Adaptive Modulation and Error Control for Energy Efficiency for Wireless Smart Card

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Abstract -The need for a new generation of smart cards by identification security applications such as building security has inspired this research. A new smart card that communicates through wireless links requires a reduction in its communication energy needs. This paper addresses this challenge by controlling power consumption through adapting modulation and error control while maintaining the bit error rate (BER). This adaptive approach will be based on the link quality and power available. This paper presents a protocol for the wireless smart card link using a forward error control (FEC) scheme with an adaptive Reed-Solomon code rate and an M-ary Frequency Shift Keying (M-FSK) modulation scheme with varying symbol size M over the link. In this paper the energy efficiency of a variety of error correction and modulation schemes are compared. Adaptive error correction and adaptive modulation are shown to save over 50% of the energy compared with static schemes.

I. INTRODUCTION

A key issue in applications such as this advanced wireless smart card designed for use in a biometric building access system is energy. The objective is to not require the smart card to leave the users wallet, which greatly eases the card use. This will, however, result in greatly limiting the card's power. Currently, smart cards receive energy from the card readers through a contact interface. The new concept, shown in Figure 1, will not require contact to transmit identification information messages. In this figure, a security guard allows the smart card to transmit secured identification information to the reader. The reader collects biometric features through sensors with which it is interfaced. These features are

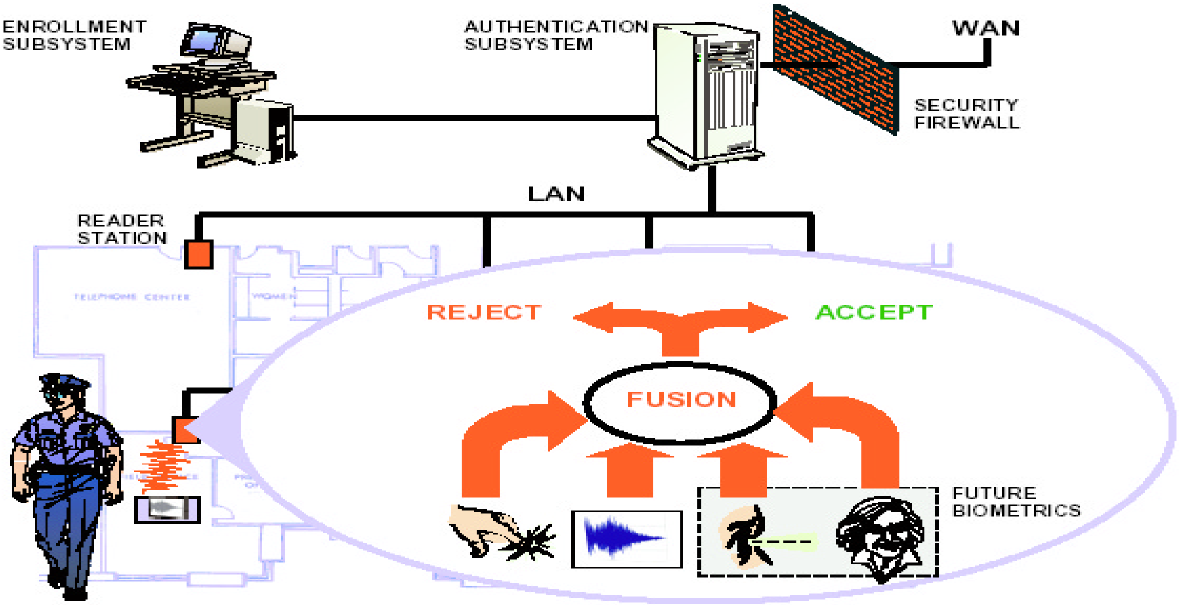

Fig. 1. Building Access System

matched with the cards data. A decision is made as to whether this is an imposter or genuine user. The system allows access to the guard after properly fusing the answers from the sensor suite.

With the emergence of many wireless communication devices on the market, battery life is a major concern. It, therefore, makes sense to look for alternative protocol strategies focused on two goals: power savings and energy management. In other words, instead of trying to improve the amount of energy stored in the power source, one could try to build devices that can perform the same function and provide the same services while reducing the overall power consumption. One way of doing this is by choosing an energy efficient modulation and error control schemes that focus on the needs of a smart card for a biometric ID system.

This paper presents novel protocol schemes that address the challenge of controlling the power consumption in the wireless smart card while maintaining the bit error rate (BER). Since high error rates are inevitable in a wireless environment due to the complex and varying channel conditions, energy efficient error control is an important issue. Imperfections in the link are due to the absorption from clothing and people as well as reflections from buildings, other objects in the surroundings, the smart card mobility, and interferences from other wireless devices. The link, therefore, experiences BER's that vary dramatically in magnitude but are based on the wireless message traffic.

These channels experience bursty bit error characteristics. Thus, the error control scheme must adapt to handle this bursty noise. Detailed comparisons of the performance of FEC and ARQ has been done by many researchers[18] and is not dealt in our paper. The conclusion that can be drawn is that while retransmission schemes can be energy efficient for high (Eb/No), the schemes introduce intolerable delay, jitter and bandwidth. This prevents fulfilling the required QoS of the application. Although more complex adaptive error correction schemes consume more energy through increased computation and communication, they can provide the constant quality and stringent delay provisions required for the smart card system. This is the rationale behind investigating both adaptive modulation and energy schemes in this paper.

A comparison of the various modulation schemes is presented in Table I , Table II , and Table III [1]. This shows that multilevel Quadrature Amplitude Modulation (QAM) is very bandwidth efficient and achieves a high bit rate using limited bandwidth. QAM, however, requires a higher signal to noise ratio (Eb/No) to achieve the same quality as M-Phase Shift Keying (M-PSK) and M-ary Frequency Shift Keying (MFSK). M-FSK has decreasing bandwidth efficiency and increasing power efficiency as M, symbol size, increases. M-FSK can maintain a reasonable BER for low Eb/No ratios. Therefore, it can be concluded from [1], M-FSK is an ideal modulation approach for adaptivity

TABLE I. BANDWIDTH AND POWER EFFICIENCIES OF M-PSK SIGNALS[1]

M	2	4	8	16	32	64
$\eta_B = R_B/B$	0.5	1	1.5	2	2.5	3
Eb/No for BER = 10^{-6}	10.5	10.5	14	18.5	23.5	28.5

B: First null bandwidth of M-PSK signals

TABLE II. BANDWIDTH AND POWER EFFICIENCY OF M-FSK SIGNAL [1]

M	2	4	8	16	32	64
η_B	0.4	0.57	0.55	0.42	0.29	0.18
Eb/No for BER = 10^{-6}	13.5	10.8	9.3	8.2	7.5	6.9

TABLE III. BANDWIDTH AND POWER EFFICIENCY OF M-QAM SIGNALS [1]

M	2	4	8	16	32	64
η_B	1	2	3	4	5	6
Eb/No for BER = 10^{-6}	10.5	15	18.5	24	28	33.5

II. CHANNEL MODEL

Propagation of radio waves inside and outside a building is a very complicated process that is strongly influenced by the layout of the building, the construction materials, and the building type. The statistics of the channel varies with time due to motion of people, equipment and objects [20]. The indoor channel is characterized by high path losses and large variations in losses. In a factory environment, the overall path loss is found to be log-normal with 7.1dB standard deviation, whereas in an office environment, the signal envelope is found to be Rician distributed. The mean is determined by the propagation losses. Motion inside and outside the buildings causes signal fading that is modelled by the Rician distribution. The probability density function of a Rician fading process is given by[1]

$$f_{\Gamma}(x) = \frac{x}{\sigma^2} e^{-\frac{(x^2 - s^2)}{2\sigma^2}} I_o\left(\frac{x^2}{\sigma^2}\right) \tag{1}$$

where the parameter *s* denotes the peak amplitude of dominant signal or non -centrality parameter of the distribution, $I_o(.)$ is zero-order modified Bessel function of the first kind, and σ is the rms value of received voltage signal before envelope detection.

The Rician distribution is often described in terms of a parameter K. K is approximately 2 dB for an office environment and defined as the ratio of deterministic signal power to the variance of the multipath or

$$K = \frac{A^2}{2\sigma^2} \tag{2}$$

The parameter K is the Rician factor and completely specifies the Rician distribution. This paper models the indoor/outdoor with a Line Of Sight (LOS) propagation and K of 6.8dB [1]. This model is appropriate since the individual will typically be within sight of the biometric device as illustrated in Figure 1 .

III. ADAPTIVE ERROR CONTROL

Error correction mechanisms traditionally detect and correct transmission errors thus optimizing performance. There are a variety of error control strategies; each has its own advantages and disadvantages in terms of latency, throughput and ultimately energy efficiency. Broadly, the available schemes fall into the categories of automatic repeat request(ARQ), FEC and hybrids of the two. ARQ schemes are energy efficient when the link quality is good and retransmissions are rare. ARQ performs poorly when the link quality degrades, which leads to many retransmissions. FEC, however, incurs a fixed overhead for every packet, irrespective of the channel conditions. So even when the link quality is good, there is unnecessary overhead which increases the energy consumption. The three error control schemes that we analyzed and compared are ARQ, Fixed code rate RS code, and varying code rate RS code.

ARQ requires two way communication and more buffering. Feedback information informs the sender or transmitter of the status of the received packet. The possibility of retransmission requires additional buffering at the transmitter and receiver. With ARQ, one pays a price in communication energy costs and time delay when messages are not received correctly the first time. This is unacceptable in the smart card system under consideration.

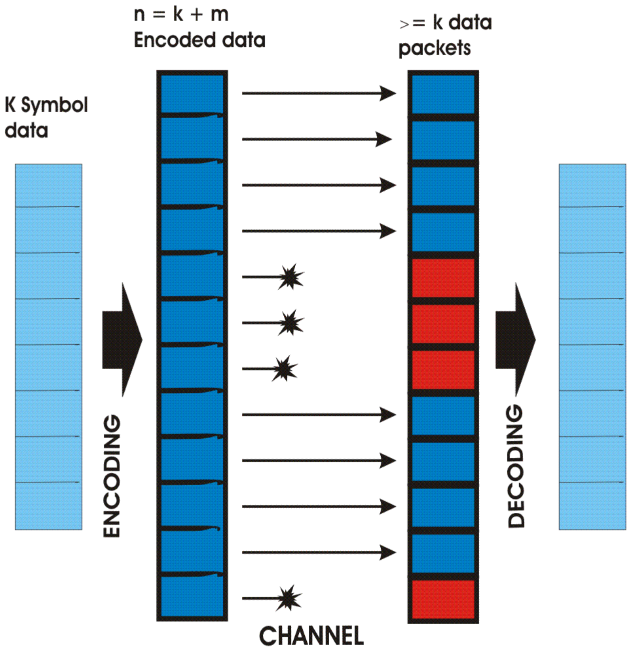

Fig. 2. Graphical representation of Error Correction

In Forward Error Correction (FEC) schemes, redundant bits are always added to enable error detection and correction. This results in a price paid in terms of energy if the channel conditions are very good. Time delay is less of an issue since the system was designed to accommodate the redundant bits. FEC does result in some over design since the code rate will be based on the worst case channel conditions. These conditions will occur rarely.

RS codes are particularly useful for bursty error correction, which behaves as memory in the communication channel [2]. With memory, the errors tend to occur together in groups. Reed-Solomon codes are non-binary cyclic codes with symbols made up of m- bit sequences, where m is a positive integer having value greater than 2. RS(n,k) codes with m bit symbols exist for all n and k for which

$$0 < k < n < 2^m + 2 \tag{3}$$

where k is the number of data symbol bits being encoded and n is the total number of code symbols in the encoded block. The ratio of redundant bits to data bits, denoted $(n-k)/k$ within a block, is called redundancy of the code; the ratio of data bits to total bits, k/n, is called code rate,'*r*'. The code rate can be thought of as the ratio of the portion of a code constituting information to the entire packet length as illustrated in Figure 2 . The optimum code rate is about 0.6 to 0.7 for a Gaussian channel, 0.5 for a Rician- fading channel (K being 7dB), and 0.3 for a Rayleigh fading channel. Rayleigh fading is the most severe and results in lower code rates to achieve comparable BER's. The error correcting capacity of an RS code is $(n-k)/2$. This code can handle a noise burst of $(n-k)\times m/2$ (e.g. RS(255, 247) can correct 26 bit noise burst).

Dynamic environments such as the smart card link prevent the previous ARQ and FEC schemes from being energy efficient. An adaptive FEC error control scheme can significantly improve energy efficiency. As previously stated, most error control protocols are designed with fixed values for the link layer parameters (e.g., coding rate), which correspond to the worst channel condition. By allowing these static protocols to dynamically react to varying channel condition, energy efficiency can be accomplished while meeting the BER requirements. Figure 3 illustrates the BER vs. bit energy per noise ratio for 5 different code rates: 0.3, 0.4, 0.5, 0.6, and 0.75. This reduces the energy required to transmit a single information bit. If the BER is computed and the code rate adapted, energy efficiency can be greatly improved.

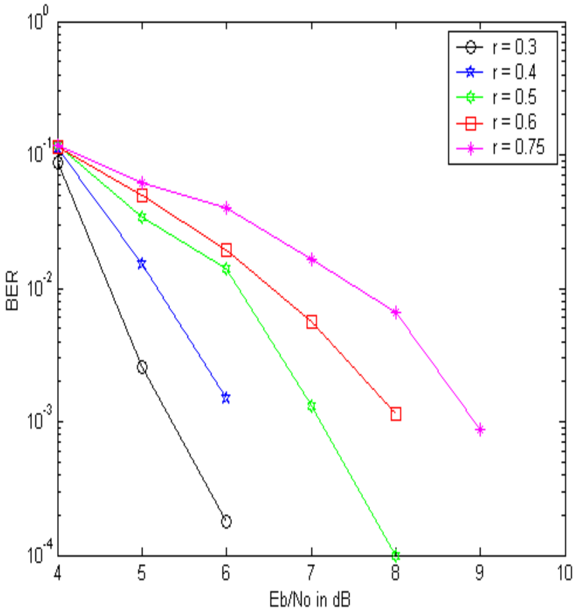

Fig. 3. SNR vs. BER for different code rates

The adaptive FEC scheme involves communication between reader and smart card. Initially a test data packet is sent, and the receiver measures the transmission efficiency by comparing the BER with the current code rate. If the BER is lower than required, an increase in the code rate may be conveyed back to the transmitter. A comparison plot between BER and code rate is given in Figure 4 . The processing details in the reader and the smart card is described in the next two sections.

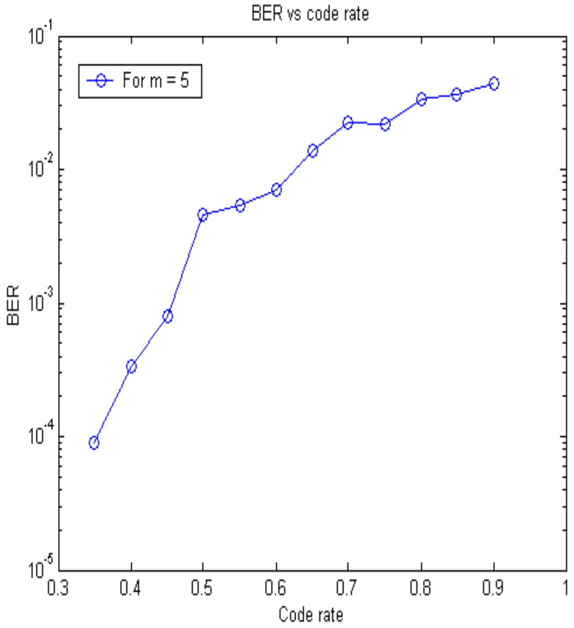

Fig. 4. BER versus Code rate ‘r’

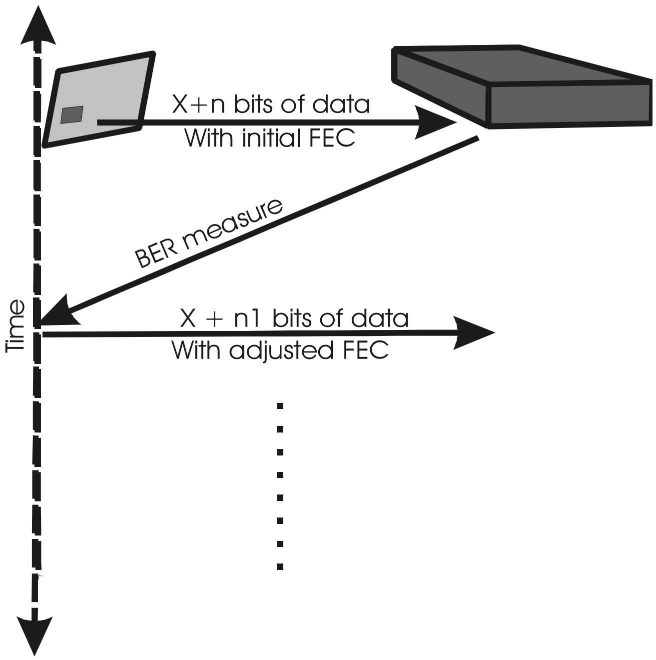

Fig. 5. Illustration Adaptive FEC scheme

III [a] . At Reader:

Let denote the number of erroneous data bits, and is the number of received data bits. The receiver computes the BER, or error efficiency ratio as

. **(4)**

This information is conveyed to the transmitter through a control packet. Thus, η_f indicates the quality of the link at the reader. This error ratio efficiency is somewhere between 0 and 1.

III [b] . At the Smart Card:

Our smart card system has to achieve an efficiency of η (10^{-3}). At the smart card or transmitter, the measured efficiency η_f is compared with η. If $\eta_f > \eta$, the number of bit errors, N_e, is more than expected, the transmitter reduces the code rate,'*r*' by *0.01* for the next data packet to be transmitted. If $\eta_f < \eta$, the transmitter increases the code rate'*r*' by *0.01* for the next data packet to be transmitted. If $\eta = \eta_f$, however, the transmitter transmits the next data packet without changing the code rate. The proposed scheme is evaluated against a fixed code rate for worst channel conditions. A Rician fading model is used to model the indoor office environment. In this model, noise power is assumed to change rapidly for fast fading and slowly for slow fading. In our simulation, for fast fading channels, the noise power varies 10 times over the packet length whereas for slow fading it varies 5 times. Table IV compares the energy consumed in the transmission of 100 data packets using the three error control strategies: ARQ, fixed code rate RS and adaptive RS. The adaptive error control strategy consumes 43-50% less energy. Table V shows the percentage of energy savings by using adaptive error correction for m =5 and BER of 10^{-3}.

TABLE IV. TOTAL ENERGY CONSUMED FOR 100 PACKETS

STRATEGY	***ENERGY (J)***
No coding (ARQ)	**5.2**
r = 0.5, m = 5	**0.96**
variable	**0.45**

TABLE V. ENERGY SAVINGS OF ADAPTIVE STRATEGY OVER FIXED CODE RATE SCHEME

Fixed code rate	***% Energy saved using Adaptive error control***
r = 0.5, m=5	**59**
r = 0.75,m=5	**46**
No coding (ARQ)	**91**

IV. ADAPTIVE MODULATION SCHEME

The performance of M-FSK in AWGN (Additive White Gaussian Noise) exceeds the performance of other modulation techniques in less ideal channel conditions such as Rician and Rayleigh. As explained in [2], for low error rates all the modulation schemes exhibit an inverse algebraic relation between error rate and E_b/N_o. This is in contrast with the exponential relationship between error rate and E_b/N_o in an AWGN channel. Operating at BER's of 10^{-3} to 10^{-6} requires roughly a 30dB to 60dB mean E_b/N_o. This is significantly larger than that required when operating over non-fading gaussian noise channel. In Figure 6 , the poor performance of M-FSK in Rician channel is due to non-zero probability of very deep fades, when the instantaneous BER can become as low as 0.5. The fading causes the performance of the M-FSK to remain at .5 in the case of Rician noise.

To maintain the desired BER along with energy efficiency for MFSK we need to use adaptive modulation. Although the basic idea of changing the modulation in real time has been used to increase the throughput in the presence of fading channels[3][4][5][6][7], the concept has not been exploited for low power purposes. This is achieved by adapting the modulation at runtime (i.e. changing the number of bits, *b*, per symbol depending on channel conditions).The goal is to minimize the energy per bit by choosing the correct values of *b* where $M = 2^b$.

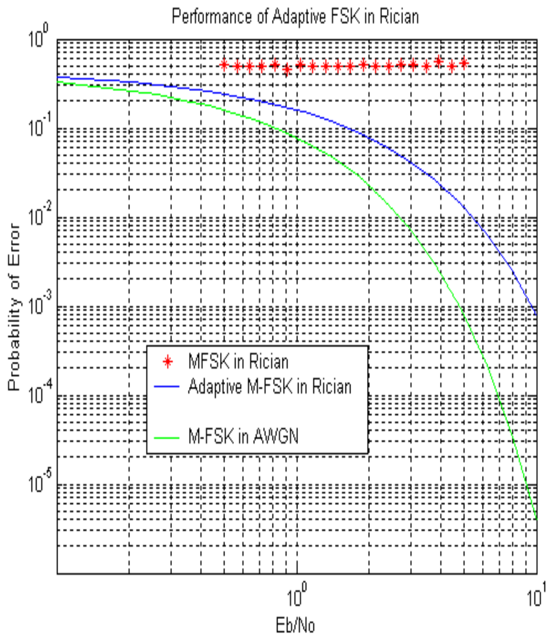

Fig. 6. Performance of M-FSK in AWGN and Rician Fading channel

First, the smart card transmits the bitstream with a high level of modulation (i.e. $b = 8$) and then waits for feedback from the reader. At the reader, the BER is calculated and sent back to the smart card. If the received BER is less than desired BER of 10^{-3}, the value of *b* is decreased by 1 and if the received BER is greater than 10^{-3}, *b* is increased by 1.

Figure 6 shows that by adapting M for varying channel conditions a performance close to that of AWGN can be obtained

V. CONCLUSIONS AND FUTURE WORK

In this paper, the adaptive FEC scheme consumes 40-91% less energy than the non-adaptive ACQ and FEC schemes. This approach improves the energy efficiency for the wireless smart card without jeopardizing the BER performance. This objective is achieved by selecting the optimal code rate for the RS code depending on channel condition. Similarly, the adaptive M-FSK modulation scheme improves the Rician channel performance so that it approaches that of an AWGN channel. Future work will be devoted to studying energy efficiency improvements through cross-layer optimization schemes involving both adaptive error correction and adaptive modulation. Also, more complex channel will be studied.

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