Exam Satellite Navigation AE4-E08
Monday January 26, 2009, 14:00-17.00, Kluyverweg 1, Room E

Question 1 – Global Navigation Satellite Systems (GNSS)

a. Describe the signal structure (carrier-frequency, modulation type, chip-rate, code) of the GPS Block II/IIA/IIR satellites.
b. The GPS Block IIR-M satellite is an upgraded version of the Block IIR satellites. What is the most important upgrade for civilian users?
c. What are the further modernization plans for the GPS system?
d. GLONASS is the Russian counterpart of GPS. What are the main differences between GLONASS and GPS signals?
e. Europe is developing its own satellite navigation system called Galileo. What are the main differences between Galileo and GPS signals?
f. What are the main differences between the GPS, GLONASS and Galileo orbits?

Question 2 – GPS/GNSS receiver

a. Give a block diagram of a generic GPS receiver outlining the main functions and dataflow.
b. Describe/sketch the working of a standard signal (code/phase) tracking channel inside a GPS receiver.
c. What are the main outputs of a signal tracking channel and what are their units?
d. How many tracking channels must an all-in-view dual frequency GPS receiver have at the very least, and how much channels would we need for a future proof GNSS multi-system multi-frequency receiver?
e. What is anti-spoofing and how do high-end professional receivers deal with it?

Question 3 – SBAS

a. What is an SBAS system and what is its role?
b. Which signal(s) is/are transmitted by a SBAS satellite?
c. An SBAS system provides three types of corrections in its data message. Which are these?
d. What do we understand under the horizontal/vertical protection level (HPL/VPL), how is it computed and how is it used?
e. How do we monitor the performance of SBAS? What is a Stanford graph?

Question 4 – Single and Double Differencing

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

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

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 $\bar{\tau}^s_{r\,k}$ the approximate travel time of the signal, with $\bar{\tau}^s_{r\,k} = \frac{1}{c}\left\| \mathbf{x}^s(t_k - \delta t_{r\,k} - \bar{\tau}^s_{r\,k}) - \mathbf{x}_{r\,k} \right\|$, λ_i the wavelength of the signal, and A^s_r 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*.

a. Give the linearized version of the above (non-linear) observation equation.
b. Describe how the observed minus computed observation is computed and point out some of the difficulties in this computation.
c. Give the linearized version of the (between receiver) single difference observation equation for a short baseline (< 3 km). Please ignore all effects that do not significantly (< 2 cm) affect the precision of the baseline.
d. Explain the effects that you have ignored in question c) and their influence on the baseline precision as function of the baseline length and other factors.
e. Give the system of single difference equations for a single epoch for all satellites in view (*m* being the number of satellites). Use your answer to question c) as starting point.
f. The system in question e) is probably rank-defect. What is a rank-defect? What is the dimension of the rank-defect of the system in question e) and how can this rank-defect be remedied?
g. Give the number of observations, unknowns and redundancy as function of the number of epochs, as well as the minimum number of satellites required for a solution, for a static baseline.
h. Give the system of double difference equations for a single epoch, and explain the differences between the system of double and single difference equations.
i. 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.
j. Answer question g) again for the double difference equations.
k. Which results in a better positioning accuracy: single or, double differences? Please explain.
l. What is the double difference phase ambiguity and which important property does it have?
m. Explain how the property mentioned in l) can be used to our advantage and the impact it has on the performance of relative positioning using carrier phase observations.

Question 5 – Water Vapour Estimation using GPS

KNMI (the Dutch Meteorological Institute) uses GPS to compute the amount of water vapour in the atmosphere.

Describe step by step how Integrated Water Vapour (IWV) is computed from ground based GPS observations. Please detail the kind of receivers and observations that have to be used, linear combinations that may have to be formed, the principles of the estimation method, external data that may be required and sources for this data, the domain of the GPS network and number of receivers involved.

Finally, outline how space based GPS receivers can be used to "sense" the Earth's atmosphere and which atmospheric parameters can be retrieved.

End of exam