Non-Uniform Constellations for Broadcasting and Multicasting Services in WCDMA Systems

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Abstract—**In this paper we apply the concept of non-uniform QAM constellations (Quadrature Amplitude Modulation) for the transmission of multicast and broadcast services in a WCDMA (Wideband Code Division Multiplexing) system. The objective is to increase the efficiency of the transmission by splitting the information in classes with different importance and mapping the bit streams of these classes to more or less protected positions of the modulation symbols. With this strategy it is possible to protect the most important information streams so they can be received by all the users while the not so relevant information will only be extracted if there are good channel conditions. We consider the use of these constellations in the downlink transmission of the UMTS FDD (Frequency Division Duplex) scheme where they are combined with the UMTS turbo code for achieving high transmission rates.**

Keywords - WCDMA, multicast transmission, non-uniform quadrature amplitude modulation.

I. INTRODUCTION

In a Wireless Communication Network it is often necessary to transmit the same information to all the users (broadcast transmission) or to a selected group of users (multicast transmission). The quality of the communication link between the transmitter and the different receivers varies since the different positions of the receivers cause different received average powers, fading and interference. As a result some of the receivers may have better signal to noise ratios (SNR) than the others and thus the capacity of the communication link for these users is higher. To take advantage of this higher capacity and improve the efficiency of the network the information should be transmitted in such a way that allows important data to be recovered by all the receiving users even with poor channel conditions while some additional data can only be extracted by the receivers with better SNR. A possible method to achieve this is to use non-uniform signal constellations which are able to provide unequal bit error protection. In this type of constellations there are two or more classes of bits with different error protection, to which different streams of information are mapped. Depending on the channel conditions, a given user can attempt to demodulate only the more protected bits or also the other bits that carry the additional information. In this approach the information is transmitted blindly in the sense that the transmitter does not knows the identity of the receivers with good transmission conditions.

An application of these techniques is the transmission of coded voice or video signals. Several papers have studied the use of non-uniform constellations for this purpose. In [1] non-uniform QAM constellations were employed for the transmission of digital high definition television signals, [2] compares the use of 64-QAM constellations with 64-DAPSK while [3] studies the use of M-PSK non-uniform constellations in multimedia transmissions. Non-uniform 16-QAM and 64-QAM constellations are already incorporated in the DVB-T (Digital Video Broadcasting - Terrestrial) standard [4].

In this paper we consider the use of 16-QAM and 64-QAM non-uniform modulations for the transmission of broadcast and multicast services in WCDMA systems. For 16-QAM two classes of bits are used while for 64-QAM we use three classes of bits. Some modifications to the physical layer of an UMTS (Universal Mobile Telecommunications Systems) based system are proposed to incorporate these modulations. Since a turbo coding scheme is emplyed, the demodulator has to compute the likelihood probabilities of the received coded bits. An appropriate method for this computation is derived. The performance of the proposed transmission scheme is evaluated by Monte Carlo simulations. This work was elaborated as a result of the participation in the B-BONE project (IST-2003-507607). Its objective is the enhancement of both FDD (Frequency Division Duplex) and TDD (Time Division Duplex) modes of UMTS release 6, in order to offer sufficiently high data bit rates to carry digital broadcast and multicast services. The structure of the paper is as follows. In Section II the design of non-uniform constellations is explained. Section III describes the modifications necessary in the transmitter structure of a WCDMA system and how the demodulation can be done for providing the likelihood probabilities to the turbo decoder. Section IV shows some performance results using the proposed transmission scheme and Section V presents the conclusions of this study.

II. NON-UNIFORM QAM SIGNAL CONSTELLATIONS

A. 16-QAM

These constellations are constructed using a main QPSK constellation where each symbol is in fact another QPSK constellation, as shown in Figure 1.

The idea is that the constellation can be viewed as a 16-QAM constellation if the channel conditions are good or as a QPSK constellation otherwise. In the latter situation the received bit rate is reduced to half. The main parameter for defining one of these constellations is the ratio between d1 and d2 as shown in Figure 1:

$$\frac{d_1}{d_2} = k \text{ , where } 0<k\leq 0.5$$

Each symbol *s* of the constellation can be written as:

$$s = \left(\pm\frac{d_2}{2} \pm \frac{d_1}{2} \right) + \left(\pm\frac{d_2}{2} \pm \frac{d_1}{2} \right) j$$

If k=0.5 the resulting constellation is a uniform 16-QAM. To analyze the bit error probability of a 16-QAM non-uniform constellation, considering that the mapping of the bits is split in two groups where one of the groups does not depend on the I axis and the other does not depend on the Q axis, it is possible to visualize that the 16-QAM constellation has two independent 4-PAM. Figure 2 shows the decision regions for each of the two classes of bits of a 4-PAM (Pulse Amplitude Modulation) constellation. Using these regions the exact bit error probability for each bit type in an AWGN channel with noise power σ^2 can be computed as

$$\mathrm{P_b}\left\{\text{bit } 1\right\} = \frac{1}{2}\cdot\left[Q\left(\frac{\frac{d_2}{2}+\frac{d_1}{2}}{\sigma} \right) + Q\left(\frac{\frac{d_2}{2}-\frac{d_1}{2}}{\sigma} \right) \right]$$

for the more protected bit.

$$\mathrm{P_b}\left\{\text{bit } 2\right\} = \frac{1}{2}\cdot\left[2\cdot Q\left(\frac{\frac{d_1}{2}}{\sigma} \right) - Q\left(\frac{d_2+\frac{d_1}{2}}{\sigma} \right) + Q\left(\frac{d_2-\frac{d_1}{2}}{\sigma} \right) \right]$$

for the less protected bit. The average bit error probability is:

$$P_b = \frac{1}{2}\left(\mathrm{P_{error}}\left\{\text{bit } 1\right\} + \mathrm{P_{error}}\left\{\text{bit } 2\right\} \right)$$

$$= \frac{1}{2}\cdot\left[Q\left(\frac{\frac{d_2}{2}+\frac{d_1}{2}}{\sigma} \right) + Q\left(\frac{\frac{d_2}{2}-\frac{d_1}{2}}{\sigma} \right) + 2\cdot Q\left(\frac{\frac{d_1}{2}}{\sigma} \right) - Q\left(\frac{d_2+\frac{d_1}{2}}{\sigma} \right) + Q\left(\frac{d_2-\frac{d_1}{2}}{\sigma} \right) \right]$$

B. 64-QAM

These constellations are constructed using a main QPSK constellation where each symbol is in fact one of the non-uniform 16-QAM constellations presented previously. In these 64-QAM constellations there are three types of bits with different error probabilities instead of the two types available in the 16-QAM constellations.

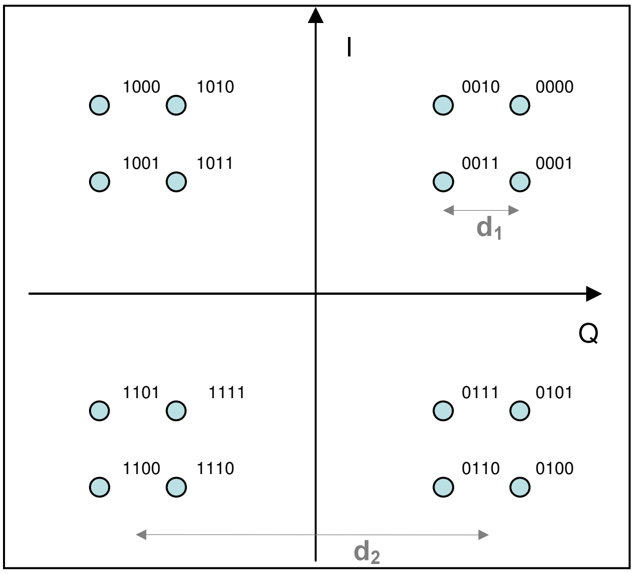

Figure 1 – Signal Constellation for 16-QAM Non-uniform modulation.

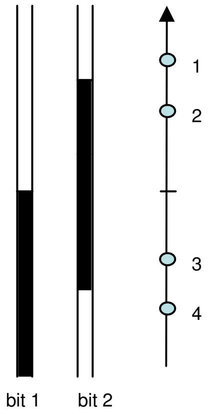

Figure 2 - Bit decision regions for a 4-PAM non-uniform constellation.

The main parameters for defining each of these constellations are:

$$\frac{d_1}{d_2} = k_1 \text{ , } \frac{d_2}{d_3} = k_2 \text{ , , where } 0<k_{1,2}\leq 0.5$$

In these expressions d_1 and d_2 have the same meaning as in Figure 1, considering that it shows a 16-QAM component constellation and d_3 corresponds to the distance between the center of one of these component constellations and any of its closest neighbors. Each symbol s_i of the constellation can now be written as:

$$s_i = \left(\pm\frac{d_3}{2} \pm \frac{d_2}{2} \pm \frac{d_1}{2} \right) + \left(\pm\frac{d_3}{2} \pm \frac{d_2}{2} \pm \frac{d_1}{2} \right) j$$

Note that when $k_1=k_2=0.5$ it results in a uniform 64-QAM constellation.

For computing the analytical bit error probability of a 64-QAM non-uniform constellation the approach is the same as the one used for 16-QAM but due to lack of space it is not presented here.

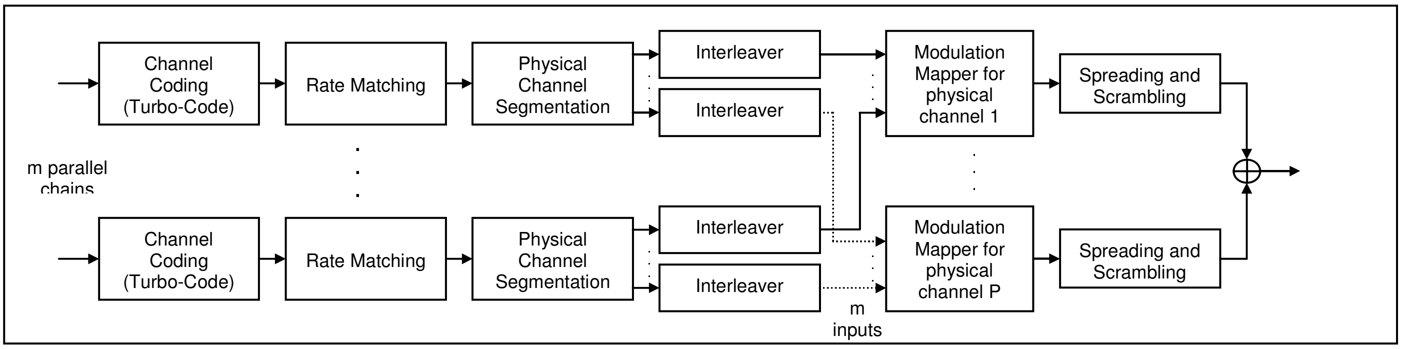

Figure 3 – Proposed transmitter chain.

III. PROPOSED WCDMA DOWNLINK SCHEME

A. Transmitter Structure

These non-uniform constellations can be incorporated in the downlink connection of a WCDMA system for increasing the efficiency of broadcast and multicast transmissions. We used the HS-DSCH (High Speed Downlink Shared Channel) of the UMTS HSDPA (High Speed Downlink Packet Access) mode [4][5] as the base system and we implemented the necessary modifications to incorporate the modulations 16-QAM and 64-QAM. Figure 3 shows the resulting transmission chain. It does not have some blocks specified for HSDPA, like CRC attachment and Hybrid-ARQ, since they are not relevant for this study. In the proposed scheme, there are *m* parallel chains for the *m* input bit streams (*m*=2 for 16-QAM and *m*=3 for 64-QAM). Each stream is turbo encoded (using the 3GPP rate 1/3 specified turbo code [4]) and rate matching is performed (usually puncturing) for fitting the output stream to the HSDPA subframe format. Then each stream is segmented in *P* physical channels (each physical channel will be spreaded by a different OVSF – orthogonal variable spreading code) which are individually interleaved. The physical channels of the *m* processing chains are then mapped to the constellation symbols in the modulation mappers according to the importance attributed to the chain. The modulated symbols are spreaded and scrambled and the resulting physical channels are summed.

B. Demodulation and Turbodecoding

In the receiver the turbo decoder needs the likelihood probabilities $p(Y|X)$ of the state transitions of the component convolutional codes. $X=\{i_1,\dots,i_n\}$ is a possible output word for a state transition and $Y=\{y_1,\dots,y_n\}$ the respective received symbol values. Note that for the turbo code used n=2. Since the bits are independently mapped to the I and Q branches of the modulation symbols, the M-QAM constellation can be analyzed as two independent √M-PAM constellations. The state transition likelihoods can be written as:

$$p(Y\,|\,X)=p\left(y_1\dots y_n\,|\,i_1\dots i_n\right)=\prod_{k=1}^{n}p\left(y_k\,|\,i_1\dots i_n\;y_1\dots y_{k-1}\right)$$

Assuming that the output words are the inputs to a noisy discrete memoryless channel (DMC), the likelihood probabilities can be simplified to:

$$p(Y\,|\,X)=\prod_{k=1}^{n}p\left(y_k\,|\,i_k\right)$$

Note that when using M-QAM modulations with M>4 where some of the bits of the output word are mapped to the same real or imaginary part of a symbol then this last simplification does not apply. In our case this does not happen since we use individual encoded streams and each one is mapped to only one position of the real and imaginary part of the modulated symbols. The likelihoods of the output bits mapped to the b^{th} position of the transmitted symbols are given by:

$$\begin{aligned}p(y_k\,|\,i_k=I)&=\frac{1}{p(i_k=I)}\sum_{s_j\in S_b(I)}p(y_k,s_j)\\&=\frac{1}{p(i_k=I)}\sum_{s_j\in S_b(I)}p(y_k\,|\,s_j)p(s_j)\end{aligned}$$

where $S_b(I)$ is the set of symbols of the constellation whose value for the b^{th} component bit is $I=\{0,1\}$. In the AWGN channel each symbol likelihood probability is computed as

$$p(y_k\,|\,s_j)=\frac{1}{\sqrt{2\pi\sigma^2}}e^{-\frac{\left(y_k-s_j\right)^2}{2\sigma^2}}$$

In multipath fading channels with L taps, and using a RAKE receiver with maximal ratio combining this probability can be written as:

$$p(y_k\,|\,s_j)=\frac{1}{\sqrt{2\pi\sigma^2\sum_{t=1}^{L}\left|\tilde{W}_t\right|^2}}e^{-\frac{\left(y_k-\sum_{t=1}^{L}\left|\tilde{W}_t\right|^2 s_j\right)^2}{2\sigma^2\sum_{t=1}^{L}\left|\tilde{W}_t\right|^2}}$$

Where $\tilde{W}_t$ is the complex channel coefficient of propagation path t. Note that usually the turbo decoder works with logarithms of probabilities which simplifies the computations of the likelihood probabilities.

IV. PERFORMANCE EVALUATION OF THE PROPOSED SCHEME

To evaluate the performance of the proposed WCDMA downlink transmission several simulations were ran for high transmission rates using the non-uniform constellations and the standardized HSDPA 16-QAM uniform modulation. All the BER results are presented as a function of E_S/N_0 (E_S - symbol energy, before spreading) since it seems a more natural choice than E_b/N_0 (E_b - bit energy) for comparing the performances of different classes of bits that are transmitted with unequal amounts of energy.

First we studied the impact of the mapping of the bits to the symbols without considering non-uniform constellations. Figure 4 compares the results of a transmission of two encoded blocks (4264 bits each) in AWGN channel. Two different cases are shown. In one case the usual 16-QAM mapping of encoded bit streams of HSDPA is used which means that both streams can either have bits mapped to more or less protected positions in the modulated symbols. In the second case we use a modified mapping where one of the streams is mapped to the more protected positions of the symbols and the other to the less protected ones. The modified mapping improves the performance of one of the streams at the cost of a small overall performance degradation relative to the usual mapping.

Using the proposed scheme, several simulations were run for similar rates (in the case of 16-QAM) or 33% higher (when using 64-QAM) to the ones of CQI 22 (Channel Quality Indicator) and CQI 30 of HSDPA [7]. TABLE 1 shows the transmitted rates simulated, the respective modulations, the possible received rates and the number of physical channels (OVSF codes) used. Note that in our proposed scheme AMC (Adaptive Modulation and Coding) is not used for broadcast and multicast transmissions. The environment simulated is the modified Pedestrian A [8], which has a line of sight component. A velocity of 3 km/h was considered. In most of the results presented there is a BER 'floor' caused by the multipath interference. This is due to QAM modulation being very sensitive to interference compared with other modulations like QPSK. This interference could be reduced using a multipath interference canceller but we did not use it since it was not very relevant for this study.

Figure 5 shows the results obtained with a transmission rate of 3.6 Mbps using 16-QAM non-uniform modulations for different values of *k*. For comparison we also show the performance of CQI 22 which has a similar transmission rate. Figure 6 presents the results for similar conditions but using 64-QAM modulations with several values of k_1 and k_2. In these cases the transmission rate is 5.4 Mbps. Level 1 constellation corresponds to the case where only the 2 more protected bits are extracted from the received symbols and the level 2 is when the following 2 more protected bits are also extracted. Figure 7 shows the results of a transmission rate of 12Mbps using 16-QAM modulation. The reference is the performance of CQI 30. Figure 8 corresponds to the same conditions but using 64-QAM modulations. The CQI 22 and CQI 30 have similar performances to the two 16-QAM uniform constellations (k=0.5) shown but the mapping used in this case allows the reception of half of the bits with better performance. The use of non-uniform constellations improves the performance of one of the bit streams even more at the cost of a degradation of the performance of the other stream. For the 64-QAM results presented we see that the performance of the level 2 constellations (which is equivalent to a 16-QAM) is worse than CQI 22 and CQI 30, for the values of k_1 and k_2 simulated. Nevertheless they can still be viable solution since one of the streams has better performance.

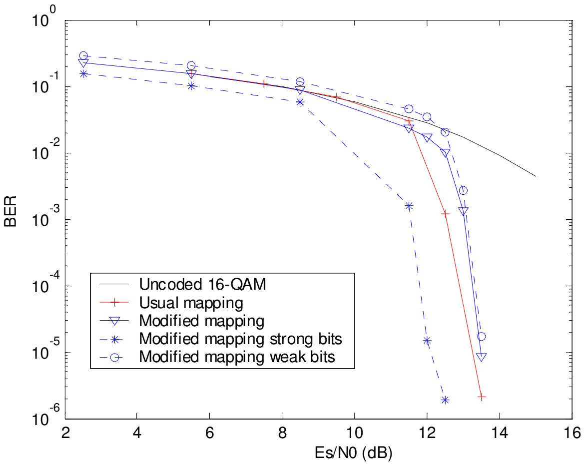

Figure 4 – Comparison of BER performance between the usual 16-QAM mapping of encoded bit streams of HSDPA and the mapping of encoded streams with unequal error protection.

TABLE 1. TRANSMITTED RATES SIMULATED.

Transmission rates	**Received rates**	**Modulation**	**Physical Channels**
3.6 Mbps	1.8 Mbps	16-QAM	5
	3.6 Mbps		
5.4 Mbps	1.8 Mbps	64-QAM	5
	3.6 Mbps		
	5.4 Mbps		
12 Mbps	6 Mbps	16-QAM	15
	12 Mbps		
18 Mbps	6 Mbps	64-QAM	15
	12 Mbps		
	18 Mbps		

V. CONCLUSIONS

In this paper we have shown that it is possible to use non-uniform constellations for improving WCDMA system efficiency in the case of transmission of broadcast and multicast services. The most important or basic information streams are mapped to the more protected bits of the modulation symbols and the additional streams are mapped to the other bit positions according to the importance level.

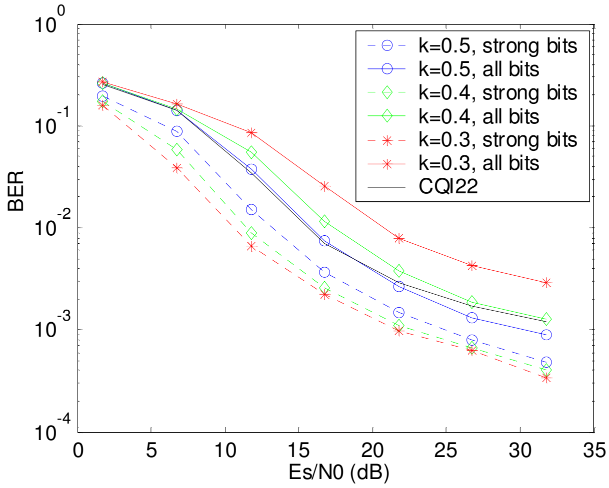

Figure 5 – 16-QAM non-uniform modulations simulation results for transmission rates of 3.6 Mbps in modified Pedestrian A environment.

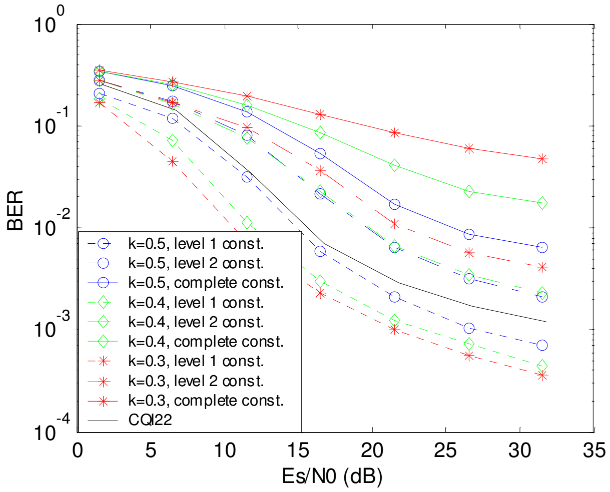

Figure 6 – 64-QAM non-uniform modulations simulation results for transmission rates of 5.4 Mbps in modified Pedestrian A environment.

The idea is that all the receivers can be able to decode the basic information streams and the more capable ones (with better reception conditions) can extract the extra information present in the transmitted signal. Using this approach significant coding gain can be obtained for the important data at the cost of some performance degradation for the rest of the data. We have shown that this principle can also be applied even if the modulation is uniform but with lower differences between the error protection capabilities obtained for the different streams. The impact of the use of an interference canceller and imperfect channel estimation in the performance of a WCDMA system using these constellation is a topic of future research.

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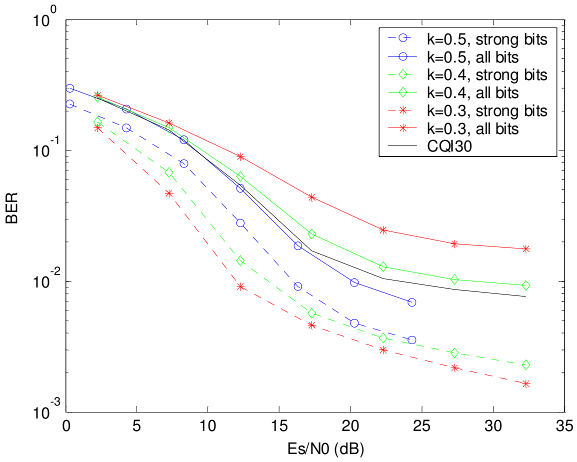

Figure 7 – 16-QAM non-uniform modulations simulation results for transmission rates of 12 Mbps in modified Pedestrian A environment.

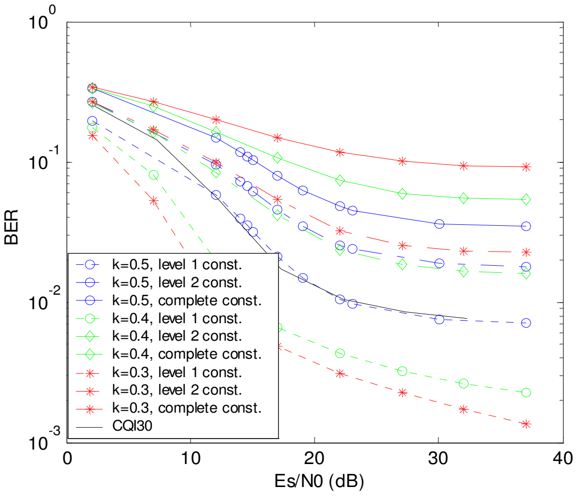

Figure 8 – 64-QAM non-uniform modulations simulation results for transmission rates (total) of 18 Mbps in modified Pedestrian A environment.