ECE 6390: Satellite Communications and Navigation Systems
Solutions to TEST 3 (Fall 2009)

1. **Short Answer Section (10 points)**

   (a) convolutional

   (b) Shannon

   (c) Cramer-Rao

   (d) pseudolite

   (e) False – also depends on code complexity

2. **Short Discussion Section:** Answer the questions below with very concise, well-articulated answers. Verbosity will be penalized.

   (a) FEC is important in satellite communications because there is more bandwidth (allows for extra symbol redundancy) that may be used to compensate for the lower CNRs (longer distance links are lossier). Most of the credit was also given to students who reasoned that the longer satellite links made acknowledgement-and-reply schemes unwieldy for (some) applications due to the increased link latency.

   (b) For the GPS satellites to share the same spectrum, FDMA would shrink the bandwidth and harm the location resolution (longer, wider pulses); TDMA cannot be coordinated to *all* possible receiver points on earth (a set of time slots that neatly orders a series of satellite signal packets for one location on the earth would probably look like a train wreck everywhere else). Many students liked to mention the amplifier limitations of transmitting multiple FDMA signals. This is true for communications transponders, but did not make sense in the context of positioning satellites.

   (c) GPS works better at the equator. There are more satellites in view at closer distance with less oblique path loss.

   (d) No points off for this question's answer. There actually would be a slight improvement at night since there is less variability and uncertainty in tropospheric and ionospheric delay. Some students also pointed out that there would be less noise temperature because the sun would not be in view of the GPS receiver.

(e) Much better in Alpharetta since midtown Atlanta is a large city with urban blockage and multipath degradations.

3. **Radiolocation Analysis:**

(a) The base stations should be the points of an equilateral triangle with the user in the center.

(b) How do we adapt our GPS formula to this system from first principles? Since no spread-spectrum is being used, we may view this as a spread spectrum system where $M = 1$ and $T_c = T_b = T_s$.

$$\frac{C}{N} = \frac{10^{-80/10}}{10^{-95/10} + 1.3807 \times 10^{-20}\text{mJ K}^{-1} \times 2 \times 10^5\text{kHz} \times 200\text{K}} = 31.6 = 15.0 \text{ dB}$$

Thus, with $N_{sat} = 3$ in this case and with $T_{int} = 1$ms:

$$\sigma_r = cT_c\sqrt{\frac{N_{sat}T_b}{\left(\frac{C}{N}\right)_{\text{despread}} T_{int}}} = 20 \text{ m}$$

(c) Clock errors and multipath are sources of error. None of the other analogous errors with GPS (ephemeris, variable atmospheric delays, etc.) apply to a terrestrial system.

(d) Now here is a system that uses CDMA. The processing gain is not given, but that is not a problem. If the de-spread SINR is

$$\text{SINR} = M10^{-8/10} = 0.16M = 0.16\frac{T_b}{T_c}$$

then the bit periods will cancel in the ranging expression:

$$\sigma_r = cT_c\sqrt{\frac{N_{sat}T_b}{0.16\frac{T_b}{T_c}T_{int}}} = cT_c\sqrt{\frac{N_{sat}T_c}{0.16T_{int}}} = 41 \text{ m}$$

For the numbers in these problems, the CDMA system performs somewhat worse.

This problem illustrates why CDMA systems use assisted GPS, while GSM systems may use TDOA location systems. Typically, wider bandwidths make radiolocation systems work better. However, in CDMA the problem is *signal fidelity*; there is no frequency re-use in a CDMA system so adjacent cells all use the same band, making for a much lower CNR at the receiver. In this example, what is gained with the wider bandwidth is more than lost in the poor CNR.