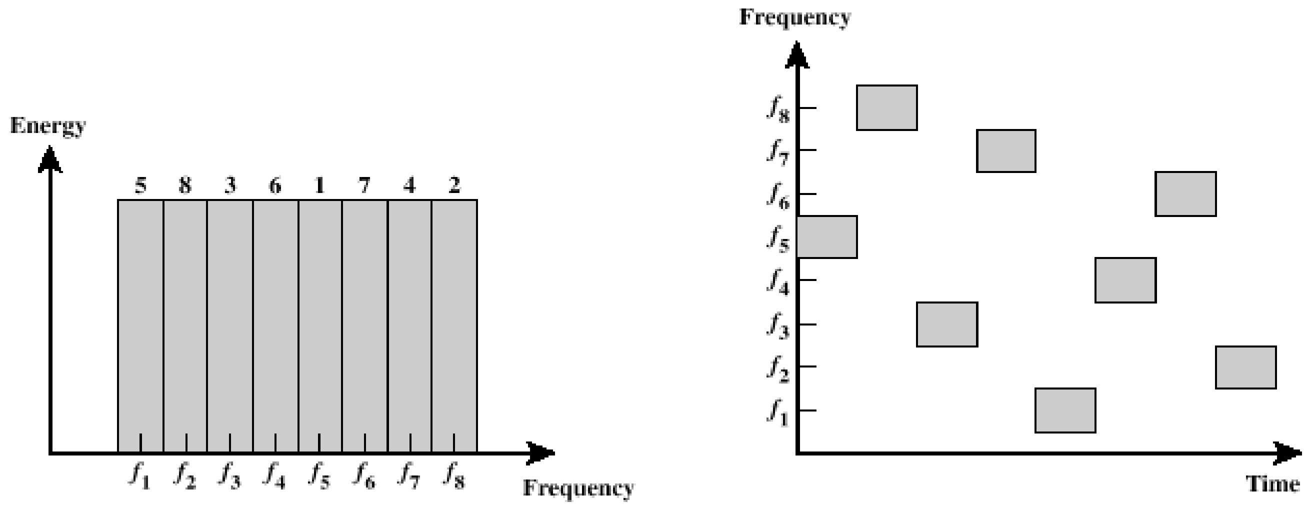
Types of Spread Spectrum

- Frequency Hopping Spread Spectrum (FHSS)
  - First type developed
- Direct Sequence Spread Spectrum (DSSS)
  - More recent technology

Frequency Hopping SS

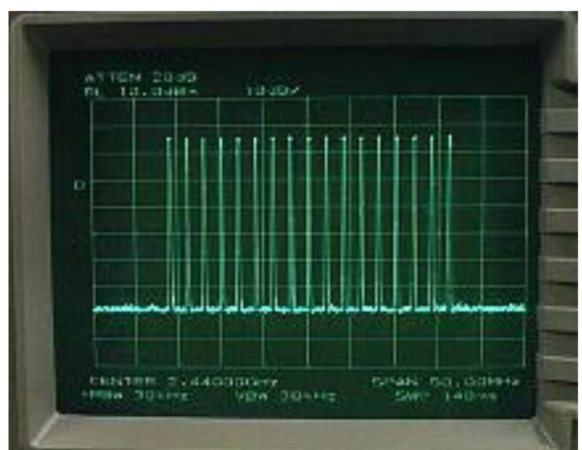
- Signal is broadcast over seemingly random series of radio frequencies
  - A number of channels allocated for the FH signal
  - Width of each channel corresponds to bandwidth of input signal
- Signal hops from frequency to frequency at fixed intervals
  - Transmitter operates in one channel at a time
  - Bits are transmitted using some encoding scheme
  - At each successive interval, a new carrier frequency is selected

Frequency Hopping SS



(a) Channel assignment

(b) Channel use



Source: ***http://murray.newcastle.edu.au/users/staff/eemf/ELEC351/SProjects/Morris/types.htm***

Frequency Hopping SS

- Hopping Sequence
  - Channel sequence dictated by spreading code
    - Pseudorandom number serves as an index into a table of frequencies

Frequency Hopping Spread Spectrum

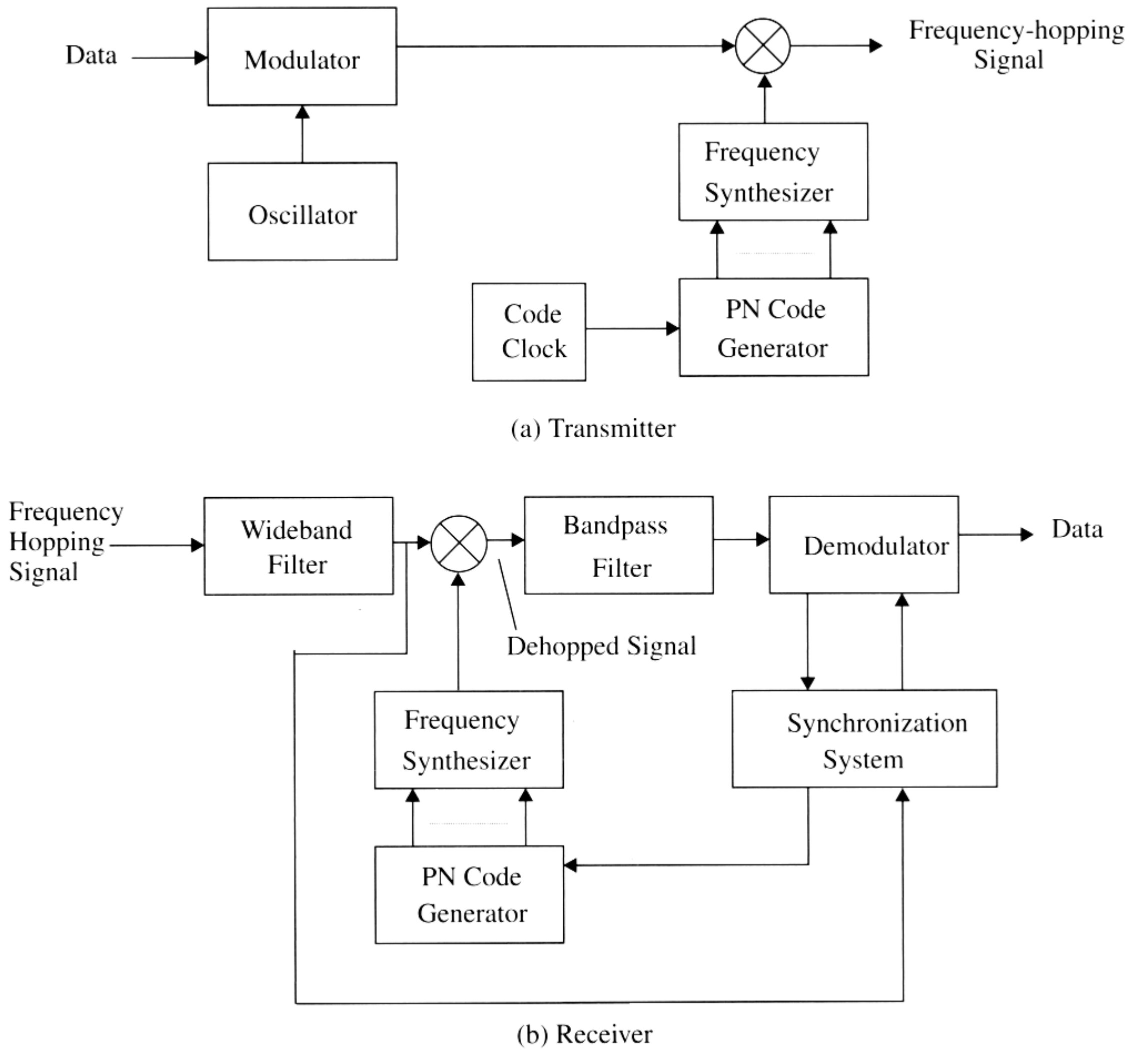


Figure 6.51 Block diagram of frequency hopping (FH) system with single channel modulation.

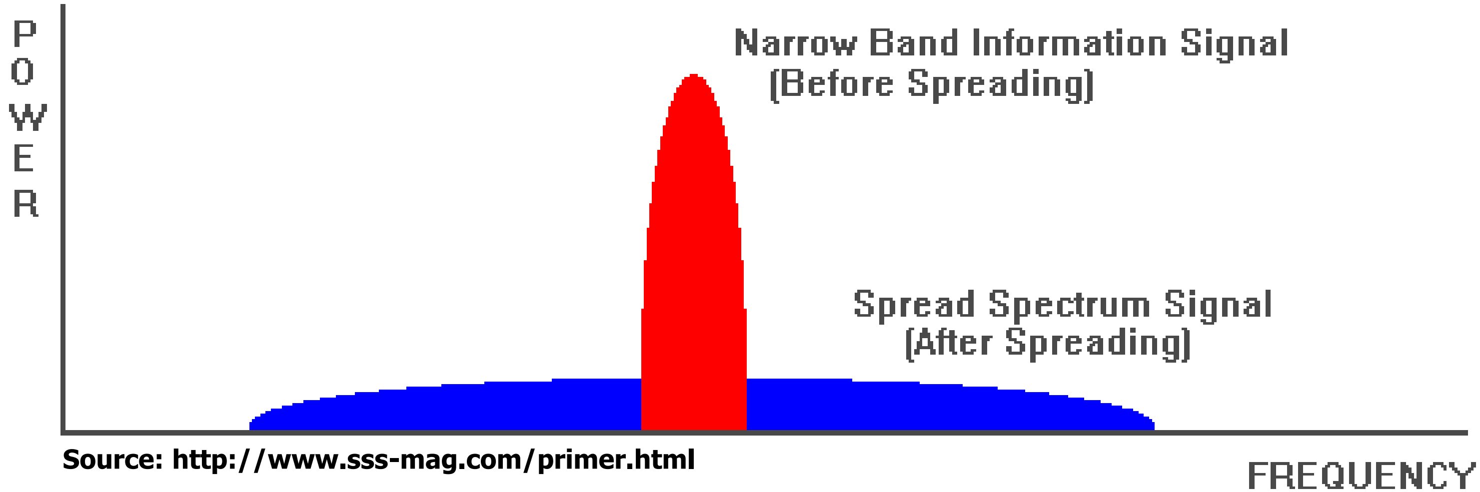
Frequency Hopping SS

- Receiver, hopping between frequencies in synchronization with transmitter, picks up message
- Advantages
  - Eavesdroppers hear only unintelligible blips
  - Attempts to jam signal on one frequency succeed only at knocking out a few bits

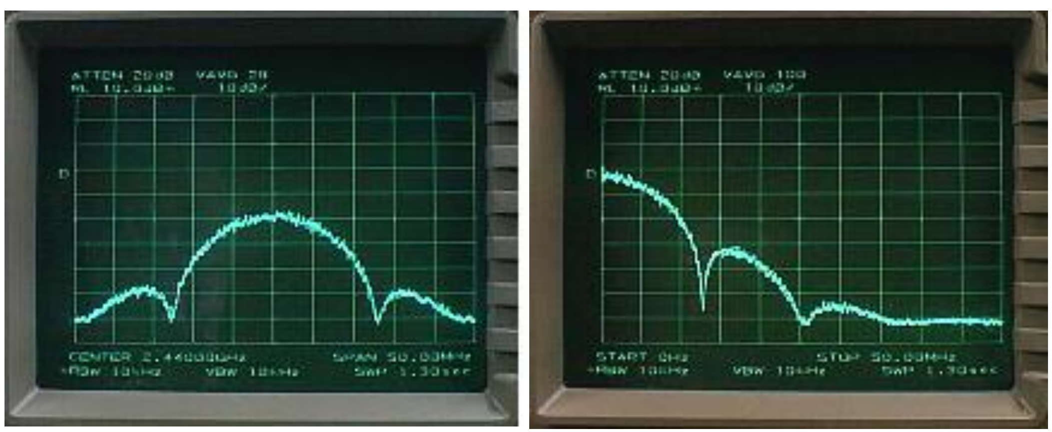
Direct Sequence SS

- Spectrum spreading is achieved by multiplying the data sequence by a PN code which has much higher rate than the data rate.
- The resulting spectrum is much wider that the data spectrum.

Direct Sequence SS

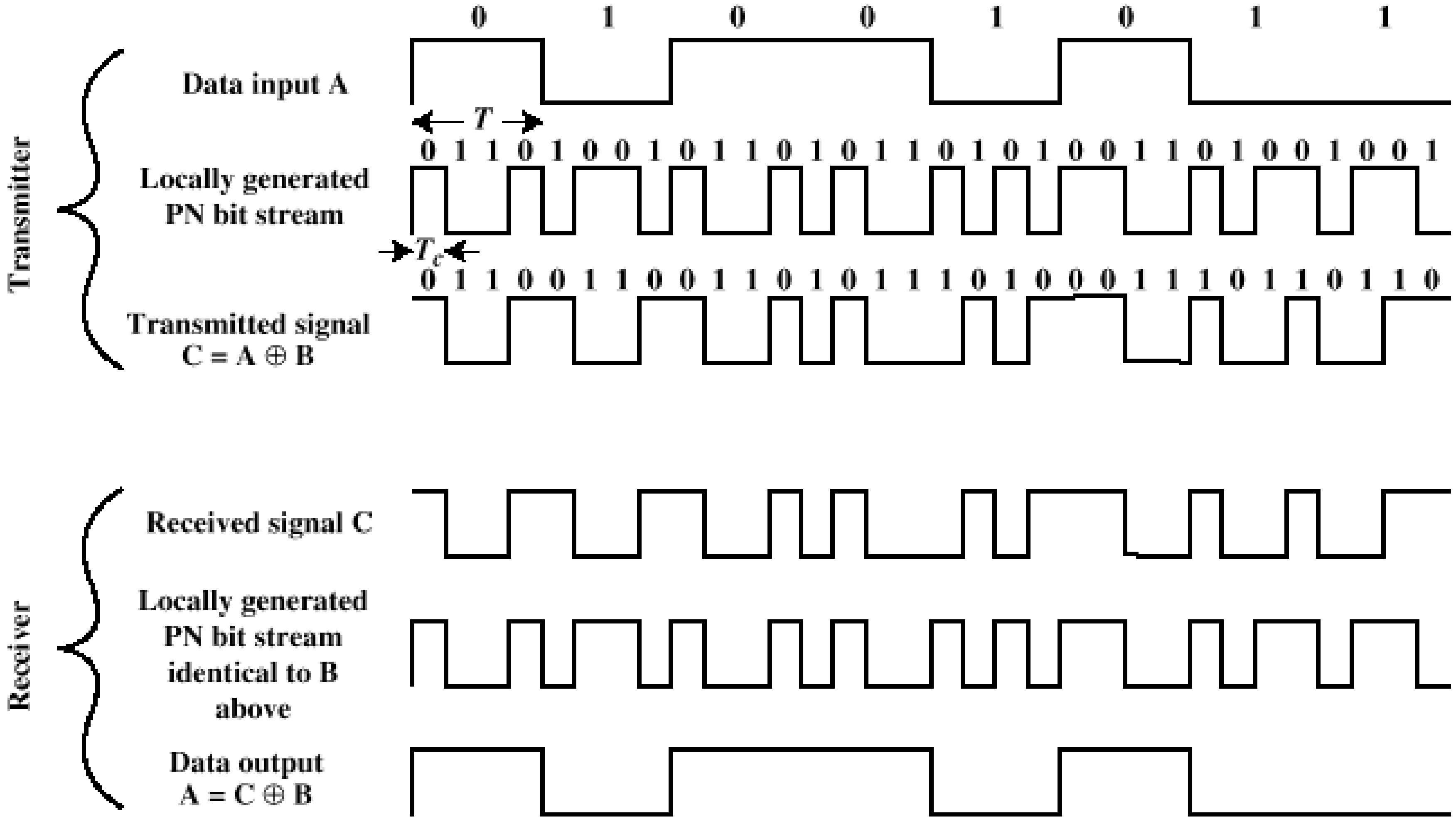


Source: http://www.sss-mag.com/primer.html



Source: http://murray.newcastle.edu.au/users/staff/eemf/ELEC351/SProjects/Morris/types.htm

Direct Sequence SS



Direct Sequence Spread Spectrum

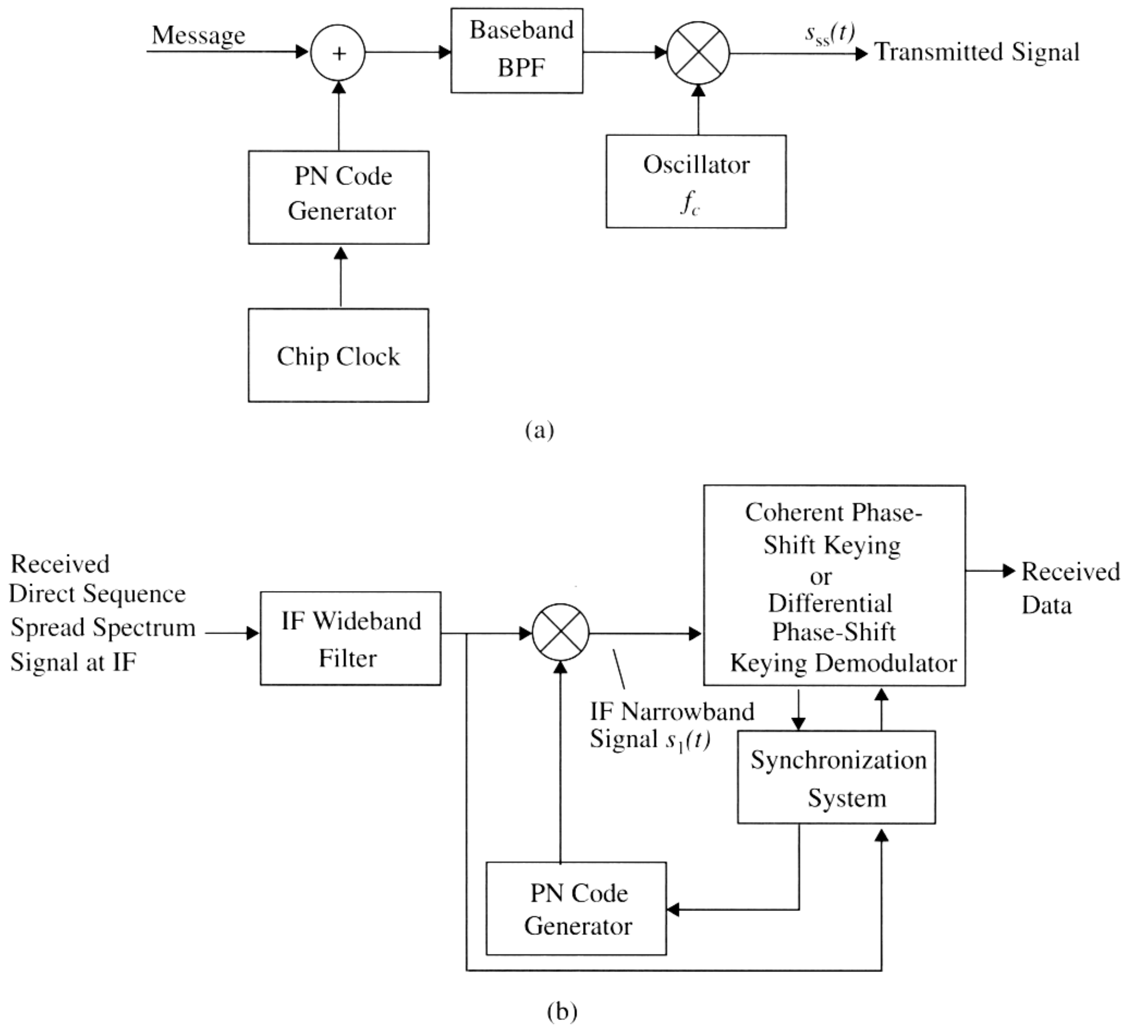


Figure 6.49 Block diagram of a DS–SS system with binary phase modulation: (a) transmitter; and (b) receiver.

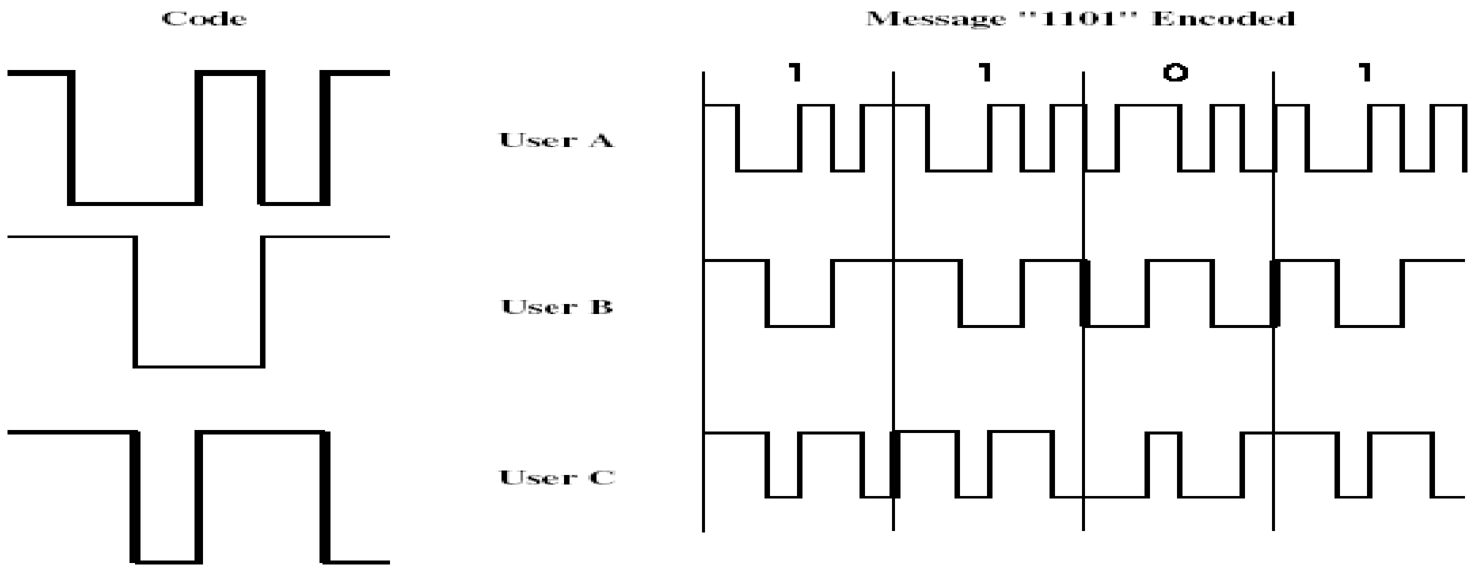
Processing Gain

- Unique property of a spread specturm system
- Process gain = T_{symbol} / T_{chip}

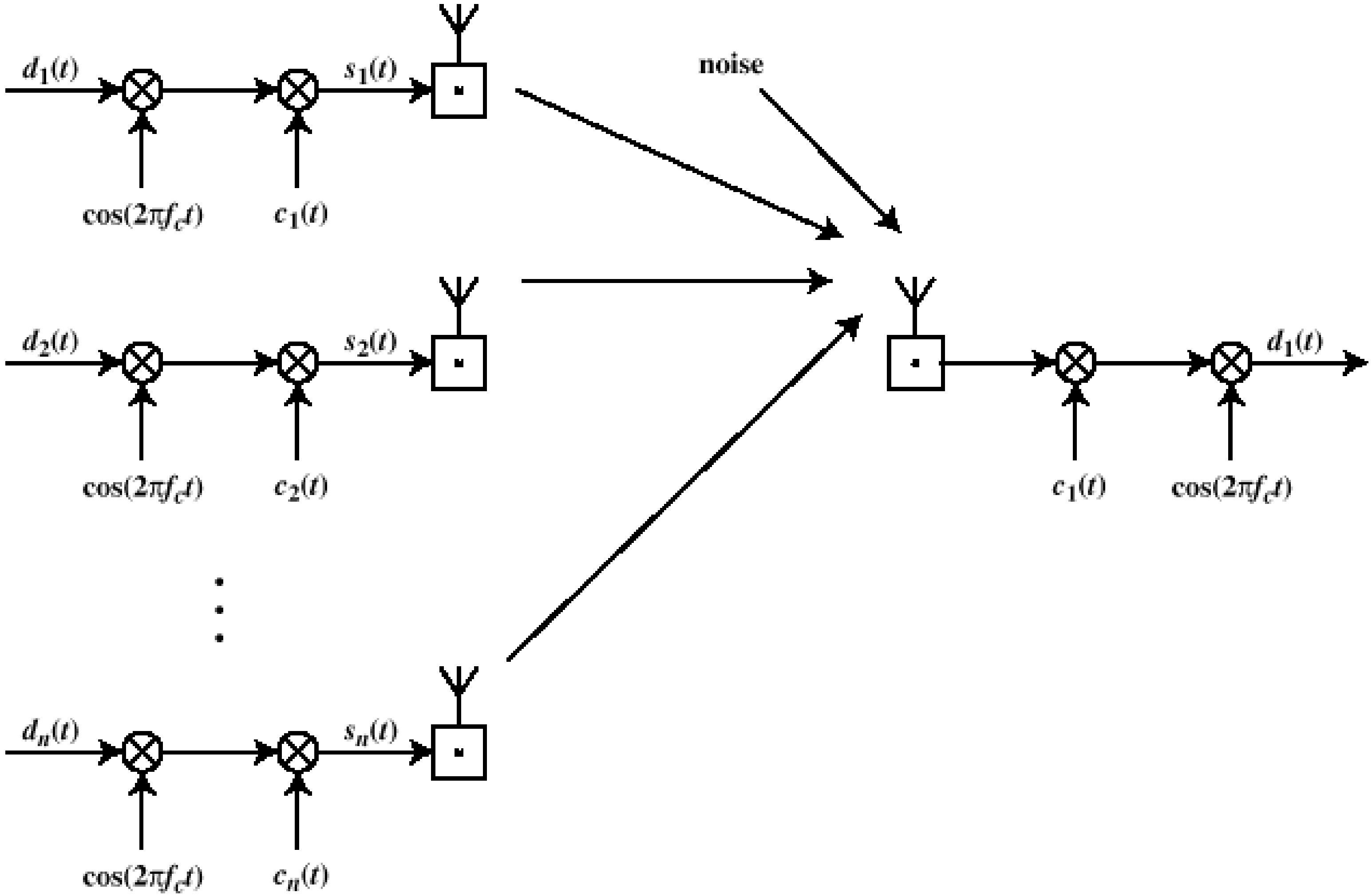
  =Chip-rate/Symbol rate
- Used to measure the amount of reduction of the Intereference power achieved by the system.

Code-Division Multiple Access (CDMA)

- Each user's data is spread using a different PN code.
- All users spread signals are transmitted in the same channel.
- The receiver uses the his own PN code to uniquely detect his data while the other users signals will appear as wide-band interference similar to Gaussian.



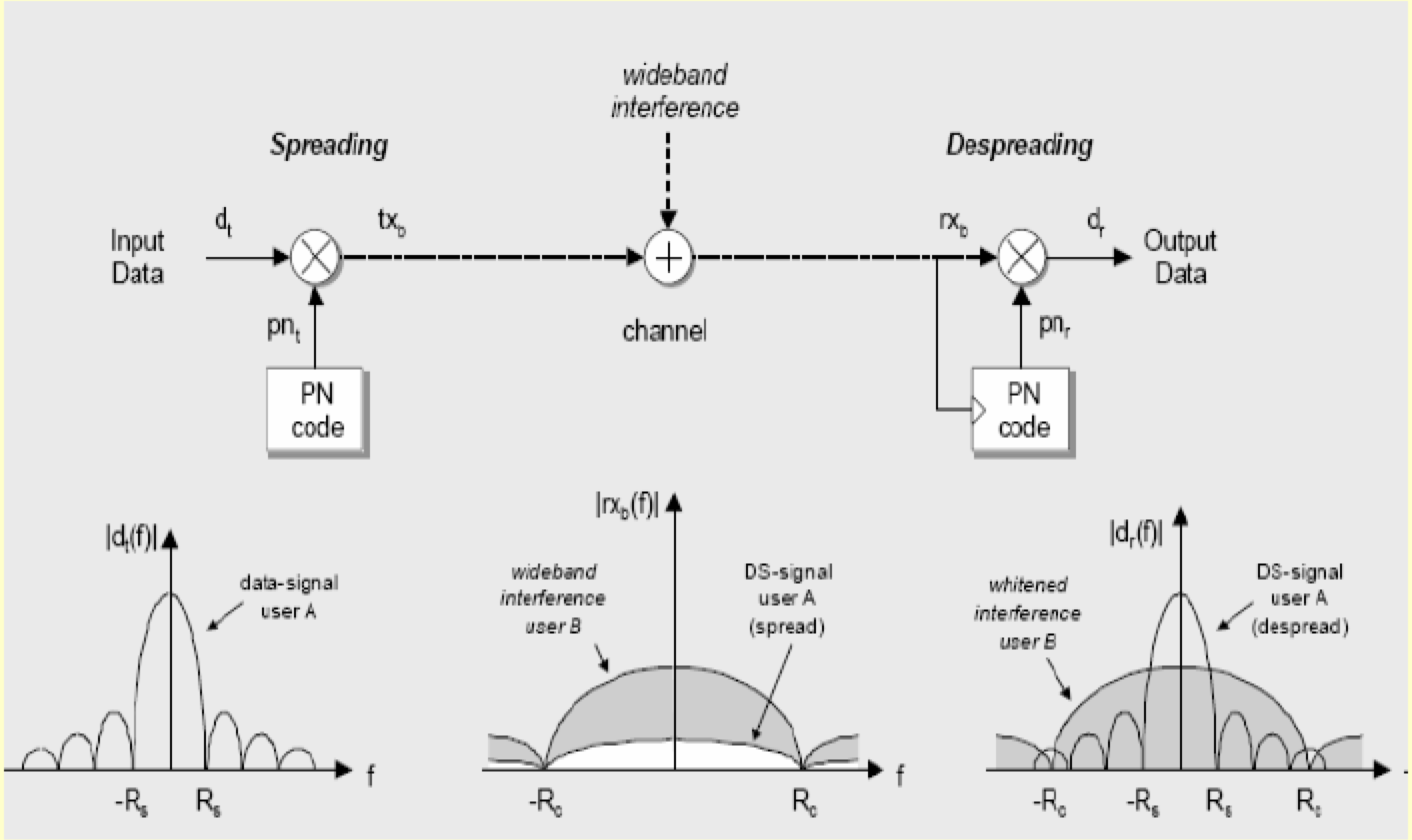
CDMA for DSSS



CDMA Example

- User A code = <1, –1, –1, 1, –1, 1>
  - To send a 1 bit = <1, –1, –1, 1, –1, 1>
  - To send a 0 bit = <–1, 1, 1, –1, 1, –1>
- User B code = <1, 1, –1, – 1, 1, 1>
  - To send a 1 bit = <1, 1, –1, –1, 1, 1>
- Receiver receiving with A’s code
  - (A’s code) x (received chip pattern)
    - User A ‘1’ bit: 6 -> 1
    - User A ‘0’ bit: -6 -> 0
    - User B ‘1’ bit: 0 -> unwanted signal ignored

Wideband Interference



Characteristics of CDMA cellular systems

- Frequency re-use factor = 1

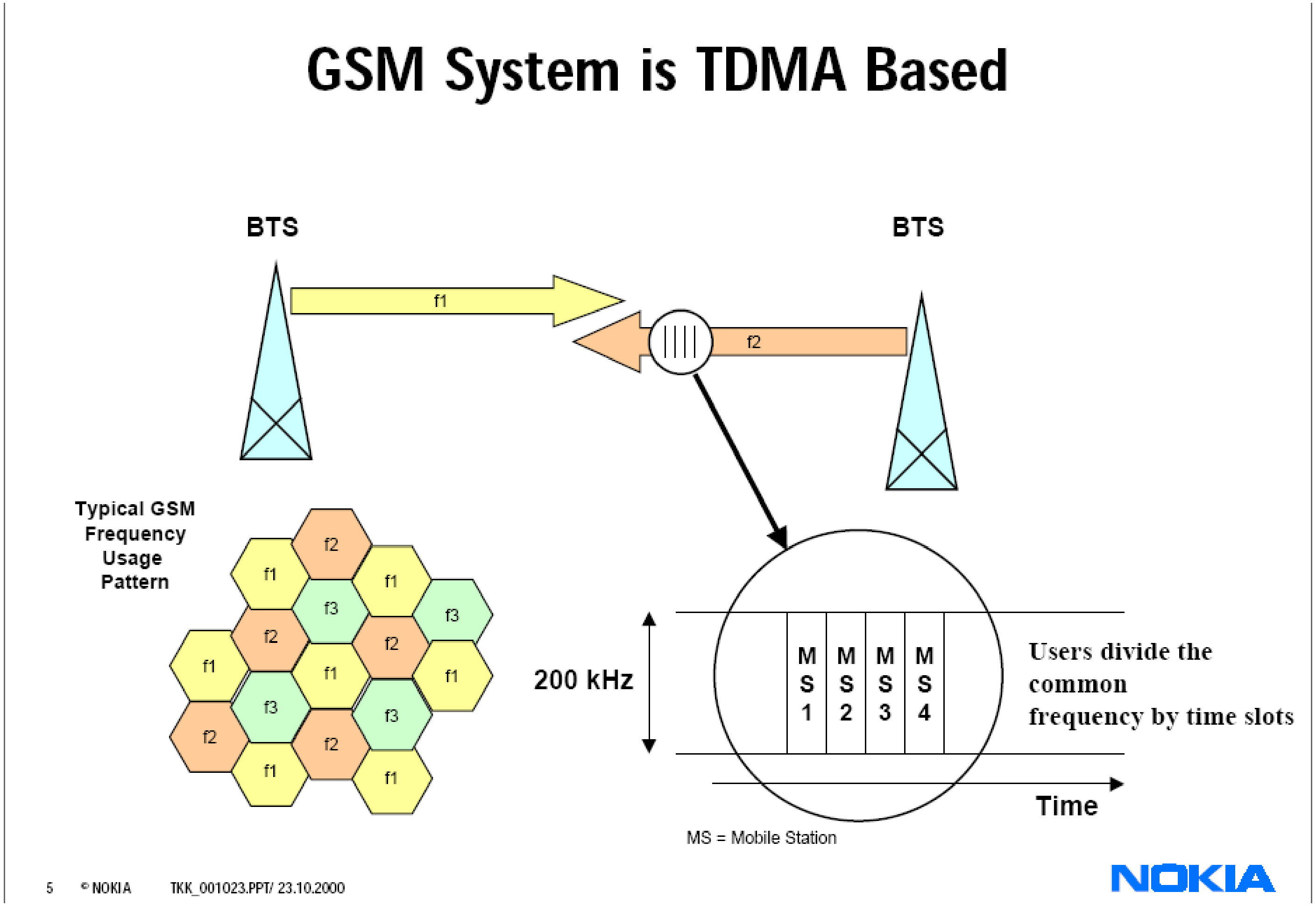
-Interfering signals from neighboring cells are strongly rejected by the de-spreading operation at the receiver (roughly by a factor of G: Process gain). This is because de-spreading at the receiver converts interfering users signals into noise-like wide-band interference.

-Therefore, no need for different frequencies for neighboring cells.

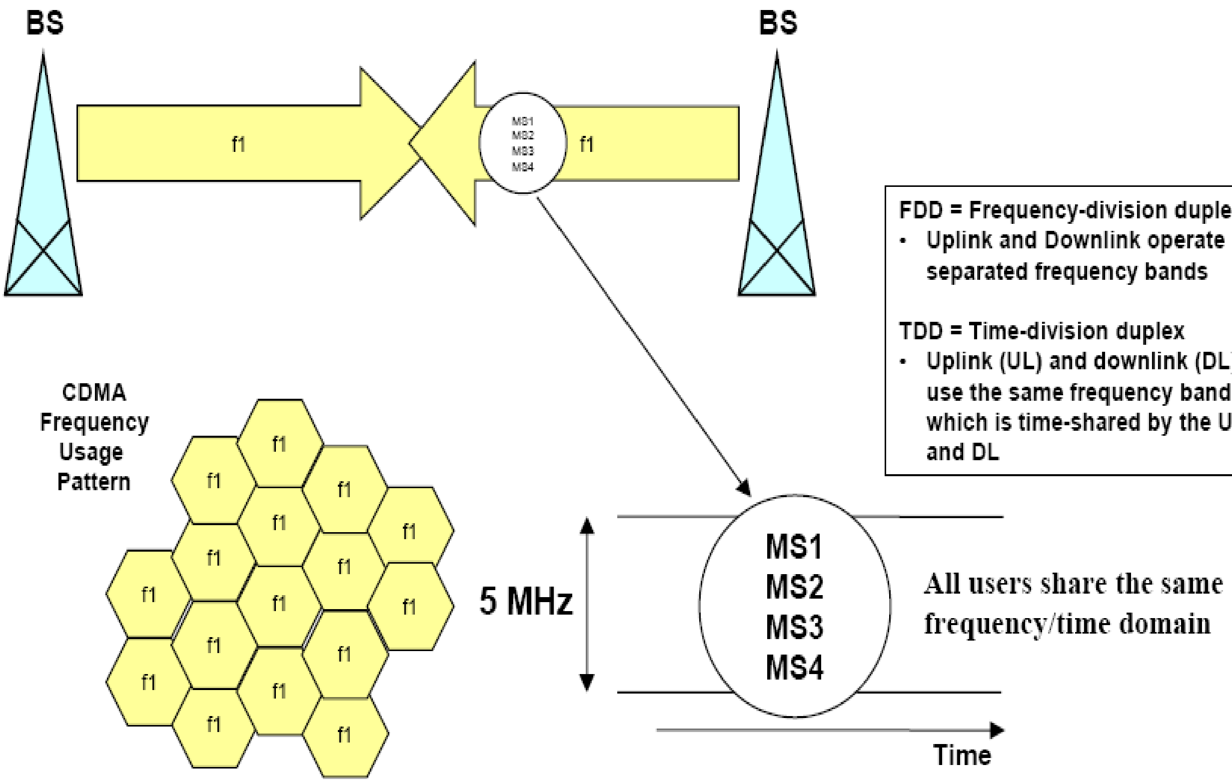
-Unlike GSM where an interfering signal (from a neighboring cell) on the same frequency is equally effective as the desired signal, except for path loss effects, therefore needing freq. re-use (usually 9-15).

Characteristics of CDMA cellular systems

- Frequency re-use factor = 1 (Unlike GSM)



UMTS System is CDMA Based



FDD = Frequency-division duplex

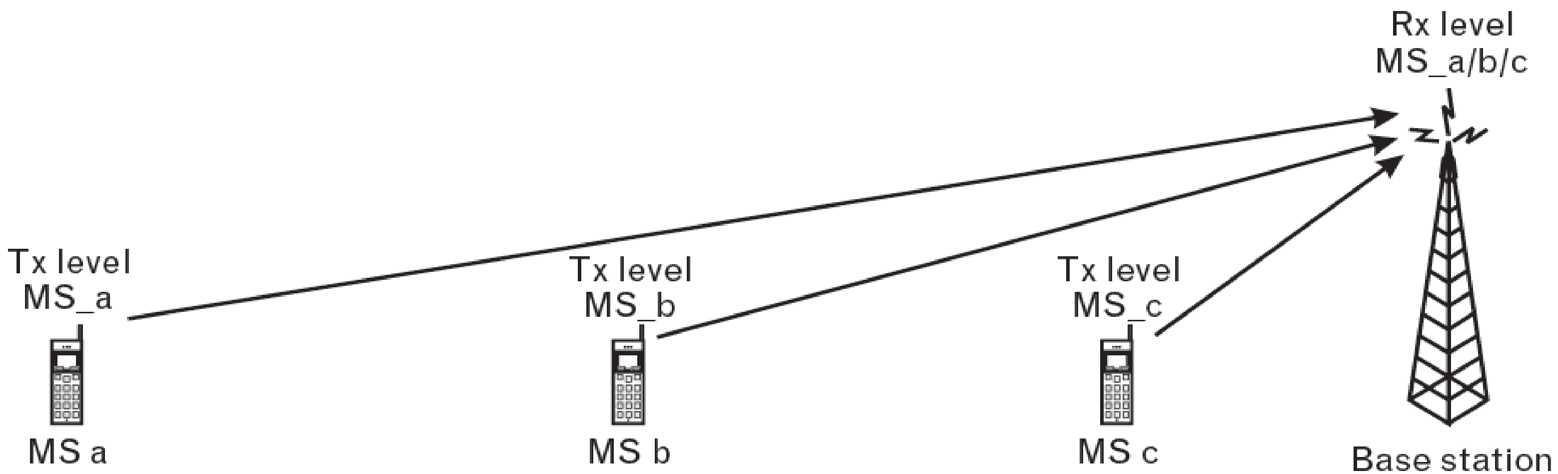
- Uplink and Downlink operate in separated frequency bands

TDD = Time-division duplex

- Uplink (UL) and downlink (DL) use the same frequency band, which is time-shared by the UL and DL

Power Control

This is essential for proper operation of CDMA systems so that interference is noise-like. Otherwise one strong signal might dominate the receiver since they are all at the same frequency.



Without power control: Tx level MS_a = Tx level MS_b = Tx level MS_c
–> Rx level MS_a < Rx level MS_b < Rx level MS_c

With power control: Tx level MS_a > Tx level MS_b > Tx level MS_c
–> Rx level MS_a = Rx level MS_b = Rx level MS_c

Up-Link PC

- In up-link PC is vital for proper operation of CDMA systems.

Open Loop power control (PC)

Compensates for large-scale fading (path loss and shadowing). It adjusts the target SIR to achieve a desired BER.

Closed loop PC

It must be fast enough to compensate for small-scale fading at the designed vehicle speed.

Uses 1.5 KHz sampling rate.

Down-Link PC

- In down-link, PC is not necessary for the CDMA to function since all signals are transmitted together from BS with equal power so there is no near-far effect.
- However it is better to do PC to minimize the interference to other cells by sending the minimum power needed for proper detection.
- For many cases open loop control is sufficient.
- The goal of downlink PC is to minimize total TX power while keeping BER above a given threshold.

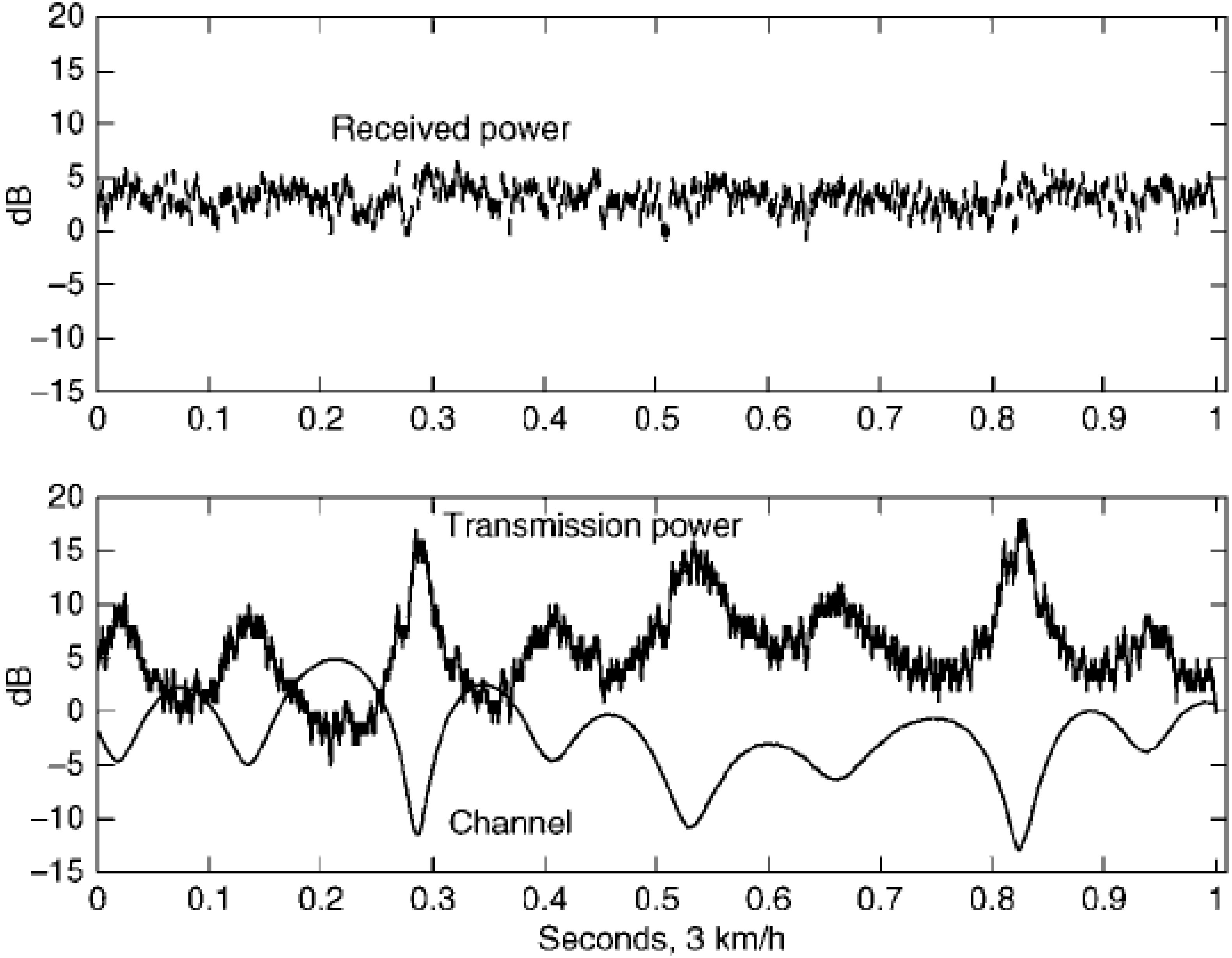
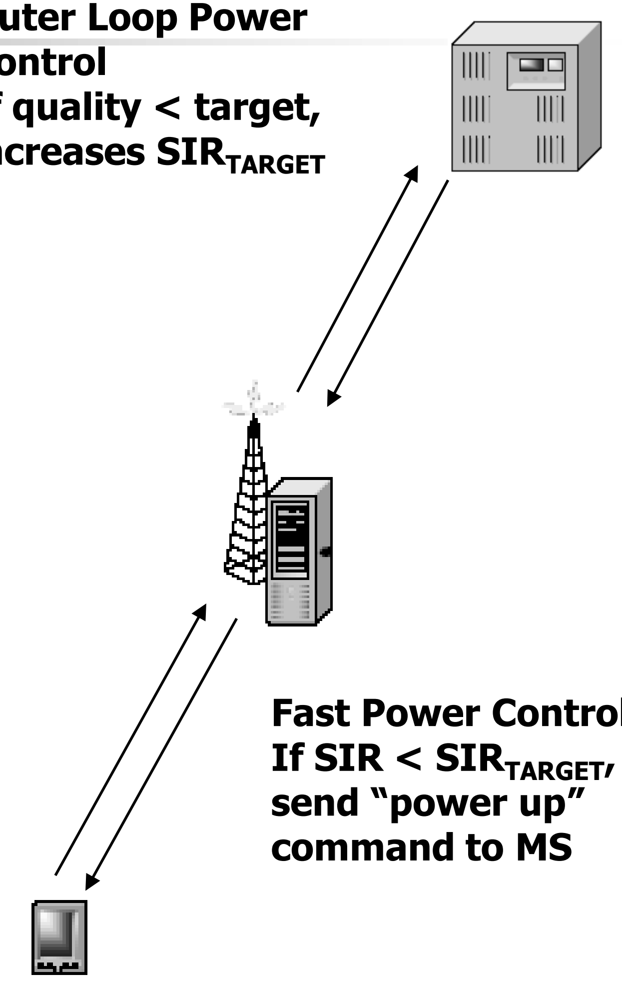


Figure 3.9. Closed-loop power control compensates a fading channel

Connection Based Function

Power Control

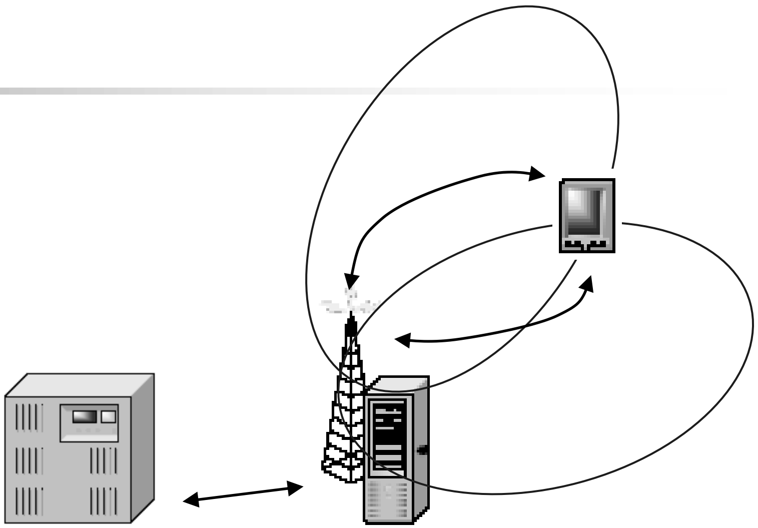
- Prevent Excessive Interference and Near-far Effect
- Open-Loop Power Control
  - Rough estimation of path loss from receiving signal
  - Initial power setting, or when no feedback channel is exist
- Fast Close-Loop Power Control
  - Feedback loop with 1.5kHz cycle to adjust uplink / downlink power to its minimum
  - Even faster than the speed of Rayleigh fading for moderate mobile speeds
- Outer Loop Power Control
  - Adjust the target SIR setpoint in base station according to the target BER
  - Commanded by RNC



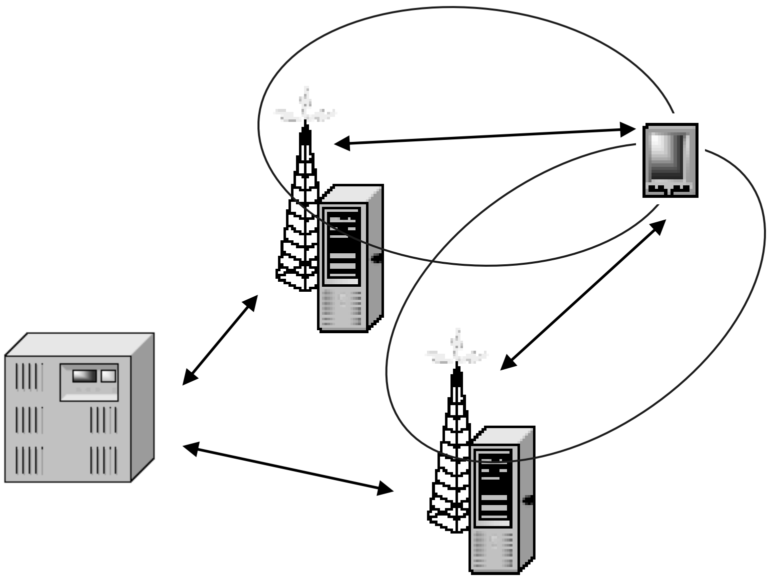
Connection Based Function

Handover

- Softer Handover
  - A MS is in the overlapping coverage of **2 sectors of a base station**
  - Concurrent communication via 2 air interface channels
  - 2 channels are maximally combined with rake receiver

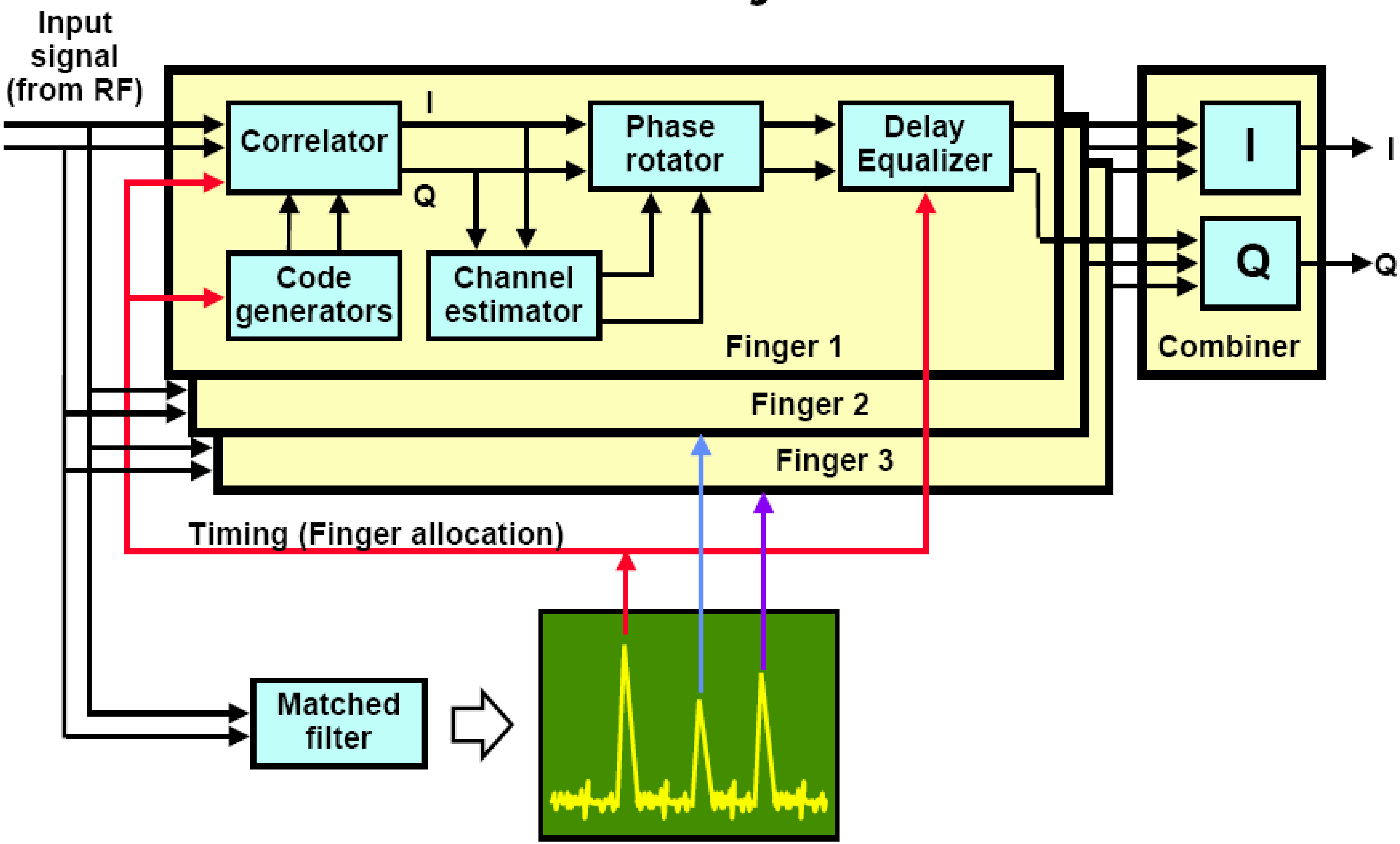


- Soft Handover
  - A MS is in the overlapping coverage of **2 different base stations**
  - Concurrent communication via 2 air interface channels
  - Downlink: Maximal combining with rake receiver
  - Uplink: Routed to RNC for selection combining, according to a frame reliability indicator by the base station



- A Kind of Macrodiversity

RAKE Diversity Receiver

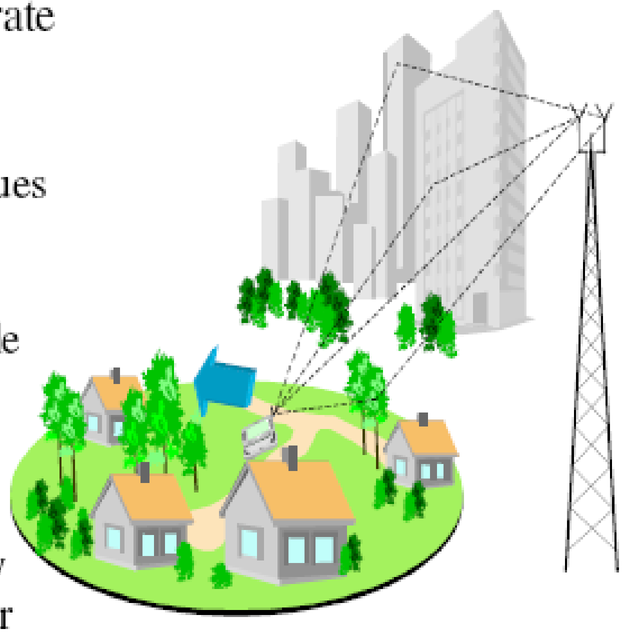


NOKIA

RAKE RECEIVER

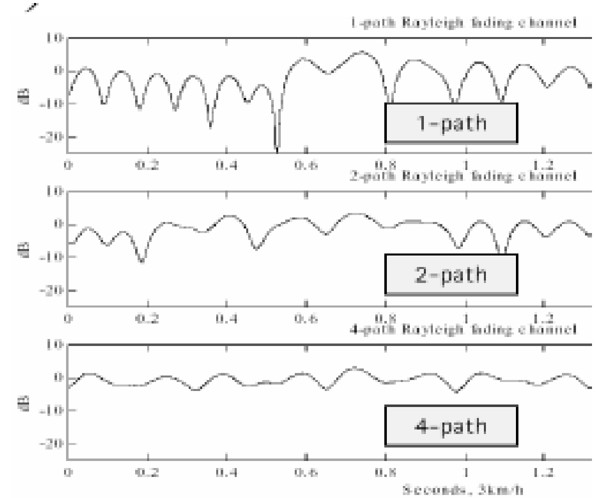
- In CDMA spread spectrum systems, the chip rate is typically much greater than the flat fading bandwidth of the channel
  - Conventional modulation and receiver techniques require an equalizer to undo the ISI between adjacent symbols
  - CDMA spreading codes are designed to provide very low correlation between successive chips
- Propagation delay spread in the radio channel provides multipath signal at the receiver
  - If multipath components are delayed in time by more than one chip duration ($1/R_c$), they appear like uncorrelated noise at a CDMA receiver, and equalization is not required

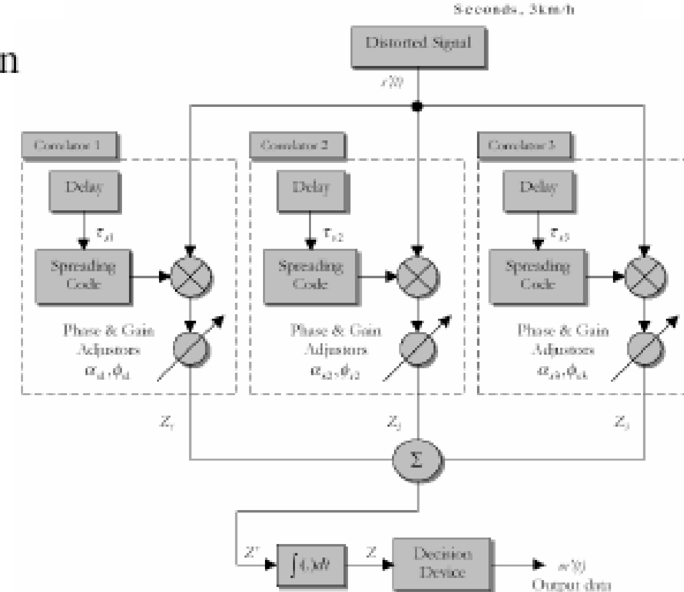
-> **RAKE type correlator receiver can be used!!!**



RAKE RECEIVER

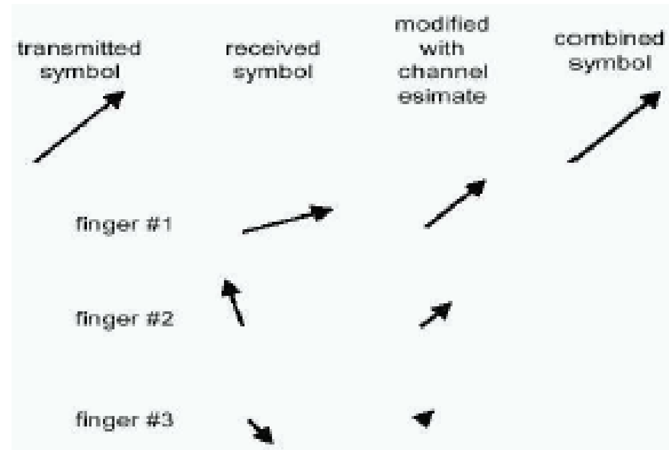
- RAKE receiver, used specially in CDMA cellular systems, can combine multipath components
  - To improve the signal to noise ratio (SNR) at the receiver
  - Provides a separate correlation receiver for each of the multipath signals
  - Multipath components are practically uncorrelated when their relative propagation delay exceeds one chip period
- The basic idea of A RAKE receiver was first proposed by Price and Green and patented in 1956

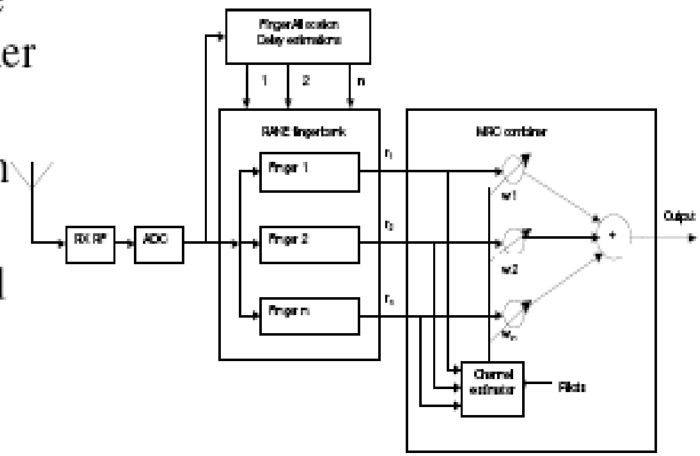




RAKE Receiver in WCDMA System (6)

- Maximal-Ratio Combining (MRC)
  - Is the optimal form of diversity combining because it yields the maximal SNR achievable
  - It requires the exact knowledge of SNRs as well as the phases of the diversity signals
  - The output symbols from different RAKE fingers are multiplied with complex conjugate of the channel estimate and the result of multiplication is summed together into the “combined” symbol
  - QPSK in WCDMA carries information in phase
  - MRC corrects channel phase rotation and weights components with amplitude estimate





Differences Between WCDMA and IS-95

- High bit rates
- High quality services + capacity
- Micro + indoor cells
- Several carriers per base station
- Different quality requirements
- Efficient packet data
- Downlink capacity

	WCDMA	IS-95
Carrier spacing	5 MHz	1.25 MHz
Chip rate	3.84 Mcps	1.2288 Mcps
Power control frequency	1500 Hz, both uplink and downlink	Uplink: 800 Hz Downlink: slow power control
Base station synchronisation	Not needed	Yes, typically obtained via GPS
Inter-frequency handovers	Yes, measurements with slotted mode	Possible, but measurement method not specified
Efficient radio resource management algorithms	Yes, provides required quality of service	Not needed for speech only networks
Packet data	Load-based packet scheduling	Packet data transmitted as short circuit switched calls
Downlink transmit diversity	Supported for improving downlink capacity	Not supported by the standard

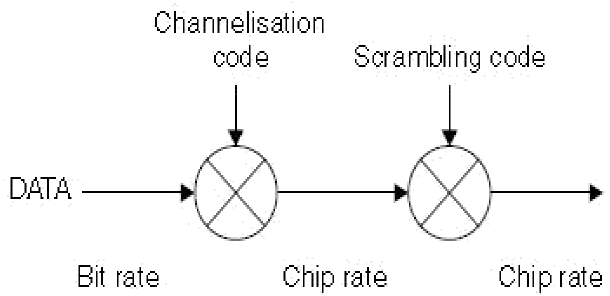
Differences Between WCDMA and IS-95

- Wider bandwidth: WCDMA: 3.84 Mcps / IS-95: 1.2288 Mcps
  - Multipath diversity improves coverage performance. In small cells ~1MHz bandwidth does not provide multipath diversity.
  - 3.84 Mcps ⇔ 1 chip corresponds to 78 m (=3e8/3.84e6)
  - 1.2288 Mcps ⇔ 1 chip corresponds to 244 m (=3e8/1.2288e6)
  - Higher multiplexing gain especially for high bit rates
- Fast closed loop power control in downlink
  - Improves downlink performance
  - Requires new functionalities in the mobile: SIR estimation, outer loop PC
- Inter-frequency handovers
  - Support for several carriers per base station

Codes in WCDMA

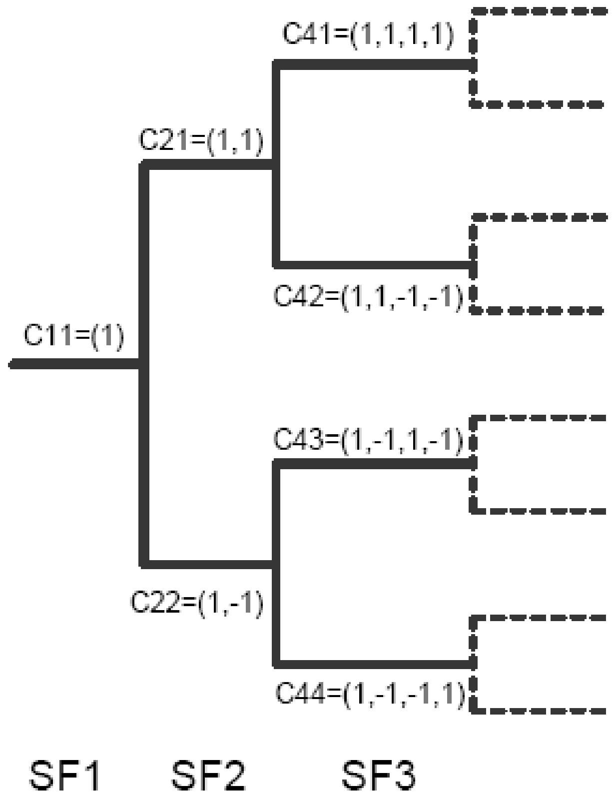
- Channelization Codes (=short code)
  - Used for
    - channel separation from the single source in downlink
    - separation of data and control channels from each other in the uplink
  - Same channelization codes in every cell / mobiles and therefore the additional scrambling code is needed

- Scrambling codes (=long code)
  - Very long (38400 chips = 10 ms =1 radio frame), many codes available
  - Does not spread the signal
  - Uplink: to separate different mobiles
  - Downlink: to separate different cells
  - The correlation between two codes (two mobiles/Node Bs) is low
    - Not fully orthogonal

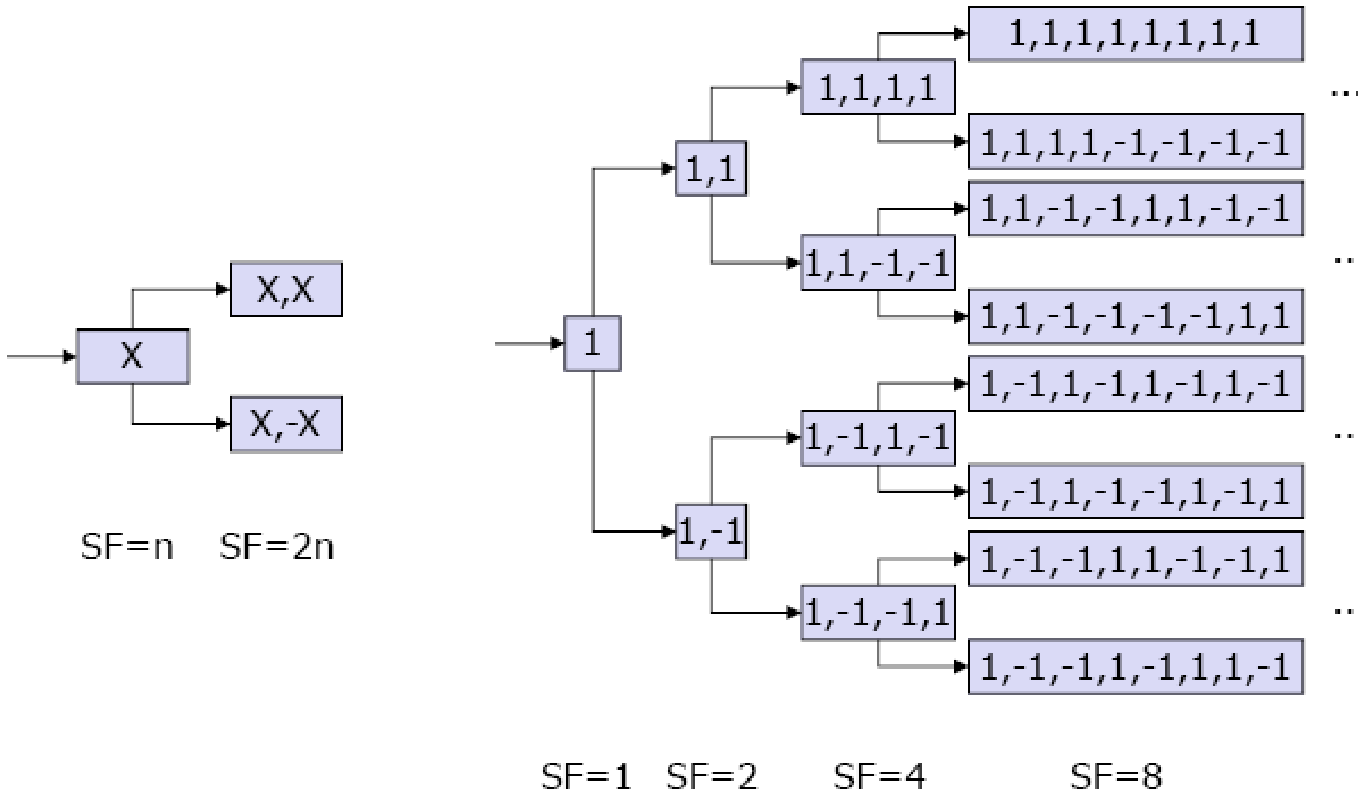


OVSF Codes for WCDMA

- Orthogonal short codes will only be useful if channel can be synchronised in the symbol level.
  - Mainly used in DL.
- Orthogonal Variable Spreading Factor technique.
- Orthogonality preserved across the different symbol rates.
- Codes must be allocated in RNC.
- Code tree may become fragmented code reshuffling may be needed.
- Provision of multiple code trees within one sector by concatenation with multiple sector specific long codes.



OVSF-Coding Tree



In UMTS, spreading factors (SF) from 4 – 512 (DL) / 4 – 256 (UL) are used:

4 x SF4, 8 x SF8 .... 256 x SF256, 512 x SF512

Spreading factor and data rates

Spreading factor	Channel symbol rate (kbps)	Channel bit rate (kbps)	DPDCH channel bit rate range (kbps)	Max. user data rate with ½ rate coding (approx.)
512	7.5	15	3-6	1-3 kbps
256	15	30	12-24	6-12 kbps
128	30	60	42-51	20-24 kbps
64	60	120	90	45 kbps
32	120	240	210	105 kbps
16	240	480	432	215 kbps
8	480	960	912	456 kbps
4	960	1920	1872	936 kbps
4, with 3 parallel codes	2880	5760	5616	2.3 Mbps

HSDPA

High Speed Downlink Packet Access

- Standardized in 3GPP Release 5
- Improves System Capacity and User Data Rates in the Downlink Direction to 10Mbps in a 5MHz Channel
- Adaptive Modulation and Coding (AMC)
  - Replaces Fast Power Control :
    User farer from Base Station utilizes a coding and modulation that requires lower Bit Energy to Interference Ratio, leading to a lower throughput
  - Replaces Variable Spreading Factor :
    Use of more robust coding and fast Hybrid Automatic Repeat Request (HARQ, retransmit occurs only between MS and BS)
- HARQ provides Fast Retransmission with Soft Combining and Incremental Redundancy
  - Soft Combining : Identical Retransmissions
  - Incremental Redundancy : Retransmits Parity Bits only
- Fast Scheduling Function
  - which is Controlled in the Base Station rather than by the RNC

Table 11.4. Theoretical bit rates with 15 multi-codes for different TFRCs not including overhead

TFRC	Modulation	Effective code rate	Max. throughput (Mbps)
1	QPSK	$\frac{1}{4}$	1.8
2	QPSK	2/4	3.6
3	QPSK	$\frac{3}{4}$	5.3
4	16 QAM	2/4	7.2
5	16 QAM	$\frac{3}{4}$	10.7

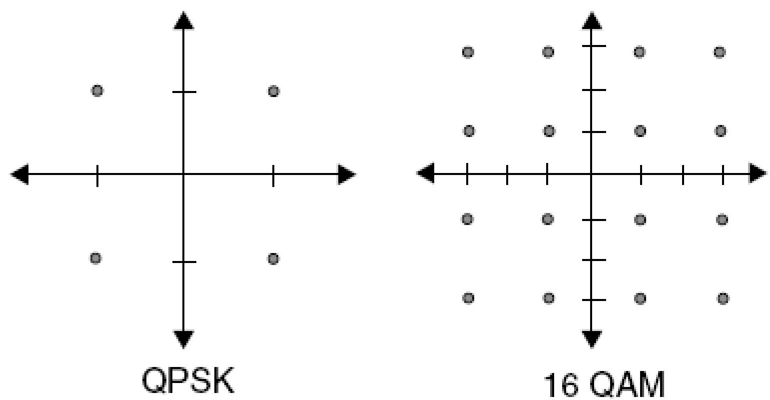


Figure 11.5. QPSK and 16 QAM constellations

8 PSK and 64 QAM were considered, but eventually these schemes were discarded for performance and complexity reasons. 16 QAM, with the constellation example shown in Figure 11.5, doubles the peak data rate compared to QPSK and allows up to 10-Mbps peak data rate with 15 codes of SF 16. However, the use of higher-order modulation is not without cost in the mobile radio environment. With Release'99 channels, only a phase estimate is necessary for the demodulation process. Even when 16 QAM is used, amplitude estimation is required to separate the constellation points. Further, more accurate phase information is needed since constellation points have smaller differences in phase

2.2. Fast HARQ

HARQ, which combines soft information from re-transmissions requested by UE with soft information from the original transmission prior to decoding, greatly improves performance and adds robustness against link adaptation errors. It also serves to fine tune the effec-

2.3. Fast scheduling

The scheduler is a key element of the design. It controls the allocation of the channel to users, and to a large extent, it determines the overall behavior of the system. The scheduler exploits the multi-user diversity and strives to transmit to users when radio conditions permit high data rates. Notwithstanding, it also maintains a certain degree of fairness. Fundamentally, higher tolerance to QoS criteria means higher system capacity. The outcome of this is one of the main enhancements for best effort service, which by definition allows for a relatively large spread in quality. Since there is no need to standardize the scheduling algorithm, different schedulers can be used for different scenarios. Instead, the scheduler can be designed to suit the requirements of different operators and environments. Information on which the