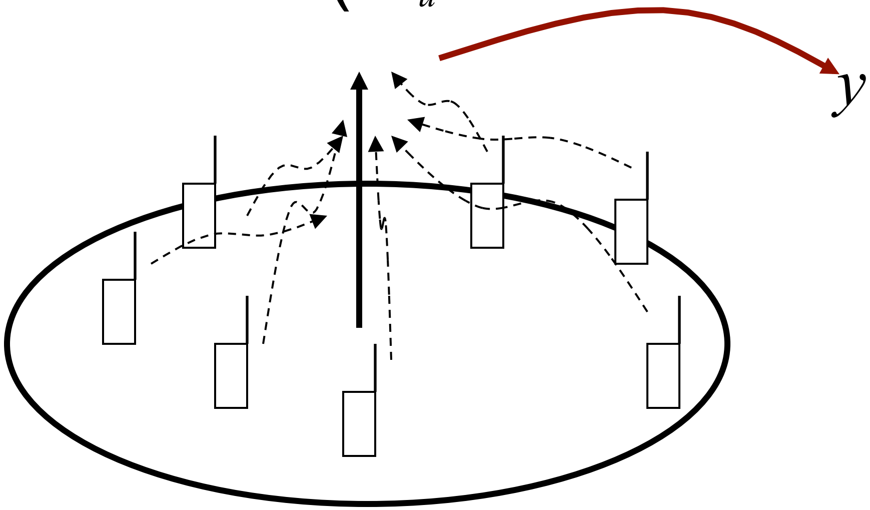
Final chapter!

Resource Partitioning in Multi-user Communications

Multi-user situation

Principle of Multiple Access - Orthogonal Resource Partitioning:

- Signal Model (N_u mobiles to base station)



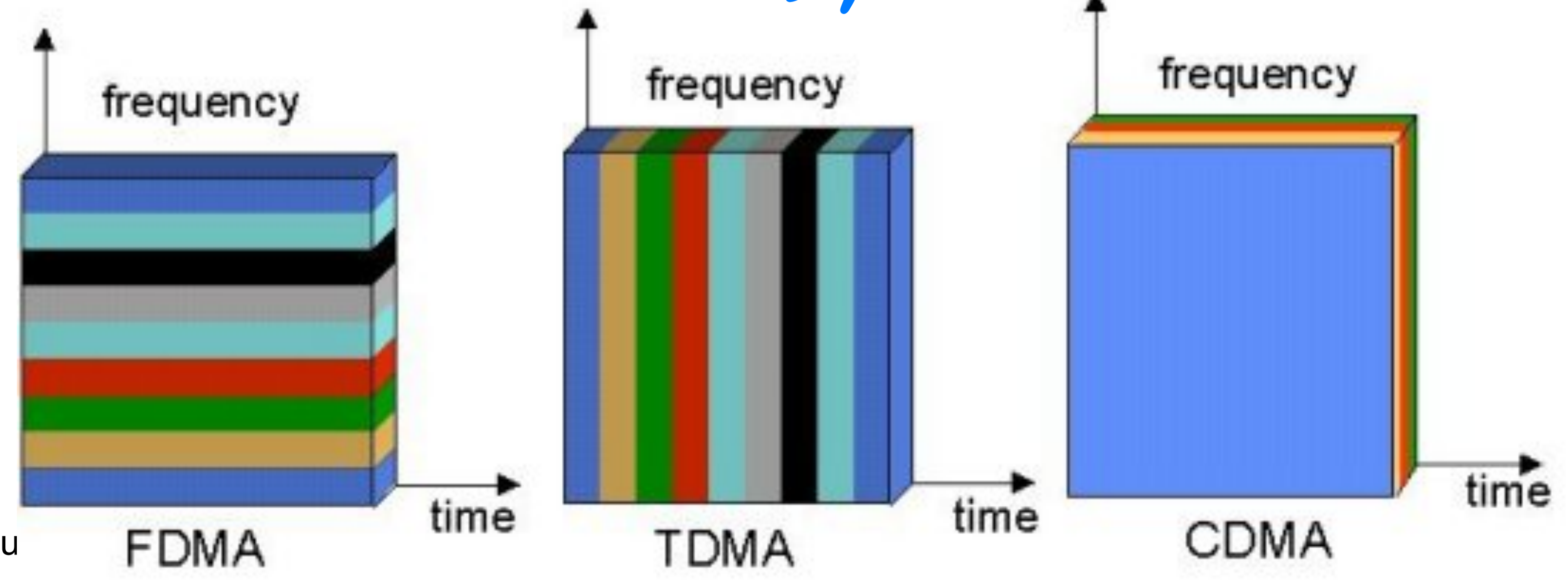
$$y(t) = \sum_{k=1}^{N_u} \alpha_k s_k(t) + n(t)$$

- Base Station → separates signals from K users from observing y(t) only.
- Needs some kinds of coordination among the K users for easy signal separations.

Orthogonal Multiple Access

- Three popular schemes
  - FDMA →Partition of resource in frequency domain.
  - TDMA →Partition of resource in time domain.
  - Deterministic CDMA → Partition of resource in code domain.

different spreading sequence



FDMA:

- The allocated spectrum (W) is divided into N frequency slots.
- Each channel has a bandwidth of W/N.
- Different mobiles are assigned to transmit at different frequency slots.
- No interference of signals between different users → **Orthogonal channels**

TDMA:

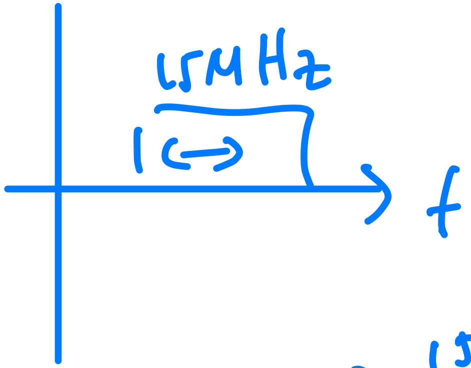
- All users use the same allocated spectrum W.
- Each user takes turn to use the BW.
- Channels == Time Slots.
- No interference of signals between different users → **Orthogonal channels**.

Comparison of FDMA / TDMA

- FDMA → partition resource in frequency dimension.
- TDMA → partition resource in time dimension.
- ***Q: Which way is more effective?***

(15 MHz spectrum)

FDMA



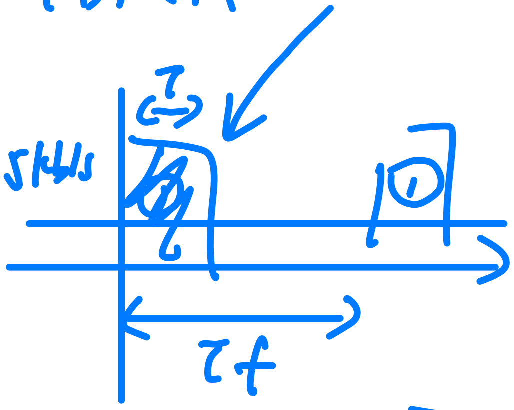
QS: Binary mod (1bit/symbol)

- $\overline{R_b}$ = 25kb/s bit rate per user

25kb/s

TDMA

$R_b = 15Mb/s$



$$N_{FDMA} = \frac{15MHz}{} = \frac{15M}{25k} = 600$$

$$N_{TDMA} = \frac{\tau f}{\tau}$$

$$\overline{R_b} = \frac{\#\text{ of bits tx per frame}}{\tau f}$$

$$25kb/s = \frac{R_b \tau}{\tau f}$$

$$25kb/s = \frac{15M\tau}{\tau f}$$

$$\frac{\tau f}{\tau} = 600$$

a) $W_{tx} = \frac{1}{\tau_s}$

$$R_b = \cancel{(\log_2 M)}^{1} \frac{1}{\tau_s}$$

↑ 25kb/s

W_{tx} = 25kHz

Comparison of FDMA / TDMA

only worry diversity

first generation

- FDMA
  - Requires N transceivers in the base station → Bulky.
  - Physical transmission rate per user is low → no need for equalizer

air conditioning, very hot!!!

- TDMA
  - Requires single transceiver in the base station → smaller size

only one radio!

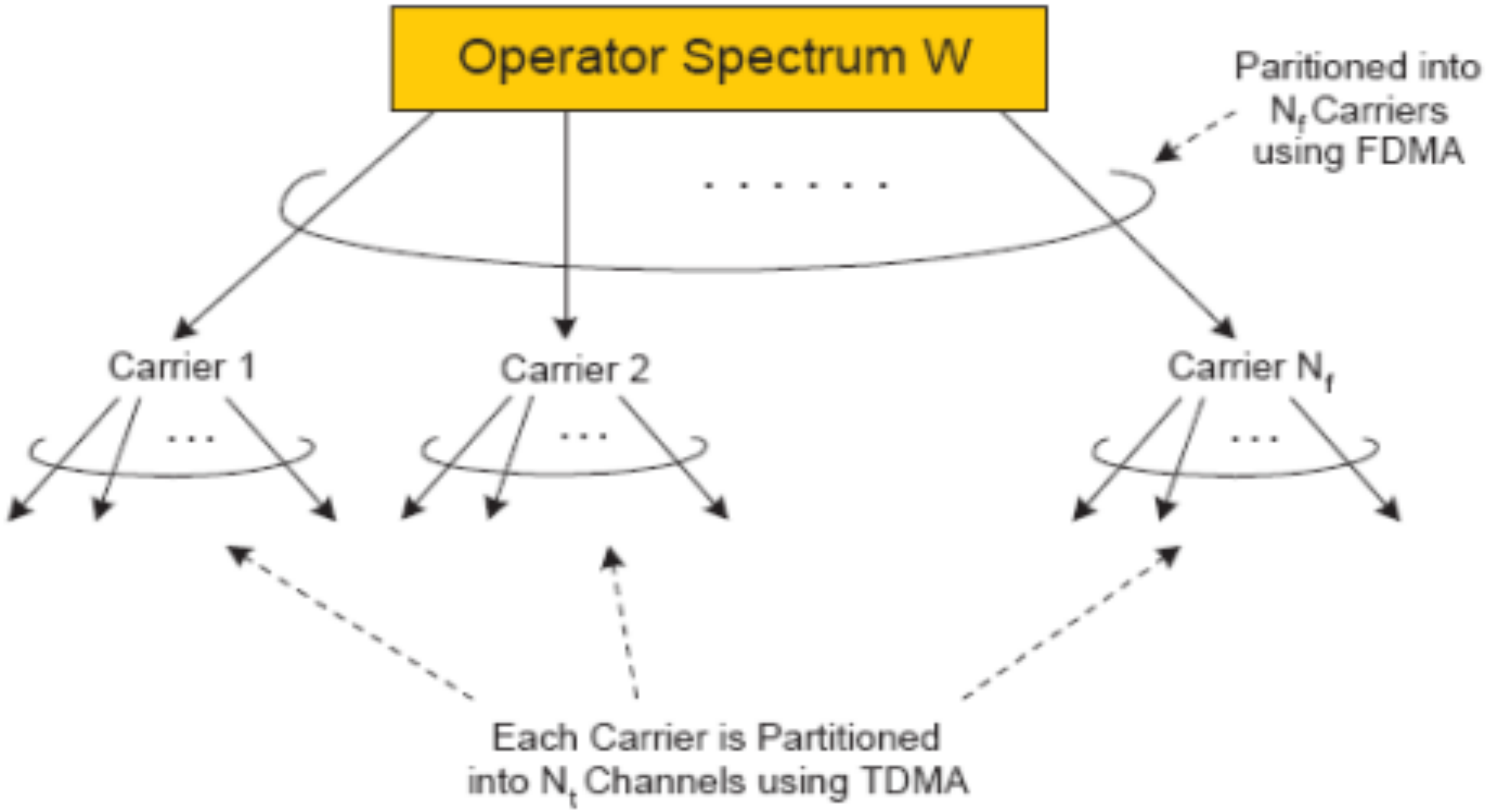
  - Physical transmission peak rate is very high → may need equalizer at the receiver.

exponential complexity

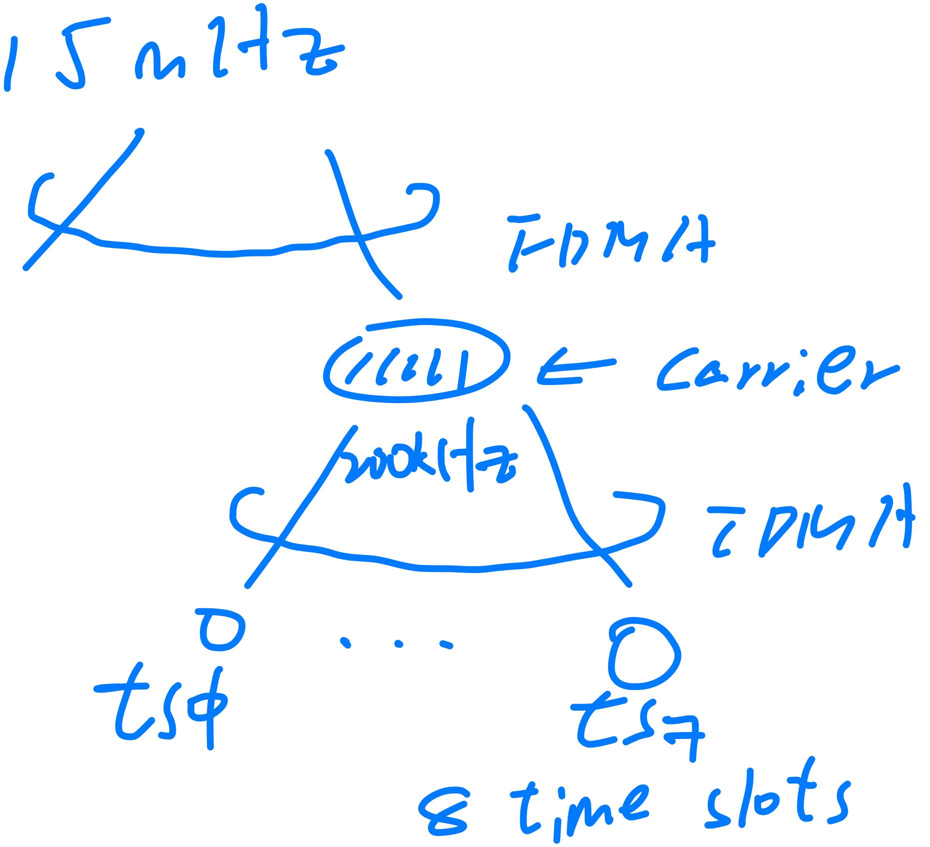
- Hybrid Design (2G)
  - FDMA/TDMA

Single Cell Capacity Comparisons.

- Example 3.1 - TDMA & FDMA
  - Suppose a spectrum of 15MHz is allocated to a mobile operator. Let the modulation throughput be 1 (bit per symbol), the data rate of individual user be 25kbps. Find out if FDMA or TDMA is better for the operator.
- Example 3.2 - Hybrid TDMA/FDMA
  - Suppose the channel coherence bandwidth is 200kHz. Using the same requirement and parameters as in Example 3.1, design a resource partitioning scheme which minimize the number of RF units in the base station at the constraint that no equalizer is used in the receiver.



Operator Spectrum W
Paritioned into N_f Carriers using FDMA
Carrier 1
Carrier 2
Carrier N_f
Each Carrier is Partitioned into N_t Channels using TDMA



$BW_{tx} = 200\text{kHz}$ # of radios = 75

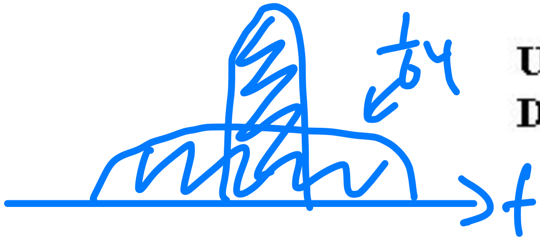
$B_c \approx 100\text{kHz}$

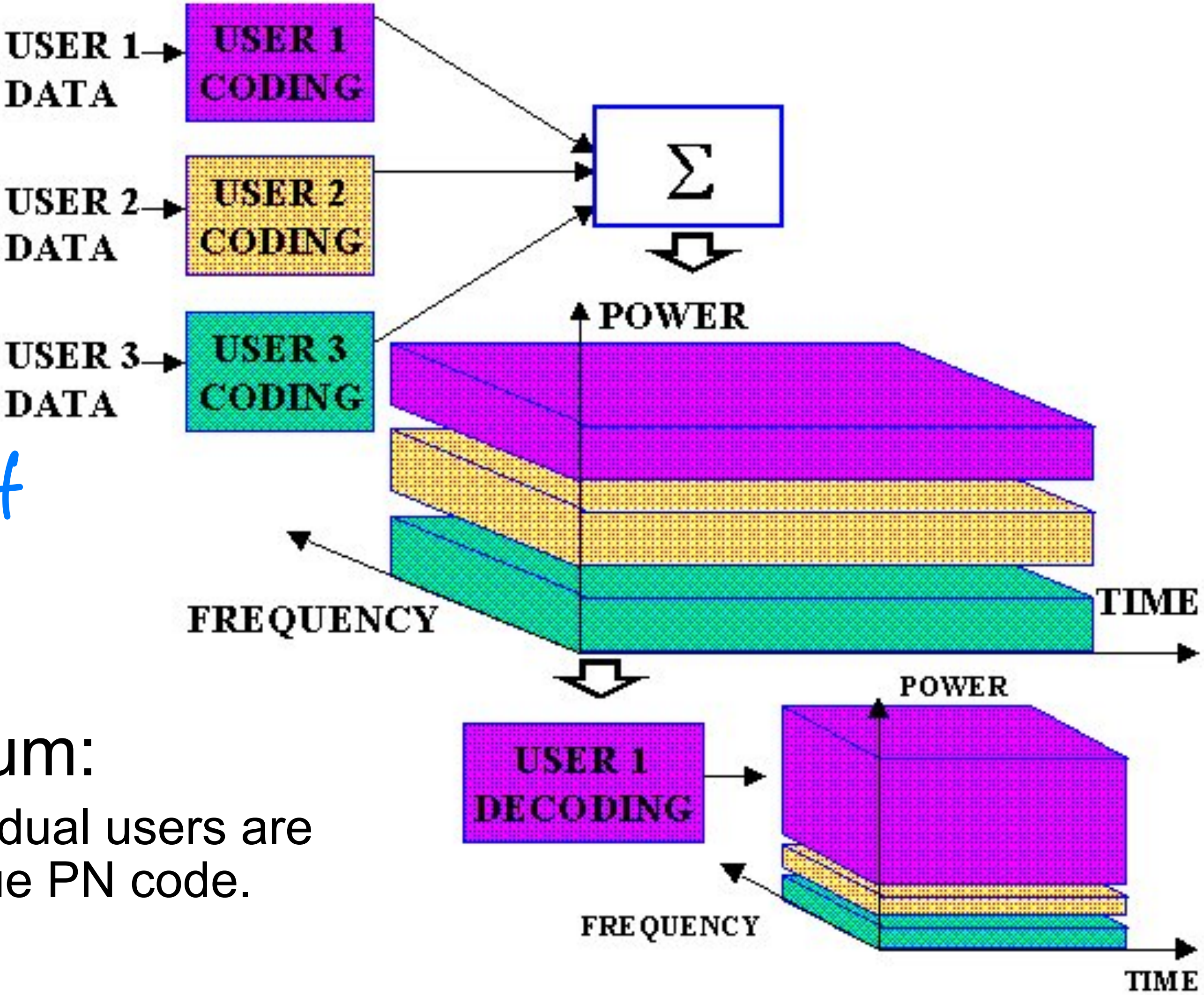
$L = 2$

CDMA:

$SF = \frac{1}{64}$

ISI due to freq. selective fading!





Spread-Spectrum:

- Signals from individual users are "spread" by a unique PN code.

CDMA

Cross-correlation between
Two codes (assigned to two
Different users)

$$W_k(t) = Despread[Y(t), c_k(t)]$$

$$= \underbrace{S_k(t)}_{\text{Signal Term}} + \underbrace{\sum_{j\neq k} S_j(t)\boxed{< c_j(t)c_k(t) >}}_{\text{Multi-user Interference}} + \underbrace{< Z(t), c_k(t) >}_{\text{Noise}}$$

- We have two types of CDMAs
  - (i) Deterministic CDMA:
    - PN codes have zero cross-correlation.

$$< c_j(t)c_k(t) >= \frac{1}{N}\sum_t c_k(t)c_j(t) = 0$$

$$\text{where } N = \frac{T_s}{T_c}$$

  - (ii) Random CDMA:
    - PN codes have small cross-correlation.

$$< c_j(t)c_k(t) >= \frac{1}{N}\sum_t c_k(t)c_j(t)$$

$$\leq \sqrt{\frac{2\log\log N}{N}} \text{ a.s.}$$

- know $c(t)$
- know timing

$$Y(t) = \sum_{i=1}^{K} \alpha_i S_k(t)\, c_k(t) + n(t)$$

$$w_k(t) = \overline{Y(t)/c_k(t)}$$

$$= \alpha_k s b(t) + \sum_{j \neq k} \underbrace{\alpha_j s_j \overline{c_j(t)\, c_k(t)}}_{\text{multiuser interference}} + \text{noise}$$

$$R_{jk} = \underline{\underline{0}} \quad \text{if } j \neq k$$

$\Rightarrow$ Deteministic CDMA

$$
\begin{array}{ll}
c_1(t) = & + \quad - \quad + \quad - \\
c_2(t) = & + \quad + \quad - \quad - \\
\hline
\frac{1}{4} & + \quad - \quad - \quad +
\end{array}
$$

$= 0$

$\langle c_1, c_2 \rangle = 0$

$\Rightarrow$ orthogonal sequence.

# of orthogonal set $\leq$ SF

# of users (O-CDMA) $\leq$ SF

Requires Synchronous Dispersing

not use D-CDMA on up-link

use D-CDMA on down-link

use Random CDMA

$c_j(t)\, c_k(t-\tau) = $ small

plenty combinations!

Random code: $\overline{c_j(t)\, c_k(t-\tau)} \le O\left(\sqrt{\frac{2\log |F}{ST}}\right)$

① Not code-limited !!!

② Asynchronous dispersing (no need o offset!)
(uplink!)

不一定有 2000 spreading sequences ∃ 2000 users

bottom neck?

multiuser interference > 0 !!!

How much interference you can tolerate!

Deterministic CDMA

- Capacity = # of PN codes in the set.

  → Code limited.
- Define "spreading factor" as the number of chips per modulation symbol.
- Cardinality of orthogonal PN code set = "spreading factor".
- Necessary condition
  - synchronization between codes.
  - only feasible in the forward link direction.

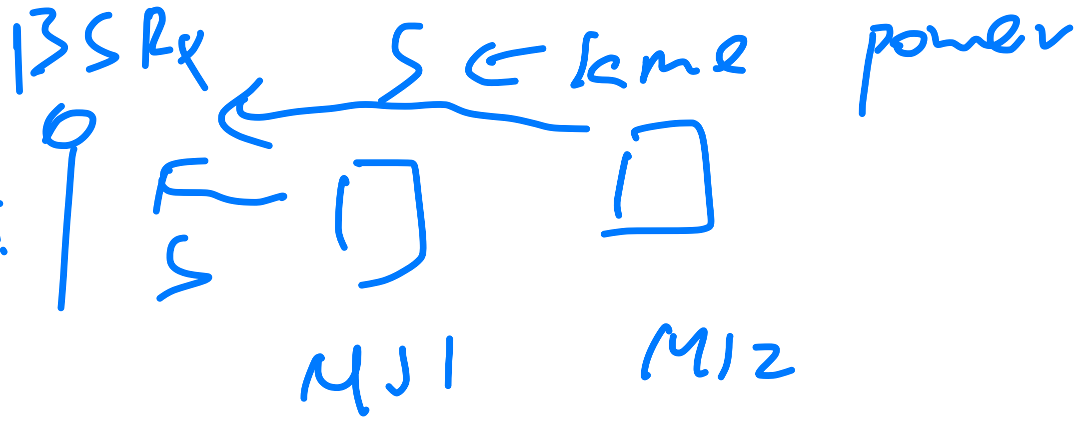
Random CDMA.

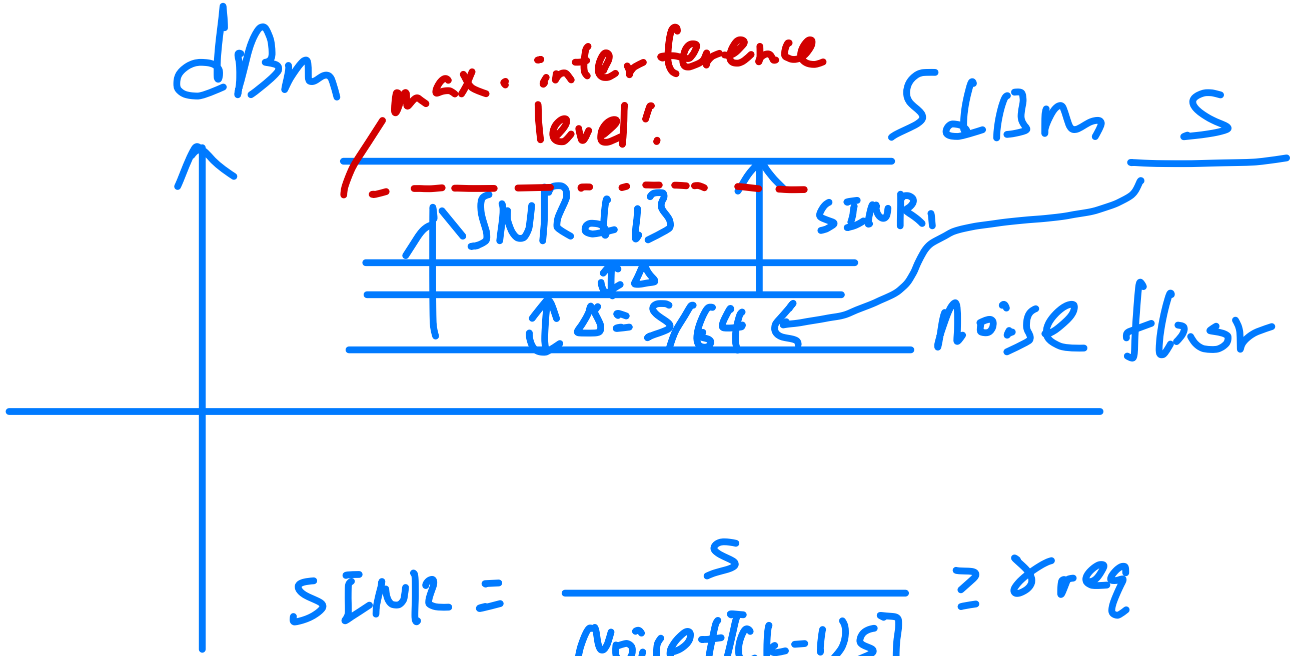
- Channels are not orthogonal!!!
- Yet, the effective interference of the other user is reduced by a factor called “processing gain”.

$$\Pr ocesin g\_Gain = \frac{T_b}{T_c}$$

- The capacity is not limited by the size of PN code set
- **Interference limited**.
- Used in the reverse link.

Assume that every user transmits same power !!!





$$SINR = \frac{S}{Noise + \left[\frac{(k-1)S}{SF}\right]} \geq \gamma_{req}$$

$$= \frac{SF}{k-1 \to k}$$ (noise small!)

$$k \leq \frac{SF}{\gamma_{req}}$$

Random CDMA

- Random CDMA suffers from the near-far problem.

  if one user transmit power very big ⇒ not work!

  - a user transmitting a very large power (or very near to the base station) will cause unacceptable interference level to the other users (because of the non-orthogonality property).
  - Power control scheme is needed to carefully control the transmitted power of each user.
  - The optimal situation is when the received signal powers from all users are equal.

OFDM
↓
OFDMA   Another coordination method

WI-FI   listen before talk, make sure that no people transmitting through the channel!