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CDMA Overview

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ABSTRACT

The purpose of this paper is to give an overview about CDMA. It is an multiple access scheme which the users are divided by different spreading codes. The basic principles of CDMA are presented and various techniques needed in CDMA are described shortly. Basic receiver techniques and more advanced RAKE receiver are presented. Also the advantages and disadvantages of CDMA are discussed.

1. INTRODUCTION

In traditional multiple access systems, like in pure TDMA and FDMA, for each user it is provided certain resources (timeslots or frequency), which are disjoint from those of any other user. This way it is assumed a perfect isolation between users and the capacity of each channel is limited by timeslot or bandwidth of resource allocated for that user and the degradation caused by noise and interference. This approach has three weaknesses. First it assumes that a user transmits continuously. But this is not the case with speech, because in a two-person conversation a voice activity period is less than 50%, meaning that over a half of the resources are reserved for non-speaking user. Second disadvantage is the re-use pattern, shown in the fig. 1. The isolation between users can not be guaranteed, if the users in the nearby cells use the same frequency. For this reason the re-use pattern is used. The consequence is that the number of channels per cell is reduced by the re-use factor. Third source of degradation, common for the all multiple access systems, is the multipath propagation. In the narrow band systems multipath fading causes more severe effects than in the wider bandwidth systems [1].

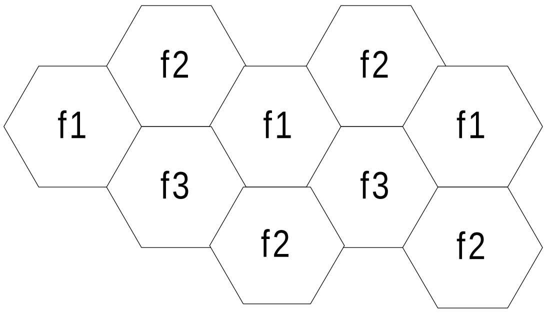

Figure 1. Re-use pattern

In **Spread Spectrum** communications the bandwidth is increased substantially, far beyond what is needed for basic communication. The idea is to allocate the resources simultaneously for all users and at the same time control the transmission power of each user. Now the effects of noise, interference caused by other users and multipath are averaged which results to the higher system capacity than in the conventional systems. Bandwidth extension can be achieved either by frequency hopping (slow or fast) or by using direct sequence spreading.

CDMA is a form of a direct sequence spread spectrum system. In CDMA users are divided by codes. These codes are known by the receivers, the codes has a pseudo noise characterise and they are almost or fully orthogonal to each other. Each user experiences the interference caused by other user as a increased noise level. [1,2]

This document gives an overview of the basics of CDMA. In chapter 2. some important aspects of CDMA are presented. Chapter 3. describes a simple BPSK and QPSK receivers for spread spectrum systems. Next in the chapter 4. more advanced receiver called as a RAKE receiver is presented. Then chapter 5. discusses about the specific problem of CDMA, near-far-effect, and describes two methods to ease it, power control and soft handover. After that some pros and cons of CDMA are listed in the chapter 6. Finally the conclusions are drawn.

2. DIRECT SEQUENCE SPREAD SPECTRUM

In direct sequence spread spectrum (SS) bandwidth expansion is achieved via bitrate extension. Assume that the bitrate of the channel coder is R bits/s and the available bandwidth is W Hz and the modulation is PSK. In order to utilise the bandwidth W, the phase of the carrier is shifted according the pseudo-noise (PN) signal which rate is W times/s. The chip interval is defined as $T_c=1/W$. Now the system bandwidth expansion factor or processing gain is defined as

$$G = \frac{W}{R} .$$

The fig. 2 shows the transmitter and the receiver model of a SS system.

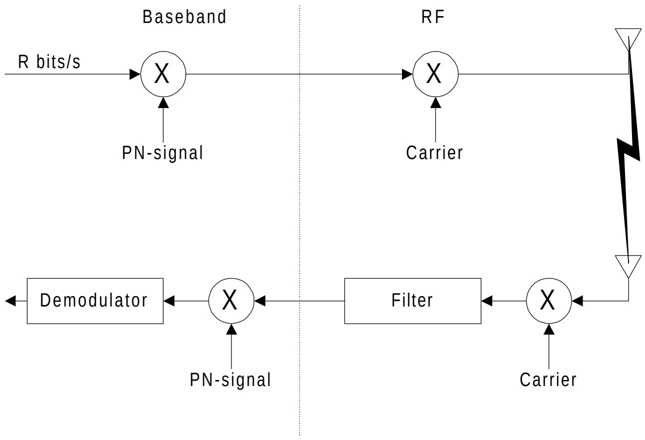

Figure 2. Spread spectrum system

2.1 **Simplified capacity of CDMA**

Capacity of a CDMA system (reverse link) can be estimated when it is assumed that modulation and demodulation are simply multiplication on the baseband and there is a synchronization between the receiver and the transmitter. Also assume that there is a perfect power control i.e. all signals are received at the base station by equal power levels. If the received power is P_s and the noise is negligible by interference power I and the number of users is k_u, then

$I = (k_u - 1)P_s$ [1].

The noise density received by each user's demodulator is

$I_o = I / W$.

The received energy per bit, when received signal power is P_s, is

$E_b = P_s / R$.

When these are combined, it can be seen that the number of simultaneous users is related to the processing gain and the demodulators E_b/I_0 requirement by

$$k_u - 1 = \frac{W / R}{E_0 / I_0} \quad [1].$$

There two factors which further improve this, gain from voice activity G_V (which is about 2.67 [1]) and gain from sectored antennas G_A (This is assumed to be 2.4 [1]). Finally it must be taken account that in cellular systems there are also co-channel cells. Their interference is determined by factor

$$f + 1 = \frac{\text{int}\,erference\_\,from\_\,other\_\,cells}{\text{int}\,erference\_\,from\_\,given\_\,cell} + 1 \approx 1.6.$$

Thus we get

$$k_u \cong \frac{W / R}{E_b / I_0}\frac{G_V G_A}{1 + f} \approx \frac{4W / R}{E_b / I_0} \qquad [1].$$

E_b/I_0 can be as low as 6 dB by using good error-correcting coding with dual antenna diversity and multipath diversity (RAKE). This means that the number of users can be approximately the same than the processing gain. However it must be pointed that this is only a gross estimate and the estimation of the real CDMA system capacity requires much detailed and sophisticated analysis. This analysis must take account issues like imperfect power control, imperfect interleaving, multipath fading caused by limited bandwidth (which may be smaller than coherence bandwidth) and non-uniform distribution of users [9].

2.2 **PN-sequences**

(Only a short overview is given about this topic, because there is a separate presentation later during this course)

In CDMA user signal is multiplied by pseudo random sequence. This sequence must be known by transmitter and also by receiver to be able to make synchronization and despreading. To be used in real systems the sequence should be able to constructed from a finite number of randomly pre-selected parameters. On the other hand PN-sequence should look a noise like signal.

A binary independent random sequence, known also as a Bernoulli sequence or 'coin-flipping' sequence, should have three following properties [1]:

1. Relative frequencies of '0's and '1's in the sequence are each 1/2.
2. Run lengths of zeroes or ones are the same as in a coin-flipping experiment. Half of the run lengths are unity, one-quarter are of length two, one-eighth are of length three and a fraction *1/2n* of all runs are of length *n*.
3. If the sequence is shifted by any non-zero number of elements, the resulting sequence will have an equal number of agreements and disagreements with the original sequence.

A determistically generated sequence that nearly satisfied these three requirements, within extremely small difference, will be a pseudo random sequence.

A pseudo random sequence can be generated by linear shift register, which an example is shown in the fig. 3.

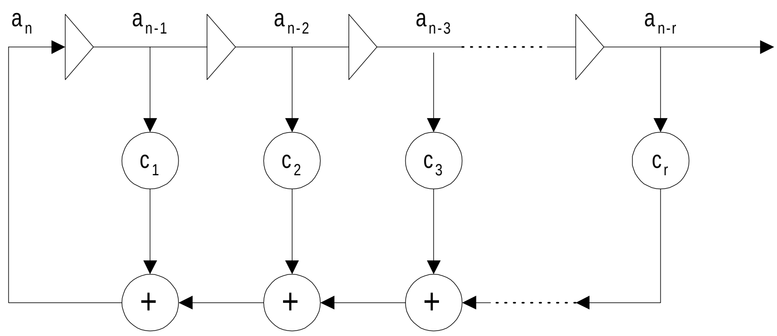

Figure 3. Linear shift register sequence generator

In each clock cycle the register shifts all its contents to the right. The sequence a_n can be written as
$a_n = c_1 a_{n-1} + c_2 a_{n-2} + \cdots + c_r a_{n-r}$,
where c_1 to c_r are the connection variables (0 for no connection and 1 for connection).

In this presentation three classes of sequences are described. They are maximal-length sequences, Gold-sequences and non-linear sequences.

Maximal length sequences generated by *n* cell shift register are 2^n*-1* chips long, meaning that they are as long as a shift register can produce. Maximal-length sequences have a number of interesting properties, which several are listed in following [5]

- a *m*-sequence contains one more one than zero. The number of ones in the sequence is *1/2*(n+1)*.
- Modulo-2 sum of an *m*-sequence and any phase shift of the same sequence is another phase of the same *m*-sequence (shift-and-add property).
- The statistical properties of ones and zeroes are well defined and always the same. Relative positions vary, but the number of each run length does not.
- Every possible state of the shift register exist at some time in a complete m-sequence. (Except the all zero state, which is not allowed.)
- The periodic autocorrelation function *R(k)* of is two-valued and is given by $R(k) = \begin{cases} 1.0, & k = \ln \\ -\frac{1}{n}, & k \neq \ln \end{cases}$,

  where *l* is any integer and *n* is the sequence period.

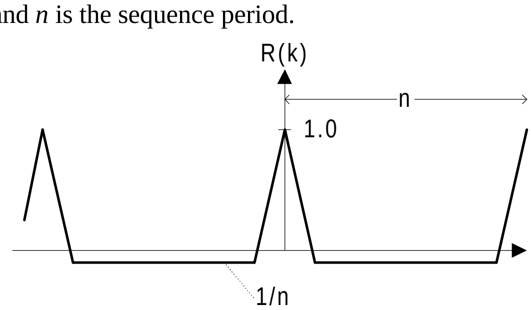

Figure. 4. Autocorrelation function for a maximal length sequence

Maximal length sequences has two not so beneficial properties. First their properties holds only for complete *m*-sequence, any part of them is not a *m*-sequence. Secondly, in the sense on security they are poor, because the shift register connections of a *m*-sequence can be determined by observing only *2n* cycles from the sequence.

Gold sequences are invented especially for code division multiple access. Their idea is to reduce the interference caused by a user to another user. For this reason Gold sequences has also good cross correlation properties. Gold sequences are generated decimating two *m*-sequences. The cross correlation of a Gold sequence can have the following values

$$-\frac{1}{n}t(k)$$

$$-\frac{1}{n} \quad ,$$

$$\frac{1}{n}\left[t(k)-1\right]$$

where

$$t(k)=\begin{cases}1+2^{0.5(n+1)}, for\_n\_odd\\1+2^{0.5(n+2)}, for\_n\_even\end{cases}.$$

Non-linear sequences are for applications where security is emphasised. The idea is to make the detection of shift register configuration difficult by observing only relatively short period of sequence. This property is achieved by non-linear sequence generators. Unfortunately their properties are difficult define and there is no general technique available for finding good non-linear sequences.

2.3 Synchronisation

(Synchronization in CDMA is a wide subject, which also a separate presentation will be made during this course. Only basic concepts are described in this paper.)

The primary goal in CDMA is to despread the received signal by pseudo noise sequence. It is clear that the local replica of the sequence must be in the same phase than the received sequence. Synchronization is thus a crucial issue in CDMA and it is not easy considering the sequence lengths and chip duration.

In general, the synchronization can be divided into *acquisition* (or initial synchronization) which is coarse alignment of the received and the replicated PN-sequences and *tracking* which is fine tuning of this alignment.

There are several **acquisition** algorithms [6]. Serial maximum-likelihood search correlates the received signal with the local PN-sequence with all possible code clock phases. After this the best correlation value defines the correct sequence phase. This is an optimum, but a slow technique. To shorten the time to acquisition an incomplete search is used according some strategy. There are various strategies like single-dwell, multiple-dwell, linear, zig-zag, expanding window etc. For example single-dwell means that correlation is done at various clock phases until the result exceeds a pre-specified threshold. This leads shorter acquisition time, but there is also a possibility for incorrect synchronization. Sequential acquisition is very fast, but requires high SNR. Another technique is to use matched filters (non-coherent detection), which yields to the lowest average acquisition time.

Tracking tackles with the problem of maintaining sequence synchronization after acquisition phase. This is needed because mobile moves and the change in the variable transmission delay has to be tracked. Tracking is done by using phase-locked techniques very similar to those used for generation of coherent carrier references. Tracking loops can be categorised to coherent and noncoherent loops. The coherent loops make use of phase information of the received carrier and noncoherent loops do not use this information. On the other hand the categorisation can be done by dividing loops into full-time and tau-dither tracking loops. The full-time loop contains two independent correlators, but tau-dither loop employs only one correlator. Both of these can be used either in coherent or in noncoherent modes. The noise characteristics of the full-time loops are better than tau-dither loops, but on the other hand they are more complex to implement.

As an example about tracking loops the optimum tracking loop for wideband signals is presented [5]. This loop is not used in modern spread spectrum systems. However, the modern tracking loops are discrete approximation of this configuration. The wideband signal *r(t)* received by the communication system contains transmitted signal delayed by T_d and noise *z(t)*. Signal *s(t)* is the replica of the transmitted signal generated by the receiver. The signal *r(t)* is multiplied by the replica *s(t)* and then low-pass filtered. The result is DC component, which is related to the phase error $(T_d - T_d')$. The latter term is the receiver generated estimate of the transmission delay. The DC component is employed to correct the transmission delay estimate.

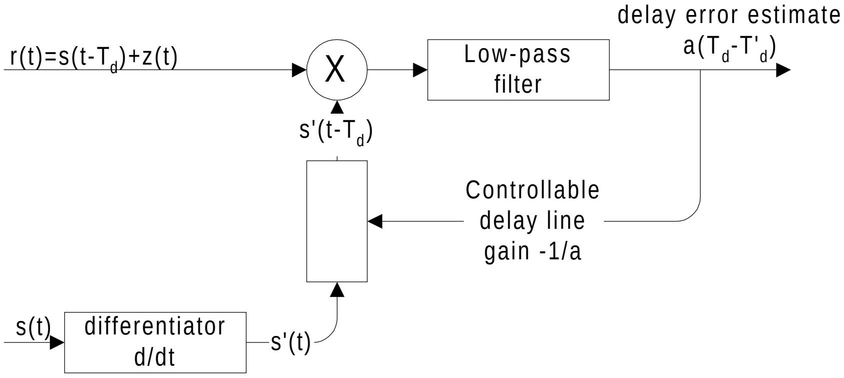

Figure 5. The optimum tracking loop for wideband signals

2.4 Multiple forms of diversity

In relatively narrowband systems the existence of multipath propagation causes severe fading. In the CDMA signal bandwidth is wider and thus there is more frequency diversity which means that fades are less deep. Higher symbol rate allows the separate processing of each independent fading path (RAKE receiver), which further mitigates fading. However multipath fading can not be completely eliminated because there are multipaths which can be only occasional processed by demodulator. [4]

Diversity is favoured approach to mitigate fading. There basically are three major diversity types: time, frequency and space diversity. In CDMA all of these are utilised by the following way: [4]

1. Multiple signal paths between mobile and base station (i.e. soft handover) produces space diversity.
2. Receiving different multipaths separately and then combining (RAKE) produces multipath diversity.
3. CDMA can benefit from multiple antennas per cell site (antenna diversity).
4. Channel coding combined with interleaving produces time diversity.
5. Wideband signal itself produces frequency diversity.

In addition previous five techniques, CDMA can and must use fast power control, which also mitigates the fading.

3. MATCHED FILTER RECEIVER

3.1 BPSK

In this chapter a BPSK modulator and demodulator for spread spectrum signal is presented. If there is the input sequence *{x_n}* and the spreading sequence *{a_n}*. The indexes denotes periods of the spreading sequence. Now the modulator is shown in the fig. 6.

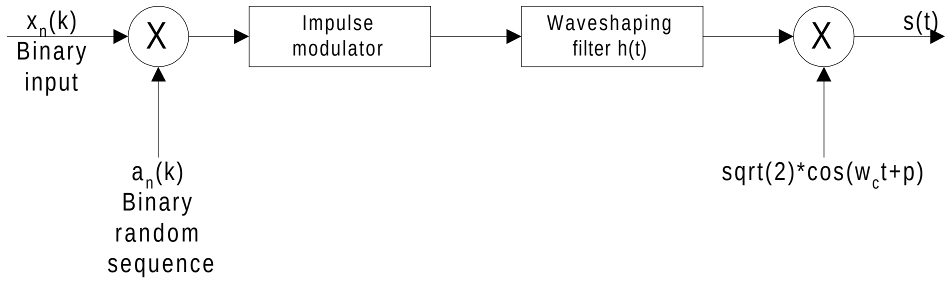

Figure 6. BPSK modulator

The input sequence *{$x_n(k)$}* can be either repetitions of the code symbols from a convolutional coder or it can be encoded by some other code. The major point is that a data bit is producing many chips in the sequence *{$x_n(k)$}*. This means that the spreading chip rate is multiple times the information bit rate.

For further analysis assume a channel model consisting only attenuation and phase shift, different for each user. Additive white Gaussian noise with one sided spectral density N_0 is added to the signal. A possible jamming is represented by *q(t).*

Demodulator is shown in the fig. 7. This structure is optimal, if the noise is Gaussian and uniform over the signal bandwidth.

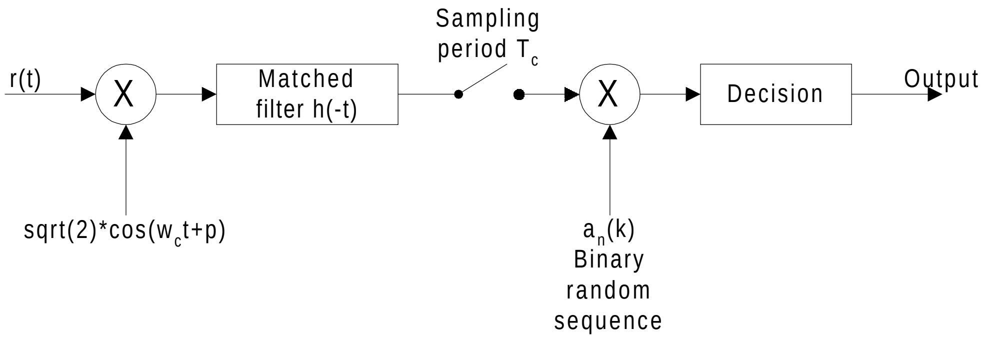

Figure 7. BPSK demodulator

Now the received signal can be written as

$$r(t) = \sum_k \sqrt{\varepsilon_k}\, h_k(t) + n(t) + q(t)\,,$$

where *n(t)* represents noise and *k* refers to the *k*'th user.

The spreading sequences of *k* users are assumed to be white and uncorrelated with one another. The jamming *q(t)* is assumed wide-sense stationary, but otherwise stationary. Normalisation of the bandlimiting filter is assumed to be

$$\int_{-\infty}^{\infty} |H(f)|^2\, df = 1\,,$$

which means that ε_k is the energy per chip for *k*'th user.

In the $y_n(k)$ the interference part can be written as

$$v_k = a_k \sum_{m \neq k} \sqrt{\varepsilon_m} a_m \cos(\phi_m - \phi_k) + \int_0^{\tau_0} [n(t) + q(t)] h_k (T_c - t) dt \ .$$

The variance of any $v_n(k)$ can be developed to

$$\sigma_v^2 = \sum_{m \neq k} \frac{\varepsilon_m}{2} + \frac{1}{2} \int_{-\infty}^{\infty} [N_0 + J(f)] |H(f)|^2 \, df$$

where $J(f)$ is the one-sided power spectral density of the interference.

If we compare the AWGN term to the interference term, we see that the effect of the interference on the variance is the same as a white noise having the same total power passband. Now the conclusion of this calculation is that an effective noise level is

$$N_{eff} = N_0 + \sum_{other\_users} \varepsilon_m + \int J(f) |H(f)|^2 \, df$$

$$\approx N_0 + \sum_{other\_users} \varepsilon_m + P_{\text{int}\,erf} \,/\, W$$

where P_{interf} is the total in-band interference power. This is also called as a interference averaging property, which causes interference diversity.

3.2 QPSK

The similar analysis than described in the previous chapter can be also made for QPSK. The modulator is described in the fig. 8. and the demodulator in fig. 9.

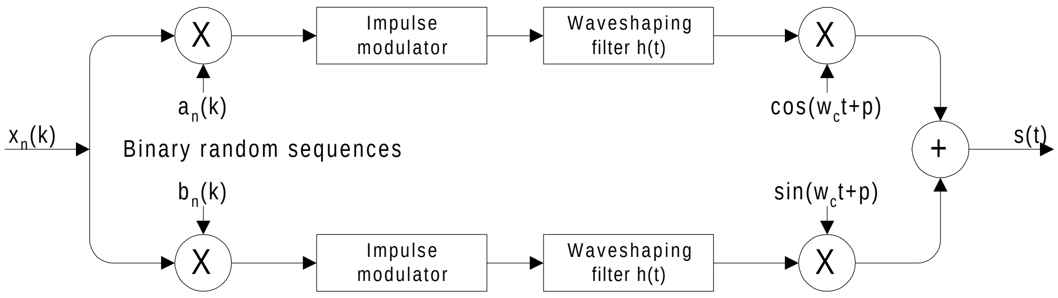

Figure 8. QPSK modulator

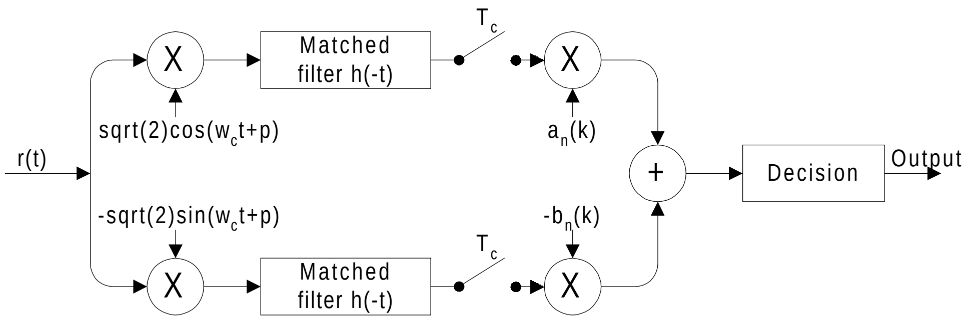

Figure 9. QPSK demodulator

Let's shortcut the most of the equations for QPSK. *I* and *Q* are like in the BPSK model, except that half of the energy appears in each channel, so ε_k is replaced by $\varepsilon_k/2$. On the other hand noise and the interference are the same in each channel, thus the detection variance can be written as

$$\sigma_v^2 = \sum_{m \neq k} \varepsilon_m + \int_{-\infty}^{\infty} [N_0 + J(f)] |H(f)|^2 \, df \, .$$

Now the signal-to-noise ratio remains the same than in the previous chapter. Thus quadrature spreading does not have effect to the performance.

4. RAKE RECEIVER

Matched filter receiver performs well if there is no multipath propagation. For Rayleigh fading multipath channel a better approach is a multipath diversity. Its target is to resolve individual multipath components and combine them in an advantageous manner. A receiver which performs this operation is called as a RAKE receiver.

A multipath channel can be described by discrete time channel model [5]. This is a tapped-delay line model where tap coefficients are given by $\{\beta(n/W,t)\}$ and it is described in the fig. 10.

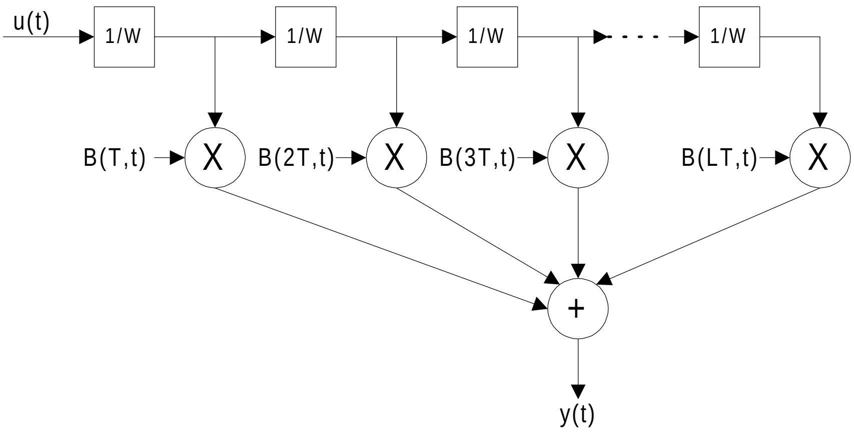

Figure 10. Tapped delay line. 1/W corresponds to delay between two taps.

The received signal *r(t)* is the transmitted signal *y(t)* plus zero-mean Gaussian noise *z(t).* (*u* refers to the spreading code)

$$r(t) = y(t) + z(t) = \sum_{n=1}^{L} \beta\left(\frac{n}{W}, t\right) u\left(t - \frac{n}{W}\right) + z(t)$$

Now the RAKE receiver is shown in the following figure.

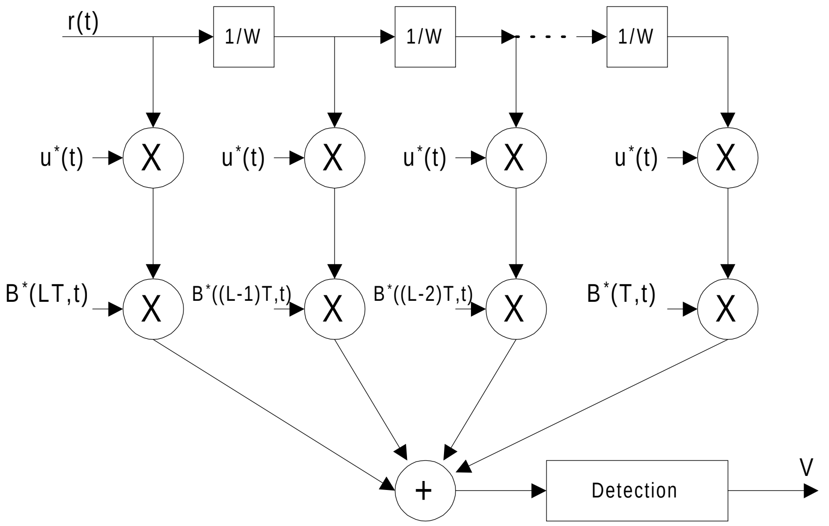

Figure 12. RAKE receiver

In [5] there is an analysis which determines the decision variables *V*. The result is that the *V* is the same than with *L*-branch maximal ratio antenna diversity combining. Hence the performance of an *L*-branch RAKE receiver in frequency selective fading is identical to that of an *L*-branch maximal ratio combiner in time-selective Rayleigh fading. The performance of *L*-branch maximal-ratio combining can be found from several books [3,4,5].

However there is couple issues which affects to the performance of RAKE receiver:

1. In the system level the transmitted power is in the case of RAKE divided among all possible multipaths. When propagation loss is neglected this means that received power is at maximum the same than the transmitted power. In the case of antenna diversity the situation is not the same, because each path receives at maximum the transmitted power. Thus the received power is $10log_{10}(L)$ decibels greater than with RAKE, assuming identical orders of diversity L.
2. The tap spacing $1/W$ in the RAKE is specified by the signal bandwidth. This spacing is not necessary the same than the spacing of the multipath components in the channel.
3. Non-orthogonal spreading codes degrades the performance of the RAKE.
4. The non-ideal channel gain estimation degrades the performance.

In the fig. 12 the RAKE receiver must has the perfect synchronization with the spreading sequence u. This can be achieved by using pilot-aided coherent RAKE demodulator. The pilot transmission is also valuable for initial acquisition and time tracking. It also makes good channel amplitude and phase estimation possible.

However it is not always possible to use pilot signals, especially not in the uplink where each user should have a own pilot signal. If they would be used they would eat system capacity dramatically. In this case it is also possible to use noncoherent RAKE.

5. NEAR-FAR-PROBLEM

In CDMA other users can be seen as a noise like interference. The processing gain G produces G-fold enhancement. However in CDMA these users are in the same band in the same cell. Now it is possible that one user is very close to the base station and another far away from the base station. Although there is processing gain, the first one may mask the second one. This effect where the signal of one user masks the signal of another user is called near-far-effect. Also fading caused by either multipath propagation or terrain configurations may degrade the strength of the signals.

The near-far-problem can be neglected by following ways:

1. Reducing the transmission power of mobiles which are close to the base station by using power control.
2. Enhancing the signal of far-away mobiles by receiving the signal from several places (i.e. soft-handover).
3. Diversity reduces the effects of fading: Multiple antennas per base station, frequency diversity, time diversity and multipath diversity by RAKE receiver.

5.1 Power control

Power control is used in CDMA because of three reasons:

1. Near-far-problem
2. Like described in chapter 2, the capacity of CDMA system is interference limited i.e. the less interference the more capacity. So it is beneficial to use as weak transmission power as possible.
3. Saving of the power in the mobile.

The target of the power control is to keep the received power constant and in the level which is just required for transmission. Power control is mainly needed in the uplink, because in downlink the received powers are the same without power control, thus there is no near-far-problem. However it is also possible to use power control also in the downlink for capacity reasons.

The target of the power control means very large dynamic range requirement, because mobiles may be very close or far away from the base station. In many environments propagation goes as the fourth power of distance, leading to the total dynamic range of path loss to be 80 dB [4]. Another problem is the fast or multipath fading which has a dynamic range of about 30 dB. However CDMA systems have large bandwidth and thus fading is less severe. Also RAKE receiver decreases the fade depth. With multipath fading the problem is that mobile can move fast and thus fading rate may exceed 100 Hz. Also multipath fading is not, like propagation loss, similar in both transmission direction. Instead up and downlink are not reciprocal, unless the system is using time division duplex.

Open-loop power control is used to provide wide dynamic range. It means that the received signal strength is measured and the transmitted power is changed according this. Open-loop control can not itself reach enough accuracy, because of lack of reciprocity.

Closed-loop power control means that the power control command is transmitted between mobile and base station. According this command the transmitted power is changed. Closed-loop power control takes lack of reciprocity into account. To be able to follow fast fades the control frequency should be much higher than the fading rate.

The real world power control algorithms are much complex than previously described including many fixed or adjustable parameters. The algorithms can instead of received power be based on the SNR or C/I. The fig. 13 tries to illustrate closed and open loop power control.

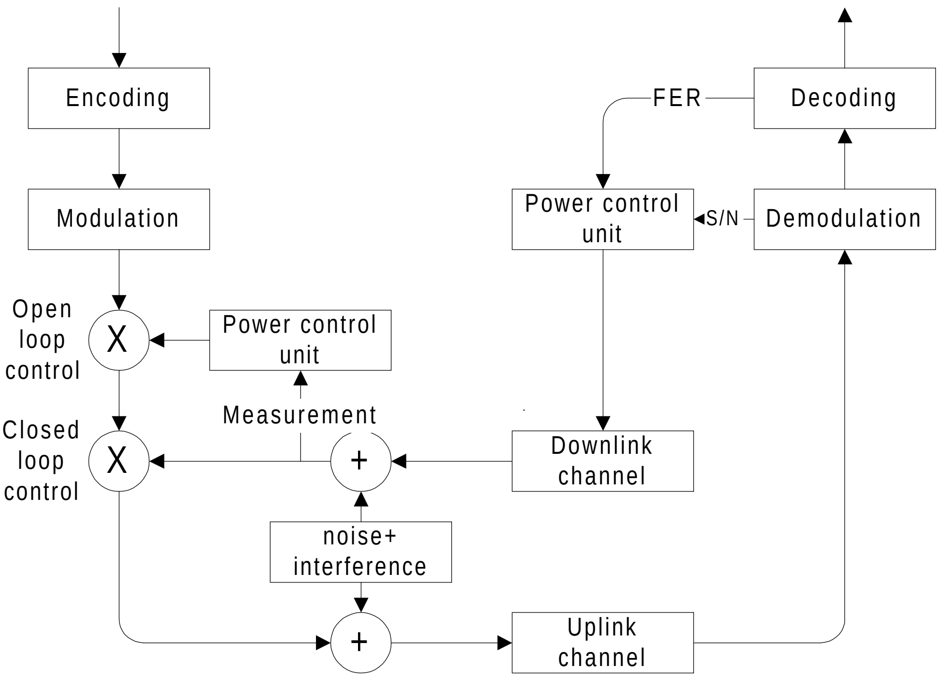

Figure 13. Simplified diagram about closed and open loop power control.

The power control has a feature that when there is high load on a cell, the users tend to increase their transmission powers. If there at the same time is a lower load in the neighbouring cells, the increased interference caused by highly loaded cell will decrease their capacity. This means that highly loaded cell borrows the capacity from less loaded cell. After the load decreases the situation turns back to the normal state. This means that there is 'soft-capacity' i.e. the capacity of a cell is not tightly bounded. This is an advantage of CDMA.

Unfortunately the previous behaviour may also cause problems. When a user increases the transmission power, the noise level of other users is also increased and thus they must also increase their power. This may lead to the power competition which must be taken account when CDMA systems are planned.

Errors on the power control are possible because the received power may be wrongly estimated and a closed-loop power control command may suffer from noise, interference or multipath propagation. This means that the received power is not anymore constant and the system capacity is decreased.

5.2 Soft handover

Soft handover applies the principle of macroscopic diversity [7]. The signal is transmitted via multiple base stations and then combined in the receiving end (see fig. 14). Soft handover can be used both in uplink and downlink. Macroscopic diversity by soft handover mitigates the slow fading caused by terrain variations. It is also beneficial when adjacent cells has an overlapping coverage area. Now the mobile located far away from the base station does not have to use so high transmission power than what is needed by using only link. Instead multiple combined transmission paths improves the performance. The lower transmission power means lower interference level for other users and apparently improves the system capacity.

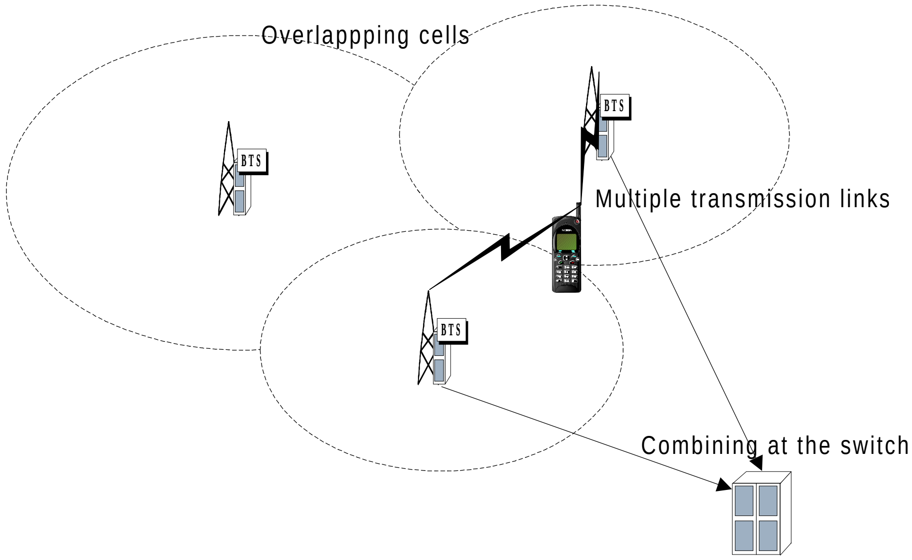

Figure 14. The concept of soft handover

Soft handover means that when a handover is planned, then the transmission link can be at the first initiated with the new cell and after this the old transmission link is released. This make-before-switch effect decreases the dropping probability caused by handovers.

Soft handover has also a system level disadvantage which can be easily seen from the fig. 14. The first place where the multiple transmission paths can be combined is the switch. This means that there must be more wirelines between base stations and the switch. Also in the downlink the signal is transmitted via multiple base stations, which means that there is more radio signals and thus more interference.

6. ADVANTAGES AND DISADVANTAGES OF CDMA

This chapter lists many advantages and some disadvantages of CDMA. Many of these advantages and disadvantages can be also found from other multiple access schemes, like in frequency hopping TDMA.

Advantages:

- **Wide bandwidth**: fading is less deep than in the narrowband systems.
- **Multipath diversity**: RAKE improves the performance, because individual multipaths can be combined. However the RAKE has to be able to estimate delays of these paths, which may be difficult. Also the implementation may limit the number of paths.
- **Narrow band interference rejection**
- **Interference averaging:** The interference caused by other users is averaged by processing gain.
- **Interference limited capacity:** Discontinuous transmission is an advantage.
- **Re-use one:** Frequency management easy. No frequency planning needed when a new cell is added.
- **Soft handover:** Improves the capacity and gives more range in cellular network.
- **Soft capacity:** Because other users are seen as noise like interference, an one extra user causes only slight degradation in the performance of other users.
- **Low peak power:** Less electromagnetic interference. Also if the peak power is limited, then more range.
- **Capacity:** The capacity of CDMA has been very controversial issue. The problem has maybe to which systems CDMA is compared. For example comparing CDMA with AMPS, tenfold capacity increment can be found [4]. However this is not fair, because AMPS is first generation system and CDMA is not. When comparing GSM1900 and IS-95, the results has been totally opposite, depending on who is presenting them. Third generation wideband CDMA and enhanced GSM is compared in [8] and the result is that there is no great differences in capacities. So, as a result it can be said that the capacity of CDMA is good.
- **Flexibility:** Wide range of bitrates (8 kbit/s to 2 Mbit/s) with one 5 MHz carrier.
- **Politically popular:** CDMA is a candidate for global 3rd generation cellular system.

Disadvantages:

- **Wide bandwidth:** High bitrates are difficult to achieve, because CDMA requires a lot of bandwidth. Due to intra-cell interference a single cell capacity is lower than in other cellular systems.
- **Near-far-problem**: CDMA requires good power control, otherwise near-far problem will decrease capacity.
- **Soft handover:** More interference and more complex network structure.
- **Fast power control:** May cause problems like power competition.
- **TDD** mode is difficult to support with CDMA.

7. CONCLUSIONS

An overview of CDMA has been given. CDMA is a spread spectrum multiple access method, where users are divided by codes. The principle is that user signal is spread by the pseudo noise sequence. This sequence has a noise like characteristics and thus other users are seen as a noise like interference. The synchronization is a vital issue in CDMA and it can be divided into acquisition and tracking. Matched filter receiver is optimum against Gaussian noise in CDMA. In the multipath environment the RAKE receiver is better, because it can despread each multipath individually and combine them afterwards. Thus RAKE produces multipath diversity. Near-far-problem is caused by a mobile located near by base station which masks other users. The problem can be compensated by power control, soft handover and diversity. Finally it is found that CDMA has many advantages, but also some disadvantages.

8. REFERENCES

[1] A. J. Viterbi, CDMA Principles of Spread Spectrum Communications, Addison-Wesley 1995

[2] R. C. Dixon, Spread Spectrum Systems with Commercial Applications, John Wiley & Sons 1994

[3] J. G. Proakis, Digital Communications, McGraw-Hill 1995

[4] J. D. Gipson, The Communications Handbook, CRC Press, IEEE Press 1997

[5] R. L. Peterson, R. E. Ziemer, D. E. Borth, Introduction to Spread Spectrum Communications, Prentice-Hall, 1995

[6] E. S. Sousa, CDMA for Personal Communications, Tutorial material, PIMRC'97

[7] W. C. Jakes, Microwave Mobile Communications, J. Wiley & Sons, 1974

[8] T. Ojanperä, P. Ranta, S. Hämäläinen, A. Lappeteläinen, Analysis of CDMA and TDMA for 3rd Generation Mobile Radio Systems, VTC'97

[9] R. Kohno, R. Meidan, L. B. Milstein, Spread Spectrum Access Methods for Wireless Communications, IEEE Comm. Mag, Jan. 1995