

Application to CDMA

- CDMA = Code Division Multiple Access
- many 3G cell phones were based on CDMA technology (as promoted by Qualcomm ^{San Diego})
 - physical layer technology (signal waveforms)
- Each user is assigned a code:
 - a unique sequence of +1's and -1's
 - PN = pseudo-noise
- recall discussion how to create Continuous-Time "baseband" waveform from +1, -1 sequence and then multiply by high-freq. sine wave to create transmitted RF waveform that is constant modulus, i.e., has constant envelope in order to use nonlinear amplifiers

- Consider 3-user case as an illustrative example \Rightarrow uplink \Rightarrow from user phones to Base Station
- $c_k[n]$, $n=0,1,\dots,N_c-1$: PN sequence of +1's and -1's assigned to k -th user of length N_c
- $b_k[m]$: information symbols to be sent for user k

• in simplest case: BPSK:

$$b_k[m] = +1 \text{ to transmit a } 1$$

$$-1 \text{ to transmit a } 0$$

for k -th user in m -th time slot

- $k=1,2,3$
- Consider two successive symbol intervals for all 3 users
- τ_k = relative timing offsets

Signal Modeling at Baseband after A/D conversion

$$x[n] = \begin{cases} b_1[k] c_1[n-n_1] + b_1[k+1] c_1[n-n_1-N_c] \\ + \\ b_2[k] c_2[n-n_2] + b_2[k+1] c_2[n-n_2-N_c] \\ + \\ b_3[k] c_3[n-n_3] + b_3[k+1] c_3[n-n_3-N_c] \end{cases}$$

- all three users' signals arrive superimposed at the Base Station (BS)
 - BS will have to use linear amplifier BUT that's OK \Rightarrow plugged into AC power line
- Suppose wlog, we seek to determine info. symbols sent by User 1

- Form: $y_1[n] = x[n] * c_1[-n]$
- Assume we synchronize to User 1 so that $n_1 = 0$
- $y_1[n] = x[n] * c_1[-n] = r_{xc_1}[n] =$

$$\begin{aligned}
 & b_1[k] r_{c_1 c_1}[n] + b_1[k+1] r_{c_1 c_1}[n - N_c] \\
 & + \\
 & b_2[k] r_{c_2 c_1}[n - n_2] + b_2[k+1] r_{c_2 c_1}[n - n_2 - N_c] \\
 & + \\
 & b_3[k] r_{c_3 c_1}[n - n_3] + b_3[k+1] r_{c_3 c_1}[n - n_3 - N_c]
 \end{aligned}$$

where: $r_{c_i c_k}[n] = c_i[n] * c_k[-n] \Rightarrow k = 1, 2, 3$
 nonzero over $-(N_c - 1), \dots, -1, 0, 1, \dots, N_c - 1$

Evaluating at $n=0$, we have:

⑤

$$y_1[0] = b_1[r] N_c$$

$$\left. \begin{aligned} &+ b_2[r] r_{c_2 c_1}[-n_2] \\ &+ b_3[r] r_{c_3 c_1}[-n_3] \end{aligned} \right\} \begin{array}{l} \text{Multi-User} \\ \text{Access} \\ \text{Interference} \end{array}$$

• Timing-offsets $n_2 \neq n_3$ are related to the distances user 2 and user 3 are from the Base-Station, relative to user 1

• Since we can't control that, desire:

$$r_{c_k c_l}[n] = c_k[n] * c_l[-n] \text{ to be } \approx 0$$

$r_{c_k c_l}$
 $k \neq l$

for all $n: -(N_c-1), \dots, 0, \dots, N_c-1$

and $r_{c_k c_k}[n] \approx N_c \delta[n] \Rightarrow$ NOT POSSIBLE!

- Gold Codes are often used in practice to approximate these desired properties
- Gold Codes are PN sequences of +1's and -1's generated by Linear Shift Registers
- See Matlab Demo: `cdmaeg.m`
- See Matlab Hmwk. 1
- Note: if there are reflections off buildings and other structures \Rightarrow multipath propagation then k -th time slot will spill into $(k+1)$ -th time slot yielding increased/additional Multi-User Access Interference and even Self-Interference