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A Proactive Forward Error Control Scheme for Mobile WiMAX Communication

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***Abstract*— The IEEE 802.16 standard, also known as WiMAX, has yet to prove its effectiveness when the end terminals are not static and free to move at vehicular speeds. High bit error rate caused by multipath fading at high vehicular speeds, is the key reason for low throughput at high speeds. Standard error control mechanisms like transmission control protocol (TCP) and forward error correction (FEC) have limited impact on the overall throughput at vehicular speeds. In this paper, we propose a proactive FEC scheme that adjusts the FEC code size based on the estimated bit error rate at various vehicular speeds. We show a mathematical model to estimate the bit error rate in WiMAX communication. We then propose a FEC scheme to proactively compute the FEC code size. We simulated the proposed scheme for a centralized video surveillance system in a public train where the train is the mobile node and sends real-time video data to the base stations. The results show that the proposed scheme achieves significantly higher throughput and lower jitter compared to existing schemes.**

Keywords-wireless communication, throughput, bit error rate, vehicular speed, error control.

I. INTRODUCTION

Following the widespread deployment and commercial success of the IEEE 802.11 standard [1], the need for further improvement in the wireless transmission rate and Quality of Service (QoS) was realized, which ultimately leads to the introduction of another set of standards, termed as the IEEE 802.16 [2, 13]. The IEEE 802.16, also commonly known as WiMAX, is designed to support rapid deployment, high scalability and high data rate of up to 75 Mbps for fixed wireless metropolitan access networks (MAN). The IEEE 802.16-2004 standard, previously known as 802.16d, was aimed at fixed access networks and in October 2005, the standard was upgraded and extended to the IEEE 802.16e to support mobile access [3, 4]. The 802.16e uses scalable orthogonal frequency division multiplexing (OFDM) and multiple antenna support through multiple input multiple output (MIMO) communications, which leads to higher data rate. Other benefits of the 802.16e standard include large coverage, power savings, frequency usage, higher bandwidth support and provision for QoS. Considering the high data rate and QoS aspects of the WiMAX technology, the standard carries huge prospects for mobile wireless communications. The ATM-like guaranteed QoS offered by the WiMAX is highly suitable for voice, video and data applications in mobile wireless communication. The future of the wireless Internet, video surveillance, video conferencing and video on demand as well as high quality video and voice conversion highly depends on the successful deployment of the WiMAX standards.

The IEEE 802.16e is capable of delivering a data rate up to 75 Mbps over a 112.6 km range. This capacity, however, is only valid for an ideal situation and in practice, the IEEE 802.16e can support up to 10 Mbps at around 10 km for the line-of-sight range. This transmission further drops significantly when the users are on the move. The other feature of the IEEE 802.16e is that many users in a given large radio sector share the available bandwidth, which ultimately provides much lower bandwidth to an individual user. Lower and inconsistent throughput at vehicular speeds offers a huge challenge for QoS management for many multimedia applications. The low data rate at high speed is mainly caused by fading of radio signal and lower range carrier frequency. Mutipath fading at high vehicular speed causes signal noises at the receiver end, which results in higher bit and packet corruption rate, limiting the effective data transmission capacity. For wireless channels at high vehicular speeds, reactive error recovery schemes like automatic repeat requests (ARQ) that attempt to address the corrupted packets by requesting new retransmissions, have limited, if not detrimental, impacts on the effective data rate because the system can not afford the extra overheads caused by the reactive protocols when the usable data rate is already very low. Reactive schemes may often require multiple attempts to send uncorrupted data to the mobile nodes because of high error rate. Error control mechanisms like forward error control (FEC) are particularly suitable for high speed wireless communication as they do not require retransmissions of packets [8, 10]. In FEC, extra parity symbols, also known as FEC code size, are added to a packet to recover the corrupted symbols in a packet. The optimal code size is highly crucial for improved network performance as unnecessary parity symbols limit the actual data transmission while insufficient information result in unrecoverable corrupted packets.

Researchers have been working hard to improve the FEC based error control mechanism for long. The key research interest remains how to make the FEC code size dynamic/adaptive instead of using fixed FEC code under all communication environments. In [5], Bolot *et al.* proposed an adaptive FEC scheme for Internet Telephony that adjusts the code size according to various communication environments. Authors modelled the problem of finding the FEC code size as an optimization problem based on the assumption that the audio packet loss in a network follows a Bernoulli process. Padhye *et al.* [6] questioned about the assumption in [5] and further improved the FEC scheme by taking into account the history of packet losses in the network. Yao *et al.* [7] proposed a dynamic FEC scheme for digital video broadcasting that dynamically adjusts the code size based on the assumption that error sequence generated by data transmission channels follows a Gilbert-Elliot model. Ahn *et al.*[8] proposed an adaptive FEC code control algorithm for sensor networks that dynamically tunes the code size based on the arrival of acknowledgment packets. In [9], Smadi *et al.* proposed an error recovery service for the IEEE 802.11b protocol that adjusts the strength of FEC code depending on the number of corrupted packets at the receiver end. All of the above mentioned works depend one way or another on some feedback information mainly in the form of packet loss rate at the receiver end. This is rather a reactive approach to adjust the FEC code size and efficiency of reactive FEC schemes is constrained by how good the feedback information represents the current environment. In a truly mobile environment, where the end node moves at vehicular speeds, the communication environment changes very quickly as the speed changes (e.g., an electric train is accelerating from a platform to reach its top speed). Under these circumstances, feedback information does not represent the current communication environment at a changed speed. Moreover, at high vehicular speeds, the usable transmission rate becomes significantly low and overheads in the form of feedback information tend to create detrimental impacts on effective data rate. Also, as the channel becomes more unreliable/noisy at high vehicular speeds, it is a common scenario that the feedback information is lost on its way to the sender. The effectiveness of reactive FEC schemes is, therefore, limited in wireless communication where the end nodes move at vehicular speeds. In this paper, we propose a new FEC scheme to proactively compute the FEC code size in WiMAX communication. We use a type of error correction code called the Reed-Solomon (RS) code. To the best knowledge of the author, there is no other work in literature that proactively computes the FEC code size at various vehicular speeds of end nodes in WiMAX communication.

II. PROPOSED SCHEME

The key idea of the proposed scheme is to first compute an estimated bit error probability as the speed of a mobile terminal changes. Based on the estimated bit error probability, the symbol error probability and then estimated number of corrupted symbols will be derived. This information will then be used to proactively compute the number of parity symbols and add to a packet. In Section 2.1, we show how to calculate the estimated bit error probability at various mobile terminal's speeds. In Section 2.2, we then show how to compute the number of parity symbols in a proactive fashion for an adaptive FEC scheme in WiMAX communication.

2.1 *Bit Error Rate and Mobile Terminal's Speed*

Rayleigh fading [11][12] is proven to be an excellent model to follow the error in radio signal caused by multipath fading when there are many objects in the environment scattering the radio signal before the receiver receives the signal. For a wireless communication channel that is characterized by the parameters: N be the number of OFDM sub carriers, f_m be the doppler frequency where $f_m = f_c(v/c)$, v be the speed of mobile nodes, c be the speed of light, f_c be the carrier frequency, T_s be the duration of each M-ary QAM symbol, E_s be the average symbol energy, E_b be the average energy per bit, N_o be the noise energy, γ_b be the received bit-energy-to-noise ratio, $\overline{\gamma_b}$ be the average received bit-energy-to-noise ratio, γ_s be the received symbol-energy-to-noise ratio, $\overline{\gamma_s}$ be the average received symbol-energy-to-noise ratio, $P_b(\gamma_b)$ be the probability of received bit error, P_P be the packet error probability. Following the Rayleigh fading model [12], we can express the density function of received symbol energy to noise ratio as

$$p_{\gamma_s}(x) = \frac{1}{\overline{\gamma_s}} e^{-x/\overline{\gamma_s}}, x \geq 0 \qquad (1)$$

and the average symbol error probability for a such channel can be expressed as

$$P_M = \int_0^{\infty} P_M(x)\, p_{y_s}(x)\ dx \qquad (2)$$

where the average received symbol-energy-to-noise-ratio is given by

$$\overline{\gamma_s} = \frac{1}{1 - \frac{1}{N^2}[N + 2\sum_{i=1}^{N-1}(N-i)J_0(2\pi f_m T_s i)] + \frac{NT_s}{\frac{E_s}{N_0}}} \qquad (3)$$

Now the average received bit-energy-to-noise ratio $\overline{\gamma_b}$ can be derived from the average received symbol-energy-to-noise ratio $\overline{\gamma_s}$ according to the following equation:

$$\overline{\gamma_b} = \frac{\overline{\gamma_s}}{\log_2 M} \qquad (4)$$

where M is the number of symbols for M-ary QAM modulation scheme. For 16-QAM, M equals 16 and for QPSK M is 4. Combining Eq. (3) and (4), we can express $\overline{\gamma_b}$ as

$$\overline{\gamma_b} = \frac{\frac{1}{\log_2 M}}{1 - \frac{1}{N^2}[N + 2\sum_{i=1}^{N-1}(N-i)J_0(2\pi f_m T_s i)] + \frac{NT_s}{\log_2 M}(\frac{1}{\frac{E_b}{N_0}})} \qquad (5)$$

For a fixed channel with unchanged values of N, NTs, relatively constant E_b/N_0 over time and a known modulation scheme, the main source of error for a mobile terminal is the velocity v that has direct impact on f_m, which in turn influences the received symbol/bit energy to noise ratio. According to the equation, higher will be the velocity, lower will be the received symbol/bit energy to noise ratio. For OFDMA air interface, the main source of bit error is the inter-carrier interference instead of interference between the OFDMA users. Additive white Gaussian noise (AWGN) [12] is often used to successfully approximate the OFDMA inter-career interference. Taking

AWGN into consideration, we can derive the bit error probability as

$$P_b = Q(\sqrt{2\gamma_b}) \tag{6}$$

where bit error probability P_b and symbol error probability P_M of OFDM are related to each other in the form of

$$P_b \approx \frac{P_M}{\log_2 M} \tag{7}$$

For M=2 or M=4, the average bit error probability is given as

$$\begin{aligned} P_b &= \int_0^{\alpha} P_b(x)\, p_{\gamma_b}(x)\, dx \\ &= \frac{1}{2}\left[1 - \sqrt{\frac{\overline{\gamma_b}}{1+\overline{\gamma_b}}}\right] \end{aligned} \tag{8}$$

For a scenario where carrier frequency f_c is 2.6 Ghz, bandwidth is 12 MHz, number of sub carriers N equals 2048, symbol period equals 149.33s, modulation scheme is QPSK and E_b/N_0 equals 5 dB, the above expressions lead to a relationship between the average bit error probability and mobile terminal's speed that can be depicted as shown in Figure 1. The Figure demonstrates that higher the mobile terminals' speed, higher is the average bit error probability.

2.2 *Calculation of FEC code size*

For a q bit symbol, the relationship between average bit error probability and average symbol error probability P_S can be expressed as:

$$P_S = 1 - (1 - P_b)^q \tag{9}$$

For a packet containing K symbols, number of estimated corrupted symbol t can be computed as:

$$t = K \text{ x } P_S \tag{10}$$

In RS code, a code size of $2t$ symbols can correct up to t corrupted symbols. The number of required parity symbols can, therefore, be given as:

$$n - K = 2K \text{ x } P_S \tag{11}$$

Now, for the proposed proactive scheme, the average bit error probability is an estimated value and is subject to some errors compared to actual error in real time. Our observation suggests that if the actual symbol error at the receiver end is greater than the estimated number even by a single symbol, the whole packet is identified as corrupted at the receiver end and overall efficiency declines. To address this issue, we propose to upgrade Equ. (11) as:

$$(n - K)_r = c\ (2K \text{ x } P_S + \varepsilon) \tag{12}$$

where, c (≥ 1) is the strength parameter of the RS code and ε represents the number of guard symbols, added to address the error in estimation. To conservatively address the variation of corrupted symbol numbers, we set ε equal to 1. Our future work will continue to optimize ε. The network provider can tune the strength parameter c for different levels of error recovery capability depending on the types of applications. For real-time application, the strength should be higher and for offline applications the strength can be set low. The overall algorithm for the proposed scheme to proactively compute the number the required parity symbols for RS code can be given as:

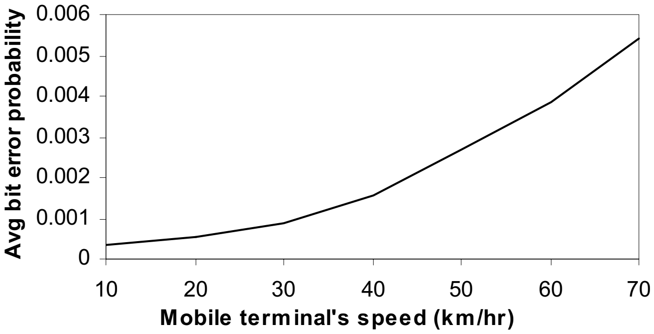

Figure 1: Average bit error probability at various mobile terminal's speed.

Procedure *compute_FEC_code_size* (v, n)
begin
avg_ber_prob = Find estimated average bit error probability at mobile terminals' speed v from the relationship as depicted in Figure 1 obtained by using expression (9).

$(n - K)_r$ = compute FEC code size based on the estimated avg_ber_prob using expression (12)
return $(n - K)_r$
end *compute_FEC_code_size*(v, n)

III. Simulation Results

The simulation is conducted in NS2 for a centralized real-time video surveillance system in a train as shown in Fig. 2. The train is equipped with 4 video cameras; each of them sending video data at a rate of 512 Kbps to the base stations using WiMAX technology. The video data are then sent through a wired optical communication network to a central control room where the security experts interpret/monitor

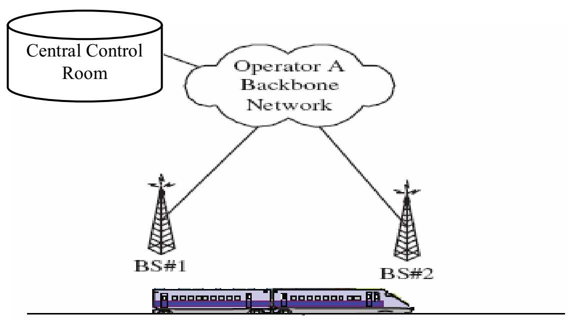

Figure 2: Simulation scenario of a real-time video surveillance system on a public train.