Lecture 29: (20 Oct 2008)

Soft handoff in CDMA systems:

Uplink:

A mobile's signal is received at multiple BSs.

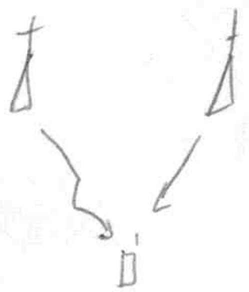
→ Decode at all BSs (need knowledge of spreading code) & select correct frame (if any) using CRC check

→ Jointly decode (after appropriate MRC combining) signals from all BSs.
- Practical for soft handoff between sectors whose BSs are colocated.

→ Soft handoff provides diversity gain.
- Requires more hardware / more complex processing (no other penalty).

→ Power control during soft handoff
- Reduce power if any BS sends down command. (OR of DOWNs)

Downlink:



- Mobile can receive from multiple BSs.
  * Uses appropriate spreading code & delay information to place additional RAKE fingers in the RAKE receiver
  * Decodes the combined signal (MRC in RAKE)
- Diversity gain achieved
  - Requires transmission from both BSs. (Power consumed at 2 BSs)
  - Requires one spreading code from each BS. (Code resource could have been used by another user).

- Power control during soft handoff
  - Both BSs transmit same power.

% of users in soft handoff should be kept at optimum level
  - Trade-off between performance & user capacity.

Sectorization in CDMA:

In GSM, sectorization leads to:

- reduced interference
- loss in trunking efficiency because servers (freq. carriers) need to be split for the sectors (possibility of high inter-sector interference due to non-ideal directional antennas) i.e., freq. reuse across sectors not possible in reality.

In CDMA, sectorization leads to:
- reduced interference
- additional inter-sector interference not dominant
  $\Rightarrow$ reuse across sectors possible

Cellular system design:

$\boxed{\text{Option 3}}$ (Based on OFDM)

In narrowband GSM systems: - Narrowband signal $\Rightarrow$ no freq. diversity
- Interference avoided
- Freq. reuse factor is low.

Increase in freq. reuse factor leads to severe interference.

Since no. of interferers is small & their power high, worst-case interference is severe.

In CDMA systems:

- Freq. reuse factor is high
- Inter-cell & intra-cell interference.
  * Since interference is from many users at diff. locations, interference is averaged & worst-case interference is less severe.
- Wideband transmit signal ⇒ freq. diversity.

In OFDM-based systems: (eg. Flash-OFDM)

- Intra-cell interference not present
- Inter-cell interference is averaged by freq. hopping.
- Wide-band tx. signal ⇒ freq. diversity.

OFDM cellular system example:

- Use OFDM to split available BW into N_c subchannels (subcarriers) (tones) (N_c non-interfering parallel channels)
- These N_c subcarriers are allocated among users in a cell such that
  * there is no intra-cell interference (users get non-overlapping allocation of subcarriers)
  * inter-cell interference is averaged (frequency hopping is used)
  * allocated subcarriers are spread across the whole BW for each user.

Suppose each user is allocated n subcarriers.

(i.e. $\frac{N_c}{n}$ users get n (non-overlapping) subcarriers each).

These n subcarriers should be

- spread out over the BW
- hopped over time with a different hopping pattern for each BS.

Construction of these hopping patterns can be simplified by choosing

- periodic hopping patterns with a period of N_c OFDM symbols
- N_c to be a prime number.

<u>Toy Example:</u>

The above hopping pattern can be represented by a $N_c \times N_c$ square matrix. Each entry in this matrix is the virtual channel index (between 0 & $N_c - 1$)

→ Each virtual channel hops over different subcarriers at different OFDM symbol times

→ Each user is allocated n virtual channels.

We require that in a hopping pattern

- each virtual channel hops over all the sub-carriers during the period of the pattern
- During any OFDM symbol time, different virtual channels occupy different sub-carriers.

⇒ Each row & column should contain every virtual channel number $(0, 1, \ldots, N_c - 1)$

Eg: $N_c = 5$

$$\begin{bmatrix} 0 & 1 & 2 & 3 & 4 \\ 2 & 3 & 4 & 0 & 1 \\ 4 & 0 & 1 & 2 & 3 \\ 1 & 2 & 3 & 4 & 0 \\ 3 & 4 & 0 & 1 & 2 \end{bmatrix} \rightarrow \text{I}$$

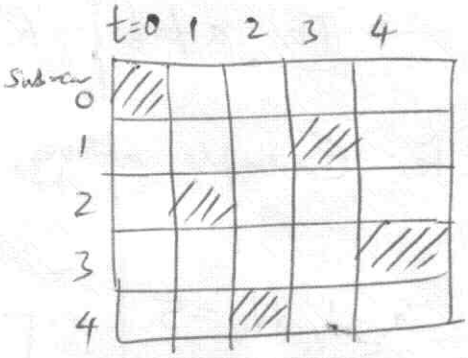
$\boxed{\text{Lecture 30:}}$ (21 Oct 2008)

$(i,j)^{th}$ entry of matrix : i^{th} sub-carrier in OFDM symbol j is assigned to the virtual channel index mentioned

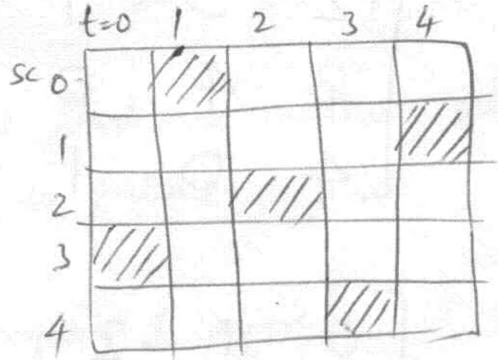
$i, j, \in \{0,1,2,3,4\}$.

Virtual channel 0 :

Subcarrier 0 at time 0
2 at time 1
4 at time 2
1 at time 3
3 at time 4



Virtual channel 1 :



& so on.

Each matrix like the one above (I) is called a <u>Latin square</u>.

Each BS uses a different Latin square.

For prime N_C, we can find $N_C - 1$ latin squares such that every pair of virtual channels of 2 different BSs is mutually orthogonal. Orthogonal $\Rightarrow$ exactly one time/subcarrier collision occurs for every pair of virtual channels.

For $a = 1, 2, \ldots, N_C - 1$

define an $N_C \times N_C$ matrix R^a with $(i,j)^{th}$ entry

$$R^a_{ij} = (ai + j) \text{ modulo } N_C.$$

Result:

→ R^a is a latin square

→ For $a \neq b$, R^a & R^b are orthogonal.

For Example above, $a = 2$, $N_C = 5$.

$a=1, N_c=5$

$(i+j) \bmod 5$

$i = 0,1,2,3,4$
$j = 0,1,2,3,4$

$$\begin{bmatrix} 0 & 1 & 2 & 3 & 4 \\ 1 & 2 & 3 & 4 & 0 \\ 2 & 3 & 4 & 0 & 1 \\ 3 & 4 & 0 & 1 & 2 \\ 4 & 0 & 1 & 2 & 3 \end{bmatrix}$$

$a=2, N_c=5$

$(2i+j) \bmod 5$

$i = 0,1,2,3,4$
$j = 0,1,2,3,4$

$$\begin{bmatrix} 0 & 1 & 2 & 3 & 4 \\ 2 & 3 & 4 & 0 & 1 \\ 4 & 0 & 1 & 2 & 3 \\ 1 & 2 & 3 & 4 & 0 \\ 3 & 4 & 0 & 1 & 2 \end{bmatrix}.$$

$a=3, N_c=5$

$$\begin{bmatrix} 0 & 1 & 2 & 3 & 4 \\ 3 & 4 & 0 & 1 & 2 \\ 1 & 2 & 3 & 4 & 0 \\ 4 & 0 & 1 & 2 & 3 \\ 2 & 3 & 4 & 0 & 1 \end{bmatrix}$$

~~$a=4, N_c=5$~~

$$\begin{bmatrix} 0 & 1 & 2 & 3 & 4 \\ 4 & 0 & 1 & 2 & 3 \\ 2 & 3 & 4 & 0 & 1 \end{bmatrix}$$

$a=4, N_c=5$

$$\begin{bmatrix} 0 & 1 & 2 & 3 & 4 \\ 4 & 0 & 1 & 2 & 3 \\ 3 & 4 & 0 & 1 & 2 \\ 2 & 3 & 4 & 0 & 1 \\ 1 & 2 & 3 & 4 & 0 \end{bmatrix}$$

$N_c - 1$ latin squares that are mutually orthogonal can be constructed if N_c is prime.

Let BS1 use latin square 1 above

& BS2 use latin square 2 above

Consider Virtual Channel 1 in BS1

	1			
1				
				1
			1	
		1		

Interference from BS2 at time 0 → VC 1
1 → VC 1
2 → VC 0
3 → VC 4
4 → VC 3

Similarly VC 2 in BS1 sees interference from BS2 as follows –

time 0 → VC4
1 → VC3
2 → VC2
3 → VC1
4 → VC0

<u>Therefore, we have</u>

① Each virtual channels hops over the entire band (freq. diversity)

② Each virtual channel sees interference once from N_c different virtual channels in another cell during a period of N_c symbols
⇒ No single strong virtual channel can cause severe degradation in performance.

Above discussion assumes
– <u>synchronization</u> of users within a cell ~~to~~ their corresponding base-station
– <u>synchronization</u> of transmissions of neighbouring BSs
<u>at the level of OFDM symbols.</u> (somewhat coarse synch.)

Due to the symmetry above, it is enough to assess the performance of one single virtual channel.
Coding over several OFDM symbols allows freq. div. & interference averaging.

Sectorization:

In GSM: - Interference reduced

- Freq. reuse may not be possible across sectors
  → can significantly reduce SINR

In CDMA: - Interference reduced

- Freq. reuse across sectors will not reduce SINR significantly.

In OFDM: - Interference reduced

- Freq. reuse across sectors will reduce SINR (like GSM)

SINR in GSM: High SINR because of low freq. reuse

CDMA: Low SINR because of intra-cell & inter-cell interference

OFDM: High SINR close to BS, Low away from BS (because of no intra-cell interference)

Flash OFDM example: (See pp. 153-154)

$N_c = 113$ over 1.25 MHz.

Summary of various cellular systems studied:

	Narrowband system (GSM)	Wideband CDMA (IS-95)	Wideband OFDM (FlashOFDM)
Signal	Narrowband	Wideband.	Wideband
Intra-cell	Orthogonal allocation + No interference	Pseudo-random + Significant interference	Orthogonal + No interference
Inter-cell	Partial reuse + Bursty interference	Full reuse + Averaged interference	Full reuse + Averaged interference
Operating SINR	High	Low	Range: Low to High
Power control accuracy	Low	High	Low
PAPR	Low	Medium	High.