ECE 6390: Satellite Communications and Navigation Systems
Solutions to TEST 3 (Fall 2007)

1. **VSAT Communications Link Design:**

   (a) Raw BER at the (ideal) receiver:

   $$\text{BER for } M\text{-QAM} \approx 4\left(1 - \frac{1}{\sqrt{16}}\right) \mathrm{Q}\left(\sqrt{3 \times 10^{9/10}/(16-1)}\right) = 3\mathrm{Q}(1.26) = 0.31$$

   (b) The symbol period should be

   $$T_s = [4 \text{ Mbit/s} \times 1 \text{ symbol}/4 bits]^{-} 1 = 1 \mu s$$

   For roll-off $\kappa = 0.5$, we see from the raised-cosine graph that

   $$B = 2f_o \times (1+\kappa) = \frac{1}{T_s} \times (1+\kappa) = 1.5 \text{ MHz}$$

   (c) We must transmit 8/5 (+60%) more bits in real time so the bandwidth increases to

   $$B' = B \times 8 \text{ coded bits}/5 \text{ raw bits} = 2.4 \text{ MHz}$$

   (d) For a 2.4 MHz channel with 4 Mbit/s of real data, the required CNR is

   $$CNR = 2^{C/B} - 1 = 2.17 = 3.4 \text{ dB}$$

   Thus, the turbo code must allow near-perfect operation at CNR = 4.4 dB.

   The uncoded system was operating at CNR = 9 dB, but that was at 1.5 MHz. With the additional bandwidth, the CNR would have dropped to 7.0 dB due to the additional noise allowed into the communications link. Thus, the turbo code could have achieved (and then greatly exceeded) the terrible performance of BER of 0.31 in part (a) with 2.6 dB less received power.

   (e) Answer is a 4×4 square grid of points on the IQ diagram, centered at the origin.

   (f) Each user require 2.4 MHz for their coded signal plus another 200 kHz for guard interval, a total of 153 users could be fit into this 400 MHz spectrum.

2. **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 $T_c = T_b = T_s$.

$$\frac{C}{N} = \frac{10^{-80/10}}{10^{-100/10} + 1.3807 \times 10^{-20}\text{mJ K}^{-1} \times 2 \times 10^5\text{kHz} \times 150\text{K}} = 99.96 = 20.0 \text{ dB}$$

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

$$\sigma_r = cT_c\sqrt{\frac{N_{sat}T_b}{\left(\frac{C}{N}\right)_{\text{despread}} T_{int}}} = 12 \text{ m}$$

(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

$$\text{SINR} = M10^{-10/10} = 0.1M = 0.1\frac{T_b}{T_c}$$

then the bit periods will cancel in the ranging expression:

$$\sigma_r = cT_c\sqrt{\frac{N_{sat}T_b}{0.1\frac{T_b}{T_c}T_{int}}} = cT_c\sqrt{\frac{N_{sat}T_c}{0.1T_{int}}} = 52 \text{ m}$$

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.