Block Matrix Multiplications

- $\begin{bmatrix} \vec{c}_1 & \vec{c}_2 & \cdots & \vec{c}_n \end{bmatrix}_{m\times n} \begin{bmatrix} \vec{x} \end{bmatrix} = x_1\vec{c}_1 + x_2\vec{c}_2 + \cdots + x_n\vec{c}_n$ where $\vec{c}_j$ is $m\times 1$ and $\vec{x}$ is $n\times 1$.
- $\begin{bmatrix} \underline{r}_1 \\ \underline{r}_2 \\ \vdots \\ \underline{r}_n \end{bmatrix}_{n\times m} \begin{bmatrix} \vec{x} \end{bmatrix} = \begin{bmatrix} \underline{r}_1\vec{x} \\ \underline{r}_2\vec{x} \\ \vdots \\ \underline{r}_n\vec{x} \end{bmatrix}$ where $\underline{r}_i$ is $1\times m$ and $\vec{x}$ is $m\times 1$.
- $\underline{x} \begin{bmatrix} \underline{r}_1 \\ \underline{r}_2 \\ \vdots \\ \underline{r}_n \end{bmatrix}_{n\times m} = x_1\underline{r}_1 + x_2\underline{r}_2 + \cdots + x_n\underline{r}_n$ where $\underline{r}_i$ is $1\times m$ and $\vec{x}$ is $1\times n$.

CDMA: DS/SS

- The receiver performs **a time correlation operation** (inner product) to detect only the specific desired codeword.
- All other codewords appear as noise due to decorrelation.

Q: why not 0?
A: In practical system, can not hope for perfect orthogonality

- For detection of the message signal, the receiver needs to know the codeword used by the transmitter.
- **Each user operates independently with no knowledge of the other users**.
- Unlike TDMA or FDMA, CDMA has a **soft capacity limit**.
  - Increasing the number of users in a CDMA system raises the noise floor in a linear manner.
  - There is no absolute limit on the number of users in CDMA. Rather, the system performance gradually degrades for all users as the number of users is increased and improves as the number of users is decreased.

[Rappaport, 2002, Ch9]

Analogy [Tanenbaum, 2003]

- An airport lounge with many pairs of people conversing.
- TDMA is comparable to all the people being in the middle of the room but taking turns speaking.
- FDMA is comparable to the people being in widely separated clumps, each clump holding its own conversation at the same time as, but still independent of, the others.
- CDMA is comparable to everybody being in the middle of the room talking at once, but with each pair in a different language.
  - The French-speaking couple just hones in on the French, rejecting everything that is not French as noise.
  - Thus, the key to CDMA is to be able to extract the desired signal while rejecting everything else as random noise.

Go watch [The Interpreter (2005)]

CDMA: Near-Far Problem

- At first, CDMA did not appear to be suitable for mobile communication systems because of this problem.
- Occur when many mobile users share the same channel.
- In an uplink, the signals received from each user at the receiver travel through different channels. This gives rise to the near-far effect, where users that are close to the uplink receiver can cause a great deal of interference to user's farther away.
  - In general, the strongest received mobile signal will **capture** the demodulator at a base station.
- Stronger received signal levels raise the noise floor at the base station demodulators for the weaker signals, thereby decreasing the probability that weaker signals will be received.
- Fast **power control** mechanisms solve this problem.
  - Regulate the transmit power of individual terminals in a manner that received power levels are balanced at the base station.

How many orthogonal signals?

- No signal can be both strictly time-limited and strictly band-limited.
- We adopt a softer definition of bandwidth and/or duration (e.g., the percentage of energy outside the band [-B, B] or outside the time interval [0, T] not exceeding a given bound ε.
- Q: How many mutually orthogonal signals with (approximate) duration T and (approximate) bandwidth B can be constructed?
- A: About 2TB
  - No explicit answer in terms of T, B, and ε is known.
  - Unless the product TB is small.
- A *K*-user orthogonal CDMA system employing antipodal modulation at the rate of R bits per second requires bandwidth approximately equal to

$$B = \frac{1}{2} RK$$