Lecture 23 : (30 Sep 2006)

$$\underline{y} = \underset{\uparrow}{H_c}\, \underline{d} + \underline{w}$$

circulant matrix

$$F\underline{y} = F H_c \underline{d} + F\underline{w}$$

($F H_c = H F$ where H is diagonal, from previous page).

$$\Rightarrow F\underline{y} = H F \underline{d} + F\underline{w}.$$

Suppose we want to send $\tilde{\underline{d}}$, we sent $F^H \tilde{\underline{d}}$.

We will receive $F\underline{y} = H F F^H \tilde{\underline{d}} + F\underline{w}$

$$\Rightarrow F\underline{y} = H\tilde{\underline{d}} + F\underline{w}$$

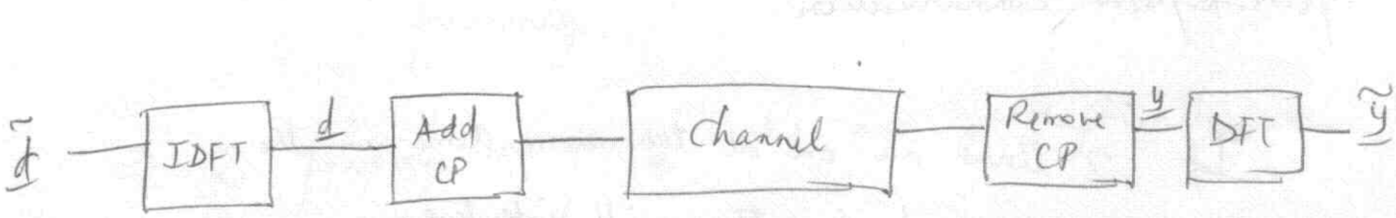
$$\text{(or)} \quad \tilde{\underline{y}} = \underset{\uparrow}{H}\tilde{\underline{d}} + \tilde{\underline{w}}$$

diagonal matrix

Thus, we have a set of N parallel channels

$$\tilde{y}_i = H_i \tilde{d}_i + \tilde{w}_i \quad i = 0, 1, \ldots, N-1$$

Equivalent block diagram for the above system:



$\tilde{\underline{w}} \sim CN(\underline{0}, N_0 I)$ similar to $\underline{w}$.

$H_i \sim CN\left(0, \frac{1}{N}\sum_{l=0}^{L-1} E[|h_l|^2]\right) \rightarrow$ Each channel is a Rayleigh fading channel (div. gain 1).

Since channels are correlated, appropriate coding + interleaving is necessary to achieve div gain. This is similar to the time diversity coding problem.

- Coh. bw to be considered here instead of coh-time.

  Successive symbols of the diversity code should be transmitted over almost independent fading channels (separated by coh. BW).

- coh. bw inversely proportional to delay spread L.

  Available BW could be decomposed into L independently fading bands approximately

  $\Rightarrow$ Total div. gain achievable $= L$.

Each channel corresponds to a particular freq (because of the DFT). Several orthogonal frequency channels are used in parallel.

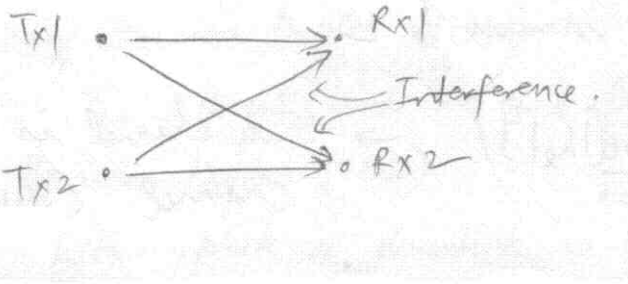
Hence the name Orthogonal frequency division multiplexing (OFDM)

Impact of channel uncertainty on diversity $\}$ Self-study.

- See Section 3.5

Now, we move on to systems with multiple wireless links active at the same time. So far, we talked only about point-to-point communication.

If 2 links are on at the same time in the same frequency band, they will interfere.

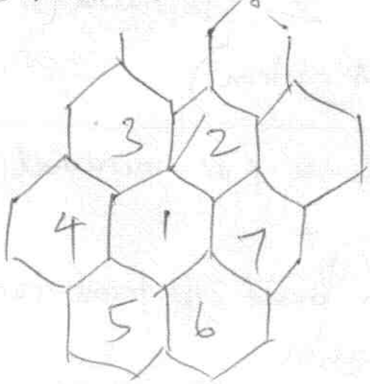


To build a wireless system with several potential transmitters & receivers, it is important to manage the interference.

In a cellular system, interference management is crucial. There are many ways to do this. We will discuss a few options.

Eg: Interference management can be done by
- cell partitioning
+
frequency planning.

Step 1: Divide coverage area into cells



Step 2: Divide available BW into partitions.
Assign frequency bands to cells such than neighboring cells do not use the same frequency.

$\Rightarrow$ 2 possibly interfering links are geographically well separated.

$\boxed{\text{Lecture 24:}}$ (6 Oct 2008)

Cellular system design:

In a cellular system, the area to be covered is divided into cells. Each cell has a "base-station" connected to the network we want to access (the wireline telephone network or the internet). "Mobile users" access the network & communicate through these "base-stations". The bandwidth (spectrum) allocated for the cellular system is assumed to be fixed.

How can this system be set up so that interference is managed well?

Need Uplink (or Reverse Link) design & Downlink (or Forward link) design)

$\boxed{\text{Option 1:}}$ (Eg: GSM system)

Inference avoidance (or minimal interference)   +   PHY link design based on point-to-point communication discussed earlier.

Uplink: Transmission from "mobile users" to "base-station"
Downlink: Transmission from "base-station" to "mobile users".
These are the 2 types of links possible given that all communication has to happen thro' the base-station.

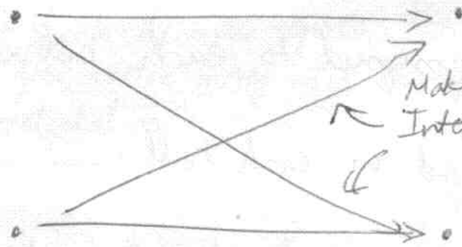
The uplink and downlink are usually separated in 2 ways.

1. Frequency Division Duplex (FDD)
   Two different frequency bands are used for uplink & downlink
2. Time Division Duplex (TDD)
   Either uplink or downlink is on at any <u>time</u>

Therefore, we will only talk about one link (either uplink or downlink) for now. A similar design could be used for the other link.

Interference avoidance:

Ensure that 2 transmissions in the same freq. band at the same time happen only at geographically well separated locations so that the interference between the links is small compared to the noise in each link (or) the required signal-to-interference-plus-noise ratio (SINR) is achieved.



Make sure this Interference is not too high & required SINR can be achieved.

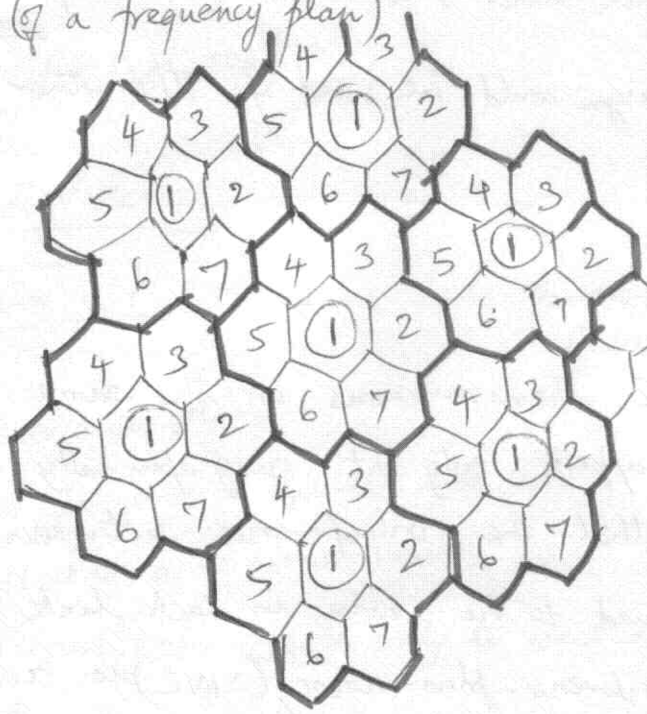
(1) Given bandwidth W Hz for uplink (or) downlink, divide into N bands of $\frac{W}{N}$ Hz.

(2) If one of these N bands is used in a cell, in what other cells can it be reused?

Or, How can these bands be allocated to the cells to meet the SINR requirement? What efficiency can be achieved in this reuse?

This is referred to as "frequency planning".

Eg: (of a frequency plan)



~~N = 7~~

~~(W is divided into 7 parts)~~

(See problem 4.1 for coloring problem equivalence)

$\rightarrow$ W is divided into N bands of $\frac{W}{N}$ each.

$\rightarrow$ n of these bands are assigned to each cell.

$\Rightarrow \frac{n}{N} W$ Hz is used in each cell.

Defn: Frequency Reuse factor $= \frac{n}{N} = \frac{1}{7}$ (in this example)

(A given band is used only once in 7 cells)

Defn: Cluster: A group of cells that share orthogonal resources with no interference or conflicts.

(Orange boundaries denote clusters in above example)

Number of cells in a cluster = 7

$\frac{W}{7}$ Hz could be assigned to each cell $\Rightarrow$ Reuse factor $= \frac{1}{7}$.

(assuming equal allocation to all cells)

GSM example

One band: $\frac{W}{N} = 200$ kHz Shared by 8 links using time-division.

For freq. reuse factor of $\frac{1}{7}$, $\approx \frac{W}{7} \frac{\times 8}{200\times10^3}$ users can be supported per cell.

If $W = 5$ MHz, $\frac{W}{7} \times \frac{8}{200\times10^3} = \frac{5000}{200} \times \frac{8}{7} = \frac{200}{7} \approx 28$ users per cell.

$\boxed{\text{Lecture 25:}}$ (7 Oct 2008)

A given freq. plan gives a particular SINR.

To increase users/cell, we need to increase the freq. reuse factor.

Can this be done while maintaining the SINR requirement?

Point-to-point link design gives the SINR requirement.

$\Rightarrow$ Change in freq. reuse may need change in point-to-point link design.

Sample SINR calculation:

* Consider the downlink.

P_r: Power received by mobile in cell 1 from base-station in cell 1

$$P_r = P_0 \left(\frac{d}{d_0}\right)^{-n}$$

P_0 : Transmit power

d : distance between mobile & base-station

d_0 : reference distance

n : Path loss exponent.

Power received from other cells transmitting in the same band

$$= \sum_{i=1}^{N_I} P_0 \left(\frac{d_i}{d_0}\right)^{-n}$$

d_i: Distance between mobile & i^{th} interfering base-station

Ratio of signal power to interference power

$$= \frac{S}{I} = \frac{P_0\left(\frac{d}{d_0}\right)^{-n}}{\sum_{i=1}^{N_I} P_0\left(\frac{d_i}{d_0}\right)^{-n}} = \frac{(d)^{-n}}{\sum_{i=1}^{N_I}(d_i)^{-n}}$$

$$\approx \frac{R^{-n}}{6\,D^{-n}}$$ where R : Radius of cell

D : Distance between cluster centers.

(First-tier of interfering cells
+
Farthest from desired base-station
+
Freq. reuse factor $\frac{1}{7}$)

For the hexagonal geometry above, $\frac{D}{R}$ can be shown to be $\sqrt{3N_c}$

where N_c is the number of cells in a cluster.

$$\Rightarrow \frac{S}{I} \approx \frac{\left(\sqrt{3N_c}\right)^n}{N_I} = \frac{\left(\sqrt{21}\right)^n}{6} \text{ for } N_c = 7$$

To guarantee an SINR, a minimum cluster size can be determined.

$$\left(SINR = \frac{S}{I+N} \approx \frac{S}{I} \text{ if } I \gg N\right).$$

Advantage of this approach:

+ Minimizes interference & simplifies link design to point-to-point link optimization.

Disadvantages:

— Frequency reuse factor low ⇒ inefficient use of spectrum because of static allocation of frequency resource.

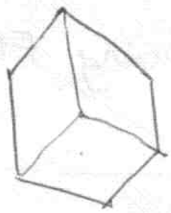
— Planning & incremental reconfiguration are complicated

— Nature of interference if frequency reuse is increased is severe ⇒ Not much averaging of interference leading to large variations

— Diversity in a channel of BW 200 kHz (narrowband channel) over a time slot ($\approx 577\mu s$) in GSM is likely to be 1. Frequency hopping + coding across slots necessary to improve diversity gain.

Sectorization:

What is it?



- Divide cell into sectors
- Each sector is served by a directional antenna to minimize interference between sectors.
- Base-stations for each sector colocated at the same site.

Advantages

+ Reduces no. of interfering users (N_I) (only users in the direction of coverage can interfere ⇒ $N_I = 2$ for 1/7 reuse instead of 6)

+ If sectors are ideal (coverage area of directional antennas are strictly disjoint), same frequency can be reused in all sectors ⇒ more capacity for the overall cell.

Disadvantages

— Sectors are not strictly disjoint ⇒ frequencies allocated to cell might have to be split among the sectors.

Eg For 3 sector case : n freq. assigned to cell. ↓ $\frac{n}{3}$ freq. assigned to each sector. } static splitting of resources among sectors may not be efficient.