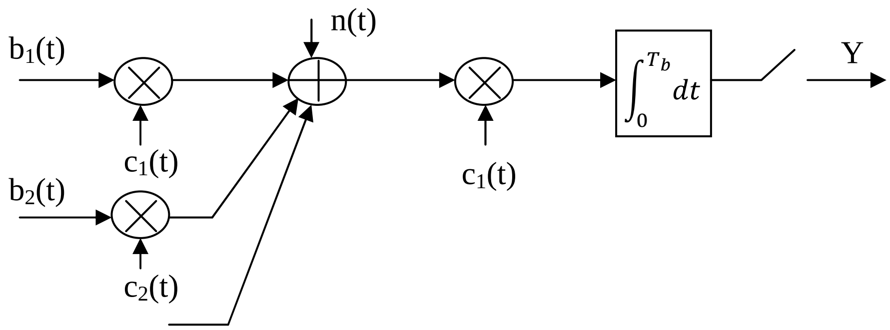
NANYANG TECHNOLOGICAL UNIVERSITY
School of Electrical and Electronic Engineering

E6101 DIGITAL COMMUNICATIONS

Tutorial 4

1. For the synchronous CDMA system shown in Figure below, $b_i(t)$ is the binary data and $c_i(t)$ is the spreading code of the i-th user, $n(t)$ is additive white Gaussian noise, and $T_b = 10^{-4}$ s.



(a) Assuming that $n(t)$ is negligible, show that the receiver output Y and the BER have the following expressions:

(i) $Y = \pm T_b + T_c \sum_{i=2}^{M} b_i(t)\, \phi_{i1}(k=0)$

(ii) $BER = Q\left(\frac{PG}{\sqrt{\sum_{i=2}^{M} E[\phi_{i1}^2(k=0)]}}\right)$

where $Q(x)$ is the Gaussian Q function. In your answers, define all mathematical symbols clearly.

(b) Full period spreading is implemented in the above CDMA system. The spreading code used is a set of Gold sequences generated from a preferred pair of m-sequences with m = 7. Given that Gold sequences have cross-correlation values -1, $-t(m)$, or $t(m)-2$ where $t(m) = 2^{(m+1)/2} + 1$ (if m is odd) or $2^{(m+2)/2} + 1$ (if m is even), determine

(i) The system bandwidth,

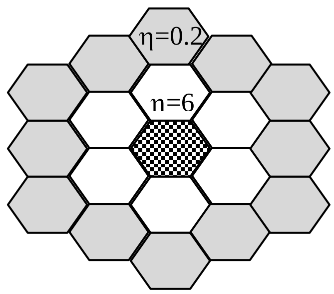
(ii) The total number of spreading codes available, and

(iii) The worst-case BER in the form of $Q(x)$ of the CDMA system.

2. Figure below shows a cellular CDMA service area consisting of 19 regular hexagonal cells, each served by a based station located at the centre of the cell. All users in the system are perfectly power-controlled by their respective base-stations, which are equipped with omni-directional uplink antennas. With reference to the central cell, the

figure shows that the uplink MAI from the inner ring of neighbouring cells has an average loading factor η of 6% per user, while MAI from the outer cell ring has η = 0.2% per user. All users are assumed to transmit power continuously. Random binary spreading and coherent de-spreading are used. Chip rate after spreading must be 1.28 Mcps.

(a) If the cellular operator managing the above CDMA system plans to support 10 kbps voice communication at a BER of 10^{-3}, derive the expression for E_b/I_0 for the uplink signal received by the central cell. Compute the number of active voice users that can be supported in the central cell at any one time. You may assume that the BER in a perfectly power-controlled coherent CDMA channel is given by $Q\left(\sqrt{2E_b/I_0}\right)$.



(b) If instead of voice communication, the cellular operator wants to provide wireless data services with BER = 10^{-4} to 10 users in every cell, what is the maximum average data rate available to each user in the central cell?

3. Consider DS-CDMA cellular downlink transmission. A basestation wants to transmit 1 bit information to a user in the same cell. It is common that the user data is first spread by a Walsh-Hadamard (WH) code and then scrambled by an m-sequence. The WH code assigned is [1010] and the m-sequence is [1110010]. The downlink channel is a multipath fading channel which contains 2 equal-power paths separated by 2-chip duration and the noisy received chip signals ***r*** by the user are (where the left most digit is the earliest received);

$$\boldsymbol{r} = [+0.53,\ +0.87,\ -1.14,\ -1.19,\ -0.04,\ -0.06]$$

(a) Given that the system makes use of the binary mappings 1 → +1 and 0 → −1 for transmission, determine the transmitted bit using an equal gain combining (EGC) RAKE receiver.

(b) The bit-error rate (BER) performance of the RAKE receiver with maximum ratio combining (MRC) under the frequency-selective fading channel with L slow Rayleigh paths is approximately given by:

$$BER \approx \binom{2L-1}{L} \prod_{i=1}^{L} \left[\left(\frac{4E_b}{N_0 + I_0} \right)_i \right]^{-1}$$

where E_b, N_0 and I_0 are the average energy per bit, channel noise power spectral density and average interference power spectral density, respectively. With only one user, the received E_b/N_0 is 13 dB. Given that the interference due to the multiple users in the cell, I_0, is only 10% of E_b, find the BER of the user MRC-RAKE combiner receiver with 3 RAKE fingers.