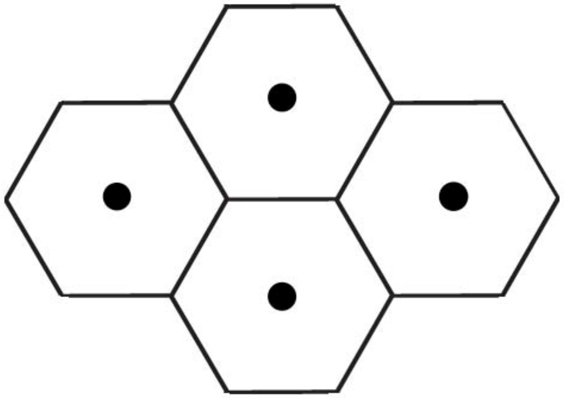
4. Cellular Systems: Multiple Access and Interference Management

Cellular Systems

- So far we have focused on point-to-point communication.
- In a cellular system, additional issues come into forefront:
  - Multiple access
  - Inter-cell interference management



Some History

- Cellular concept (Bell Labs, early 70's)
- AMPS (analog, early 80's)
- GSM (digital, narrowband, late 80's)
- IS-95 (digital, wideband, early 90's)
- 3G/4G systems

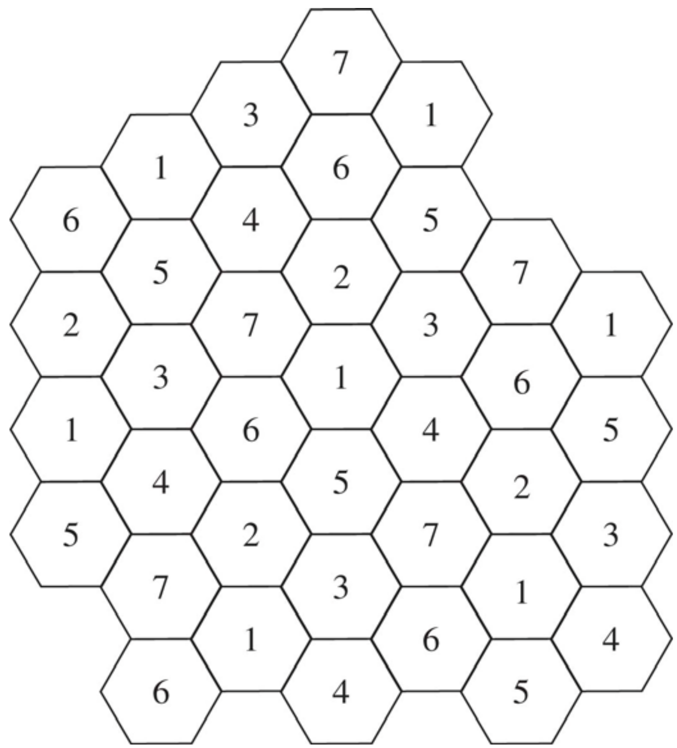
Four Systems

- Narrowband (GSM)
- Wideband system: CDMA (IS-95)
- Wideband system: OFDM (Flash OFDM)
- Opportunistic Communication (1x EV-DO) (later)

Narrowband (GSM)

- The total bandwidth is divided into many narrowband channels. (200 kHz in GSM)
- Users are given time slots in a narrowband channel (8 users)
- Multiple access is orthogonal: users within the cell never interfere with each other.
- Interference between users on the same channel in different cells is minimized by reusing the same channel only in cells far apart.
- Users operate at high SINR regime
- The price to pay is in reducing the overall available degrees of freedom.

Frequency Reuse



Frequency reuse is poor in narrowband systems because of lack of interference averaging.

Wideband System: CDMA

- Universal frequency reuse: all the users in all cells share the same bandwidth (1.25 MHz in IS-95 and 1x)
- Main advantages:
  - Maximizes the degrees of freedom usage
  - Allows interference averaging across many users.
  - Soft capacity limit
  - Allows soft handoff
  - Simplify frequency planning
- Challenges
  - Very tight power control to solve the near-far problem.
  - More sophisticated coding/signal processing to extract the information of each user in a very low SINR environment.

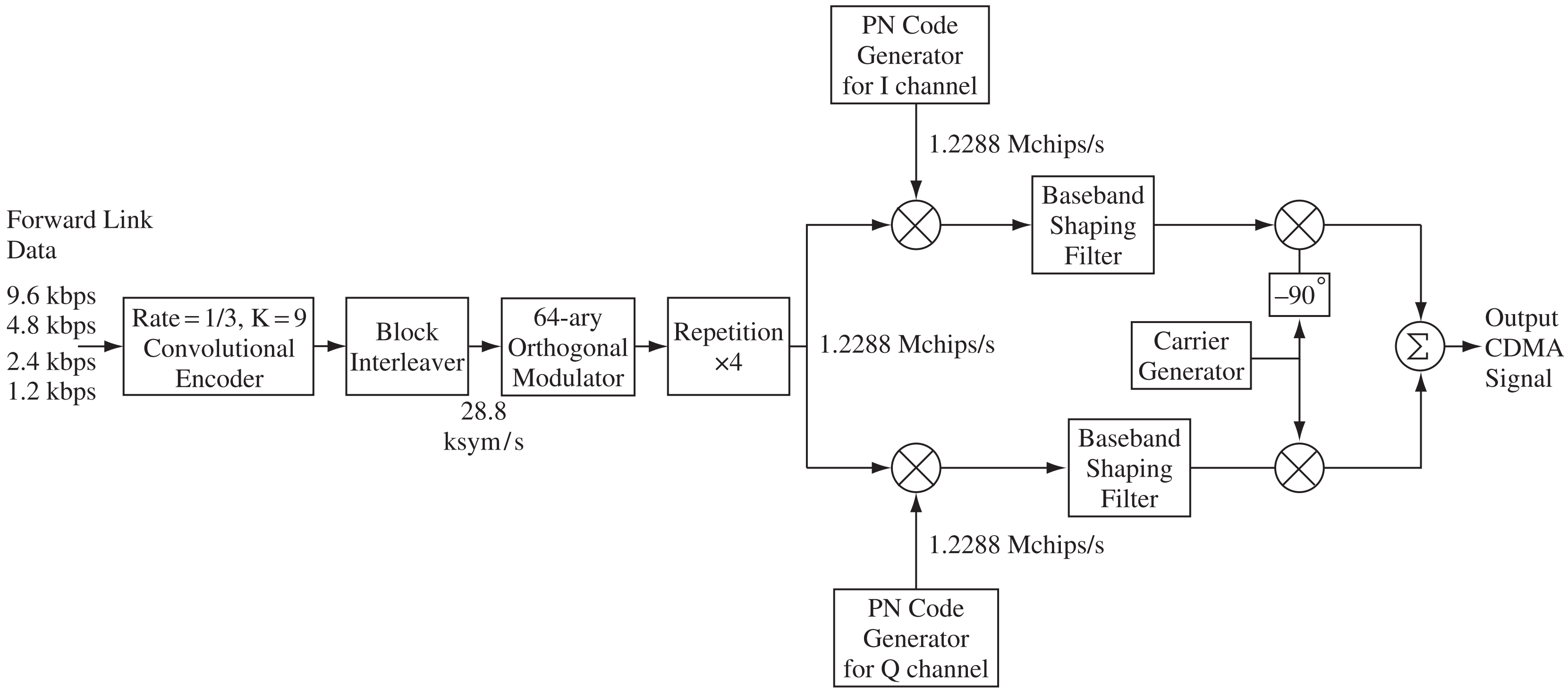
Design Goals

- 1) make the interference look as much like a white Gaussian noise as possible:
  - Spread each user's signal using a pseudonoise noise sequence
  - Tight power control for managing interference within the cell
  - Averaging interference from outside the cell as well as fluctuating voice activities of users.
- 2) apply point-to-point design for each link
  - Extract all possible diversity in the channel

Point-to-Point Link Design

- Extracting maximal diversity is the name of the game.
- Time diversity is obtained by interleaving across different coherence time and convolutional coding.
- Frequency diversity is obtained by Rake combining of the multipaths.
- Transmit diversity in 3G CDMA systems

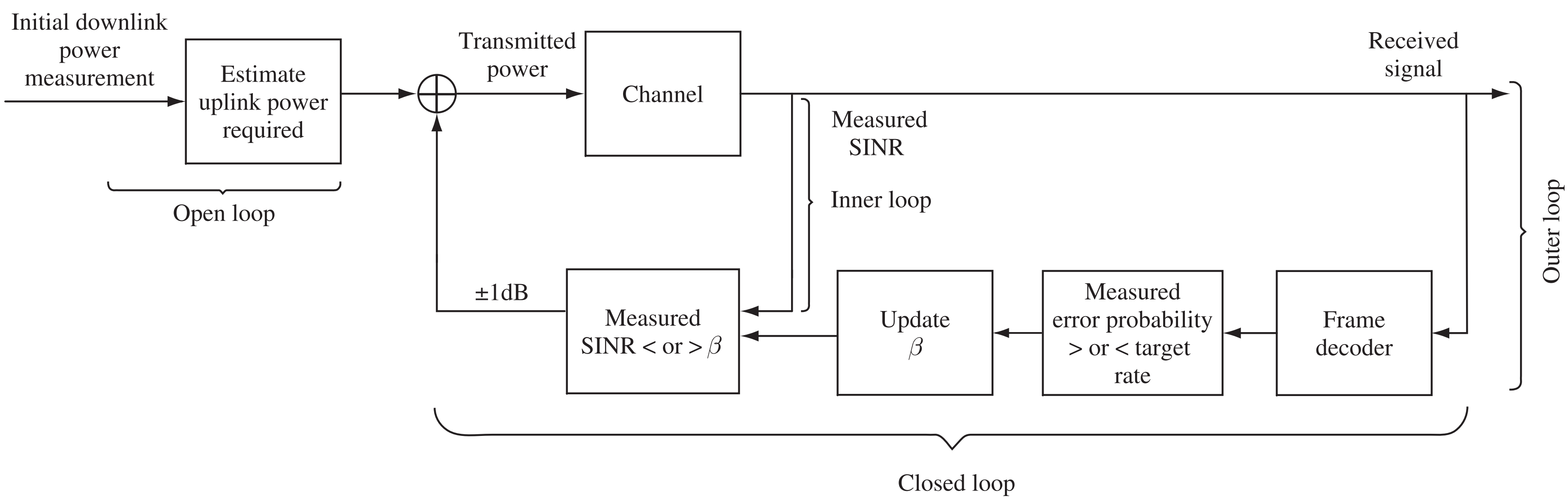
IS-95 Uplink


PN Code Generator for I channel
1.2288 Mchips/s
Baseband Shaping Filter
Forward Link Data
9.6 kbps
4.8 kbps
2.4 kbps
1.2 kbps
Rate = 1/3, K = 9 Convolutional Encoder
Block Interleaver
64-ary Orthogonal Modulator
Repetition ×4
1.2288 Mchips/s
28.8 ksym/s
–90°
Carrier Generator
Σ
Output CDMA Signal
Baseband Shaping Filter
1.2288 Mchips/s
PN Code Generator for Q channel

Power Control

- Maintain equal received power for all users in the cell
- Tough problem since the dynamic range is very wide. Users' attenuation can differ by many 10's of dB
- Consists of both open-loop and closed loop
- Open loop sets a reference point
- Closed loop is needed since IS-95 is FDD (frequency-division duplex)
- Consists of 1-bit up-down feedback at 800 Hz.
- Consumes about 10% of capacity in IS-95.
- Latency in access due to slow powering up of mobiles

Power Control



Interference Averaging

The received signal-to-interference-plus-noise ratio for a user:

$$\mathsf{SINR} = \frac{P}{N_0 + (K-1)P + \sum_{i \notin \mathsf{cell}} I_i}$$

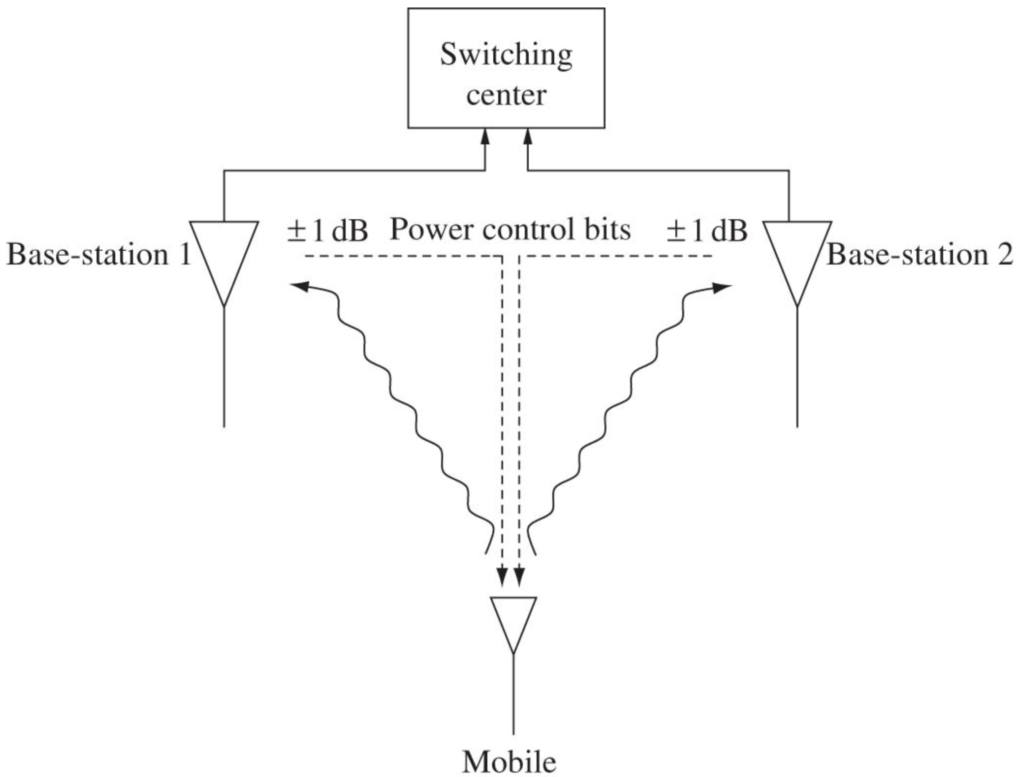
In a large system, each interferer contributes a small fraction of the total out-of-cell interference.

This can be viewed as providing **interference diversity**.

Same interference-averaging principle applies to voice activity and imperfect power control.

Soft Handoff

- Provides another form of diversity: macrodiversity



Uplink vs Downlink

- Can make downlink signals for different users orthogonal at the transmitter. Still because of multipaths, they are not completely orthogonal at the receiver.
- Rake is highly sub-optimal in the downlink. Equalization is beneficial as all users' data go thru the same channel and the aggregate rate is high.
- Less interference averaging: interference come from a few high-power base stations as opposed to many low-power mobiles.

Issues with CDMA

- In-cell interference reduces capacity.
- Power control is expensive, particularly for data applications where users have low duty cycle but require quick access to resource.
- In-cell interference is not an inhererent property of systems with universal frequency reuse.
- We can keep users in the cell orthogonal.

Wideband System: OFDM

- We have seen OFDM as a point-to-point modulation scheme, converting the frequency-selective channel into a parallel channel.
- It can also be used as a multiple access technique.
- By assigning different time/frequency slots to users, they can be kept orthogonal, no matter what the multipath channels are.
- Equalization is not needed.
- The key property of sinusoids is that they are eigenfunctions of all linear time-invariant channels.

In-cell Orthogonality

- The basic unit of resource is a virtual channel: a hopping sequence.
- Each hopping sequence spans all the sub-carriers to get full frequency-diversity.
- Coding is performed across the symbols in a hopping sequence.
- Hopping sequences of different virtual channels in a cell are orthogonal.
- Each user is assigned a number of virtual channels depending on their data rate requirement.

Slide 18

d1 mention about how OFDM in the downlink can avoid the equalization issues in CDMA. maybe a separate discussion on DL and UL.
dtse, 8/4/2005

d2 dtse, 8/4/2005

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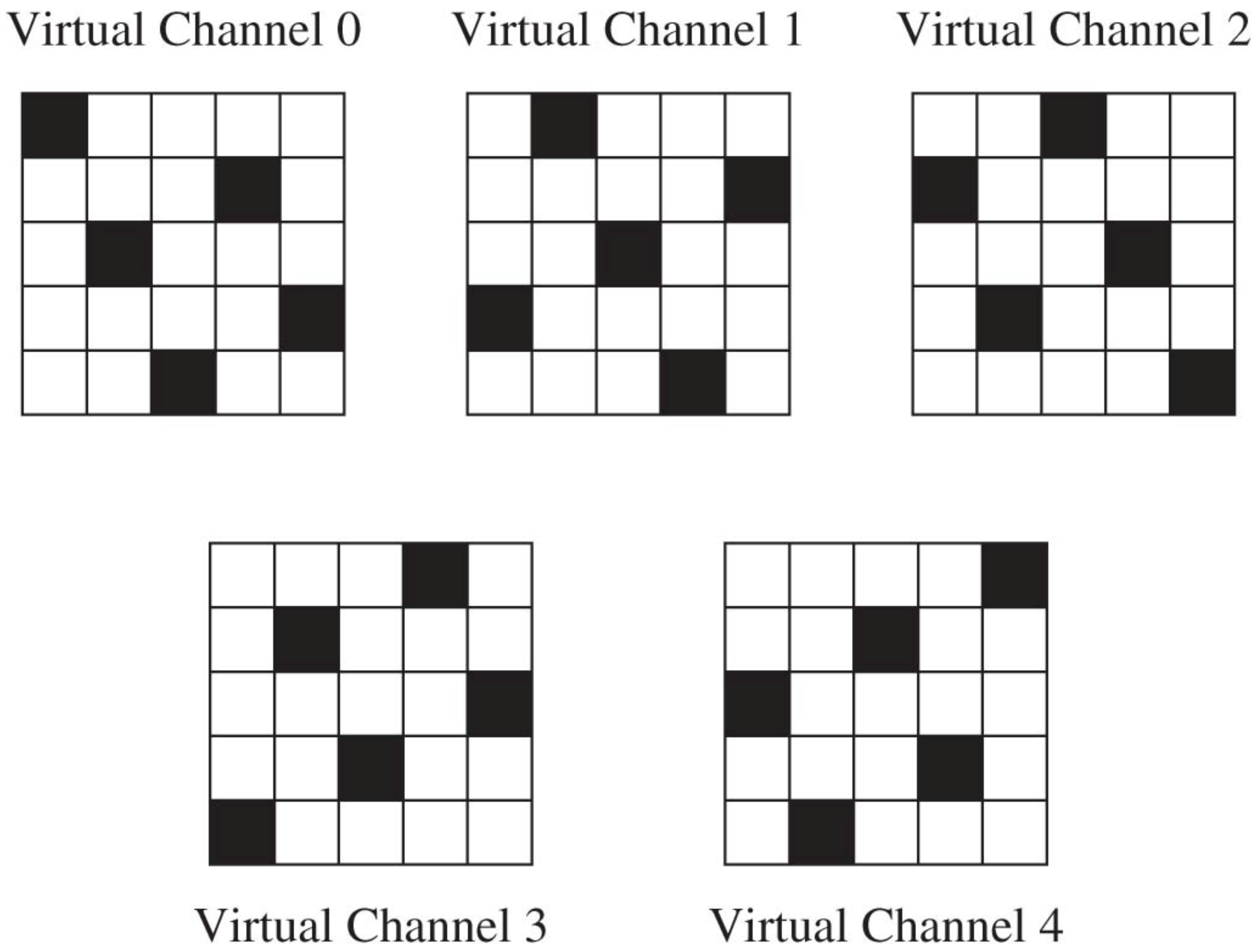
Example


Virtual Channel 0
Virtual Channel 1
Virtual Channel 2
Virtual Channel 3
Virtual Channel 4

Out-of-Cell Interference Averaging

- The hopping patterns of virtual channels in adjacent cells are designed such that any pair has minimal overlap.

- This ensures that a virtual channel sees interference from many users instead of a single strong user.

- This is a form of interference diversity.

Example: Flash OFDM

- Bandwidth = 1.25 Mz
- # of data sub-carriers = 113
- OFDM symbol = 128 samples = 100 μ s
- Cyclic prefix = 16 samples = 11 μ s delay spread

OFDM symbol time determines accuracy requirement of user synchronization (not chip time).

Ratio of cyclic prefix to OFDM symbol time determines overhead (fixed, unlike power control)

States of Users

- Users are divided into 3 states:
  - Active: users that are currently assigned virtual channels (<30)
  - Hold: users that are not sending data but maintain synchronization (<130)
  - Inactive (<1000)
- Users in hold state can be moved into active states very quickly.
- Because of the orthogonality property, tight power control is not crucial and this enables quick access for these users.
- Important for certain applications (requests for http transfers, acknowledgements, etc.)

Summary

	Narrowband system	Wideband CDMA	Wideband OFDM
Signal	Narrowband	Wideband	Wideband
Intra-cell BW allocation	Orthogonal	Pseudorandom	Orthogonal
Intra-cell interference	None	Significant	None
Inter-cell BW allocation	Partial reuse	Universal reuse	Universal reuse
Inter-cell uplink interference	Bursty	Averaged	Averaged
Accuracy of power control	Low	High	Low
Operating SINR	High	Low	Range: low to high
PAPR of uplink signal	Low	Medium	High
Example system	GSM	IS-95	Flash-OFDM