Reducing the feedback information in OFDM-based Adaptive Modulation Systems for 4G

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Abstract

In this paper several strategies for reducing the feedback information are proposed and simulated in order to check their possibilities. Several algorithms for compressing feedback data based on time and frequency correlation are simulated. In this way, adaptive modulation techniques for 4G applications can be implemented with lower feedback bandwidth requirements and therefore these techniques are closer to be used for future networks.

I. INTRODUCTION

Nowadays wireless communications are one of the key technologies for future business workers and entertainment. In these scenarios, high bitrate at high mobility is one of the main requirements. For this reason, Super 3G (evolution of 3G) or 4G are looking for modulation schemes that fulfill these high demanding requirements. One of the strongest candidates for the downlink is Adaptive modulation in OFDMA (Orthogonal Frequency Division Multiple Access)-based systems [1], [2]. Following these ideas, in [3] a complete downlink OFDMA scheme is devised where an adaptive modulation system is proposed, however authors do not go into details about the feedback implementation.

Adaptive modulation basically uses the best modulation and coding scheme depending on the instantaneous channel characteristics during the transmission. In an OFDM-based system, every sub-carrier can be modulated independently based on the sub-carrier quality [4] or in groups of sub-carriers [3]. Depending on how fine the adaptation is performed the strategy is named Link Adaptation (LA) as in the IEEE 802.11a standard [5], Sub-carrier Adaptation (SCA) or Sub-band Adaptation (SBA) as in IEEE 802.16a standard [6] or [3]. It should be noted that this information about channel characteristics and therefore modulation scheme is usually available at the receiver side where channel estimation/prediction is performed and must be fed back in order to be used for the transmitter.

In these schemes mentioned above for the downlink, a feedback information channel is needed in order to inform the transmitter about the modulation scheme at every time. The amount of data needed to feedback the modulation scheme can be very high and therefore it will be a waste of bandwidth in the uplink. Moreover, usually in wireless communications, the uplink has less bandwidth allocated. For this reason, some proposals for compressing these data are addressed in this paper.

The remaining of the paper is organised as follows. In section II an idea to reduce the feedback information based on channel properties is addressed denoted as likely feedback . Then in section III several algorithms for conditioning in the right way the feedback information in order to get some compression when used with *Huffman* codes are proposed and in section IV some conclusions are obtained.

II. LIKELY FEEDBACK

In a cellular scenario where a base station (BS) or similar is present, the transmission scheduling is performed at the BS side. In order to choose which users will transmit into following frames, all the willing terminals in the network have to inform about their allowable modulation schemes depending on their channel conditions. These data must be updated as often as possible in order to be able to take advantage on channel characteristics and therefore improve performance.

Usually, the scheduler will try to maximize the capacity criterion except for fairness strategies [1] and therefore it will choose users with best modulation schemes available (depending mainly on their channel conditions), i.e. the maximum order modulation schemes. By using this criterion, terminals with poor channel quality at a moment

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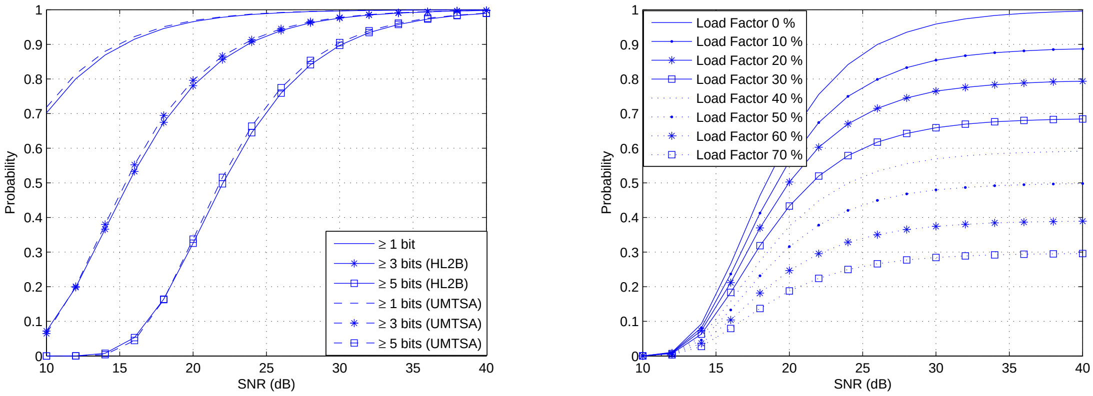
[1] The fairness has not been considered in this paper. Recent papers on fairness can be found in [7] or [8].



(a) Probability comparison

(b) Probability of supporting 4 or more bits

Fig. 1. ***Probability of supporting bits in a channel. Target SER*** $= 10^{-5}$***. 64 fully-loaded sub-carriers***

never will be selected for transmitting and therefore feeding back their information is a waste of bandwidth. Based on the instantaneous load of the cell (the more load the more quality channel requirements for feeding back), the BS can broadcast a parameter informing about the minimum quality for data to be fed back. This is what is called likely feedback in this paper.

In fig. 1a a comparison on probability of supporting a certain number of bits (the quality) between two radio channels is shown. It can be seen that the probability of at least one sub-carrier supports more than a certain number of bits decreases as the required *quality* increases. Besides, the higher signal to noise ratio the higher probability of supporting more bits, which makes sense. The system used was an OFDM-based one with 64 fully-loaded sub-carriers.

These probabilities will depend on the load factor, i.e, for a network where only the 30 % of the sub-carriers are available for transmitting these probabilities will be lower than for a system in which 70 % of sub-carriers are free. In fig. 1b, it can be seen the probability of being able to transmit a different number of bits in at least one sub-carrier for a given terminal in an UMTS Vehicular type A channel. If the load parameter broadcasted by the BS is set to 4, the reduction in feedback information will be around 50 %. For this reason we have called this scheme *likely feedback*: only data is fed back if it is likely that it will be selected. As it was mentioned before, except for fairness criteria, by taking into account these probabilities, interesting reductions can be obtained. A simple idea just for taking into account the fairness (which mainly is handled by the scheduler and it is out of the scope of the paper) can be the following: feedback information instantaneously only when it is above the quality factor broadcasted by the BS and periodically even if the quality is not good enough. In this way the scheduler can use it and apply fairness techniques.

III. COMPRESSION OF FEEDBACK DATA

The feedback information is quite important and critical and therefore it must be sent protected in order to guarantee that it is decoded correctly. Therefore the amount of data increases. Even using likely feedback it is still needed to reduce the amount of feedback data. Therefore the complementary idea is to compress the feedback information, for example, by using the wellknown Huffman codes. These codes encode the most probable data with less bits and the less probable with more bits. In order to use them and get some compression, data have to be well conditioned, i.e. a few symbols with very high probability of occurrence and the others with less probability. Initially, feedback data are not well conditioned as it can be seen in figure 2. In this figure the probability of transmitting the different number of bits is shown for a UMTS Vehicular A channel in a wide range of signal to noise ratio. It can be seen that except for the BPSK (1 bit) modulation, the others are equally probable. By applying directly the *Huffman* coding there will be an expansion of data instead of compression.

In order to better condition the data, in this paper several algorithms that exploit the time and frequency correlation of this information are proposed. Basically these algorithms change the symbol occurrence probabilities by using

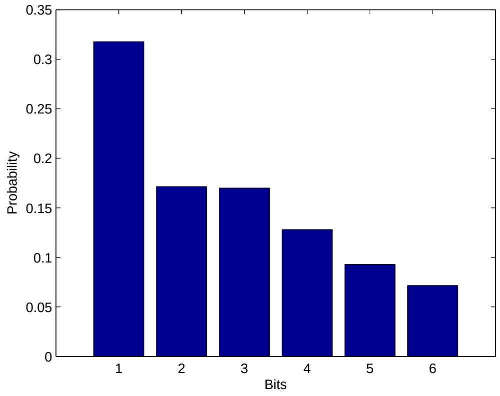
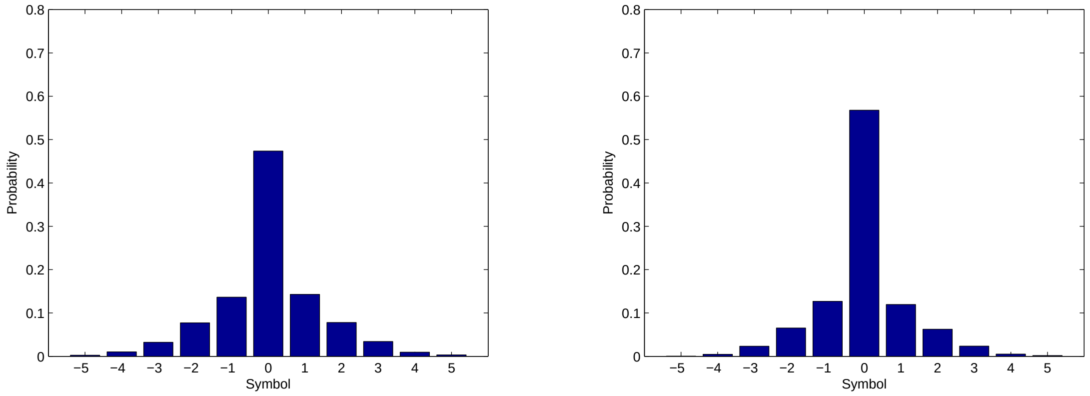


Fig. 2. ***Histogram of bad-conditioned data***



(a) Time Correlation

(b) Frequency Correlation

Fig. 3. ***Symbol Occurrence Probability using time and frequency algorithms***

correlation properties and obtain a well conditioned data stream for being encoded by using *Huffman* codes [9]. First only the time or frequency correlation properties are used and then both at the same time are leveraged.

A. Time or Frequency Algorithms

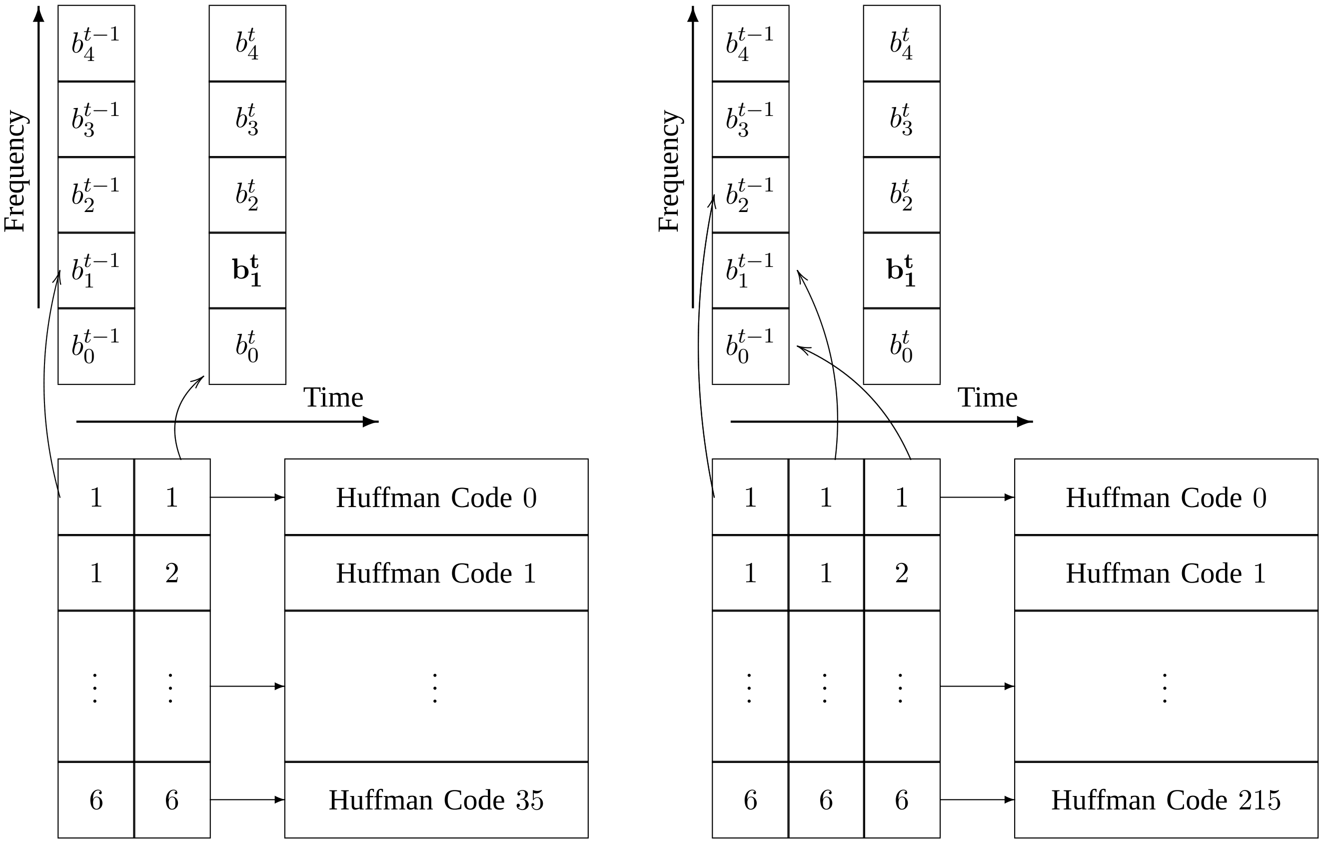
It is likely that the modulation in a specific bin will be similar to that in the previous frame. Therefore, instead of sending directly the modulation it is better to send:

$$c_m^t = b_m^t - b_m^{t-1} \tag{1}$$

where m is the bin-index and t is the time index. The *Huffman* code will be designed according to properties of c_m instead of b_m (as it has been shown before, b_m was bad conditioned, see fig. 2). For the Chalmers' system [3], the number of sequences are 11 (from -5 to 5. Modulations from BPSK to 64QAM). In fig. 3a the histogram for transformed symbols can be seen. Indeed a high time correlation is shown because the 0 (modulation equal to the previous one) is rather higher than the others. These data are already well conditioned for *Hufmman* coding therefore. A similar approach is shown in [10] where the feedback channel only allows a change in one bit (± 1).

For the frequency point of view, the same approach can be used. It is likely that the modulation in one bit is rather similar to that in the neighbor bin. In this case, feedback data will be:

$$c_m^t = b_{m+1}^t - b_m^t \tag{2}$$



(a) Iterative Time-Frequency (b) Block Time-Frequency

Fig. 4. ***Time-Frequency Algorithms***

Again, the number of sequences is 11. As in time correlation, in fig. 3b the modified symbol probabilities by using the frequency correlation algorithm is show. It can be seen that again the frequency correlation is high and moreover, it is even higher than in time so better results (in terms of compression) can be expected.

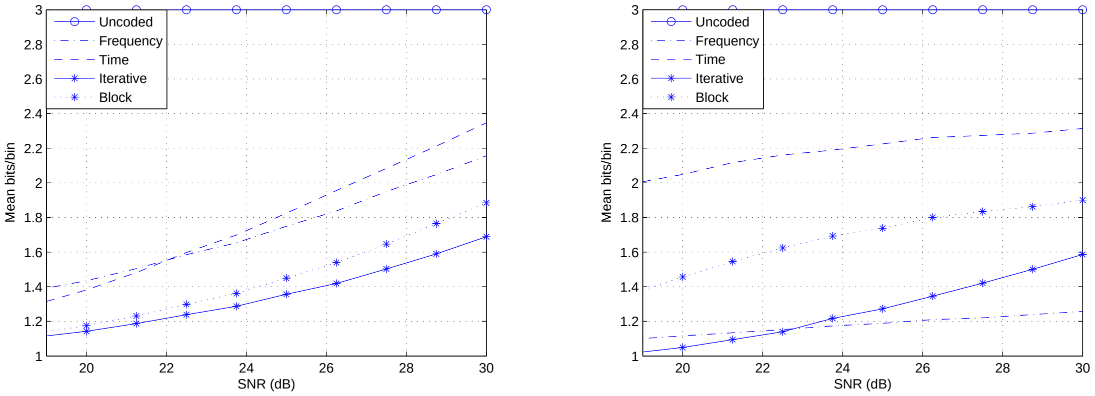
B. Time-Frequency Algorithms

As it was shown in previous section, there exists a high correlation both in time and in frequency. In order to exploit both domains two different algorithms have been designed, namely *Iterative Time-Frequency* and *Block Time-Frequency*.

The first one, *Iterative Time-Frequency* scheme uses not only the actual modulation in a specific bin but also the modulation in previous and in neighbor bin. For instance, if we want to encode the actual frame bin, i.e. b_1^t, the number of bits in the previous bin will be used, b_1^{t-1} jointly with the adjacent bin, b_0^t. If both are for example 2, it is very likely that b_1^t will be also 2 or very similar. For this reason, a specific *Huffman* code is designed for this case and for the other combinations, in total 36 (in general, the number of different *Huffman* codes will be $b_{max}^{b_{max}}$ where b_{max} is the maximum number of bits to be transmitted per sub-carrier). Once the b_1^t has been encoded, next one is taken, b_2^t and the algorithm proceeds iteratively. The decoding procedure is similar. Except for the first bin which is a special case (there is not bin -1). In fig. 4a a graphical description is depicted.

The main disadvantage of this algorithm is that an error in decoding is propagated non linearly to the others. For this reason this information has to be very well protected as pointed out at the beginning of the section. Besides, each certain number of frames it is suggested to send without compressing the data in order to refresh them at the transmitter. Another alternative is doing it adaptively depending on the decoding error probability as in [11] or [12].

The second scheme, the *Block Time-Frequency* uses the neighbor bins information for encoding data, i.e.: b_{m-1}^{t-1}, b_m^{t-1} and b_{m+1}^{t-1}. As in the previous case, for encoding b_1^t, the neighbor bins in previous frame is taken b_0^{t-1}, b_1^{t-1} y



(a) Vehicular A. 120 km/h

(b) Pedestrian A. 10 km/h

Fig. 5. ***Algorithms comparison for UMTS channels***

b_2^{t-1} and depending on them the *Huffman* code is selected. At the receiver, as all the previous data are available a block decoding is performed. In this case there are two special cases, the two bins at the borders. In this algorithm 216 different *Huffman* codes have to be designed. This number can be reduced by observing the symmetries of the problem. In figure 4b the scheme has been depicted.

IV. Results and Discussion

In order to evaluate the proposed algorithms the Chalmers' downlink proposal for 4G has been used. This proposal grouped the 500 data sub-carriers into 25 bins (20 sub-carriers each) and the same modulation scheme was applied for the whole bin [3]. In fig. 5a and 5b the mean number of bits per bin (without compressing 3 bits are needed) is shown for UMTS Vehicular A and Pedestrian A channel respectively. It can be observed in figures that schemes that exploit time and frequency are much better that the others that only exploit time or frequency. In fact, by using one of these algorithms, at 20 - 25 dB the amount of information can be reduced to half of the original data stream. It should be noted that the iterative algorithm performs slightly better than the block one for Vehicular channel. The reason is that the iterative one makes also use of the actual frame information whereas the block one uses only the previous data. It can be seen that iterative and block algorithms, specially the first one, obtain almost a reduction of 50 %, what jointly with the likelihood feedback leads to a reduction of four times in the feedback information.

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