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WiMAX Performance Analysis of MAC layer Error Correction Schemes

K. V. Narayanaswamy
Department of EEE, MSRUAS, Bangalore, India.

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ABSTRACT
IEEE 802.16 family of standards (also known as WiMAX) is a broadband wireless access technology that is designed to offer high-speed connectivity. Broadband access to Internet is currently dominated by wired technologies like DSL and cable. WiMAX technology provides wireless alternative to broadband access and need to support various Internet traffics and applications. In this paper focus is to simulate and transfer of different traffics with different error correction techniques implemented in MAC layer and provides the comparative analysis of the throughput and end-to-end delay characteristics. Channel error rate is varied to observe the performance differences. Simulation results show that the error control techniques at MAC layer provides substantial improvements in end-to-end throughput and delay characteristics at lower error rates. Hybrid ARQ mechanism outperformed all other error control schemes even at significantly high error rates.

Introduction

WiMAX (Worldwide Interoperability for Microwave Access) is a broadband wireless access technology aims to provide fixed (first generation, 802.16-2004) broadband wireless access as well as mobility (IEEE802.16e) to end-user. Typical applications for IEEE 802.16 in the commercial sector may include cellular backhaul, broadband on demand and best-connected wireless service [1]. WiMAX (is the trade name for a group of wireless technologies that emerged from the IEEE 802.16 family of standards. Due to all the potential options in the standards, as well as the huge ranges of data rates, ranges, and other performance measures that are being quoted as achievable for 802.16, there is presently a significant amount of confusion about what type of performance can really be expected from WiMAX-compliant systems in the near future. WiMAX was originally billed as a wireless technology that can deliver 70Mbps and extend coverage to 50 kilometers, or roughly 30 miles [2].

In order to achieve this level of performance a fixed wireless point-point technology with LOS (line of sight) locations and directional antennas is required. Achieving 70Mbps in a mobile environment with WiMAX will not be feasible or economical in the foreseen future. Further, when the 70Mbps data rate in a fixed point-to-point Line of Sight (LOS) environment was demonstrated, a radio channel of 20MHz bandwidth was used [2]. In order to achieve higher performance MAC layer also need to support a range of physical layer technologies and provide an efficient sharing mechanism for utilizing this high bandwidth shared media. Standard (IEEE 802.16a) specifies ARQ error control mechanism at MAC to improve the performance. The ARQ mechanism is an optional part of the MAC layer and can be enabled on a per-connection basis [3]. An earlier study [4] and a new proposal to IEEE802.16 standard [5] recommend the usage of Hybrid ARQ schemes at MAC layer.

Various applications demand certain throughput and end-to-end delay characteristics from the underlying layers and transmission techniques utilized by them. Through this thesis an attempt is made to analyze the performance of different ARQ schemes in the MAC layer with various traffic sources when channel is subjected to different error rates. The trend obtained would help in understanding the effect of BER on WiMAX performance and the magnitude improvement achieved through different error control schemes.

Research Objectives and Methodology

Simulation is chosen as the methodology to analyze the performance and NS-2 simulator [6] was modified and used to study the system. Focus of the simulation model was limited to MAC Layer error control mechanisms and hence the simulation model does not implement the layers as per standard specification as shown in the model figure.1

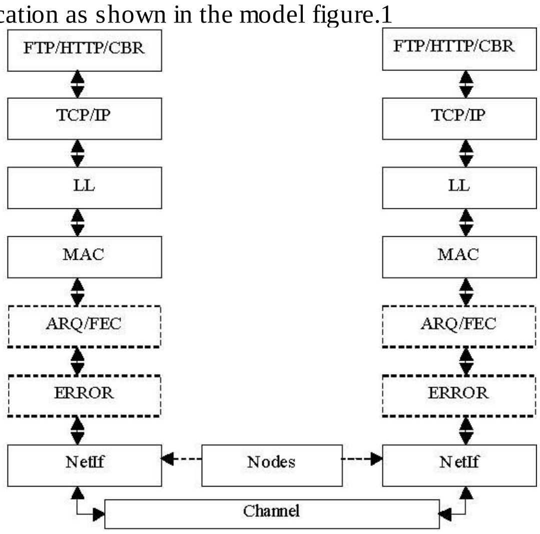

Figure.1 Illustrates the simulation model used for this analysis

MAC Layer

A simple TDMA/TDD based MAC is integrated with the error control mechanism is used for this simulation. Unlike contention-based protocol, a TDMA MAC protocol allocates different time slots for nodes to send and receive packets. Though this scheduling is different from standard specification, it works satisfactorily as single connection is simulated in this

Tele:
E-mail addresses: drkvn21@gmail.com

analysis with this protocol, a TDMA frame contains preamble besides the data transmission slots. Within the preamble, every node has a dedicated sub-slot and uses it to broadcast the destination node id of outgoing packet. Other node listens in the preamble and records the time slots to receive packets.

Error control mechanisms

Forward Error Correction (FEC), Automatic Repeat request (ARQ)'s Selective Repeat (SR) and Go Back N (GBN) and combination of FEC and ARQ-SR were modeled as error control techniques.

FEC

A forward error correction (FEC) protocol transmits redundant information along with the data, so as to allow reconstruction of corrupted data at the receiver without feedback or retransmissions. This reduces delay in high delay environments, but wastes bandwidth when there is no need for recovery or when the redundancy included is insufficient for reconstruction. The FEC model (class FEC Model) implemented here adds redundant information to header, but errors are fixed based on the FEC strength set, which is configurable.

ARQ

Existing extension to NS-2 (version 2.1) for multi service link layer [7] are ported to NS-2 (version 2.8), modified and used for this simulation. ARQ-Selective Repeat and Go Back N schemes were integrated with MAC module in this simulation. An automatic repeat request (ARQ) protocol uses retransmissions to recover from losses. This leads to high and variable delays, but relatively low overhead since redundant data are only transmitted when requested. The ARQ schemes implemented here are window based, where the window is a circular buffer of packets. When a packet is sent, it is stored at the next available position in the buffer. If the packet is not acknowledged on time or if a NACK arrives, the packet is retransmitted. If the packet is acknowledged, it is removed from the buffer. The buffer size n (configurable) determines how many packets may be awaiting acknowledgment at the sender, and large enough to allow continuous transmissions until acknowledge are returned by the receiver, otherwise the sender will stall. At each point in time, some consecutive slots are used in the circular buffer by pending packets. This is the window that slides as new packets are transmitted and old ones are acknowledged.

The GBN (Go Back N) protocol uses a real window of size n and makes retransmissions. When a packet is sent, a timer is started for it. If the packet is received in sequence and without error, it is passed to the higher layer, and a delayed acknowledge is scheduled to be returned to the sender. If the packet is not received in sequence or if the packet is received with errors, it is dropped and NACK is sent. When NACK is received or when the sender times out for the lost packet (the oldest un acknowledged one), and all un acknowledged packets are retransmitted, since the receiver drops them. When an ACK is received, either by itself or as part of a regular packet, the acknowledged packet and all previous ones are released and their timers are cancelled. This class defines an array of pointers to buffered packets and an array of timers, one per packet. When a timer expires, it returns the number of the packet for which it was set. Note that acknowledge refer to the next packet expected, not the last packet accepted by the receiver.

GBN wastes a lot of bandwidth as it retransmits all pending packets after each loss. SR (Selective Repeat) modifies the GBN scheme so as to only retransmit packets that were actually lost. This requires a buffer at the receiver to store all incoming packets. When packets are received out of sequence, they are stored at the proper position, with gaps left for missing packets. The first missing packet is negatively acknowledged (N acknowledged). A NACK means that everything before this packet was received, but the N acknowledged packet was not. Therefore, only one NACK is sent when multiple losses occur. When the first missing packet is received, another NACK may be sent for the next gap in the sequence. A NACK packet has the same format as an ACK but a different type.

The sender works as in GBN when sending packets. If the timer expires or a NACK is received for a packet, only this packet is retransmitted. When an ACK or a NACK arrives, all buffers corresponding to acknowledged packets are released and their timers cancelled. At the receiver side, whenever a packet is received, all consecutive packets that are stored in the buffers are released to higher layers. Thus, if a missing packet arrives, all packets with higher sequence numbers that were already received are released along with it. Sequence number space is 2 for n buffers, unlike GBN where the sequence number space is n for n + 1 buffers. Two packet numbers correspond to each buffer, so arithmetic modulus is used to make the translation and on timeouts, inside the buffered packet must be looked to see which one it is.

Type I hybrid ARQ scheme, which is designed for simultaneous error correction and error detection, is implemented by integrating ARQ-SR module and FEC module by pointing the send-target of the ARQ-SR module to FEC module and up-target of the FEC module to ARQ-SR. When error detected in a received message, the receiver first attempts to locate and correct the errors (FEC module). If the number of errors is within the designed error correcting capability, the errors will be corrected and the decoded message will be passed to the ARQ module to be saved in a buffer until it is ready to be delivered. If an uncorrectable error pattern is detected, the receiver rejects the received message and requests a retransmission (ARQ module).

Error Model

A uniform and exponentially distributed error model is used. Based on the packet size, probability of error is computed and value of the exponentially distributed error is compared with the probability of the error to decide on whether the error introduced and whether it is within the limits of FEC strength.

Simulation and Results

A simple architecture with one base station and one subscriber station used for this simulation. Based on this architecture, several applications are defined between nodes: FTP, HTTP and CBR.

For each application, simulation is carried out in the following scenarios:

a. Without error control mechanism, bit error rate is varied from 0 to 0.004 ($4x10^{-3}$) and error level varied from 0 to 0.4.

b. With ARQ-SR error control mechanism, bit error rate is varied from 0 to 0.004 ($4x10^{-3}$) and error level varied from 0 to 0.4.

c. With ARQ-GBN error control mechanism, bit error rate is varied from 0 to 0.004 ($4x10^{-3}$) and error level varied from 0 to 0.4.

d. With FEC error correction mechanism, bit error rate is varied from 0 to 0.004 ($4x10^{-3}$) and error level varied from 0 to 0.4.

e. With Hybrid-ARQ error control mechanism, bit error rate is varied from 0 to 0.232 ($2.32x10^{-1}$) and error level varied from 0 to 23.2.

In this simulation, BER, not SNR, is the metric that directly affects performance. BER depends on both the modulation scheme and the SNR. Therefore, in the simulation a given BER value corresponds to different SNR values for different modulation schemes. Subsequent sections analyze and compare the results obtained through varying BER for different applications.

TCP-Vegas implementation was used as transport agent for FTP application, as it showed better results at source when compared to TCP Reno implementation. Trend observed was similar even with TCP-Reno implementation, but due to its congestion and flow control (resulted in frequent window adjustment), it yielded lesser throughput and observed varying performance results.

Observed FTP result Figure.2 shows that error correction scheme at MAC layer would yield in significant improvement of throughput. This is because, without any error control scheme at MAC layer, it is TCP that retransmits the packet, which were lost due to errors. TCP doesn't differentiate congestion and packet drops due to channel error, due to which, window size is reduced with every packet drop and gradually increased. Effectively, TCP slows down in both the case.

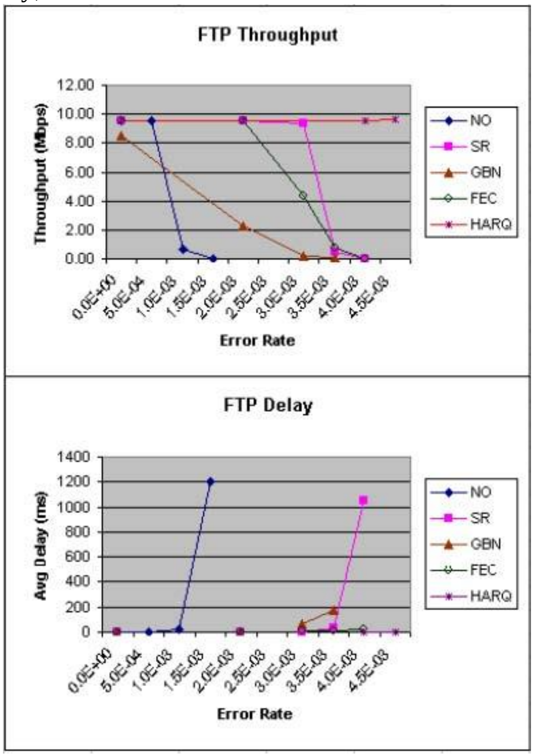

Figure.2 FTP Throughput and end-to-end delay

Even with the low error rates, it was observed that end-to-end performance in terms of throughput and delay were severely impacted in the absence of a proper error correction/control scheme.

FEC scheme found to be impacted only by the packet error level, i.e., whether the number of bits corrupted in the packet is within the range of FEC error correction strength or not. If it is, then varying error rate doesn't have any impact on the throughput or delay (ignoring the processing or error correction delay which is insignificant here). But for bursty errors with many bits corrupted within a packet, FEC doesn't fix the errors and it's left for higher layers to recognize and retransmit the packet. In this simulation, both error level and error rates were increased gradually to observe the performance degradation at higher error levels. Results show that ARQ–Selective Repeat provides considerable improvement in throughput at lower BERs. Observed that change in error level doesn't impact the ARQ performance, but change in error rate does. This is because, ARQ scheme sends a NACK and requests for retransmission regardless how many corrupted bits that packet contains. At significantly high error rate (>$3.5x10^{-3}$), ARQ performance starts to degrade. This is in line with the ARQ performance provided in the earlier analyses [4] [5].

ARQ-GBN technique didn't yield in considerable performance improvements due to the multiple retransmissions caused the buffer to overflow and drop the packets. End-to-end delay shown in Figure.2 and delay variance show similar trend. Without any error control scheme, end-to-end delay increases rapidly even with slight increase in BER. Large part of this is contributed by timeout and retransmission at TCP. With FEC or ARQ in place at MAC layer significant amount of IP/LL queue delays are eliminated and retransmissions from higher layers are avoided.

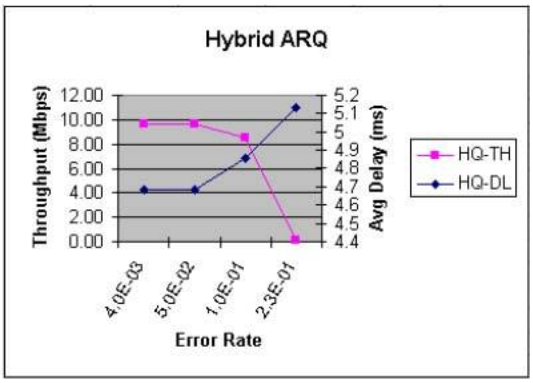

Figure.3 FTP Throughput and end-to-end delay with Hybrid-ARQ

Throughput and end-to-end delay characteristics with hybrid ARQ mechanism are shown in Figure 3. With the error correction capability of FEC sufficiently large enough, this error control mechanism provided significant improvement in the results. This simulation reused the parameter settings, which were used for FEC and ARQ-SR performance measurement, so that the results are performance enhancements are comparable.

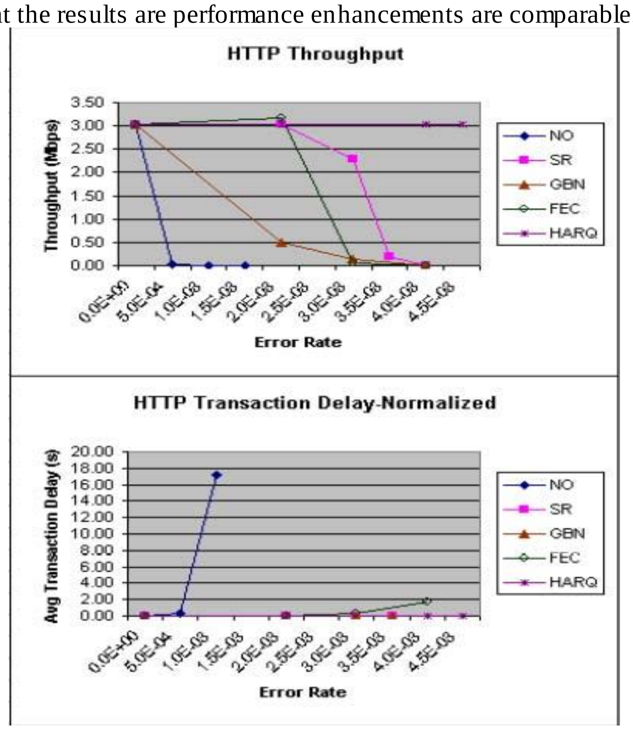

Figure.4 HTTP Throughput and normalized transaction delay

In case of HTTP application simulation, focus of performance measurement is transaction delay. Throughput results are provided here just for reference and as indicative figure to the amount of data transferred. Results shown in Figure 4 indicate that even with HTTP application, throughput trend follows similar response obtained in FTP. Transaction delay is the time difference between the request generation and the time when the page is successfully received. As the transactions achieved varied with the change in error rate, average transaction delay obtained are normalized here for comparative analysis. Without error control scheme, transaction delay was observed to increasing rapidly with the increase in error rate, as was the case with FTP. FEC showed increased transaction delay for error level higher than 0.3.

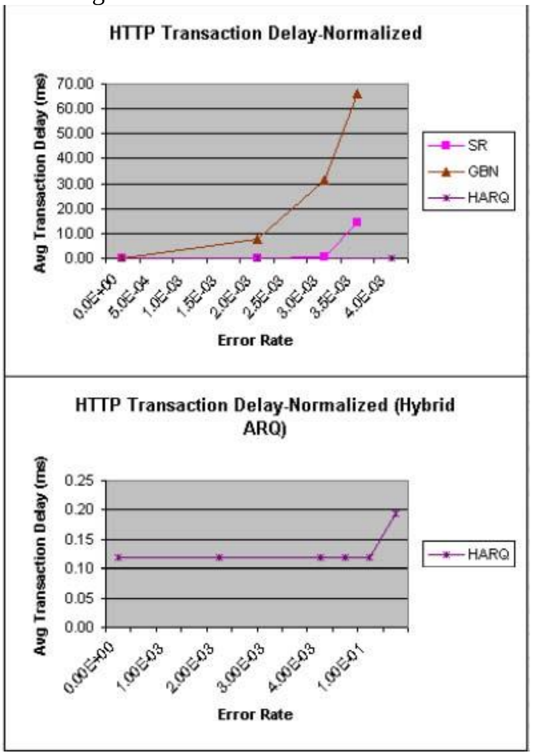

Figure.5 HTTP normalized transaction delay with different ARQ schemes

HTTP transaction delay results with hybrid ARQ shown in Figure 5 gives the clear indication of improvement achieved by this error control scheme. Lowest delay results were observed with hybrid ARQ under all error conditions.

CBR application maintains a constant traffic and impacted by the delay introduced by the error correction scheme. Average delay and delay variance remained constant for CBR applications even with the introduction of error correction schemes. Usage of ARQ-SR and hybrid ARQ for CBR application maintained a constant delay and loss percentage with the varying error rate shown in figure 6 and 7.

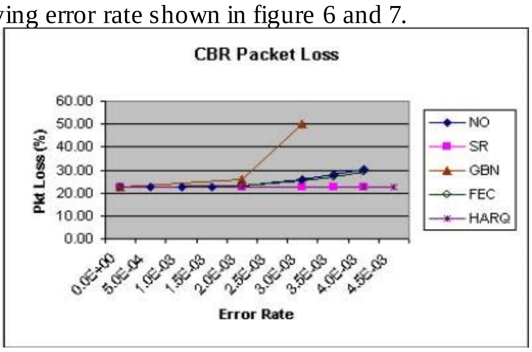

Figure.6 CBR Packet loss

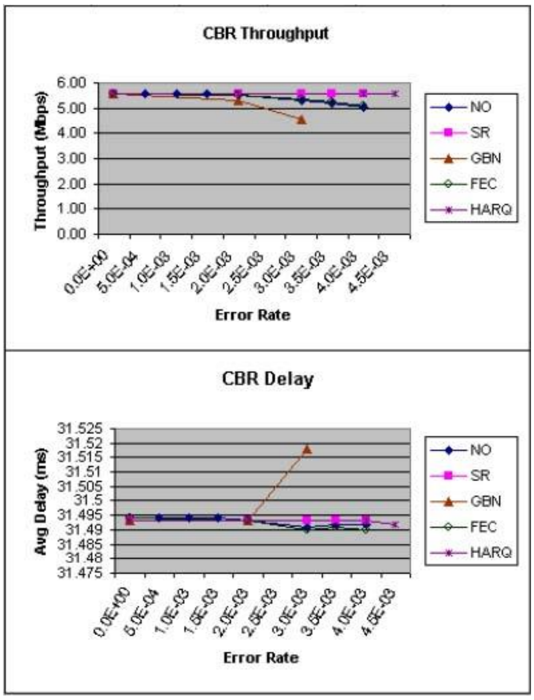

Figure.7 CBR Throughput and average delay

Conclusion and future work

Different ARQ schemes were modeled for IEEE 802.16 MAC layer and simulated by using NS-2 simulator. Throughput and end-to-end delay characteristics were observed with various traffic types and error control mechanisms. Simulation results were validated against the analytical results provided in the earlier proposals to enhance the MAC layer performance. It was observed that if the error levels were within the limits of the FEC correction capability, FEC would give the best performance regardless of the error rate. If the errors are bursty in nature, with higher number of bits in a packet are corrupted, using FEC doesn't yield any improvement in performance.

Simulation results show that higher the error rate, lower the performance of ARQ. The error level doesn't impact this mechanism as packet re-transmission takes place for all the error packets. Therefore, a pure ARQ mechanism is suitable only if errors are less frequent in transmissions. It was also observed that combining these two schemes to create a hybrid ARQ error correction/control mechanism provides enhanced throughput and improves end-to-end delay characteristics. Hybrid ARQ scheme outperformed all other error control schemes for all the traffic types and with both burst errors as well as significantly high error rate.

Further Current simulation model can be extended to cover the complete MAC specifications of the standard, mainly to include the scheduling mechanism. Additional enhancements can be carried out for the inclusion of physical variables like transmission power, frequency, which may vary depending on the specific condition and implementation.

Additional analyses can be carried out with modifications to test conditions. These changes in test conditions may include the following:

a. Multiple connection scenarios
b. Effect of the physical layer FEC

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Author Biography:

K.V. Narayanaswamy, received his Bachelor and Post graduate degree in Electrical Engineering, from Bangalore University, an additional Master degree in Computer Science & Networks form Jawaharlal Nehru Technological University, JNTU, Andra Pradesh and Ph.D degree in Electrical & Electronics Engineering, Specialised in Wireless Communications and Networks from Visvesvaraya Technological University, Belgaum, Karnataka, India. He has more than 22 Years of Teaching & Research experience in the field of Electrical, Electronics & Telecommunication Engineering. His research interests are in the areas of next-generation wireless communication and networks, Mobile Ad-hoc & wireless sensor networks, Advanced optical network design, automotive communication protocols and standards. Carried several research, consultancy and funded projects. Delivered number of corporate trainings in India and abroad, Published more than 16 papers in peer reviewed international journals including IEEE, IJCA, IJCET, IJSRPB etc., and several conference papers.