the late 1980s. Peer-to-peer transmissions are used for both communications and passive ranging. EPLRS operates in the 420–450 MHz band. To provide interference resistance, encryption and ranging precision, DSSS is used with a chipping rate of 5 Mchip s^{-1}. However, TDMA is used for channel sharing [8].

Each user derives pseudo-range measurements using signals received from about ten peers. Position is updated using the user's pseudo-range measurements and the positions and clock offsets of its peers. This is a hybrid of the relative navigation chain and relative navigation network approaches (see Section 7.1.2). The horizontal position accuracy is typically 5–15m for static users, 10–30m for mobile ground-based users and 15–50m for aircraft [8].

Current EPLRS implementations also use GPS and barometric altimetry.

F.4.2 Datatrak

Datatrak is a proprietary medium-range positioning system, designed for land vehicle location. A Datatrak chain comprises between 4 and 32 time-synchronized transmitters spaced at intervals of approximately 150 km. This is sufficient to cover a small country. The first Datatrak chain was opened in the UK in 1989. At the time of writing, chains were operating only in the UK and Argentina while, in the past, the system also operated in Austria, Belgium, Luxembourg, Malta, the Netherlands, and South Africa.

Each chain uses two frequencies in the 130–150 kHz band, each divided into 32 ~100 ms timeslots with the transmission cycle repeating every 3.4 s. Each transmitter broadcasts during one or two timeslots on each frequency with different timeslots used on the two frequencies. Ranges are determined predominantly from phase measurements on the two frequencies. Low frequency modulation of the carriers is used for ambiguity resolution and enables a limited amount of data to be carried. The accuracy is around 30m (1σ), though this can be degraded by vehicle acceleration due to the relatively long duty cycle of the system [9, 10].

F.4.3 Argos

Argos is a satellite communication and tracking system, established in 1978 and jointly operated by Centre National d'Etudes Spatiales (CNES) and the National Oceanic and Atmospheric Administration (NOAA) with support from the National Aeronautics and Space Administration (NASA) It is used to relay data from remote environmental monitoring stations to their operators via around six satellites and a ground station network. Applications include meteorological and oceanographic data collection, animal tracking, and tracking of adventurers and yacht racers.

The satellites occupy polar orbits at a height of 850 km with a period of about 100 minutes. Each transmitter on the ground is visible from at least one satellite for around 14 10-minute periods each day. At higher latitudes, transmitters are visible from more than one satellite, while at the poles, they are visible from all satellites. Argos incorporates a positioning system that provides one position fix per satellite pass, accurate to 150m for a stationary transmitter. It can also relay GNSS position fixes.

Doppler positioning (Section 7.1.7) is used to determine the transmitter location. Assuming the transmitter is stationary with respect to an ECEF frame and that the satellite position and velocity are known, each Doppler shift measurement may be used to define an approximately cone-shaped locus of position. Two cones are obtained from Doppler-shift measurements near the beginning and end of each observation period. A third surface of position (SOP) is defined by the transmitter height, obtained from a digital elevation model. The two points at which the three SOPs intersect are the possible position solutions.

Whichever of these is closest to the previous reported position is normally assumed to be correct [11]. Note that transmitter motion during a satellite pass is neglected.

F.4.4 Doppler Orbitography and Radiopositioning Integrated by Satellite

DORIS is a Doppler positioning system, used for satellite orbit determination since 1990. It is operated by a French consortium, including CNES. It is used by a number of remote sensing and altimetry satellites and also by the geodesy community to aid reference frame determination. Between 50 and 60 ground stations at known locations transmit signals that are received by the satellites. Each of these beacons transmits at 200 MHz and 2 GHz. By measuring the frequency shift, the range rate of the satellite with respect to the beacon may be determined. The DORIS range-rate measurements are typically combined with measurements from other positioning technologies, such as GNSS and satellite laser ranging, and with orbital force modeling to determine a satellite's position and orbit.

F.4.5 Deep Space Network

The Deep Space Network is used to track and communicate with NASA and international spacecraft on interplanetary missions. It comprises three tracking stations in Australia, California, and Spain, separated by approximately 120° in longitude. Both passive ranging and two-way ranging are used, with the latter initiated by the tracking stations. Note that a response from a spacecraft may be received by a different tracking station to that sending out the original ranging signal. For older missions, the ranging signal comprises sinusoidal tones phase modulated onto the carrier. For newer missions GNSS-like DSSS PRN ranging codes are used. Range-rate measurements are obtained from the Doppler shift. Range and range rate may be measured to an accuracy approaching 1m and 1 mm s^{-1}, respectively [12].

Whenever a signal from a spacecraft is receivable by two tracking stations, its angle of arrival may be determined using very long baseline interferometry (VLBI). This uses a similar method to GNSS attitude determination (Section 10.2.5). Transmitter direction information is deduced from the difference in time of signal arrival between the two receivers. Two different baselines must be used to obtain both components of direction. An accuracy of approximately 2 nrad may be obtained [12].

DSN position update rates may be anything from three times a day to weekly, noting that the network is used to track many different spacecraft.

F.5 Phone Positioning Terminology

The description of phone positioning in Section 11.3 uses generic terminology. This section briefly defines some of the key terms used in the phone positioning community, noting that these often vary between standards [13–15].

- Advanced forward-link trilateration (AFLT) is self-positioning by passive ranging using the downlink control signals in IS-95 and IS-2000 systems.
- CDMA2000 is a contraction of CDMA IS-2000.
- Enhanced cell identity (E-CID) or Adaptive enhanced cell identity (AECID) is a hybrid positioning method used in LTE that combines the TA and uplink AOA of the serving cell with downlink RSS measurements and identities of neighboring cells.
- Enhanced observed time difference (E-OTD) is an obsolete GSM positioning technique whereby the difference in downlink TOAs between a mobile station and an LMU is measured.
- A location measurement unit (LMU) is a reference station used for differential positioning in an unsynchronized system such as GSM or UMTS. It is also a component of a base station used for measuring the TOA of uplink signals.
- The measured results list (MRL) comprises the RSSs of the downlink control signals in a UMTS system. It is designed to aid base station handover but can also be used for positioning by RSS pattern matching.

- Observed TDOA-idle period downlink (OTDOA-IPDL) is a positioning method used in UMTS whereby the difference in downlink TOAs between a mobile station and an LMU is measured during idle periods in the downlink during which it is easier for the mobile to receive neighboring base stations.
- Round-trip time (RTT) is the signal propagation delay from the mobile station to the base station and back in a UMTS system.
- A serving mobile location center (SMLC) calculates user positions within the network from LMU measurements.
- Timing advance (TA) is the signal propagation delay from the mobile station to the base station and back in a GSM system.
- Uplink-TDOA (U-TDOA) is a UMTS and 4G positioning method in which uplink signals from the mobile are received at four or more LMUs.
- Wideband CDMA (WCDMA) is an alternative name for UMTS.

F.6 Digital Television and Radio Broadcasts

This section provides further information on positioning using digital television and radio broadcasts, discussed in Section 11.4.5. Television standards are described first, followed by positioning using DAB and other digital radio standards.

F.6.1 Television Standards

Globally, there are four standards for static-reception digital terrestrial television. The Advanced Television System Committee (ATSC) standard is used in North America, South Korea, and parts of Central America. The Digital Terrestrial Multimedia Broadcast (DTMB) standard is used in China. The Digital Video Broadcasting – Terrestrial (DVB-T) standard is used in Europe, Russia, Australia, New Zealand, and many Asian and African countries. Finally, the Integrated Services Digital Broadcasting – Terrestrial (ISDB-T) standard is used in Japan, the Philippines, and most of South America. DTMB is also suitable for mobile reception, while a mobile version of DVB-T, known as Digital Video Broadcasting – Handheld (DVB-H) has been deployed in a few countries and mobile versions of ASTC and ISDB are under development. Digital Video Broadcasting – Satellite service to Handhelds (DVB-SH) uses satellite transmission, supplemented by terrestrial fillers and may be deployed at frequencies up to 3 GHz.

DTMB, DVB-T, and ISDB-T all use OFDM with QPSK, 16-QAM, or 64-QAM modulation (see Section 7.2.1). This allows the operation of a multi-transmitter single-frequency network. ATSC uses 8-ASK with a vestigial sideband (VSB). Detailed descriptions of ATSC and DVB may be found in [16].

For DVB-T and ISDB-T, certain subcarriers are devoted to synchronization signals, while for ATSC and DTMB, synchronization sequences proceed each block of unknown data. The number of synchronization symbols per second is about 86,000 for ATSC, 840,000 or 1,890,000 for DTMB, 452,000–754,000 for DVB-T, and 467,000 for ISDB-T.

At the time of writing, many countries were still broadcasting analog television signals, either alongside or instead of digital signals. However, most countries plan to transition to an exclusively digital television infrastructure by the end of 2015. Therefore, positioning using analog signals, though possible, is not considered.

F.6.2 Digital Audio Broadcasting and Digital Radio

DAB, together with its derivatives, DAB+ and Digital Multimedia Broadcasting (DMB) or Radio Numérique Terrestre (RNT), is the terrestrial digital radio standard for Europe and several other countries. DMB is also used for mobile television in South Korea. Multi-program multiplexes are transmitted in the 174–230 MHz band using OFDM with differential quadrature phase-shift keying (DQPSK) modulation. The channel width is 1.5 MHz (excluding the guard interval). DAB multiplexes are transmitted using national and local SFNs, some with more than a hundred transmitters. Consequently, all transmitters are tightly time synchronized, with offsets from UTC varying between transmitters to prevent destructive interference [17].

As with digital television, ranging may be performed by correlating synchronization sequences. Where the transmitter time offsets are known, passive ranging may be performed; otherwise, differential ranging must be used. In DAB, each 96-μs frame of data begins with a null multi-carrier symbol, followed by the time-frequency-phase reference (TFPR) multi-carrier symbol. Altogether, there are 16,000 TFPR sub-carrier symbols each second. As SFNs are used, multiple correlation peaks are obtained on a given channel, each corresponding to a different transmitter. These can be identified using the transmitter identification information (TII). The TII is transmitted on alternate null symbols and comprises activation of only 16 of the 1536 sub-carriers, with each transmitter activating a different combination.

DAB positioning was first demonstrated using TII correlation only, giving an accuracy of around 3 km [18]. However, using both the TII and the TFPR, an accuracy of about 150m has been achieved using a prototype software-defined radio [19].

Other digital radio technologies include Digital Radio Mondiale (DRM), designed for use in the LF, MF, and HF broadcasting bands; DRM+, proposed for the FM broadcasing band (87.6–108 MHz); the US In-Band On-Channel (IBOC) systems, used in the MF and FM broadcasting bands; and the Japanese ISDB-T_{SB}, which is similar to DAB [17]. These all use OFDM and could be used for positioning.

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