A Combined Modulation and FEC Adaptive Scheme to Wireless Multiaccess ATM Networks

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Abstract - Several adaptive transmission schemes have been proposed to improve the performance of wireless networks. In this context, adaptive modulation has received a lot of attention in the last few years. In this paper we have compared, based on analytical expressions, the adaptive FEC (Forward Error Correction) and adaptive modulation approaches. We have proposed and analysed a hybrid adaptive system that use adaptive FEC and modulation together. We have shown that this system works better than the systems using only adaptive FEC or only adaptive modulation.

1 - Introduction

Broadband and wireless are presently the two major drivers in the telecommunications industry. The challenge to provide a broadband wireless network with Quality of Service (QoS) is the very noisy and time-varying environment of the radio link. Two important parameters of QoS, time-delay and throughput, are significantly affected by the Bit Error Rate (BER) in the wireless link. To reduce the BER effects on the QoS we can use Automatic Repeat Request (ARQ), or Forward Error Correction (FEC) and/or to reduce the number of symbols in the transmitted constellation of the modulation scheme. To improve the performance of the wireless networks, several adaptive transmission techniques have been proposed, with the adaptive modulation playing an important role [1]-[9].

Adaptive modulation schemes vary the number of transmitted bits per symbol as a function of the channel characteristics. Considering a TDMA (Time Division Multiple Access) scheme on the radio link, the modulation can be defined on a frame by frame basis. The main idea is the following: if the bit error rate in the channel exceeds a given threshold, the number of transmitted bits per symbol is reduced (reducing the transmission rate in the channel, while keeping the transmitted average symbol energy at a constant level) improving the BER. Thus, the modulation scheme used is dependent on the instantaneous BER (or on the instantaneous Signal-to-noise Ratio - SNR) in the wireless link.

Recently, Cameron et al [10,11] have presented a simulation based comparison between adaptive modulation (with and without ARQ) and FEC. Their conclusions indicate that the adaptive modulation may render FEC redundant. In this paper we have made an analytical comparison between adaptive modulation, in the absence of FEC and ARQ, and adaptive FEC (with a fixed modulation). In opposite of the conclusions presented by Cameron in [10,11], we have shown that the adaptive FEC system works better than the adaptive modulation system in a wide SNR range. Then, we have proposed a hybrid adaptive system that varies both the modulation and FEC parameters and we have shown that this system works equal or better than the systems using only adaptive modulation or only adaptive FEC in whole SNR range.

The remainder of the paper is organised as follows: in the next section the reference scenario is defined; in section III the comparisons between adaptive modulation and adaptive FEC are evaluated; in section IV the hybrid adaptive system is proposed and analysed; the conclusions are presented in section V.

2 - Reference Scenario

As a scenario for comparison of the schemes analysed in this paper, we consider a system composed by one wireless link and optical wired links. The multiple access technique used in the system is like a DAMA-TDMA (Demand Allocation Multiple Access – Time Division Multiple Access) multiple access. In the DAMA-TDMA scheme, the time is divided in frames, each frame being divided in downlink and uplink periods. In the downlink period the base-station transmits to terminals by using Time Division Multiplexing (TDM). The uplink period is divided in a contention period and a transmission period. The terminals send requests in the contention period by using a random multiple access (like Slotted-Aloha) and, when allowed, transmit data in the transmission period by using TDMA. The transmission period is divided in slots, each one transmitting one ATM cell. The modulation used in the uplink frame is defined by the base station (based on some control information or power measurement) and broadcasted to the terminals in the downlink period. Figure 1 illustrates the frames and their periods in the wireless link.

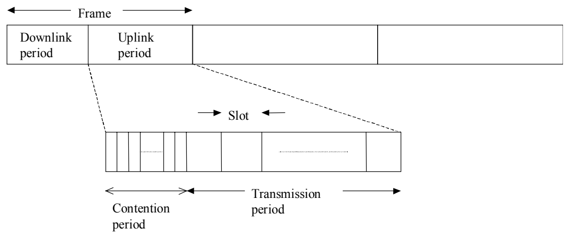

Figure 1 – Frame structure in the wireless link.

The modulation schemes considered in our analysis are: BPSK, QPSK, 8-PSK and M-QAM (M = 16,32,64,128 and 256). In the QAM systems, we have considered square constellation for M=16,64 and 256 and rectangular constellation for M=32 and 128. The expressions to compute the bit error rate in each considered modulation, as a function of E_S/N_O, can be obtained in [12].

When the system switches from one modulation to another, the average symbol energy (or transmission power) is kept constant. Accordingly, the parameter E_b/N_O (average bit energy to noise density ratio) changes at the switch time. Therefore, the performance evaluation of the modulation schemes is made as a function of the parameter E_S/N_O (average symbol energy to noise density ratio).

In the adaptive FEC system and in the hybrid adaptive modulation and FEC system, the BCH (Bose, Chaudhuri and Hocquenghem) codes are considered. The BCH codes form a large class of powerful random error-correcting cyclic codes to implement the FEC scheme. For any positive integers m ($m \geq 3$) and t ($t < 2^{m-1}$), there exists a binary t-error-correcting BCH code with the following parameters: block length $n = 2^m - 1$; number of parity-check digits $n - k \leq mt$; minimum distance $dmin \geq 2t + 1$. [13]

In the conclusion of the reference [14], Cain and McGregor have indicated that the error control scheme in the wireless link must make the physical layer in the wireless link work like an optical link, concerning bit error characteristic. Then, the error correction capacity of the FEC codes, in the adaptive FEC and hybrid schemes, and the switching point in the adaptive modulation scheme are defined considering that the probability of the wireless link to hand a correct cell to the optical link and the probability of an optical link to hand a correct cell to the next optical link are the same.

Considering that the bit error rate in the optical link is 10^{-8}, the probability of an optical link to hand a correct cell to the next optical link (not considering the error correction capacity in the header of ATM cells) is given by $Q_o = (1-10^{-8})^{424} = 0.99999576$.

3 - Comparing the Adaptive Modulation Scheme with Adaptive FEC Scheme

The criterion used to compare both systems is the throughput in the wireless channel. The normalised throughput is defined considering a modulation scheme as a reference and can be computed by

$$V_n = \frac{\log_2 M_i}{\log_2 M_r} \cdot \frac{k}{n_i} \quad (1)$$

where M_i is the number of points in the constellation of the current modulation, M_r is the number of points in the constellation of the reference modulation, k is the number of information bits in each cell in the wireless link and n_i is the total number of bits in each cell in the wireless link (k plus the number of parity bits).

For the adaptive modulation scheme FEC is not used ($n_i = k$), and the normalised throughput is given by

$$V_{mn} = \frac{\log_2 M_i}{\log_2 M_r} \quad (2)$$

In this case, the probability of the wireless link to hand a correct cell to the optical link (not considering the overhead in the wireless link) can be computed by

$$Q_m = (1 - BER_i)^{424} \quad (3)$$

where BER_i is the bit error rate of the current modulation. The modulation switching points are determined in such a way that $Q_m \geq Q_o$, i.e., the wireless link will perform as good as an optical link.

For the adaptive FEC scheme, the modulation used is the modulation fixed as reference in the normalised throughput definition ($M_i = M_r$), and the normalised throughput can be written as

$$V_{fn} = \frac{k}{n_i} \quad (4)$$

In this case, the probability of the wireless link to hand a correct cell to the optical link, in the adaptive FEC scheme, can be calculated by

$$Q_f = \sum_{j=0}^{t} \binom{n_i}{j} BER^j (1-BER)^{n_i - j} \quad (5)$$

The bit error correction capacity and the number of parity bits can be computed considering the properties of the BCH code, assuring that $Q_f \geq Q_o$.

To compare the performance of adaptive FEC and adaptive modulation schemes, the normalised throughput of the both systems are computed and shown in Figure 2 (for the 256-QAM modulation as reference) and Figure 3 (for the 64-QAM modulation as reference).

As we can see, the adaptive FEC scheme works better than the adaptive modulation scheme in most of Es/No range considered.

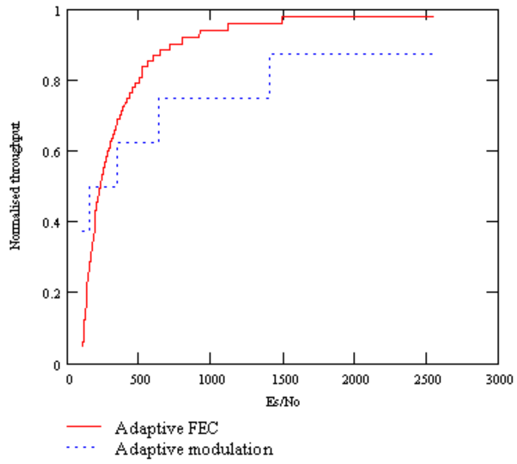

Figure 2 - Normalised throughput as a function of Es/No for the adaptive FEC and adaptive modulation schemes (the 256-QAM is the reference modulation)

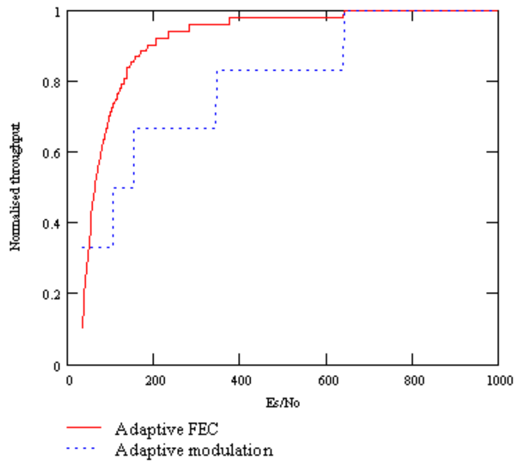

Figure 3 - Normalised throughput as a function of Es/No for the adaptive FEC and adaptive modulation schemes (the 64-QAM is the reference modulation)

4 - A Hybrid System Using Adaptive Modulation and Adaptive FEC

In this section we propose and analyse a hybrid system using adaptive FEC together with adaptive modulation. The criterion is the same used in the previous section, i.e., the probability of the wireless link to hand a correct cell to the optical link and the probability of an optical link to hand a correct cell to the next optical link are the same.

To define the switching points, we have computed the normalised throughput, for each considered modulation scheme, as a function of E_S/N_0, considering the 256-QAM as reference. The results are shown in Figures 4 and 5 (a zoom of Figure 4). The optimum switching point between any two modulations is obtained by the cross point of the corresponding curves. The performance of the adaptive modulation system is also plotted for comparison.

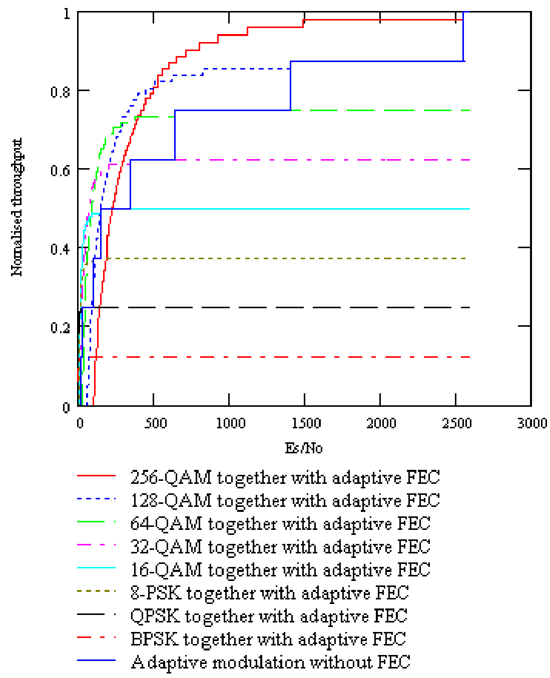

Figure 4 - Normalised throughput as a function of Es/No

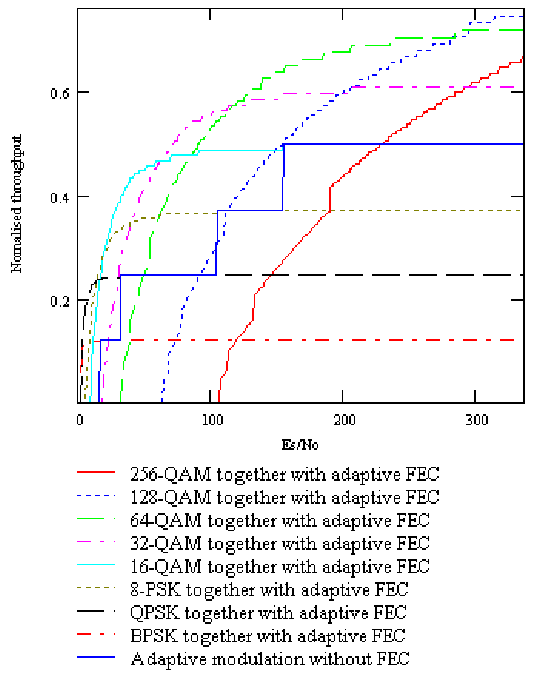

Figure 5 - Normalised throughput as a function of Es/No (a zoom of Figure 4)

From Figure 5, the performance of the wireless link can be improved if a hybrid system with adaptive modulation and FEC is used. Figure 6 compares the performance of the hybrid system with the systems using only adaptive FEC or adaptive modulation. The hybrid system works equal or better than the others systems in whole range of ES/NO.

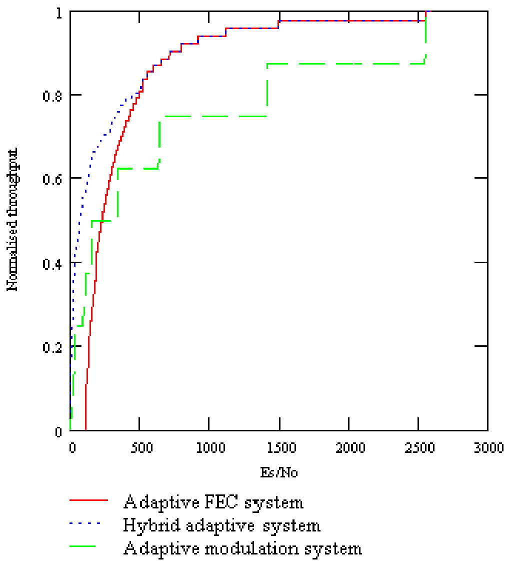

Figure 6 - Comparing the performance among the hybrid system, the system using only adaptive FEC and the system using only adaptive modulation.

5 - Conclusion

In this paper we have compared the adaptive FEC and adaptive modulation approaches to improve the performance of the wireless link, concerning bit error rate. We have shown that the adaptive FEC system works better than the adaptive modulation system in most of SNR range; but the adaptive modulation system can work better if the SNR ratio is poor. Then, we have considered a hybrid strategy combining actions in the physical layer (choice of modulation constellation) and in the data link layer (choice of FEC codes) to provide quality of service to wireless ATM networks. We have shown that our hybrid system works equal or better than the adaptive FEC and adaptive modulation systems in whole range of SNR.

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