# ECS455 - 4 - 6 - CDMA

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3:18 PM

Uplink CDMA

user 1 wants to transmit $\overset{s_1}{14}$ .. send $14 \times \underline{c}_1 = 14 \times \overbrace{[1\ 1\ 1\ 1]}^{\underline{c}_1}$

" 2 " " $20 = s_2$ $\quad 20 \times \underbrace{[1\ 1\ -1\ -1]}_{\underline{c}_2}$

" 3 " $26 = s_3$ $\quad 26 \times \overbrace{[1\ -1\ -1\ 1]}^{\underline{c}_3}$

" 4 " $-5 = s_4$ $\quad -5 \times \underbrace{[1\ -1\ 1\ -1]}_{\underline{c}_4}$

@ BS, $\underline{r} = [55\ 13\ -37\ 25]$

user $i$ will transmit $s_i \underline{c}_i$

$$\underline{r} = \sum_i s_i \underline{c}_i + \underbrace{\underline{n}}_{0}$$

At the BS (receiver),

to recover $s_3$,

let's try to compute

$$\langle \underline{r}, \underline{c}_3 \rangle = \underline{r} \cdot \underline{c}_3 = \left(\sum_i s_i \underline{c}_i\right) \cdot \underline{c}_3$$

$$= \sum_i s_i \underline{c}_i \cdot \underline{c}_3 = s_3 \underbrace{\underline{c}_3 \cdot \underline{c}_3}_{\substack{[1\ -1\ -1\ 1] \cdot [1\ -1\ -1\ 1] \\ = 4}}$$

$$= 4 s_3$$

$$\hat{s}_3 = \frac{1}{4} \langle \underline{r}, \underline{c}_3 \rangle$$

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$$\downarrow$$

$$\hat{s}_i = \frac{1}{4} \langle \underline{r}, \underline{c}_i \rangle$$

MATLAB

Define the code matrix $\quad C = \begin{bmatrix} \boxed{\quad \underline{c}_1 \quad} \\ \boxed{\quad \underline{c}_2 \quad} \\ \boxed{\quad \underline{c}_3 \quad} \\ \boxed{\quad \underline{c}_4 \quad} \end{bmatrix}$

Note that $\quad CC^T = 4 * I \qquad = N * I$

$$\begin{bmatrix} \boxed{\quad \underline{c}_1 \quad} \\ \boxed{\quad \underline{c}_2 \quad} \\ \boxed{\quad \underline{c}_3 \quad} \\ \boxed{\quad \underline{c}_4 \quad} \end{bmatrix} * \begin{bmatrix} \boxed{\underline{c}_1^T} & \boxed{\underline{c}_2^T} & \boxed{\underline{c}_3^T} & \boxed{\underline{c}_4^T} \end{bmatrix} = \begin{bmatrix} 4 & 0 & 0 & 0 \\ 0 & 4 & 0 & 0 \\ 0 & 0 & 4 & 0 \\ 0 & 0 & 0 & 4 \end{bmatrix}$$

$$= 4I$$

Define message (row) vector

$$\underline{s} = [s_1 \quad s_2 \quad s_3 \quad s_4]$$

The received (row) vector

$$\underline{r} = \sum_i s_i \underline{c}_i = [s_1 \quad s_2 \quad s_3 \quad s_4] \begin{bmatrix} \underline{c}_1 \\ \underline{c}_2 \\ \underline{c}_3 \\ \underline{c}_4 \end{bmatrix}$$

$$= \underline{s} C$$

To recover $s_j$, we compute

$$\hat{s}_j = \frac{1}{4} \langle \underline{r}, \underline{c}_j \rangle = \frac{1}{4} \underline{r} \, \underline{c}_j^T$$

$$\hat{\underline{s}} = [\hat{s}_1 \ \hat{s}_2 \ \hat{s}_3 \ \hat{s}_4] = \left[\tfrac{1}{4}\underline{r}\,\underline{c}_1^T \ \ \tfrac{1}{4}\underline{r}\,\underline{c}_2^T \ \ \tfrac{1}{4}\underline{r}\,c_3^T \ \ \tfrac{1}{4}\underline{r}\,c_4^T\right]$$

$$= \tfrac{1}{4}\underline{r}\left[\underline{c}_1^T \ \ \underline{c}_2^T \ \ \underline{c}_3^T \ \ \underline{c}_4^T\right]$$

$$= \tfrac{1}{4}\underline{r}\,C^T$$

Conclusion : Start with $\underline{s}$, $C$

Tx : $\underline{s}C \rightarrow \underline{r}$

Rx : $\frac{1}{4}\underline{r}\,C^T \rightarrow \hat{\underline{s}}$

check: $\frac{1}{4}\underline{r}C^T = \frac{1}{4}(\underline{s}C)C^T = \frac{1}{4}\underline{s}\,4I = \underline{s}$

**Downlink**

BS $\longrightarrow$ MS's

BS knows $s_1, s_2, \ldots, s_N$
$\underline{c}_1, \underline{c}_2, \ldots, \underline{c}_N$

Transmit $\underline{s}C = \sum_i s_i \underline{c}_i$

Each MS
Receives $\underline{r} = \underline{s}C + \underline{n} \rightarrow 0$

$i^{th}$ MS recovers $s_i$ by

$\frac{1}{N}\underline{r}\,\underline{c}_i^T$

only need its own code.

**Uplink**

MS's $\longrightarrow$ BS

$i^{th}$ MS only knows $s_i$, $\underline{c}_i$

Transmit $s_i \underline{c}_i$

these signals from different users are combined in the air.

$\underline{r} = \sum_i s_i \underline{c}_i = \underline{s}C$

BS recovers

$\hat{\underline{s}} = \frac{1}{N}\underline{r}\,C^T$

need to know all $\underline{c}_i$