Impact of the Alamouti diversity technique on a CDMA platform

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1. Introduction

1.1 Background

Diversity methods have been object of study in several research centers, universities and companies in the last decades. The capacity of these methods to improve the performance of wireless communications, has attracted all this attention. Actually, diversity has been proved as one of the best techniques to solve the multipath effect, which is considered as the most limiting factor. The most famous diversity technique is space diversity, where several antennas, commonly in the receiver, get multiple uncorrelated replicas of the transmitted signal. Then, they can be combined positively to improve the results of the symbol detection.

Another point of view is to implement the spatial diversity in the transmitter. With his famous paper “A simple transmit diversity technique for wireless communications”, Alamouti founded the basis to apply that idea to the transmitter. The advantages of the technique were interesting: easy implementation, inexpensive and low computing complexity.

1.2 Tasks

This thesis is based on the study of the BER in link level of a cellular CDMA platform developed by Wireless Research Group of BIT. For that, and firstly, we have focused on the theory relative to the spread spectrum communications systems.

Later, and taking into account that the main goal of the thesis is the empirical comprovation of the improvements introduced by Alamouti technique in the platform, general review of diversity fundamentals are also given, plus a detailed discussion about the Alamouti technique. This first part of the thesis corresponds to the revision of all this concepts, papers and literature, hence it has theoretic orientation.
On the other hand, and much more practical, we have built an Alamouti transmitter/receiver using the RUNE toolbox of Matlab. This implementation, whose details and characteristics can be consulted later on, has the goal to show, in the most clearly way, the impact of using the Alamouti technique in the link level performance. Such impact will be obtained from several simulations under some different settings, whose results will be presented and analyzed in detail. We will elaborate a set of final conclusions as well.

1.3 Outline of the thesis

The thesis has been developed as follows:

**Chapter 2. Fundamentals of CDMA.**

In this chapter, a theoretical approximation to the Code Division Multiple Access technique is given. To begin with, a review of the spread-spectrum concept is done, and then more detailed discussions about CDMA are provided. This involves concepts such as frequency reuse, bandwidth, interference, orthogonal codification, etc. To finish with, a comparison with other access methods is given.

**Chapter 3. Fundamentals of Diversity.**

In this chapter we are going to review the basic concepts of diversity methods to improve the quality over radio channel. Here, we will discuss some of the most interesting diversity schemes as, space-diversity, frequency diversity, time diversity, polarization diversity, etc.

**Chapter 4. Alamouti Scheme**

Based in the paper “A Simple Transmit Diversity Technique for Wireless Communications” from Siavasha Alamouti, a deep study of this space-time diversity scheme is provided.
Chapter 5. CDMA platform review

In this chapter, we present the code that has been added in order to improve the transmitting stage of the CDMA platform. That contains an Alamouti coder for the transmitter, an Alamouti decoder for the receiver. All the new functions, and the platform itself, make use of existing functions of RUNE toolbox, developed with Matlab by Magnus Almgren of Ericsson Research (Sweden). We explain in detail the functions and give some of the main facts about the CDMA simulation platform as well.

Chapter 6. Results

The results are given in this section. To prove the Alamouti improvement, we have carried out simulations for several environments. Discussions and graphs are also given here.

Chapter 7. Conclusions

The conclusions of the thesis can be found here, as well as recommendations and guidelines for future work.
2. Fundamentals of CDMA

2.1 Introduction

Spread spectrum communication systems are characterized because they use a bandwidth much higher than the transmission rate needed to send the information. This is the expansion factor or processing gain, \( G = \frac{\Delta \omega}{R_b} \), in case of a spread spectrum signal is much greater than unity. This large redundancy, inherent in spread spectrum signals, was used at the beginning as a protective mechanism of communication in hostile or high interference environments. Hence, the first applications of this modulation technique were used in the military field, where the most important goal was the protection of the information integrity from external agents.

To achieve a spectrum spreading of the signal to transmit, specially in cell systems, pseudo-random sequences are used. This also can be denominated characterization of the waveform used in the coding. These pseudo-random sequences are to force the transmitted signal to adopt spectral characteristics similar to the white-gaussian noise, for that reason, they are also known as a pseudo-noise (PN) sequences. The goal was to avoid a correct demodulation of the signal from those who don’t have the right sequence, that is to say, from the attackers. Far from that, in commercial applications, CDMA became a way to divide the radio spectrum into channels. This is achieved by encoding different users with different signature sequence or codes.

![Spread spectrum modulator basic scheme. Source [1]](image-url)
2.2 CDMA system characteristics

It is well known that for a hypothetic scenario, with ideal gaussian channel, any of the access techniques (CDMA, FDMA, TDMA) are the same, in the framework of the channel capacity. Nevertheless, the difference between the access techniques come out when real radio channels are applied. In the next section, basic characteristics of CDMA scenarios are explained.

2.2.1 Complete frequency reuse

FDMA/TDMA scheme is based on the distance attenuation to control the co-channel interference. As a result, adjacent cells must use separated frequency sets. As we can see in the following figure, DS/CDMA systems apply an unitary frequency reuse, that means there is no frequency planning.

![Diagram showing complete frequency reuse in CDMA systems](image)

*Figure 2.3: Each colour shows a frequency or set of frequencies. On the left, the normal TDMA frequency distribution; on the right, complete reuse of the CDMA system. Source[2]*
In consequence, if within a single region the offered traffic rises, the introduction of new base stations just involves a readjustment of the maximum emitting power of the existing ones. The fact that only one frequency is used in all the cells not only improves the system capacity, makes unnecessary the frequency planning study as well. On the contrary, CDMA requires a different study which may take into account aspects as power level emission and synchronization of the pilot signals in each base station.

2.2.2 Channel bandwidth

The bandwidth used in mobile radio communication network can be seen as a compromise between the multipath effect mitigation, the receiver complexity and its performance. CDMA systems are characterized by using a bandwidth large enough, not only to counteract the multipath effect, but also take advantage of it and improve the quality of communication [3].

For open air communications, most of the sites involve an impulsive response with a delay spread within the first 10 µs. However, it’s usual that the main part of the symbol energy received in multipath channels is gathered within the 3 first µs.

![Figure 2.4. Typical power delay profile (PDP). Source [2]](image)

On one hand, signals transmitted with a finite bandwidth have a temporal resolution equivalent to the inverse of the transmitted signal bandwidth. So that, a transmitted bandwidth equal or inferior to the inverse of the delay spread means that there is no enough resolution to distinguish the successive echoes that appear within the temporal margin of the delay spread. This phenomenon makes the narrow bandwidth communication experience a flat channel response.
On the other hand, if a bandwidth 2 or 3 times bigger than the inverse of the delay spread is used, in reception it is possible to frame the multipath signal within 2 or 3 windows within the delay spread's interval. In practice, to recover the maximum of the energy, it's necessary to use a receiver which is able to demodulate the information coming from 3 different paths. For that, RAKE receivers are used in the base stations and mobiles, normally with a number of correlators enough to make profit from this essential feature of the spread spectrum communications. For example, QUALCOMM uses only three branches.

2.2.3 Interference

Another feature of the CDMA systems is related with the statistic of the observed interference, as a sum of the signals coming from the other connections. Specifically, this statistic approximates to the Law of Large Numbers (LLN); the more number of simultaneous communications, the more it approximates to this law. With that, to assure the quality of the communication, what is related to get a Eb/No relation bigger than a specific threshold, the variations of the useful signal is more critic than the variations of the interference signal. Moreover, CDMA systems (and due to bandwidth spread) are not as sensitive as TDMA/FDMA in terms of noise. That is the reason why they are normal referred as a interference-limited systems.
### 2.2.4 Detailed characteristics

Apart from the outstanding characteristics about CDMA that have been mentioned before, in this section we are going to provide some of the characteristics of the IS-95, which is the international standard definition of the system.

<table>
<thead>
<tr>
<th></th>
<th><strong>Downlink</strong></th>
<th><strong>Uplink</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Frequency band</strong></td>
<td>869-894 Mhz</td>
<td>824-849 Mhz</td>
</tr>
<tr>
<td><strong>Access method</strong></td>
<td>FDD/FDMA/CDMA</td>
<td>FDD/FDMA/CDMA</td>
</tr>
<tr>
<td><strong>Frequency reuse</strong></td>
<td>1, sectorial</td>
<td>1, sectorial</td>
</tr>
<tr>
<td><strong>Chip rate</strong></td>
<td>1.2288 Mcps</td>
<td>1.2288 Mcps</td>
</tr>
<tr>
<td><strong>DS-spreading</strong></td>
<td>Period $2^{15}-1$</td>
<td>Period $2^{15}-1$</td>
</tr>
<tr>
<td><strong>Scrambling</strong></td>
<td>$2^{42}-1$</td>
<td>$2^{42}-1$</td>
</tr>
<tr>
<td><strong>Modulation</strong></td>
<td>QPSK with Walsh orthogonal covering</td>
<td>OQPSK with 64 orthogonal signaling</td>
</tr>
<tr>
<td><strong>FEC</strong></td>
<td>R=1/2, k=9, convolutional</td>
<td>R= 1/3 , k=9, convolutional</td>
</tr>
<tr>
<td><strong>Interlacing</strong></td>
<td>20 ms block</td>
<td>20 ms block</td>
</tr>
<tr>
<td><strong>Voice codification</strong></td>
<td>Q-CELP: 9.6, 4.8, 2.4, 1.2 Kpbs</td>
<td>Q-CELP: 9.6, 4.8, 2.4, 1.2 Kpbs</td>
</tr>
<tr>
<td><strong>Frame duration</strong></td>
<td>20 ms</td>
<td>20ms</td>
</tr>
<tr>
<td><strong>Receiver</strong></td>
<td>RAKE 4 branches</td>
<td>RAKE 3 branches</td>
</tr>
<tr>
<td><strong>Diversity</strong></td>
<td>Frequency, space, time</td>
<td>Idem, and also in antenna</td>
</tr>
</tbody>
</table>

*Figure 2.5. feature table of the IS-95 standard. Source [4]*

The access method FDD/FDMA/CDMA indicates that there is a frequency duplexing, as well as we can find in the GSM system. The operational bands for uplink and downlink can be found between the 800 and 900 Mhz. In this bandwidth, both uplink and downlink band frames are divided in 1.25 Mhz channels. Finally, a multiplexing by code division in each of that channels is applied. This multiplexing has a maximum of 64 sub-channels, control channels included. This limit is due to the maximum number of Walsh-Hadamard codes.

As it has been said before, the frequency reuse is unitary, that is to say, all cells and sectors use the same radio channel. The transmission speed of the air signal is 1.2288 Mcps, that is to say, there is a bandwidth spread of 128.
The spectral spreading is realized by the combined use of two pseudo-random sequences, with lengths of \(2^{15}-1\) and \(2^{42}-1\) respectively. The reason why two pseudo-random sequences are used will be reviewed in the next paragraph.

The used modulation is different for uplink and downlink. On one hand, in the uplink a QPSK modulation is used, on the other hand, the downlink uses an offset-QPSK, with a delay between the phase and quadrature of \(\frac{1}{2}\) chip.

The error correction scheme uses a emission channel coder with \(\frac{1}{2}\) rate for the downlink, that is to say, for each bit of information one redundant bit is generated. For the uplink, a \(\frac{1}{3}\) rate is used due to the fact of its inconsistency. It is also used a interleaving of 20 ms, which is the normal to protect voice transmission. The frame duration is also fixed to 20 ms.

A brief description of the transmission scheme is explained next. The output signal from the voice coder is transmitted with a variable rate between 1.2 kbps and 9.6 kbps. Then, the signal is convolutionally coded with a \(\frac{1}{2}\) rate, with bit repetition for those codifications inferior to 9.6 kbps. As a result of that, the rate at the convolutional coder is 19.2 kbps. The next step is the interleaving. The PN sequence is decimated to match the 19.2 kbps, so the OR-exclusive sum can be done. With this, it is possible to encode the communication and force the flattening of the resulting signal. Finally, another OR-exclusive sum it is done, in this case with one of the 64 Walsh codes. As it's been said before, this codes are orthogonal one another, and each communication, paging and sync channels use one of them. The pilot signal uses the first code, all zeros, what is the same to say that \(2^{14}-1\) length sequence is transmitted without any modulation.

The use of the Walsh codes assure the orthogonality between all the communications transmitted from the base stations. As a consequence, all the channels are summed in OR-exclusive way, in order to obtain the quadrature and phase signals that are summed again with the PN sequence of \(2^{15}-1\). Later, each symbol in phase or quadrature is sent to the pulse conformer filter and finally, modulate the correspondent carrier. This is the way how the QPSK modulation is reached. The joint use of the Walsh codes and the short PN sequence achieve a much more efficient behaviour. The Walsh codes assure the orthogonality, but they have a bad spectral behaviour. The PN sequences have an almost flat spectral behaviour, and good orthogonal properties.
Moreover, this way of working doesn’t require that each communication makes its own synchronisation (different form the $2^{15}-1$ length sequence), which is beneficial to reduce the synchronisation time. The uplink share most of the specification, but also include slight differences. The coded voice signal is sent to the convolutional coder with a rate of 1/3, and then, to the interleaving block. Next, the bits are taken in blocks of 6 to obtain, as an output of the 64 modulator, the correspondent 64 length symbol word. That produces a signal, as an output from the modulator, with a rate of 307.2 kcps. Next, the OR-exclusive sums are done with the outputs of the long-length and short-length PN generators. The delay of $\frac{1}{2}$ chip between the signals in phase and quadrature produce the desired modulation OQPSK.

2.3 Comparison with other access methods

In this section, a brief table of the most significant differences with the most common systems is given:

<table>
<thead>
<tr>
<th></th>
<th>FDMA</th>
<th>TDMA</th>
<th>CDMA</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Timing control</strong></td>
<td>Not required</td>
<td>Required</td>
<td>Required</td>
</tr>
<tr>
<td><strong>Carrier frequency stability</strong></td>
<td>High stability is required</td>
<td>Low stability is acceptable if large number of channels are multiplexed</td>
<td>Low stability is acceptable if chip rate is sufficiently high</td>
</tr>
<tr>
<td><strong>Near-far problem</strong></td>
<td>Not affected</td>
<td>Not affected</td>
<td>Fast power control is required</td>
</tr>
<tr>
<td><strong>Peak/average power ratio</strong></td>
<td>1</td>
<td>K</td>
<td>1</td>
</tr>
<tr>
<td><strong>Variable trans. rate</strong></td>
<td>Difficult</td>
<td>Easy</td>
<td>Easy</td>
</tr>
<tr>
<td><strong>Received signal level monitoring</strong></td>
<td>Difficult</td>
<td>Easy</td>
<td>Easy</td>
</tr>
<tr>
<td><strong>Suitable zone radius</strong></td>
<td>Any size is OK</td>
<td>Any size is OK (time alignment required)</td>
<td>Large size is not suitable</td>
</tr>
<tr>
<td><strong>Antimultipath fading technique</strong></td>
<td>Diversity, high coding rate FEC</td>
<td>Diversity, high coding rate FEC adaptive equalizer (if Nch is large)</td>
<td>RAKE diversity low coding rate FEC, fast power control</td>
</tr>
</tbody>
</table>

*Figure 2.6, Access methods comparison. Source [1]*
2.4 Conclusions: advantages and disadvantages

The use of spreading codes in order to separate user channels, which is the basis of CDMA, give us many advantages, as commented in [1]:

1. **Timing in the subscriber stations (mobiles) is to be established, at least in part, by synchronizing with the code transmitted by the base stations. The goal is to eliminate any need for accurate timekeeping in the mobiles when they are idle.**

2. **The mobiles identify base stations, at least in part, by correlating with a priori known base station spreading codes.**

3. **The process of synchronization in the mobiles should be rapid enough that the placement of a call from a “cold start” takes no more than a few seconds.**

4. **Access to base stations by mobiles should not require any prearrangement. That is, it should not be necessary for the base station to have a database of authorized users in order to establish radio communications. The base station, once physical layer access has been achieved, may choose to deny service for administrative reasons, such as nonpayment of the bill, but communication through the air interface should always be possible to cover emergency access.**

5. **In the CDMA forward link, the fact that each base station is transmitting multiple channels Walsh coding can be used beneficially to decrease mutual interference.**

6. **The acquisition search rate for reverse CDMA channel signals in the base stations can be speeded up if the mobiles can precorrect their timing so that their signal arrives at the base station as close to system time as possible.**

As we can deduce by paying attention to the characteristics mentioned above, synchronization in CDMA environments is not as problematic as TDMA systems. Again, frequency planning is not necessary, due to the fact that there is complete reuse of frequencies.
If we focus deeply in mobile communications over CDMA, some advantages are stand out [1]:

- **Universal one-cell frequency reuse.**
- **Narrowband interference rejection.**
- **Inherent multipath diversity in DS CDMA.**
- **Soft handover capability.**
- **Soft capacity limit.**
- **Inherent message privacy.**

On the contrary, also some disadvantages have to be taken into account [1]:

- **Stringent power control requirements with DS CDMA.**
- **Handoffs in dual-mode systems.**
- **Difficulties in determining the base station power levels for deployments.**
  that have cells of differing sizes.
- **Pilot timing.**
3. Fundamentals of diversity

3.1 Introduction

The performance of a communication system can be heavily disrupted by the multipath effects and doppler spreading effect. Diversity implementations can help to counteract this undesired effect in many ways. These ways can be either built in transmission or reception, and the usage only depends on the increment cost that we can assume or the environment conditions.

Diversity techniques make profit from the random nature of the radio channel, by sending the information in different channels, which means that we have at the output different versions of the same signal. If the channels characteristics vary independently, the probability of a simultaneous deep fading in all of them is lower. In practice, we cannot expect a perfect independence between all the channels involved, however, it is sufficient if their behaviour is low correlated. With that, we can achieve notable drop in the SNR. This SNR reduction is called diversity gain.

Figure 3.1, b shows an equivalent channel with a selection diversity system. Source [5]
As an example of this concept, in the picture above, we can see a simulation of two uncorrelated channels and the equivalent channel that would see a receiver in the case of using selection diversity, that is keeping the channel with better properties and discarding the bad one.

It is interesting to note that, although both of the channels have deep fadings, the equivalent channel has much more flat behaviour. Mathematically, if a single channel has a $p$ probability of suffering deep fading, if we use $N$ uncorrelated channels, the same probability falls as $p^N$.

3.2 Types of diversity

When we talk about diversity systems, many different methods come up easy, some of them are completely different to the others in terms of physical concept, implementation or performance. We can make a first easy distinction between those systems that are implemented at the receiver or those implemented at the emitter. We can also make a distinction between the systems in terms of which physical phenomenon is related. Here, we could find space diversity, frequency diversity, time diversity or polarization diversity. Again, another selection can be done by the way how the replicas are used: selection diversity, feedback diversity, combining diversity (MRRC) or equal gain combining (EGC). In the next Points a brief review of the most common methods is given.

3.2.1 Space diversity

Space diversity is one of the most common diversity technique in wireless communication systems. It also can be found in the literature with the name of antenna diversity. The main goal of this technique is that each of the antennas are separated enough to get different versions of the signal due to the uncorrelated multipath behaviour of the channel. The separation between the antennas is different if we talk about the mobile or the base station. While in the mobile a separation of $0.5\lambda$ could be enough due to the proximity of architectural scattering elements, in the base stations usually is needed $10\lambda$ or more. A more detailed view will be given in the next chapter as a part of Alamouti and space-time code literature.
3.2.2 Frequency diversity

When the information is transmitted in more than one carrier, we talk about frequency diversity. The goal is that signals with an enough spectral separation don’t suffer from the same instantaneous behaviour of the channel. Dependent on the channel’s coherence bandwidth, which indicates how correlated are the different frequencies within the channel, two carriers may experience total or partial uncorrelated fadings. A negative point is that coherence bandwidth can be a large part of the total bandwidth, hence, the disadvantage of having to use bigger bandwidth often occurs. It might be also necessary to increase the number of receivers, at least one for each diversity channel. However, this technique is usually deployed on in-sight links using FDM and for critic routes. In transmission diversity systems, it is possible to use the frequency diversity by using space-frequency codes.

3.2.3 Time diversity

In time diversity systems, the symbols are retransmitted in different time, so that the repetition could be done in independently fading conditions. The retransmission of the signal reduces the output speed, and what is more, due to the necessity of repetitions to be separated a bigger time than medium average duration of the fadings, also a notable latency is introduced.

On the other hand, although N times more bandwidth is necessary, the advantage goes to the fact that hardware is very simple because all of the processing is done at base band. This is the reason why this technique is suitable for CDMA systems, where the spread of the bandwidth doesn’t represents a trouble. We should note, however, that this technique is not advantageous when the mobile velocity is near to zero, because under this circumstance, the time separation of the interval is too large. Moreover, it is not possible to get time diversity when the mobile is in static position.

3.2.4 Polarization diversity

Polarized horizontal and vertical signals present good levels of uncorrelation. This is understandable if we take into account that each surface provide different kind of reflection depending on the polarization, which cause the signals to acquire quiet
uncorrelated phase and amplitude. If this process occurs many times, as we would expect in real environments, a high level of uncorrelation is possible between the signal, making easy to obtain a diversity gain.

### 3.2.5 Receiver diversity

Inside receiver diversity, selection diversity is one of the most easiest techniques. To implement that solution it is necessary to count with N demodulators and N RF chains to obtain the N branch diversity. Then, it is as easy as choosing the branch with a higher SNR. Another way of operation is the unique use of one demodulator and one RF chain, that entails the selection of the branch with higher SNR.

On the other, if we want to apply selection diversity in the transmitter, a communication between the transmitter and receiver is a must; this last instance has to observe periodically all the channels and inform the transmitter which is the channel with best quality.

In Maximal Ratio Receiver Combining (MRRC), the signals are weighted according to their SNRs and then are summed. The signals at the receiver must have the same phase in order to make the sum, which requires an individual receiver and an alignment phase circuit for each antenna. The next figure, which shows a two-branch MRRC scheme, is provided in order to give the basis for a later comparison with the Alamouti scheme in the next chapter.

![Figure 3.2, Two-branch MRRC scheme. Source [8]](image)
This method, produces as an output a SNR that is the weighted sum of the individual SNRs. Hence, the system is capable to produce a signal with a sufficient SNR level even when any of the received signals reach that level. In fact, MRRC gives the best statistical fading reduction any of the combined linear diversity techniques.

Variable weighting capacity of MRRC is not always possible, so all the weights are to be established equal to one, but the signals are aligned in phase. This is principle of the EGC. The capability of producing an acceptable signal from many unacceptable inputs is maintained. Althought it has a lower performance in comparison with the MRRC, it is still better than selection diversity average. EGC offers an easier alternative to the MRRC, but phase deviations produced by the channel must be estimated and counteracted.

3.3 Conclusions

To end this chapter and to give a fast comparison between the most common physical phenomena method, the next table is attached.

<table>
<thead>
<tr>
<th>Diversity Scheme</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Space diversity</td>
<td>Easy to design. Any number of diversity branches are ( L ) selectable. No extra power nor bandwidth is necessary. Applicable to macroscopic diversity.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hardware size could be large (depends on device technologies). Large antenna spacing is necessary for microscopic diversity at the base station.</td>
<td></td>
</tr>
<tr>
<td>Polarization diversity</td>
<td>No space is necessary. No extra bandwidth is necessary. Only two-branch diversity schemes are possible. Three decibels more power is necessary.</td>
<td></td>
</tr>
<tr>
<td>Frequency diversity</td>
<td>Any number of diversity branches ( (L) ) are selectable. ( L ) times more power and spectrum are necessary.</td>
<td></td>
</tr>
<tr>
<td>Time diversity</td>
<td>No space is necessary. Any number of diversity branches ( (L) ) are selectable. Hardware is very simple. ( L ) times more spectrum are necessary. Large buffer memory is necessary when ( fd ) is small.</td>
<td></td>
</tr>
</tbody>
</table>

Figure 3.3, comparison between diversity methods. Source [6]
4. Alamouti scheme

4.1 Introduction to SBTC

It is possible to apply all the diversity schemes seen in the last chapter either to the transmitter or the receiver. In the majority of dispersive environments, the antenna diversity is an easy and effective solution, hence, it is widely used to reduce the multipath fading. The most common scheme is to use some antennas in the receiver, and combined with that, one of the combining methods explained before to enhance the quality of the received signal.

However, the main problem of this technique is how to apply it to mobile units, due to the increasing cost, size and power consumption. A system with multiple antennas and radio frequency channel chains might be bigger and costly. This limitations are less worrying in a base stations, because one of them can give service to hundreds of mobile subscribers, so the increment of cost is assumable. For this reasons, diversity techniques have been in the past an exclusive field of the base stations. However, the same base stations that is a receiver in the uplink, also is a transmitter in the downlink, so the antennas can be used in both ways as well.

For the transmission, there are different techniques to obtain diversity gains which can be separated in open or closed bounds, according to the use or not of a feedback from the receiver to the emitter. Anyway, it is necessary to implement some kind of signal in both sides of the system.

Exhaustive information can be found in the literature. The pioneer of this scheme was Wittneben in the mark of MULTICAST, which includes the time delay scheme of Seshadri and Winters as an particularly case. In time diversity or delayed scheme, two-transmit antennas are used, but the information in one of them is delayed respect the other one. Later, Foschini worked on space-time architectures that were built in layers with multiple antennas, which consist on schemes that are able to get diversity with or without codification. In this scheme, the transmitted signals are not orthogonal, so they can arrive corrupted by signals of the other layers. Hence, an interference cancellation system is a must in the receiver.
Later, the space-time coding was considered as a good method to use with high-speed transmission in slow varying channels. In [6] a space-time trellis codification was proposed, which is based in the joint use of codification, modulation and diversity in transmission and reception. Although the great performance of this technique, the complexity on the decoding stage could be unbearable due to its exponential growing with the diversity and transmission speed.

In his paper “A Simple Transmit Diversity Technique for Wireless Communications”, Siavash M. Alamouti found out a diversity implementation in open bound (this is to say, without using bidirectional communication as a feedback) with to transmit antenna and on receiver antenna. Besides, this scheme can easily be extended to the case of many receiver antennas. This scheme would be later referred as space-time block codes (STBC). The main characteristic of the STBC is the simple decoding algorithm, due to the fact that is only necessary a linear processing of the received signal. Later, Tarokh [7] developed the idea and extended it to the use of a given number of transmit antennas.

4.2 Introduction to Alamouti technique

The Alamouti technique can be considered as the most simple diversity STBC. Although its simplicity, as it only uses two-transmit antennas and a simple signal processing at the receiver, it provides a clear improvement on the received signal. The diversity order obtained with this technique is the same we would get from MRRC with two antennas at the receiver. It is also possible to extend two the case of two-transmit antennas and N receiver antennas, what would provide a diversity order of 2N. Furthermore, all this advantages are reached with any kind of feedback from the transmitter antenna, any spread of the bandwidth and what is more interesting, it doesn’t need a strong computational complexity to implement the coding and decoding stage. The reduction of the undesirable effects of path fadeings, thanks to Alamouti technique or any other diversity technique, make possible to introduce higher level modulation patterns in order to increase the bit rate, increase the coverage in the cells, or provide better quality of service.
4.3 Two-branch transmit with one receiver

4.3.1 Scheme

Next figure shows the basic two-branch transmit Alamouti scheme, with only one antenna at the receiver. The core of this implementation resides in three stages: the codification and the transmission sequence, the combining method at the receiver, and finally, the symbol detection procedure in the maximum likelihood detector.

![Diagram showing the two-branch transmit Alamouti scheme](image)

Figure 4.1, two-branch transmit Alamouti scheme. Source [8]

4.3.2 Codification and transmission

Each time we want to transmit one symbol, we make it twice. If we denote that $s_0$ is the symbol sent from antenna 0 and $s_1$ is the symbol sent from antenna 1 at a given time $t$, then, in the next symbol period ($t+T$) we transmit from antenna 0 the symbol $-s_1^*$ and from antenna 1 the symbol $s_0^*$. In can be clearly understood in the next figure.

<table>
<thead>
<tr>
<th></th>
<th>Antenna 0</th>
<th>Antenna 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>$t$</td>
<td>$s_0$</td>
<td>$s_1$</td>
</tr>
<tr>
<td>$t+T$</td>
<td>$-s_1^*$</td>
<td>$s_0^*$</td>
</tr>
</tbody>
</table>

Figure 4.2, transmission sequence in two-branch transmit Alamouti scheme. Source [8]
It is also interesting to note that this space-time diversity can easily be exported to space-frequency diversity. It is only necessary to use two adjacent carriers in the same way we use two adjacent time periods.

One of the most important assumptions in this technique, is that the channel will not vary in two consecutive symbol periods. With this, we can denote the channel 0 as $h_0$ and channel 1 as $h_1$. With the same notation and adding complex random variable $n_x$ in order to express noise and interference, we obtain the following received signals:

$$r_0 = r(t) = h_0 s_0 + h_1 s_1 + n_0$$
$$r_1 = r(t + T) = -h_0^* s_1 + h_1^* s_0 + n_1$$

### 4.3.3 Combining scheme

The combining scheme presented in the figure 4.1 gets the received signals and follows the next rule in order to send them to the maximum likelihood detector:

$$s_0 = h_0^* r_0 + h_1^* r_1^*$$
$$s_1 = h_1^* r_0 - h_0^* r_1^*$$

Taking into account that channels can be expressed as follows:

$$h_0 (t) = h_0 (t + T) = h_0 = a_0 e^{j \theta_0}$$
$$h_1 (t) = h_1 (t + T) = h_1 = a_1 e^{j \theta_1}$$

We can finally express the symbols sent to the maximum likelihood detector as:

$$\hat{s}_0 = (a_0^2 + a_1^2) s_0 + h_0^* n_0 + h_1^* n_1^*$$
$$\hat{s}_1 = (a_0^2 + a_1^2) s_0 + h_0^* n_1 + h_1^* n_0$$
4.3.4 Maximum likelihood detector

The combined signals last seen, are sent to the ML detector in order to obtain the symbol decision. In case of PSK or BPSK (that is to say, equal energy constellations) the detection rule can be expressed as follows:

\[ d^2(s_0, s_i) \leq d^2(s_0, s_k) \quad \forall i \neq k \Rightarrow \text{choose symbol } s_i \]

It is interesting to note that the signals at the output of the combiner are equivalent to the signals we would obtain in the two-branch MRRC (seen in figure 3.2). That is the reason why we can affirm that the Alamouti scheme with two-branch transmit diversity is equal to the two-branch MRRC, in terms of diversity order. A slight difference is that noise components are rotated, however, this fact doesn't affect the SNR.

4.4 Two-branch transmit with M receivers

Under some circumstances, when the air channel presents bad characteristics or when it is possible to implement more than one antenna at the receiver, the use of a higher order of diversity could be interesting. The order that we would get in a system with two-transmit antennas and N receive antennas is 2N. In this chapter, detailed view of the two-transmit and two receive antennas is given with the aim of simplicity, but the generalization can be easily done in the case of using any number of antennas. The figure 4.5 shows the scheme in this particularly case.

The next two figures, provide a quick view of the notation used. In one hand, figure 4.3 shows the theoretical channels between the transmit and receive antennas. On the other hand, figure 4.4 shows the signal notation for each antenna in each symbol time.

<table>
<thead>
<tr>
<th>Rx antenna 0</th>
<th>Rx antenna 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rx antenna 1</td>
<td>h_0</td>
</tr>
<tr>
<td>Rx antenna 1</td>
<td>h_1</td>
</tr>
</tbody>
</table>

*Figure 4.3, Channel definition between the transmit and receive antennas. Source [8]*
The codification and the transmitted sequence follow the same rule showed in figure 4.2 for the easy system, as long as the transmitting stage is not modified. With that, the received signals at the receive antennas can be expressed as follows:

\[ r_0 = h_0 s_0 + h_1 s_1 + n_0 \]
\[ r_1 = -h_0 s_1^* + h_1 s_0^* + n_1 \]
\[ r_3 = h_2 s_0 + h_3 s_1 + n_2 \]
\[ r_4 = -h_2 s_1^* + h_3 s_0^* + n_3 \]

Where again, \( n_x \) are the theoretical representation of thermal noise and interference.
We can finally express the symbols sent to the maximum likelihood detector as:

\[
\hat{s}_0 = (\alpha_0^2 + \alpha_1^2 + \alpha_2^2 + \alpha_3^2)s_0 + h_0^*n_0 + h_1^*n_1 + h_2^*n_2 + h_3^*n_3^\ast
\]
\[
\hat{s}_1 = (\alpha_0^2 + \alpha_1^2 + \alpha_2^2 + \alpha_3^2)s_1 - h_0^*n_1 + h_1^*n_0 - h_2^*n_3 + h_3^*n_2^\ast
\]

The combined signals seen above are equal to those ones we would obtain using a four-branch MRRC. Hence, the diversity order obtained with the two schemes is the same. Another property is that the combined signals of the receive antennas are simply the addition of the combined signals from each receive antenna, so it is possible to implement a combiner for each antenna and then simply sum the output of each combiner.

### 4.5 System performance

The aim of this chapter is to review the performance of the Alamouti scheme. For this, some assumptions are done. The first assumption is that the total power transmitted by the two antennas in the Alamouti scheme is equal as the power that unique antenna in MRRC scheme would transmit. Another assumption is that fading along all paths between transmit and receive antenna are mutually uncorrelated and follow a Rayleigh distribution. Moreover, it is supposed that the average power received in every single receive antenna is the same and that the receiver has a perfect knowledge of the channel. In essence, this strong assumption will be adopted as characteristics for the implementation of the Alamouti coder/decoder system in the next chapter.

It is true that all this assumptions are far away from reality, but taking them into account may result in a easier way to compare the results. In figure 4.6, the BER performance comparison between Alamouti’s scheme and the MRRC is shown. If we have told that the performance of Alamouti scheme, in diversity terms, is equal to MRRC, why the two-branch transmit Alamouti results are 3dB under the MRRC? The reason is one of the assumptions that have been made, that is that each antenna transmit half of the power, so in total, the power radiated by the two antennas is the same to the power radiated by the single antenna in MRRC. If each of the antennas in the Alamouti scheme would transmit the same power as the single antenna, the results would be overlapped.
The most important conclusion we can get from this graphs is the fact that the Alamouti scheme provides the same performance as the MRRC, independently from the codification and modulation used.

4.6 Practical restrictions

In the last chapter, It was proved that Alamouti scheme with two-transmit antenna and N receive antennas provides the same performance as a single transmit antenna and 2N receive antennas of the MRRC scheme. In this chapter, a review of the most important practical issues is given and also some intrinsic behaviour of the system is discussed.
4.6.1 Power requirements

As it has been said previously, if we want to maintain the total power radiation, we have to transmit half of the energy symbol in each of the two antennas. That is the reason why the BER of the Alamouti scheme stands 3dB under his equivalent in MRRC. However, this 3dB reduction can became positive if we take into account that transmit chains could have smaller dimensions, could be less expensive or present better grade of linearity.

4.6.2 System latency

It is easy to see that if we use a scheme with N transmit branches, the symbol information is transmitted within N symbol periods, that is to say, there is a delay in the decoding stage of N symbol periods. As long as the common use of this technique should be the use of two or four transmit antennas, the delay can be considered negligible in most of the applications. However, if space-frequency is used and each repetition is send by different carriers, we wouldn’t experience any delay at all.

4.6.3 Channel estimation

We have considered that the receiver has perfect knowledge of the channel although it is an underestimation of the practical behaviour of the system. The channel estimation can be done with an interpolation of a known sequence (from both sides) in the data to transmit. This is often called pilot signal.

Pilot signalling is a process that can suffer from many issues in practical environments, such as \textit{mismatched interpolation coefficients and quantization effects}. \textit{The dominant source of estimation errors for narrowband systems, however, is time variance in the channel...Source [8].} However, the channel estimation error can be reduced if the frequency of the pilot insertion is above the channel Nyquist sampling rate, although even if the channel is over sampled, it is not possible to avoid a residual degradation.

One interesting point to note is that pilot signalling in diversity schemes is quite different. This is because we have N channels to estimate and only one received signal
to extract the information from. Thereby, it is necessary a pilot signal rotation between all the antennas or single pilot for each antenna. In both cases, it is necessary to use N more times pilots.

4.6.4 Antenna configuration

The basis of diversity is the decorrelation between the signals transmitted from different antennas. Another desirable feature is average power of each antenna is equal to the others (less than 3dB of difference. Source [8]).

As long as the air channel present the same behaviour in both ways, we can apply the same configurations for transmit and receive antennas. The problem resides on the huge difference between the base stations and the mobile units. At the base station, as it is reviewed in the literature, the antennas might be separated about ten wavelengths or more, while in the mobile units and due to the presence of near scatterers, three wavelengths could be enough.

4.6.5 System failure

The main goal of diversity schemes is to provide a better transmission performance, but it is not the only one. The redundancy of transmitted signal allows the system to avoid an interruption of the communication in case of one or more of the paths were disrupted. This is because, for example in a two-branch transmit scheme, if one chain suffers from a total failure, the other chain can keep on with loss of performance proportional to the diversity order. When this particular case occurs, we talk about soft failure. For example, in the same previous case, a soft failure would cause the system to work as if there was not diversity.
4.7 Conclusions

To finish this chapter, a set of the main conclusions will be stand out:

- *With two transmit antennas and one receive antenna, the Alamouti technique is comparable as the MRRC with two receive antennas and one transmit antenna, in the words of diversity.*

- *3dB of disadvantage from the BER performance in comparison with the MRRC. That is because each antenna transmit half power in order to maintain the total radiated power.*

- *Generalisation can be done by adding more receive antennas. In this case the diversity order reaches up to 2N*

- *Low computation complexity, similar to MRRC.*

- *When pilot symbol insertion and extraction is implemented to estimate the channel, twice as many pilots as in the two-branch receiver combining scheme are needed.*

- *The latency related to the decoding stage is proportional to the symbol time diversity.*

- *Soft fail advantages, multiple transmission branches assure the communication when one of them is disrupted.*
5. CDMA platform review

5.1 Introduction

The main goal of this thesis is to test how the Alamouti code (hence, diversity) improves the performance of the link level in comparison to a single antenna system (SAS). The CDMA platform implemented with RUNE toolbox by Wireless Research Group of BIT is tested with the addition of the new functions.

System specifications were one of the most important stages of the procedure. As we wanted to focus on the performance of the Alamouti codification, some of the characteristics have been scaled down. This also matches with the idea avoiding high computational complexity that would have become in slower simulations. For example, it is commonly assumed that the limiting channel CDMA cellular systems is the uplink, this is because in this particularly link, the near-far effect is much stronger. Hence, only the uplink has been simulated.

Another assumption for the aim of simplicity, is that only the steady state for a number of users has been tested. This is because we are not interested in new arrivals or departures, as they wouldn’t allow us to keep the same number of users for the whole simulation time. All other characteristics related to the link level have been taken into account: user distribution, mobility, handover, fast and slow fading and interference. As CDMA systems are interference-limited and we only want to see the impact on the results, thermal noise has been deactivated.
5.2 System characteristics

5.2.1 Site characteristics

The site characteristics is the first step to define our system. In the platform, it is possible to choose from 1, 3 or 7 cells. The site with one cell doesn’t allow us to perceive the real behaviour of a CDMA system, due to the inexistence of inter-cell interference. However, it is a good way to validate the system model as we know the theoretical results for the particularly case of synchronized transmission. In such case, neither intra-cell or inter-cell is experienced and taking into account that there is no noise added, the resulting BER of any of the users may be zero.

A site with 3 cells is much more a realistic case, with a clear inter-cell interference. In addition, the 7 cells case allow us to compare how distanced cells interfere one to another.

In terms of user distribution, they are randomly distributed inside the system limits. This is achieved by the use of a random placement inside of a temporal cell and then, sent to any of the created cells. As an example, the next figure shows 40 users randomly distributed in a 7 cell site. The blue rhombus define the users and the red circles represent the base stations.

Figure 5.1, Randomly distributed users in a 7 cell site.
5.2.2 Transmission

The transmission procedure is programmed to match the IS-95 specification. Each user transmits arrays of 512 bits during the service time, which are modulated in BPSK. The CDMA technique used is direct sequence CDMA (DS-CDMA), which means that each user owns a unique spreading code that multiplies directly the BPSK-modulated signal. There are a total of 64 different Walsh-Hadamard codes, which guarantees the total orthogonality data transmission for a number of users up to 64, in the ideal case of a synchronized transmission.

\[
\begin{bmatrix}
1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\
1 & -1 & 1 & -1 & 1 & -1 & 1 & -1 \\
1 & 1 & -1 & 1 & 1 & -1 & -1 & -1 \\
1 & -1 & -1 & 1 & 1 & -1 & -1 & 1 \\
1 & 1 & 1 & -1 & -1 & -1 & -1 & -1 \\
1 & -1 & 1 & -1 & -1 & 1 & -1 & 1 \\
1 & 1 & -1 & -1 & -1 & 1 & 1 & 1 \\
1 & -1 & -1 & 1 & -1 & 1 & 1 & -1 \\
\end{bmatrix}
\]

*Figure 5.2, Example of 8 Walsh-Hadamard orthogonal codes.*

Once the data is channelized with the correspondent Hadamard code, each string is sent to the Alamouti stage, in case we have selected that option. The Alamouti stage's scheme is based on the two-transmit antennas and one receive antenna. The implementation follows exactly the theoretical rules given in the chapter “4.3 Two-branch transmit with one receiver”.

The power control is also an essential part of the transmission stage. As an example of how important it is to count with it, we can present the following case. The mobile phone can be placed at any point within a cell, that is to say than can be under the base station or at 40 km. In the air environment, where the propagation loss could be in the order of \(d^4\), if the mobile phone transmits with the same power in both cases, the dynamic range of the received power in the base station can reach a value of 80dB. In addition, also fast fading can occur due to the multipath effect or slow fading due to the terrain configuration, which give us 20 or 30 dB more of fluctuation.
Taking into account that we are dealing with a CDMA system and all the users transmit in the same bandwidth, those communications that are received with a stronger signal will experience a better SIR, and hence, they will achieve a better BER. This phenomena is commonly referred as the near-far effect and should be avoided by the use of a power control algorithm. The final aim is to implement a fair system by giving all the users the same chances of communication.

In the platform, the power control used is a simple Constant Received Power algorithm (CRP). This algorithm works by pre-amplifying the user signals in order to get at the base station the same power level for all of them. As we can deduce, the implementation is really easy as we have assumed perfect knowledge of the channel.

Alamouti coder for the transmitter stage is reviewed in detail in the 5.3 section.

5.2.3 Radio channel characteristics

In its way to the base station, the signal may experience many undesirable effects that decrease the overall quality and involve communication errors.

The fast fading is a consequence of the multipath propagation. That means that the signal arrives at the receiver scattered from several environment structures. This effect is also known as proximity echoes and is main responsible of the inter-symbol interference. In the platform, the fast fading effect is modelled as a Rayleigh fading where the impulsive response of the channel is a Gaussian process with zero-mean and power spectral density $2\sigma^2 = 1$. As we would expect, this distortion only provides fadings in the signal and not amplifications, as the variance is unity.

Let’s focus now in the slow fading. It is often related with the shadow areas that big structures, such as buildings or mountains, cause to the signal. The slow power varying can be expressed as a lognormal probability function, or Gaussian if it is given in dB. Slow fading affects the average received power of the signal, but it is assumed to be almost constant during the transmission time.
The slow fading is implemented by one of the RUNE basic tools. In particularly, the function `crelognmap`, *generates a lognormal fading map of the region given by rombvec. The upper border of the map has the same values as the lower border of the map. It is the same for the left and right border. Within rombvec a certain number of maps are fitted to avoid resonance with base.* Source [RUNE help].

As an example of how this function works, two figures will be given. The first one shows the lognormal map with a correlation distance of 1m and the second one, with a correlation distance of 110m. The correlation distance is a parameter that defines when the distance until the correlation in the map has decreased to 1/e. The bigger correlation distance, the more slow varying the lognormal fading in the map will be.

![Figure 5.3 Lognormal example map with a correlation distance of 1m.](image)
In practice, the system allows us to choose from several preset environments such as COST 231 Walfish Ikegami Model, COST 231 Hata Model, Hata Model, McGeehan and Griffiths Model or Walfisch and Bertoni Model.

5.2.4 Reception

Once the signal has reached the receiver, it must be processed. In the case of using SAS, the signal received will be directly the transmitted plus the total interference. That includes the interference coming from other cells (inter-cell interference) and the interference cause by the unsynchronised signals of the users within the cell (intra-cell interference). In this particularly case, no Alamouti processing is needed, only time undelay, despreading and BPSK demodulation is done.

If Alamouti codification is applied, some extra processing is required. The basis of the function $alamouti_{rx}$ is to separate the two branches of received symbols and to built the original sequence that later will be sent to the detector. The combining scheme implemented follows the rules explained in the chapter “4.3.3 Combining scheme”. As we are dealing with equal energy constellation (BPSK), the maximum likelihood detector can be easily implemented with the following rule, as it was seen in the chapter 4.3.4:

$$\forall i \neq k \Rightarrow \text{choose symbol } s_i$$

$$d^2(s_0, s_i) \leq d^2(s_0, s_k)$$
5.2.5 Feature summary

In the next table, an exhaustive look over is done with all the system specification and parameter definition.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>User distribution</td>
<td>Pseudo-random</td>
</tr>
<tr>
<td>Cluster size</td>
<td>1, 3 or 7 hexagonal cells.</td>
</tr>
<tr>
<td>Link of interest</td>
<td>Uplink, which is more affected by the near-far effect.</td>
</tr>
<tr>
<td>System behavior</td>
<td>Mobility and handover allowed. Arrivals, departures and thermal noise deactivated.</td>
</tr>
<tr>
<td>Modulation</td>
<td>BPSK</td>
</tr>
<tr>
<td>Spreading code</td>
<td>DS-CDMA with exclusive signature c(t) for each user, Walsh-Hadamard sequence.</td>
</tr>
<tr>
<td>Spreading factor</td>
<td>64</td>
</tr>
<tr>
<td>Synchronisation</td>
<td>Users can either transmit synchronized or not.</td>
</tr>
<tr>
<td>Diversity technique</td>
<td>Alamouti coding scheme with two-transmit antennas. For comparison, also a single antenna system is implemented (SAS).</td>
</tr>
<tr>
<td>Power control</td>
<td>Constant received power algorithm (CRP).</td>
</tr>
<tr>
<td>Channel characteristics</td>
<td>Models: COST 231 Walfish Ikegami, COST 231 Hata, Hata, McGeehan and Griffiths or Wallisch and Bertoni.</td>
</tr>
<tr>
<td>Interference</td>
<td>Intra-cell and inter-cell interference implemented.</td>
</tr>
<tr>
<td>Noise</td>
<td>Supposing large number of users and an interference-limited system, no noise is added.</td>
</tr>
<tr>
<td>Sectors per site</td>
<td>1</td>
</tr>
<tr>
<td>Gain constant</td>
<td>-24</td>
</tr>
<tr>
<td>Lognormal fading correlation</td>
<td>corrdist=110 m.</td>
</tr>
<tr>
<td>Lognormal correlation</td>
<td>Depending on the model</td>
</tr>
<tr>
<td>Cell radius</td>
<td>1000 m.</td>
</tr>
<tr>
<td>Lognormal fading</td>
<td>Depending on the model</td>
</tr>
<tr>
<td>Alpha (path loss)</td>
<td>Depending on the model</td>
</tr>
<tr>
<td>Maximum number of users</td>
<td>64, relative to spreading factor</td>
</tr>
<tr>
<td>Chip duration</td>
<td>1 sample</td>
</tr>
<tr>
<td>Data bit duration</td>
<td>Chip duration*spreading code length (spreading factor)</td>
</tr>
<tr>
<td>Number of users</td>
<td>1 to 12 users per cell.</td>
</tr>
<tr>
<td>Data</td>
<td>Random</td>
</tr>
</tbody>
</table>

Figure 5.5 System feature summary
5.3 Alamouti code implementation

In this chapter we are showing the implementation of the Alamouti coder and decoder with the RUNE toolbox. As it will be tested in a generally purpose CDMA platform, some previous check has to be done before the codification.

5.3.1 Coder

The first step of the Alamouti coder is to check if the global variable that enables/disables the codification is set. If Alamouti codification is not actived, the output will be directly the input. That means that we are using the SAS transmission and only one branch (one antenna) will be used for the communication. No additional processing is needed.

On the contrary, if the flag is active, a couple of verifications must be done in order to guarantee the correct codification. The first one is to check that data is multiple of two. This is strictly necessary if we want to ensure that Alamouti codification with 2 transmit antennas and 1 receive antenna is done without any bit loose.

```matlab
% Comprovation of the multiplicity of input data
numbits = length(data) / Tb;
if (mod(numbits,2)~= 0)
    error('number of bits must be multiple of 2');
end
```

The second checking is related to the codification. As we are using a BPSK, we have to make sure that the bit string is multiple of the carrier period. This is controlled by Tb variable.

```matlab
% Verification of the multiplicity of the samples
numsamples=length(data);
if (mod(numsamples,Tb)==0)
    error('number of bits must be multiple of Tb');
end
```
If the data is consistent we can keep on with the time and space diversity procedures. The time diversity can be performed with two arrays that store half of the bits each. The first one stores the current bits and the second one stores the “next symbol” bits (denoted as $s_0$ and $s_1$ in the figure 4.1).

```matlab
for i=0:(numbits/2-1)
    % codification at bpsk level (64*tc), 1..64, 128...
    t_bit = [ t_bit (2*i*Tb + (1:Tb)) ];
    T_bit = [ T_bit ( (2*i+1) * Tb + (1:Tb)) ];
end
```

For the space diversity, we just have to follow the rule given in the figure 4.2. On one hand, the first antenna transmits $s_0$ in the first symbol time ($t$) and $-s_1^*$ in the second ($t+T$). On the other hand, the second antenna transmits $s_1$ in the first symbol time ($t$) and $s_0^*$ in the second ($t+T$).

```matlab
% split the data in 2 branch
branch0(:,t_bit) = data(:,t_bit);
branch0(:,T_bit) = -conj(data(:,T_bit));
branch1(:,t_bit) = data(:,T_bit);
branch1(:,T_bit) = conj(data(:,t_bit));
```

For the aim of simplicity, all the data manipulation is done at bit package level instead of sample by sample. For the simulations, this is not determinant, as we are only concerned about the bit error rate. Obviously, in a real deployment, this way of working would become into unacceptable latency if the data package is long enough.

### 5.3.2 Decoder

The previous stages of the decoder follow the same rules of the coder. Firstly, if Alamouti transmission has been disabled, there is no need to do more processing. The output is directly the received data multiplied by the channel estimator.

```matlab
else %if Alamouti is not activated
    out = conj(ch0.* data);
end
```
On the contrary, if Alamouti codification has been enabled, the same two verifications of multiplicity are carried out. Although they are not strictly necessary (as we have implemented them in the transmitter), it is interesting to use them as a control error point during the execution.

As we have implemented in the coder, two array for the 2 branch bits are necessary.

```matlab
for i=0:(numbits/2-1)
    t_bit = [ t_bit (2*i*Tb + (1:Tb)) ];
    T_bit = [ T_bit ( (2*i+1) * Tb + (1:Tb)) ];
end
```

The decoder stage follows the rule given by the expressions seen in the point 4.3:

\[
\begin{align*}
    r_0 &= r(t) = h_0 s_0 + h_1 s_1 + n_0 \\
    r_1 &= r(t + T) = -h_0 s_1^* + h_1 s_0^* + n_1
\end{align*}
\]

Where the signal is combined again to construct the original bit string. As we are not dealing with thermal noise, the expressions can be reworked as follows:

```matlab
% Alamouti decodification
out(:,t_bit)=conj(ch0(:,t_bit)).* data(:,t_bit)
    + ch1(:,T_bit).* conj(data(:,T_bit));
out(:,T_bit)= - ch0(:,T_bit).* conj(data(:,T_bit))
    + conj(ch1(:,t_bit)).* data(:,t_bit);
```

As we did in the coder, all the processing is done at received array level.
6. Results

6.1 Introduction

In this chapter, some results about the improvement of using Alamouti codification over the CDMA platform are shown. To quantify this improvement, we are focusing on the BER parameter. For that, we are performing two kind of user behaviour: asynchronous and synchronous transmission. The performance will be showed for systems with 1, 3 and 7 cells in function of the average number of users per cell (up to 12). These systems cover wide range of situations, from non inter-cell/intra-cell interference of the 1 cell system (synchronous) to a high inter-cell/intra-cell interference for a 7 cell system with 84 as a total number of users.

To obtain statically correct measures of the BER, as a function of the number of users in the system, a loop is launched to run 100 iterations for each number of users. In each iteration, each of the users transmit packets of 512 bits and finally, the output results are plotted for a more convenient comparison.

6.2 System with 1 cell

In this case we will not experience inter-cell interference, only users in the same cell will contribute (intra-cell interference). There is, though, one particularly case where no interference is added. If the synchronism is activated all the users’ signals arrive completely orthogonal to base station, and taking into account that there is no noise and the channel is perfectly estimated, no errors should be obtained.
As we expected no BER appears in the graphic. If now we deactivate the synchronism, PN orthogonality is lost and hence, inter-cell interference and errors start to appear.

Here, the use of Alamouti codification (marked as enabled) is clearly welcomed. As we can see in the graphic, if we take as a reference an average BER of 1%, without
Alamouti our system would be able to hold around 5 users, while if we make use of the Alamouti codification, this number would be increased up to 11 users. It is interesting to note that this is not the real capacity of the system, because we don't know how this error affects the each particular user, we only know that the average BER is 1%. To show that, we have plotted the BER result with high load (20 users) for a single simulation of 64 kB of transmitted data.

<table>
<thead>
<tr>
<th>User</th>
<th>BER in %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5.5000</td>
</tr>
<tr>
<td>2</td>
<td>5.2500</td>
</tr>
<tr>
<td>3</td>
<td>11.2500</td>
</tr>
<tr>
<td>4</td>
<td>2.0000</td>
</tr>
<tr>
<td>5</td>
<td>1.2500</td>
</tr>
<tr>
<td>6</td>
<td>1.5000</td>
</tr>
<tr>
<td>7</td>
<td>2.0000</td>
</tr>
<tr>
<td>8</td>
<td>0.2500</td>
</tr>
<tr>
<td>9</td>
<td>4.2500</td>
</tr>
<tr>
<td>10</td>
<td>11.2500</td>
</tr>
<tr>
<td>11</td>
<td>2.7500</td>
</tr>
<tr>
<td>12</td>
<td>0</td>
</tr>
<tr>
<td>13</td>
<td>0.7500</td>
</tr>
<tr>
<td>14</td>
<td>0.5000</td>
</tr>
<tr>
<td>15</td>
<td>2.0000</td>
</tr>
<tr>
<td>16</td>
<td>0.2500</td>
</tr>
<tr>
<td>17</td>
<td>0.5000</td>
</tr>
<tr>
<td>18</td>
<td>1.5000</td>
</tr>
<tr>
<td>19</td>
<td>0.7500</td>
</tr>
<tr>
<td>20</td>
<td>0.2500</td>
</tr>
<tr>
<td><strong>Average BER</strong></td>
<td><strong>2.6875</strong></td>
</tr>
</tbody>
</table>

Figure 6.3 BER for 20 users with enabled Alamouti codification.

It is clear that, although the average BER is “just” 2.68%, users number 3 and 10 are evidently experiencing a bad communication.
6.3 System with 3 cells

In this simulation we are providing the BER results for a system with 3 cells, either with synchronism or without it. In case that we are transmitting with synchronism, only the inter-cell interference will disturb the communication, while if we transmit without synchronism we will experience both inter and intra cell interference.

Figure 6.4 BER in function of users in a 3 cell site with synchronous transmission

Figure 6.5 BER in function of users in a 3 cell site with asynchronous transmission
We obtained even better results for 3 cell simulation, because we have reduced a 34.6% (from 4.553% to 2.979%) the average BER for the high load case (8 users transmitting asynchronously).

Another thing that should call our attention is the comparison between the synchronous and asynchronous transmission without taking into account Alamouti code. For 8 users transmitting synchronous we get about 1.8% of average BER, while in the same conditions, for the asynchronous we get 4.553%. Seems like the inter-cell interference affects much less than the intra-cell. Being more accurate, under this conditions in our system, inter-cell represents 30% of the intra-cell. These numbers don’t match with the common assumption that inter-cell interference is around 60% of the intra-cell interference in real deployments (source [2]). The cause of this disagreement should be found in the simplicity of the platform and its intrinsic limitations.

6.4 System with 7 cells

The next figures show the same kind of simulations before, but for the 7 cell system.
6.7 BER in function of users in a 7 cell site with asynchronous transmission

Again, we have proved that Alamouti codification results in a better BER average in any circumstances, either with synchronous transmission or not. It is interesting to note that the improvement in the case of asynchronous transmission is much notable, we have reduced the BER from 4.854% to 3.207% (that is a 34% of reduction for 8 users). In the synchronous case the reduction is only the 20%. This is because the more interference is present, the more advantage Alamouti code provides in comparison with the single antenna scheme.

As we are dealing with a simulation tool, we have to assume that we are working with pseudo-random sequences. That sequences are generated for each iteration and affect directly parameters like user’s distribution, transmitting time (synchronism), lognormal fading, rayleigh fading, etc. One particular iteration, under the same circumstances than the others, can show big differences in its performance. This is the reason why a large number of iterations are needed if we want to obtain statically correct results. To understand that concept, next figure shows two particularly outputs of the 100 realisations needed for the 6.5 result.
Figure 6.8 Two realization for 7 cell site with asynchronous transmission
6.5 Comparative results

The aim of this point is to compare the three different systems that have been analysed before, plotting the results in the same figure in order to characterize the differences between them. For a more easier visualization, only the asynchronous case has been simulated.

What is interesting to note here is the small difference between the performance of 3 cell and 7 cell system. Although it could be surprising, there are grounded justifications for that. We have to take into account that the increase, in terms of inter-cell interference, between the 3 cells and the 7 cells is smaller than between the 1 and the 3 cell. The reason is, despite having more cells (and hence, more interferers), some of them are far enough to avoid interaction. In essence, with an increasing number of cells in the simulation platform, the capacity would tend asymptotically to a threshold. It is easier to understand this concept looking the figure 6.10. The average interference caused along the time by the user placed inside the green cell, can be depreciated for the users placed in the red cells.

Figure 6.9 BER for 1, 3, 7 cell system with enabled/disabled Alamouti codification
Figure 6.10 Cell distribution example created by the function crecells ()
7. Conclusions

Over the development of this thesis, we have reviewed the fundamentals of spread spectrum systems and specially, the Code Division Multiple Access (CDMA) scheme. Taking into account that the main objective of this thesis is to analyse the improvement that diversity method suggested by Alamouti, also a review of diversity concepts has been done. This background, gained in the first steps of this thesis, has been a clue for the correct understanding of the results.

On one hand, the results of the simulations demonstrates how, as we expected, the introduction of the Alamouti’s diversity scheme improves the performance. To prove this, we have tested multiple sceneries: 1, 3 and 7 cells sites, both synchronous and asynchronous transmission, different system loads, etc. The Alamouti scheme has provided, under any kind of circumstances, better BERs in comparison with the single antenna system. We have also proved a fact that we could have suspected by reading the literature: the more interference is present in the system, the more advantage we would take from the alamouti codification. This is noticable by comparing the results between the synchronous and asynchronous tests, especially with the bigger loads.

On the other hand, the results obtained also show us the deficiencies of the simulation platform. Trying to combine simplicity and low computational complexity, has leaded into a valid model for the Alamouti comprovation, but not as a real CDMA simulation platform. The reason is that we haven’t taken into account the additive noise, new arrivals, departures, etc. For example, we have realised that the inter-cell interference is stronger than the intra-cell interference, when in real deployments it is considered that the first one is about 60% of the second one.

We have also seen that the system capacity is limited. For example, taking as a reference the system with 7 cells, 5 users per cell (the closest to a real scenario), with Alamouti codification we obtained a BER of 2%.
It could be interesting, as a future work, see how the system behaves without a perfect channel estimation, new arrivals or departures. With this new specifications, the system performance would decrease, hence some methods to counteract them might be implemented. In this case, some modifications in the CDMA platform would be necessary if we want be coherent with the given results, for example, by guaranteeing that the average number of users per cell remains equal along all the iterations.

An easiest technique to improve the BER could be carried out by introducing a higher level of diversity. For example, the use of the Alamouti scheme with two-transmit antennas and N receiver antennas would provide a diversity order of 2N. However, this increment of the computational complexity would entail a more detailed study of the latency.
8. Bibliography

Quot bibliography:


Other consulted bibliography


9. Annexes

9.1 Matlab code

% DESCRIPTION
% This function implements the Alamouti codification for a package
% of bits in its entrance. The total number of bits conforming the
% data array must be a multiple of 2.

% [branch0,branch1] = alamouti_coder(Tb, data)

% INPUTS
% Tb          bit duration
% data        bit array to code

% OUTPUTS
% branch0     array containing branch0 of space time coding
% branch1     array containing branch1 of space time coding

function [branch0,branch1] = alamouti_coder(Tb,data)

if (par.alamouti)  %if alamouti coding is activated

    % Comprovation of the multiplicity of input data
    numbits = length(data) / Tb;
    if (mod(numbits,2)~= 0)
        error('number of bits must be multiple of 2');
    end

    % Comprovation of the multiplicity of the samples
    numsamples=length(data);
    if (mod(numsamples,Tb)~=0)
        error('number of bits must be multiple of Tb');
    end

    % time diversity array separation
    t_bit = []; %bit transmitted in t time
    T_bit = []; %bit transmitted in t+T time

    for i=0:(numbits/2-1)

        % codification at bpsk level (64*tc), 1..64, 128...
        t_bit = [ t_bit (2*i*Tb + (1:Tb)) ];
        T_bit = [ T_bit ( (2*i+1) * Tb + (1:Tb)) ];
    end

end
% split the data in 2 branch
branch0(:,t_bit) = data(:,t_bit);
branch0(:,T_bit) = -conj(data(:,T_bit));
branch1(:,t_bit) = data(:,T_bit);
branch1(:,T_bit) = conj(data(:,t_bit));

else %if alamouti is not actived
    branch0 = data;
end
DESCRIPTION

This function implements the Alamouti decodification for a package of bits on its entrance.

out=alamouti_decoder(Tb, data, ch0, ch1)

INPUTS
- data: bit array to decode
- Tb: bit duration
- ch0: channel estimation for branch 0
- ch1: channel estimation for branch 1

OUTPUTS
- out: decoded signal

function out=alamouti_decoder(Tb, data, ch0, ch1)

if (par.alamouti) %if Alamouti coding is activated

    % Comprovaion of the multiplicity of the bits
    numbits=length(data) / Tb;
    if (mod(numbits, 2)~=0)
        error('number of bits must be multiple of 2');
    end

    % Comprovaion of the multiplicity of the samples
    numsamples=length(data);
    if (mod(numsamples, Tb)~=0)
        error('number of bits must be multiple of Tb');
    end

    % time diversity array separation
    t_bit=[]; %bit received in t time
    T_bit=[]; %bit received in t+T time
    for i=0:(numbits/2-1)
        t_bit=[t_bit(2*i*Tb + (1:Tb))];
        T_bit=[T_bit((2*i+1)*Tb + (1:Tb))];
    end

    % Alamouti decodification
    out(:,t_bit)=conj(ch0(:,t_bit)).* data(:,t_bit)
    + ch1(:,T_bit).* conj(data(:,T_bit));

    out(:,T_bit)= -ch0(:,T_bit).* conj(data(:,T_bit))
    + conj(ch1(:,t_bit)).* data(:,t_bit);

else %if Alamouti is not activated

    out = conj(ch0.* data);
end
clear all;
clc;

% make choice of the channel model
global type1;
global type2;
global type3;
%output the choice of all models

disp('1. COST 231 Walfish Ikegami Model');
    %Frequency f: 800-2000 MHz
    %Base station height Hb: 4-50 m
    %Mobile height Hm: 1-3 m
    %Distance d: 0.02-5 km
    %Height of buildings Hroof (m)
    %Width of road w (m)
    %Building separation b (m)
    %Road orientation with respect to the direct radio path Phi

disp('2. COST 231 Hata Model');
    %Frequency f: 1500-2000 MHz
    %Base station height hb: 30-200 m
    %Mobile height hm: 1-10 m
    %Distance d: 1-20 km
    %Large and small cells (i.e. base station antenna heights above
    %roof top levels of buildings adjacent to the base
    %station).»

disp('3. Hata Model');
    %Frequency f: 150-1000 MHz
    %Base station height hb: 30-200 m
    %Mobile height hm: 1-10 m
    %Distance d: 1-20 km
    %Large and small cells (i.e. base station antenna heights above
    %roof top levels of buildings adjacent to the base
    %station)

disp('4. McGeehan and Griffiths Model');
disp('5. Walfisch and Bertoni Model');

type1=input('please input the number of your choice: ');
switch type1
    case 1
        disp('1.medium sized city and suburban centres with moderate
tree density');
case 2
    disp('1.medium sized city and suburban centres with moderate tree density');
    type3=input('please input the choice: ');
    disp('2.metropolitan centres');
    type3=input('please input the choice: ');
    case 3
        disp('1.Urban');
        disp('2.Suburban');
        disp('3.Rural (Quasi open)');
        disp('4.Rural (Open Area)');
        type2=input('please input the choice: ');
        disp('1.medium sized city and suburban centres with moderate tree density');
        disp('2.metropolitan centres');
        type3=input('please input the choice: ');
    case 4
        disp('1.an older city with narrow and curving street');
        disp('2.a medium sized city with long and straight and wide street');
        disp('3.suburb with some rural area');
        disp('4.open area');
        type2=input('please input the choice: ');
    case 5
        disp('no need to make the other choice');
        otherwise
            error('wrong input');
end

%% Initializing
% by Han Yantao
% initialize the cell and the MS
% set simulation parameter par if not present as an input
%TRY
%[par, sta, sys] = nrunef;
tic;
disp('initializing the cell and the MS, Please wait!!');
if ~exist('par', 'var')
    par = nsetpar; % default parameter setting
end

% Create the sys variable if not present as an input.
if ~exist('sys', 'var') isempty(sys)
% generate base station position and directions
    clear sys
    [sys.xyb, sys.fib,sys.rombvec] = crecells(par.cellradius,par.sps,par.km,par.lm);
    fib1=change(sys.fib,par.sps);
    xybb=sys.xyb;
    s=par.km^2+par.km*par.lm+par.lm^2;
    sys.xyb=m_to_n(sys.xyb,par.sps);
    sys.xyb=ex_sort(sys.xyb);
    sys.xyb=sys.xyb.';
    sys.xyb_ind(:,1)=sys.xyb;
    sys.xyb_ind(:,2)=[1 : s]';
    sys.xybind=sys.xyb;
%sys.xyb---the coordinate matrix of the sites and have already arrayed.
%   size is (number of sites)*1
%sys.xyb_ind---the index matrix of the sites. the second row is
%   the grade of the sites. Size is (numbers of sites)*2;
%the grades of the sites
%   18   12   17
%   19   7   1   4   16
%   8    2    3   10
%   14   9   15
sys.fibind=fibl(1:3).';
%sys.fibbind----the index matrix of the sectors;Size is 3*1;
%sps=3, the index is
%      2
%      1
%      3
sys.fib=sys.fib.';
%p=(par.nk/par.m)*8;
p=par.nk*par.sps;
%--channels per sites
q=size(sys.xyb,1);
%---the numbers of the sites
sys.matrix_ind=ones(q,p);
%obk=crechanplan(par.nb,par. nk,par. ncluster);
%matrix_ind--sites*(channels per sites)--it's the index matrix of all
%      channels
% Create a lognormal map.
if par.sigma > 0
  % Is a lognormal map needed (takes a few seconds to generate).
  % The lognormal map is dependent on the seed.
  oseed = setseed(par.seed); % Set seed of pseudo random generator
  % for the map.
  [sys.lognmap, sys.lognmapvec] = crelognmap(sys.xyb, sys.rombvec, 
      par.corrdist);
  setseed(oseed); % Restore seed to original value.
else
  sys.lognmap = 0; % Give fake arguments to pathgain,
  sys.lognmapvec = 0; % the values doesn't matter anyway.
end
end

if ~exist('sta', 'var') | isempty(sta)
clear sta
  sta.nbas = size(sys.xyb,1);
  % sta.nmob = par.offtraf*sta.nbas;
  sta.nmob = par.offtraf;
  sta.nchannel = par.nk*par.sps;

  sta.xym=nans(sta.nmob,1);
  sta.xyv=nans(sta.nmob,1);
  sta.b=nans(sta.nmob,1);
  sta.k=nans(sta.nmob,1);
  sta.pul = nans(sta.nmob,1);
  %sta.pdlm = nans(sta.nmob,1);
  %sta.pdlb = nans(sta.nmob,1);
  %sta.pdlb = nans(sta.nbas,sta.nchannel);
  sta.cdl = nans(sta.nmob,1);
  sta.idl = nans(sta.nmob,1);
  sta.sirdl = nans(sta.nmob,1);
  sta.ferdl = nans(sta.nmob,1);

sta.cdl = nans(sta.nmob,1);
sta.idl = nans(sta.nmob,1);
sta.sirdl = nans(sta.nmob,1);
sta.ferdl = nans(sta.nmob,1);
% Initialize the MS
sys.rombvec);  
% sta.xyv----Size is (number of MS)*1; the coordinate matrix of the MS
% hold on
% plot(sta.xyv,'b*') plot user position
end

disp([num2str(toc/60) ' min']);
% init the interference matrix
% disp('init the interference matrix');
% [matrix_sam_fre,matrix_200k_fre,matrix_400k_fre]=init_matrix_fre;
% disp([num2str(toc/60) ' min']);
%
% antenna model
lobevector=lobe(par.sps);
% Allocate base and channel for the exiting users
% first get the gain matrix based on the exiting users
sta.pathgain=propagain(sys.xyb,sta.xym,par hb,par.hm,par.f,par.corrdis
t,par.sps,par.sigma,par.raa,...
sys.lognmap,sys.lognmapvec);
[sta.b,sta.k,sys.matrix_ind] =
assign(sta.b,sta.k,sta.pathgain,sys.matrix_ind,par.homargin);
% Make a realisation of new users.
nmob=mrequest(par.offtraf,par.frametime,par.mht,sys.xyb); % nmb is the
% number of new users.
% update some parameters for the newcomer
nt1 = nans(nmob,1); % NaN vector used as concatenation of xym xyb etc.
ntb = nans(nmob,size(sys.xyb,1)); % nan vector used to concatenate
gmb pumb etc.
keep = isfinite(sta.k); % Clean out all users with k == nan
sta.b = [sta.b(keep); nt1];
sta.k = [sta.k(keep); nt1];
sta.xym = [sta.xym(keep); nt1];
sta.xyv = [sta.xyv(keep); nt1];
sta.pathgain = [sta.pathgain(keep,:); nt1];
sta.pul = [sta.pul(keep); nt1];

% sta.pdlm = [sta.pdlm(keep); nt1];
% sta.pdlb = [sta.pdlb(keep); nt1];
sta.cdl = [sta.cdl(keep); nt1];
sta.idl = [sta.idl(keep); nt1];
sta.sirdl = [sta.sirdl(keep); nt1];
sta.ferdl = [sta.ferdl(keep); nt1];
% set the position for the newcomers.
% [sta.xyv]=ms_init(sta.xyv,sys.rombvec);
% update the gain matrix
sta.pathgain=propagain(sys.xyb,sta.xym,par hb,par.hm,par.f,par.corrdis
t,par.sps,par.sigma,par.raa,...
sys.lognmap,sys.lognmapvec);
% try to assign channels to new calls.
[sta.b,sta.k,sys.matrix_ind] =
assign(sta.b,sta.k,sta.pathgain,sys.matrix_ind,par.homargin);
% set the initial power for the newcomers.
sta.pul(~isnan(sta.k)) = par.pinitm; % Set power to new users
sta.pdlm(~isnan(sta.k)) = par.pinitm;
sta.pdlb = zeros(sta.nbas,sta.nchannel);
sta.pbdlb(:,1) = par.pinitb;
%tl = isfinite(sta.k)&isfinite(sta.b); % this are ture links
%index = index(sta.b(tl), sta.k(tl), size(sys.matrix_ind));
%sta.pdlb(index) = par.pinitb; % init the max power for the ture link

%sta.pul(isnan(sta.k)) = nan; % set power to nan to users without any channel.
%sta.pdlm(isnan(sta.k)) = nan;
%sta.pdlb(isnan(sta.k)) = nan;

%keep = isfinite(sta.k);
nuser = size(sta.k(keep), 1); % the number of the links
blockloss_num = zeros(nuser, 1);
sta.b = sta.b(keep); % only keep the user get the ture link
sta.k = sta.k(keep);
sta.xym = sta.xym(keep);
sta.xyv = sta.xyv(keep);
sta.pathgain = sta.pathgain(keep, :);
sta.pul = sta.pul(keep);

sta.cdl = sta.cdl(keep);
sta.idl = sta.idl(keep);
sta.sirdl = sta.sirdl(keep);
sta.ferdl = sta.ferdl(keep);

% the Voice traffic model
disp('Generating the Voice Traffic model, Please wait!!');
if ~exist('voice', 'var') || isempty(voice)
clear voice
simultime = 120;
voice.meantime = 120;
voice.meantalk = 1.846;
voice.meansilence = 1.197;
voice.minitalk = 0.04;
voice.minisilence = 0.205;
[voicedata, voicenumdata] = voicetraffic(simultime, voice, nuser);
end
disp(['loop times: ' 'iframe']);
fprintf(1, 'frame number: %f
', iframe);
disp(['loop times: ' 'iframe']);
fprintf(1, 'frame number: %f
', iframe);

if mod(iframe, 1040) == 0 || iframe == 1
    Lu = Lufading(sys.xyb, sta.xym, par.hb, par.hm, par.f, par.corrdist, par.sps);
    G = antennagain(sys.xyb, sta.xym, par.hm, par.sps);
end
fastlos=fastsfading(sta.xym);
if mod(iframe,1040)==0||iframe==1
    logn=lognfading(sys.xyb,sta.xym,par.sigma, par.raa,sys.lognmap,
    sys.lognmapvec);
end
sta.pathgain=G+logn-Lu;
disp([num2str(toc/60) 'min']);
end

% Perform handoff if possible.
disp('Perform handoff if possible.');
if mod(iframe,104)==0 % perform every 480ms.
    [sta.b, sta.k, sys.matrix_ind,sta.pdlb] = handoff_cdma(iframe,sta.b,
    sta.k, sta.pathgain,sys.matrix_ind,par.homargin,sta.pdlb,par.pinitb);
    fail = ~isfinite(sta.k); % change due to the handoff fail
    handfail_num=handfail_num+sum(fail);
    keep=isfinite(sta.k);
    sta.b =sta.b(keep);
    sta.k =sta.k(keep);
    sta.xym =sta.xym(keep);
    sta.xyv =sta.xyv(keep);
    sta.pathgain =sta.pathgain(keep,:);
    sta.pul =sta.pul(keep);
    sta.cdl =sta.cdl(keep);
    sta.idl =sta.idl(keep);
    sta.sirdl =sta.sirdl(keep);
    sta.ferdl =sta.ferdl(keep);
voicedata=voicedata(keep,:);
voicenumdata=voicenumdata(keep,:);
blockloss_num=blockloss_num(keep,:);
end
disp([num2str(toc/60) 'min']);

% Calculate the carrier power, interference power and C/I
disp('Calculate the carrier power, interference power and C/I');
t2=isnan(voicedata(:,iframe));
if t2~=0
    index= index(sta.b(t2), sta.k(t2), size(sta.pdlb));
    sta.pdlb(index)=0; % set to 0 if the calling is over
end
[sta.cdl, sta.idl, sta.sirdl]=transmitdl_cdma(sta.b,sta.k, sta.pdlb,
sta.pathgain, par.noise,par.ef,par.vf);
disp([num2str(toc/60) 'min']);

% power control step 60ms(13frame)
disp('power control');
sta.pdlb = pcdl(iframe,sta.b,sta.k,sta.sirdl, par.pcrang, sta.pdlb,
par.pdlmax, par.pdlmin);
disp([num2str(toc/60) 'min']);
sta.sirdll = sta.sirdl+fastlos; % the fast loss
% sta.sirdll is for the sir stastics and sta.sirdl is for the PC.
% Collect C/I for mobiles
sirdmbt(:,iframe) = sta.sirdll;
if mod(iframe,13)==0
    sirdmbtp(:,iframe)=sta.sirdll;
    iframe=iframe+1;
end
for m=1:length(CIR)
    N(m,1)=N(m,1)+sum(sirdmbt(:,iframe)<=CIR(m,1));
end
% L2S Model get the link simulation result from the fer vs. C/I curve

sta.ferdl=interp1(CIR_link,FER_link,sta.sirdll);
ferdmbt(:,iframe) = sta.ferdl;
rand1=rand(size(sta.ferdl,1),1);
for k=1:size(sta.ferdl,1)
    if rand1(k)<=sta.ferdl(k)
        blockloss_num(k)=blockloss_num(k)+1;
        if isnan(voicedata(k,iframe))
            blockloss_num(k)=blockloss_num(k)-1; %
        end
    end
end
end

% calculate the simulation result.

tranblock=voicenumdata;
%tranblock=[50;60;87;60];
%blockloss_num=[2;3;1;2];
reciveblock =max(0,tranblock-blockloss_num);
fer_mean=blockloss_num./tranblock;
hold_time=par.blocktime.*tranblock;
% Sat.Erlang
Erl=hold_time./simultime.*(1-fer_mean);
Erlsys=sum(Erl); % the erlang of the whole system
ErlperTrx=Erlsys/(5*57); % the Erlang per TRX.
SpectralEfficiency=Erlsys/60.4; % Erl/MHz/Site
EFL=Erlsys/19/(45*8);
satisfusertag=zeros(size(fer_mean,1));
for j=1:size(fer_mean,1)
    if fer_mean(j,1)<=0.02
        usersatisf_tag(j,1) = 1;
    end
end
usersatisf=satisfusertag/size(fer_mean,1);

% CDF curve
    for m=1:length(CIR)
        N_P(m,1)=N(m,1)/N(length(N),1);
    end

% ------------------------ display, write files and plot figure
plot( CIR(:,1), N_P);
grid on
xlabel('C/I [dB]');
ylabel('C.D.F');
fprintf(1,'User\tCIR1\tCIR2\tCIR3\t....\tTranblocknum\treceviblocknum\nErlang\n');
for i=1:size(fer_mean,1)
    fprintf(1,'%2.1f\t', i);
    fprintf(1,'%f\t', sirdmbt(i,1));
    fprintf(1,'%f\t', sirdmbt(i,1+par.statime));
    fprintf(1,'%f\t', sirdmbt(i,1+2*par.statime));
    fprintf(1,'%f\t', sirdmbt(i,1+3*par.statime));
end
fprintf(1, '\%f\t', sirdmbt(i,1+4*par.statime));
fprintf(1, '\%f\t', sirdmbt(i,1+5*par.statime));
fprintf(1, '\%f\t', sirdmbt(i,1+6*par.statime));
fprintf(1, '...');
fprintf(1, '\%f\t', sirdmbt(i,par.nframes));

fprintf(1, '\%f\t', tranblock(i,1));
fprintf(1, '\%f\t', reciveblock(i,1));
fprintf(1, '\%f\t', fer_mean(i,1));
fprintf(1, '\%f\n', Erl(i,1));
end
fprintf(1, 'the radio of satisfated users: \%f
', usersatisf);
fprintf(1, 'the Network Erlang is: \%f
', Erlsys);
fprintf(1, 'the Erlang per TRX is: \%f
', ErlperTrx);
fprintf(1, 'the Spectral Efficiency is: \%f
', SpectralEfficiency);
fprintf(1, 'the EFL is: \%f
', EFL);

fid = fopen('result_CDMA_6_10.dat', 'w');
fprintf(fid, 'User\tCIR1\tCIR2\tCIR3\t....\tTranblocknum\treceviblocknum\n

for i=1:size(fer_mean,1)
    fprintf(fid, '\%2.1f%\t', i);
    fprintf(fid, '\%f\t', sirdmbt(i,1));
    fprintf(fid, '\%f\t', sirdmbt(i,1+par.statime));
    fprintf(fid, '\%f\t', sirdmbt(i,1+2*par.statime));
    fprintf(fid, '\%f\t', sirdmbt(i,1+3*par.statime));
    fprintf(fid, '\%f\t', sirdmbt(i,1+4*par.statime));
    fprintf(fid, '\%f\t', sirdmbt(i,1+5*par.statime));
    fprintf(fid, '\%f\t', sirdmbt(i,1+6*par.statime));
    fprintf(fid, '...');
    fprintf(fid, '\%f\t', sirdmbt(i,par.nframes));

    fprintf(fid, '\%f\t', tranblock(i,1));
    fprintf(fid, '\%f\t', reciveblock(i,1));
    fprintf(fid, '\%f\t', fer_mean(i,1));
    fprintf(fid, '\%f\n', Erl(i,1));
end
fprintf(fid, 'the radio of satisfated users: \%f
', usersatisf);
fprintf(fid, 'the Network Erlang is: \%f
', Erlsys);
fprintf(fid, 'the Erlang per TRX is: \%f
', ErlperTrx);
fprintf(fid, 'the Spectral Efficiency is: \%f
', SpectralEfficiency);
fprintf(fid, 'the EFL is: \%f
', EFL);
fclose(fid);

fprintf('The program is over! \n');
disp([num2str(toc/60) ' min']);
9.2 Introduction to RUNE toolbox

First aproach to rune toolbox

- Introduction
- Basic functions
  - Creating sites
  - Creating mobiles
  - Calculating gain
  - Allocating channels
  - Calculating C/I
- Rune simulation examples
  - SIR
  - Log-normal shadow fading
  - Log-normal correlation
  - Wraparound
Introduction

- The aim of this presentation is to give a brief view about the use of RUNE tool for the simulation of cellular radio networks.
- Main functions and some network parameters are explained through examples, in order to understand them empirically.
- Two main guides used for this first approach are:
  - "Interference statics in wireless network systems laboratory" by unknown author, 15 March 2004- v.2.0.

Basic functions I: creating sites

- \([xyb, fib, rhombvec] = \text{crecells}(cellradius, sps, km, lm, kn, ln)\)

```
cluster size, \(km^2 + lm^2 + km*lm\)
Number of clusters, \(kn^2 + ln^2 + kn*ln\)
```
Basic functions II: creating mobiles

- Xym vector contains the mobile position and Xyv the current velocity
- That vectors are updated every time we call the function mobmove
- Mobmove function used to positioning the mobiles and moving them through the system
- \([xym,xyv]=\text{mobmove}(xym,xyv,amean,vmean,dt,rhombvec)\)

- Next figure shows a location plot of 10 mobiles in 30 iterations with a given amean (acceleration) and vmean (speed)
Basic functions IV : calculating gain

- We can use directional or omnidirectional antennas, controlled by parameter sps (sectors per site)
- For example, 3 sectors per site scheme uses 3 120° directional antennas

Basic functions V : calculating gain

- Calculation of the lognormal shadow-fading map function:
- \([\text{lognmap}, \text{mapvec}] = \text{crelognmap}(\text{xyb}, \text{rhombvec}, \text{corrdist}, \text{nlayer})\)
Basic functions VI : calculating gain

- The distance until the correlation in the map has decreased to 1/e is represented by corrdist. Another example:

\[ g = \text{pathgain}(xym, xyb, fib, asps, rhombvec, gainconst, alpha, sigma, raa, lognmap, mapvec) \]

is used to calculate pathgain of all the links between mobiles and basestations.

Basic functions VII : allocating channels

- \( \text{obk} = \text{crechanplan}(\text{nb}, \text{nk}, \text{ncluster}) \)
  - Makes a "frequency" plan with cluster size \( \text{nb/ncluster}^2 \)

- \( [\text{bass}, \text{kass}, \text{offern}] = \text{assign}(b, k, g, \text{offer}, \text{homargin}) \)
  - Assigns base and channel to new calls. If possible first base is selected and then if possible a channel.

- Obk matrix: if a mobile is assigned a channel and a specific basestation, the one in the obk matrix is set to zero in order to indicate the no availability of the channel.
Basic functions VII: calculating C/I

- Two functions for calculating the carrier, interference and SIR. CDF to plot the results
  - $[c_{dl}, i_{dl}, s_{dl}]=\text{transmitdl}(b, k, p_{dl}, g, \text{noise})$
  - $[c_{ul}, i_{ul}, s_{ul}]=\text{transmitul}(b, k, p_{ul}, g, \text{noise})$

Rune simulation examples: SIR I

- Examples made with template functions: setpart and runeft

- System parameters (other default):
  - Reuse factor: 7 (controlled by km, lm and sps)
  - 4 channels/cell
  - 2 users per cell on average
  - alpha=3.5
  - sigma=8
  - cell radius: 1000m
  - Transmitter power 1 W
  - 1,3,9,12 clusters (controlled by kn, ln)

- The aim is to see the impact of number of clusters to the SIR
Rune simulation examples : SIR II

Rune simulation examples : SIR III
Simulation: Lognormal shadow fading I

- The aim is to see the effect of lognormal shadowing to C, I and C/I in the downlink. Different sigma values (standard deviation for the lognormal fading [dB])

- System parameters:
  - Reuse factor: 7
  - 15 channels/cell
  - 60% load, 9 users per cell on average
  - alpha=3.5
  - sigma=0, 4 and 8
  - raa=0
  - Cell radius: 400 m
  - Noise floor -128 dBm (interference limited system)
  - Transmitter power 1 W
  - No fast fading, set par.usefastf to 0

Simulation: Lognormal shadow fading II

![Cell power histogram for sigma=0](image.png)
Simulation: Lognormal shadow fading III

carrier downlink power histogram for sigma=4

Simulation: Lognormal shadow fading III

carrier downlink power histogram for sigma=8
Simulation: Lognormal shadow fading VI

Simulation: Lognormal shadow fading VII
Simulation: Lognormal shadow fading VIII

The aim is to see the effect downlink correlation parameter (raa) in the C, I relation. Scattered plots are used for the downlink:

System parameters
- Reuse factor: 7
- 15 channels/cell
- 60% load, i.e. 9 users per cell on average
- alpha=3.5
- sigma=8
- raa= 0, 0.5, 1
- Cell radius: 400 m
- Noise floor -128 dBm (to get an interference limited system)
- Transmitter power 1 W
- No fast fading
Simulation: Lognormal correlation II

Simulation: Lognormal correlation III
Simulation: Lognormal correlation IV

The aim is to see how the wraparound run method works, that is, how the mobiles are connected to the basestations.

System parameters:

- Reuse factor: 3/7
- 4 channels/cell
- 1 user per cell on average
- alpha = 3.5
- sigma = 8
- raa = 0.5
- Cell radius: 1000 m
- Noise floor: -128 dBm (interference limited system)
- Transmitter power: 1 W
Simulation: Wraparound test II
9.3 Introduction to Alamouti codification

Two-branch transmit diversity scheme using Alamouti code and ML detector

- Introduction
- Requirements
- Diversity
- MRRC vs Alamouti scheme
- Alamouti scheme results
- Advanced results
- Conclusions

Introduction

- The aim of this presentation is to give a brief view of two-branch transmit diversity scheme and discuss strong and weak points.
- Main part of the content is extracted from two papers:
  - "A Simple Transmit Diversity Technique for Wireless Communications" by Siavash M. Alamouti, Oct. 1998
Requirements

- Wireless systems requirements are increasing quickly
- High bit rate data services are being common
- Remote units are supposed to be small and lightweight:
  - Battery size restrictions
  - Power consumption restrictions
    - Simple designs
    - Low computation complexity
    - Power transmission limitations
- **Solution**: Diversity implemented at the base stations

Diversity I

- The most difficult disadvantage of wireless communications is the time-varying multipath fading
Diversity II

- Some possible solutions:
  - Higher transmit power
  - Additional bandwidth
  - Advanced transmitter power control.
  - Feedback from the receiver, in order to estimate the channel
  - Time interleaving
  - Space time trellis-coding

- Some of these solutions are against the requirements

Diversity III

- Solution proposed by Alamouti is a simple space-time diversity:
  - Space: because two or more antennas are used for the transmission
  - Time: because each antenna transmits a sequence of two symbols

<table>
<thead>
<tr>
<th>time</th>
<th>Tx0</th>
<th>Tx1</th>
</tr>
</thead>
<tbody>
<tr>
<td>( t )</td>
<td>( s_0 )</td>
<td>( s_1 )</td>
</tr>
<tr>
<td>( t+T )</td>
<td>(-s_1^*)</td>
<td>( s_0^*)</td>
</tr>
</tbody>
</table>
MRRC vs Alamouti scheme I

- Remembering a classical two branch MRRC (maximal-ratio receiver combining)

MRRC vs Alamouti scheme II

- Alamouti scheme proposed
MRRC vs Alamouti scheme III

- Comments
  - The Encoding and Transmission Sequence is a space–time coding. It’s also possible a space–frequency coding.
  - The Combining Scheme builds these two signals to send them to the ML detector:
    \[ \hat{s}_0 = h_0^* r_0 + h_1^* r_1 \]
    \[ \hat{s}_1 = h_1^* r_0 - h_0^* r_1. \]
  - Example of the ML detector rule for PSK signals:
    \[ d^2(\hat{s}_0, s_i) \leq d^2(\hat{s}_0, s_k), \quad \forall i \neq k. \]

MRRC vs Alamouti scheme IV

- We can generalise to the case of two transmit antennas and M receivers
Comments

- It's interesting to note that the combining scheme is identical to the case with a single receive antenna.

- Although the receiver complexity increases due to the two-branch channel estimators, it is possible to provide a diversity order of $2M$ with two transmit and $M$ receive antennas.

Alamouti scheme results I

- The following results are obtained under some restrictive assumptions:
  - The total power from the two antennas is the same as the transmit power from the single transmit antenna for MRRC.
  - Amplitudes of fading from each transmit to each receive antenna are mutually uncorrelated Rayleigh distributed.
  - The average signal powers at each receive antenna from each transmit antenna are the same.
  - Perfect knowledge of the channel.

- As all these assumptions are so far from the reality, the given results provide only reference and comparison.
Alamouti scheme results II

- BER performance comparison of coherent BPSK with MRRC and two-branch transmit diversity in Rayleigh fading.

![BER Performance Comparison](image)

Alamouti scheme results III

- Comments
  - 3-dB penalty is incurred because the simulations assume that each transmit antenna radiates half the energy
  - The new scheme provides similar performance to MRRC
  - When pilot symbol insertion and extraction is implemented to estimate the channel, twice as many pilots as in the two-branch receiver combining scheme are needed.
  - If the transformed copies of the signals are transmitted at distinct N intervals from all the antennas, the decoding delay is N symbol periods
  - Soft fail advantages, additional reliability due to multiple receive chains
  - Not deep interference impact studied in Alamouti’s results
Advanced results I

- In this brief results are provided theoretical performance of the Alamouti space-time code with less restrictions and improvements:
  - time-varying Rayleigh fading channels
  - noisy channel estimates
  - pilot filter coefficients
  - the multi-path power profile
  - Normalized Doppler frequency
  - Pilot SNR
  - Data SNR
  - Results with maximum-likelihood (ML) symbol detector with the linear combining scheme and ML space-time decoder

Advanced results II

- The effect of speed, pilot $E_p/N_0$ and data $E_b/N_0$ on $P_2$ (sym error)
Advanced results III

- The effect of speed, pilot $E_p/N_0$ and data $E_b/N_0$ on $P_2$ (symbol error) with ML space-time decoder

Advanced results IV

- Comparison between noTD and STTD
Conclusions

- Using 2 TX antennas and 1 RX antenna the scheme provides the same diversity order as maximal-ratio receiver combining (MRRC) with 1 TX antenna, and 2 RX antennas.
- 2 TX antennas and M RX antennas provides a diversity order of 2M.
- 2 times as many MRRC pilots are needed.

- Linear combining scheme is degraded when the Doppler spread is increased
- When the channels change rapidly or when the pilot $E_p/No$ is small, STTD with the linear combining scheme is outperformed by noTD.