Exam Satellite Navigation AE4-E08
Thursday April 3, 2008, 9:00-12.00, Kluyverweg 1, Room G

Question 1 - Terminology

Explain briefly (1-2 sentences) the following satellite navigation terminology

a. Ephemeris
b. Cycle slip
c. Multipath
d. Navigation message
e. Pseudo range
f. Integrity
g. Error budget
h. WGS84
i. Baseline
j. Wide-lane

Question 2 – GPS Signals and Receivers

a. How many and which navigation signals are broadcasted by a GPS Block II-R satellite?
b. Give for each of the navigation signals the carrier-frequency, chip-rate, code-length, modulation type and bandwidth, when appropriate, as function of f_0=10.23 MHz.
c. Give a block diagram of a generic GPS receiver outlining the main functions and dataflow.
d. Describe/sketch the working of a signal (code/phase) tracking channel inside a GPS receiver.
e. What are the main outputs of a signal tracking channel and what are their units?
f. How many tracking channels must an all-in-view dual frequency GPS receiver have at the very least? Please explain.
g. What is anti-spoofing and how do high-end professional receivers deal with it?
h. Describe the two new non-military signals that will be provided by GPS in the future.

Question 3 – Atmospheric Delays

a. There are two types of atmospheric delays. Which are they, and why does it make sense to distinguish between them?
b. What is the contribution of these atmospheric delays to the error budget? If necessary, distinguish between different receiver types, and/or absolute or relative positioning.
c. The tropospheric delay itself is also divided in two components. Which are these and on which atmospheric parameters do they depend? Why does it make sense to do so?
d. How does one mitigate (correct or get around) tropospheric delay (i) inside a simple hand-held receiver, (ii) for static precise point positioning (cm accuracy) applications and (iii) high precision static/kinematic surveying applications (e.g. RTK)?
e. Answer question d) again, but now for ionospheric instead of tropospheric delay.
f. How does a Satellite Based Augmentation System (SBAS) deal with the atmospheric delays?
g. IGS, EUREF and many national agencies operate permanent GPS networks. What kind of atmospheric products are, or could be, available from such networks and for which kind of users?

Question 4 – Precise Point Positioning

Our goal is to compute the position of an aircraft over the middle of the ocean with an accuracy of 20 cm or better for a geophysical survey, using measurements from a single dual-frequency receiver. Results must be available within 2 days. You may assume that you have access to the Internet to download products from the IGS. You decide on using the ionosphere free linear combination of both code and carrier phase observations.

a. Give the ionosphere free linear combination.
b. We decided on using both code and carrier phase observations. Why not only code observations? And, why not only carrier phase observations?
c. Which are the unknown parameters we have to solve for at the very least and why?
d. What kind of products do you plan to use from the IGS? What is the accuracy and latency of these products?
e. Linearize the non-linear observation equation[1] for the parameters that you wish to solve for.
f. Please describe how the observed minus computed observation is computed. What are the difficulties in this computation?
g. Give the system of linearized observation equations at a single epoch *k* and sketch symbolically the structure of the system of observation equations for epochs *k=0,1,..,N-1*. Consider only the unknowns you identified under c) and use the observations identified in the header.
h. Give a formula or table for the number of observations, unknowns and redundancy (number of observations, minus number of unknowns, plus rank-defect) as function of the number of epochs. How many satellites do we have to observe as a bare minimum? How many epochs of observations are required at the very least?
i. Answer h) again in case you would have used carrier phase measurements only.
j. What can you say about the precision of the computed position versus observation time?
k. Suppose you do not have or want to use a dual frequency receiver. Please explain how you can modify the precise point positioning application for a single frequency receiver (if necessary with reduced accuracy).
l. Discuss the trade off between dual and single frequency precise point positioning taking L2 tracking accuracy amongst other factors into account.

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[1] The observation equation for the GPS integrated carrier phase measurement p_r^s at time t_k, with *k=0,1,…,N-1* the epoch number and N the number of epochs, is

$$E\{\underline{p}_{r\,k}^{s}\} = \left\| \mathbf{x}^s(t_k - \delta t_{r\,k} - \bar{\tau}_{r\,k}^{s}) - \mathbf{x}_{r\,k} \right\| + c\delta t_{r\,k} - c\delta t^s{}_k + \gamma_i I_{r\,k}^{s} + M(e_{r\,k}^{s}) T_r(t_k) + \lambda_i A_r^s$$

with $\mathbf{x}^s$ the position of the satellite, $\mathbf{x}_r$ the position of the receiver, δt_r the receiver clock error, δt^s the satellite clock error, I_r^s the ionosphere delay with γ_i a signal dependent factor (±1|1.65), $T_r\ (t_k)$ the troposphere delay in the zenith direction and $M(e_r^s)$ a known elevation dependent mapping function, and $\bar{\tau}_{r\,k}^{s}$ the approximate travel time of the signal, with $\bar{\tau}_{r\,k}^{s} = \frac{1}{c}\left\| \mathbf{x}^s(t_k - \delta t_{r\,k} - \bar{\tau}_{r\,k}^{s}) - \mathbf{x}_{r\,k} \right\|$, λ_i the wavelength of the signal, and A_r^s the carrier phase ambiguity. All quantities, except the satellite position $\mathbf{x}^s$, refer to the time of observation t_k in the - receiver - time frame, as indicated by the lower index *k*. At epoch *k* the receiver is observing m_k satellites on two frequencies. The observation equations for the GPS pseudo-range observations are very similar, but do not include the ambiguity term.

Question 5 – Relative GPS positioning with carrier phase

a. Please explain what single- and double difference carrier phase observations are, and why they are used for relative positioning.
b. Given the choice between using either single- or double difference observations, which would you prefer to use and why?
c. Which results in a better positioning accuracy: single or, double differences? Please explain.
d. Give the co-variance matrix of the 'double difference' phase observations for a single epoch. You may assume that the original phase observations have equal standard deviation and are uncorrelated.
e. What is the double difference phase ambiguity and which important property does it have? Please explain why.
f. Please explain how the property mentioned in e) can be used to our advantage.
g. If not done so already under f), discuss the implementation aspects of algorithms that exploit the property mentioned under e).
h. If you may choose between using a single or dual frequency receiver for relative GPS positioning over short baselines, which receiver would you choose and why?

End of exam