Optimum TCP/IP Packet Size for Maximizing ATM Layer Throughput in Wireless ATM LAN

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ABSTRACT

This paper provides optimum TCP/IP packet size that maximizes the throughput efficiency of ATM layer as a function of TCP/IP packet length for several values of channel BER over wireless ATM LAN links applying data link error control schemes to reduce error problems encountered in using wireless links. For TCP/IP delay-insensitive traffic requiring reliable delivery, it is necessary to adopt data link layer ARQ protocol. So ARQ error control schemes considered in this paper include GBN ARQ, SR ARQ and type-I Hybrid ARQ, which ARQ is needed, but FEC can be used to reduce the number of retransmissions. Especially adaptive type-I Hybrid ARQ scheme is necessary for a variable channel condition to make the physical layer as SONET-like as possible.

Key Words : TCP/IP, ATM, ARQ, Throughput, FEC

Ⅰ. Introduction

Asynchronous transfer mode (ATM) technology will have an important role in the future evolution of global communication networks. ATM is a transmission procedure based upon asynchronous time division multiplexing procedure using 53 bytes cell. while ATM results in considerable advantages such as less overhead and increased throughput in an optical network, it also causes severe problems when ATM data is transmitted over an error-prone channel, wireless channel as shown in Fig. 1[1]. A terrestrial wireless channel can be approximated as an Rayleigh fading channel. The protocol layers in an ATM network were designed with the assumption of a very high quality data link. This is true not only of ATM, but also of TCP which is often used above ATM to provide reliable delivery. Many widely used applications use either TCP or UDP. TCP causes severe problems when used over noisy links. ATM cells corrupted by channel errors will result in packet discards at the AAL5 layer which will trigger the need for retransmissions by the TCP protocol[2]. This, in turn, will invoke congestion control mechanisms within TCP under the assumption that the lost packet was due to a congested network. The invocation of congestion control will lead to a potentially significant reduction in throughput. Recently, several schemes have been proposed to alleviate the effects of non-congestion-related losses over wireless links. These schemes include radio link protocols[2], fast retransmission[3], and split-TCP connection[4]. So, for TCP/IP delay- insensitive traffic requiring reliable delivery over wireless ATM links, it is necessary to adopt data link layer ARQ protocol in order to make the physical layer as SONET-like as possible[5]. Thus, J. Bibb Cain's paper analyzed GBN ARQ scheme[5]. Error control scheme considered in this paper include GBN ARQ[5,7], SR ARQ[7] and Hybrid ARQ[6,7], which ARQ is needed, but FEC can be used to reduce the number of retransmissions. Especially adaptive type-I Hybrid ARQ scheme is necessary for a variable channel condition to make the physical layer as SONET-like as possible.

This paper is structured as follows. The architecture of TCP/IP over wireless ATM LAN links is introduced in section 2. When error control

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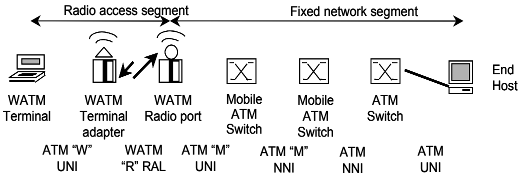
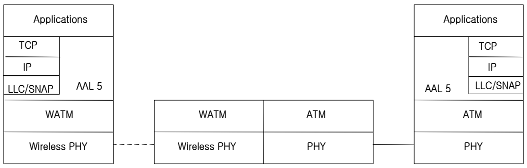
schemes are also applied in the data link layer, ATM layer throughput is derived as a function of TCP/IP data packet length for several values of channel BER and TCP/IP packet size to maximize the ATM layer throughput is calculated in section 3. Finally, we conclude this paper in section 4.

Ⅱ. TCP/IP Transport over wireless ATM LAN Links

Wireless ATM LAN network is considered as a wireless access network to interconnect the mobile users to the ATM network[1]. But there are some problems about packet mode information transport in the wireless environment, which is characterized by unreliable sharing access with finite resource and mobility. So modified or enhanced functionalities of the B-ISDN UNI, such as ATM and AAL layer protocols, are suggested to improve the wireless connectivity, which includes error control to improve the error performance and mobility support. The channel coding, interleaving, multicarrier modulation and diversity reception in the wireless physical layer and ARQ schemes in the data link layer are considered to meet service requirements. The ATM Forum Wireless ATM group has proposed a WATM system reference model. An illustration of the basic TCP/IP over ATM protocol stack is provided as Fig. 1. ATM adaptation layer 5 is employed as an example case because it is relatively common today. The ATM layer is analogous to the link layer in the OSI model. On the other hand, reliable end-to-end protocols such as TCP use ARQ mechanisms with a CRC code to insure that all data that is transmitted is received correctly at the destination node. TCP uses the Go-Back-N ARQ mechanism which requires retransmission of any lost or erroneous packet and all subsequent packets transmitted prior to the transmitter discovering that a retransmission is necessary. By contrast, the Selective Repeat ARQ mechanism is more complex but more efficient since only the lost or erroneous packet is retransmitted. Most applications use either TCP or UDP for data transport. TCP causes most of the problems when used over noisy links. The two most important metrics in evaluating the performance of this protocol are the achievable throughput and the efficiency. TCP will suffer in both respects when used over an error-prone channel. One major problem is that the window protocol mechanisms built into TCP are designed to avoid network congestion. Rather than assume that a retransmission time-out in TCP is caused by an errored packet, TCP makes the assumption that the lost packet is due to network delay induced by congestion. The packet will be retransmitted, but at the same time TCP will invoke congestion control measures reducing the TCP window size and throughput. The other problem is that higher link error rates can reduce the efficiency of the protocol significantly since a detected packet error is followed by retransmission of the entire pipeline of data with the Go Back N protocol.



(a) Network Model



(b) Protocol architecture

Figure 1. TCP/IP Transport over Wireless ATM LAN Links

So, this section investigate lower layer error control issues encountered in using TCP/IP over ATM with wireless data links. ATM must be made to perform satisfactorily over wireless data links if certain error control measures are used to insure that RF link characteristics do not impair ATM operation. Forward error correction (FEC) and data link layer automatic repeat request (ARQ) are conventionally used to improve error performance. There are a number of tradeoffs that

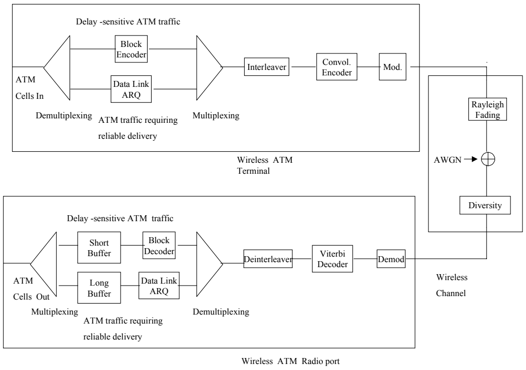


Figure 2. Link level Error control architecture with Wireless ATM Links

can be made in optimizing performance, considering error rate and throughput as tradeoff factors. Since the wireless environment can vary widely, the choices made will be strongly influenced by the wireless channel characteristics. Therefore, there will be variations in the appropriate choices of parameters for different channels. Several variations on this architecture may be more suitable depending upon channel conditions. Delay critical service make use of a concatenated code which consists of block code and convolutional code. For TCP/IP nondelay-sensitive traffic requiring reliable delivery, it is necessary to adopt data link layer ARQ protocol. ARQ Error control scheme considered in this paper include GBN ARQ, SR ARQ and Hybrid ARQ, which ARQ is needed, but FEC can be used to reduce the number of retransmissions. Recommended error control architecture is shown in Figure 2[8].

Ⅲ. Throughput analysis and optimum packet size

TCP/IP operating with AAL5 over ATM has a minimum the 20 byte TCP header, a 20 byte IP header, an 8 byte AAL5 trailer, and eight bytes for LLC/SNAP encapsulating for a total of 56 bytes of overhead as shown in Figure 3. There will also be a variable length PAD (0-47 bytes) that is needed to make the length including all overhead and data be an integral number of 48 byte cell payloads[5].

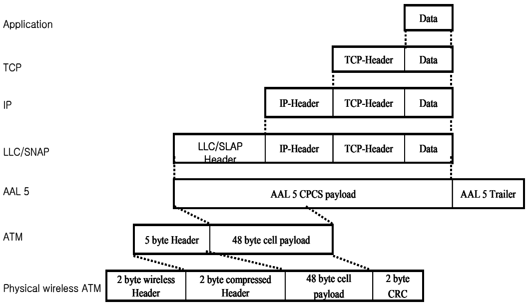


Figure 3. Protocol stack encapsulation

On the other hand, we analyze the ATM header error correction (HEC) mechanism and calculate cell loss ratio(CLR) for a wireless link. Assuming that both error bursts and errors in a burst are Poisson distributed, we get the Neyman-A contagious model. In this case, $P_B(n)$ is the probability that n errors occur in an interval of h bits when the mean error burst length is b and p denotes the bit error rate at the output of decoder. The subscript B denotes burst errors[9,10].

$$P_B(n) = \frac{b^n}{n!}\exp\left(\frac{-hp}{b}\right)\sum_{j=0}^{\infty}\left(\frac{hp}{b}\exp(-b)\right)^j\frac{j^n}{n!} \tag{1}$$

Since we are only interested in a rough approximation, CLR is modelled as the probability that more than one error occurs, neglecting the fact that ATM actually uses a dual mode operation for the HEC and neglecting undetected errors. In this case h is 16, the number of compressed ATM header bits.

$$\begin{aligned} &P_r(\text{discarded cell}) \\ &= 1 - P_B(0) - P_B(1) \\ &= 1 - \exp\left(-\frac{16p}{b}\right)\left[1 + \frac{(1+b)16p}{b}exp(-b)\right] \end{aligned} \tag{2}$$

3.1 Throughput analysis and optimum packet size of continuous ARQ

The Go-Back-N ARQ protocol is less efficient than the Selective Repeat scheme because it requires all packets in the pipeline to be retransmitted rather than just the packets received in-correctly as done with Selective Repeat. The throughput efficiency of Go-Back-N ARQ can be written as the ratio of the number of information bits per packet to the total number of bits per packet divided by the expected number of transmissions per packet[5]. By straightforward analysis, this is

$$\eta_{\mathrm{GBN}} = \frac{1-R_{\mathrm{OHD}}}{T_{\mathrm{GBN}}} = \left(1-\mathrm{R}_{\mathrm{OHD}}\right)\cdot\frac{\mathrm{P_C}}{\mathrm{P_C}+\left(1-\mathrm{P_C}\right)\cdot\mathrm{N_{WIN}}}$$

$$P_C = P_r(\mathrm{correct\quad packet}) = \left[\mathrm{P_r}(\mathrm{correct\quad cell})\right]^{\mathrm{N_{CP}}+1} \quad (3)$$

$$P_r(\mathrm{correct\quad cell}) = \left[1-\mathrm{P_r}(\mathrm{discarded\quad cell})\right]\cdot(1-\mathrm{p})^{\mathrm{L_{CP}}}$$

where the parameter R_{OHD} is the ratio of the number of overhead bits per packet to the number of overhead plus information bits per packet and N_{WIN} is the transmission window size in packets. The variable P_C is the probability that all cells in the packet are correct as well as the last ATM cell in the previous packet. N_{CP} is the number of cells per packet. The P_{r}(correct cell) can be calculated as the probability that both the cell header and the cell payload are error free which, since they are independent, is the product of these two unconditional probabilities. L_{CP} is the number of bits in the cell payload, P_{r}(discarded cell) was given previously in (2), and p is the accumulated BER for each payload. Note that the accumulation occurs over all links from source to destination since error detection and retransmission requests occur only at the destination.

The efficiency of the Selective Repeat protocol is a special case of Go-Back-N with a window size of one (N_{WIN}=1)[5].

$$\eta_{\mathrm{SR}} = \frac{1-R_{\mathrm{OHD}}}{T_{\mathrm{SR}}} = \left(1-\mathrm{R}_{\mathrm{OHD}}\right)\cdot\mathrm{P_C} \quad (4)$$

Fig. 4 shows the efficiency of Go-Back-N and Selective Repeat as a function of data packet length(n) for several values of channel BER. In ATM layer throughput η2(n, 15, 0.0001), n is the number of cells per packet, 15 is the mean error burst length, 0.0001 is the bit error rate. The PAD is fixed at a nominal one-half cell(24 byte) per packet, and the window size is fixed at ten packets. At samll packet sizes the efficiency is very low and is dominated by the inefficiency of using small packets, and at large packet sizes the loss in efficiency is due to retransmissions caused by channel bit errors. This latter effect increases dramatically with packet length. The performance of Go-Back-N is even more sensitive to BER than Selective Repeat because any packet in error will cause an entire window of packets to be retransmitted.

The probability of requiring a retransmission due to channel bit errors increases with packet length. If packets are made so large that the probability that a packet is received in error becomes too large, then a considerable amount of efficiency is lost due to retransmissions.

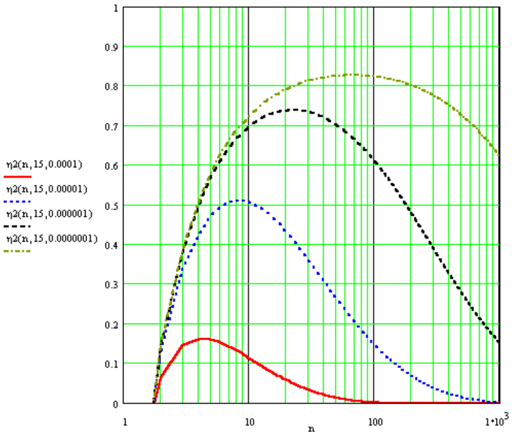
For any fixed value of BER, there is a definite peak or optimum value of packet size which is the best compromise between losses due to the percentage of overhead bytes and losses due to excessive retransmissions. The peak efficiency value also decreases rapidly as the BER increases for BER > 10^{-5}.

3.2 Throughput analysis and optimum packet size of Hybrid ARQ

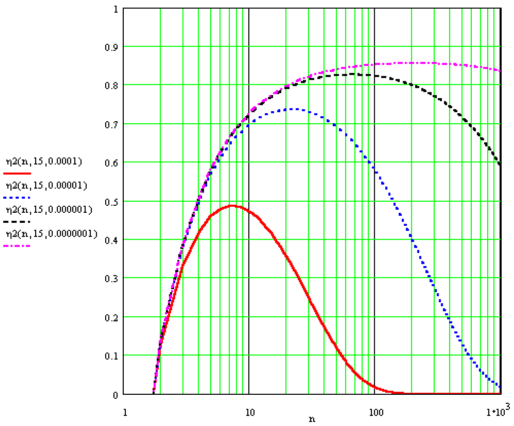
The type-I hybrid ARQ protocol is the simplest of the hybrid protocols. Each packet is encoded for both error detection and error correction. These protocols can be implemented using either one-code or two-code systems. Throughput of type-I Hybrid ARQ scheme is as follow.

$$\eta_{HARQ} = \left(\frac{k'}{n'}\right)(1-P_r\ P_{de}) \quad (5)$$

P_r is the probability that a received packet contains a detectable error pattern and thus causes the generation of a retransmission request, satisfies the equation $P_r = 1-P_c - P_e$. P_e is the probability that a received packet contains an undetectable error pattern and satisfies the equation $P_e \leq 2^{-(n_1-k)}[1+(1-2p_{be})^{n_1}-2(1-p_{be})^{n_1}]$.



(a) Go-Back-N ARQ(b = 15)



(b) Selective Repeat ARQ (b = 15)

Figure 4. Throughput efficiency of continuous ARQ

P_c is the probability that a received packet is error-free and satisfies the equation $P_c \geq (1-p_{be})^{n_1}$. p_{be} is the bit error rate at the output of viterbi decoder and satisfies the equation p_{be} (M=4) ≤1/2(7D^7+ 39D^8+104D^9 +352D^{10}), D=2 $\sqrt{\frac{p(1-p)}{M-1}}+\left[\frac{M-2}{M-1}\right]p$. p is the channel bit error rate as $p=\frac{1}{2}\left[1-\frac{1}{\sqrt{1+\frac{n_2}{k\gamma}}}\right]$. P_{de} is the probability of FEC decoder error and satisfies $P_{de} \leq$ 1-P_c , n_1 is the total length of error detection code (400 bit+9 bit), n_2 is the total length of FEC code (code rate=1/2, constraint length=7, length=409 bit+409 bit). k is the information bit length(400 bit), n' is the length of wireless ATM cell after coding(432 bit+9 bit+409 bit) and k' is the payload length of ATM cell (384 bit).

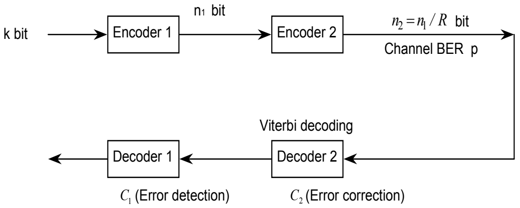


Figure 5. Throughput analysis model of adaptive Type-I Hybrid ARQ scheme

Adaptive type I hybrid ARQ scheme also estimates the channel BER in real time, and based on this channel state information, selects the best code rate to use in order to achieve the maximum throughput as shown in figure 5. Adaptive type I hybrid ARQ scheme uses two codes C$_1$ and C$_2$. The code C$_1$ is a high rate(n, k) block code used for error- detection, and the code C$_2$ is a rate R=(b-1)/b, b>1, punctured convolutional code of memory order ν used for error-correction with Viterbi decoding[11,12,13,14].

The probability that a received packet will be accepted by the receiver and delivered to the user is then $P=P_c+P_e$,,P_c denotes the probability of error-free decoding, P_e denotes the probability of undetected errors.

When P_{be} is the probability of an error event of Viterbi decoding, the probability of error-free decoding P_c may be lower bounded as $P_c \geq [1-P_{be}]^{n_1}$, which satisfies $P_{be} \leqq \sum_{d=d_{free}}^{\infty} a_d P(d)$ where d_{free} and a_d are the free distance and the weight spectra, of the code C$_2$, respectively, and where $P(d)$ is given by (7). The throughput of the type I hybrid ARQ system with selective-repeat protocol is given by (6). Table 1 shows weight spectra of convolutional code. The error-detection code C$_1$ has 9 parity-check bits and the code C$_2$ are the punctured convolutional codes produced from the rate 1/2 convolutional code of memory order ν = 7. The code rate R of C$_2$ varies from 1/2 to 7/8 and the packet length is k = 400.

$$\eta_{AHARQ}=\frac{k'}{n'}(1-P_rP_{de}) \qquad (6)$$
$$=\frac{384R}{409+32R}[1-(1-P_c-P_e)(1-P_c)]$$

where

$$P_e \le 2^{-(n_1-k)}[1+(1-2P_{be})^{n_1}-2(1-P_{be})^{n_1}]$$
$$p=\frac{1}{2}\left[1-\frac{1}{\sqrt{1+\frac{n_1/R}{k\gamma}}}\right], P_r = 1-P_e-P_c, \quad P_{de} \le 1$$

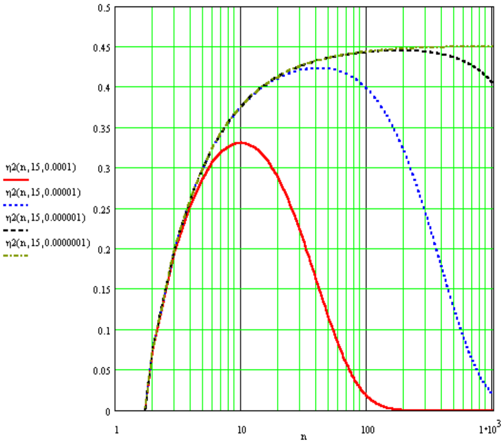
- P_c is used. k' is 384 bit, k is 400 bit, v is 7, n_1 is k + 9, R is code rate of convolutional code (7/8, 6/7, 5/6, 4/5, 3/4, 2/3, 1/2), n_2 is n_1/R, n' is n_2 + 32. Throughput is shown in Fig. 6.

$$P(d)=\sum_{j=\frac{d+1}{2}}^{d}\binom{d}{j}p^j(1-p)^{d-j} \quad (d : \text{odd})$$
$$\sum_{j=\frac{d}{2}+1}^{d}\binom{d}{j}p^j(1-p)^{d-j} \qquad (7)$$
$$+\frac{1}{2}\binom{d}{d/2}(p(1-p))^{d/2}(d : \text{even})$$

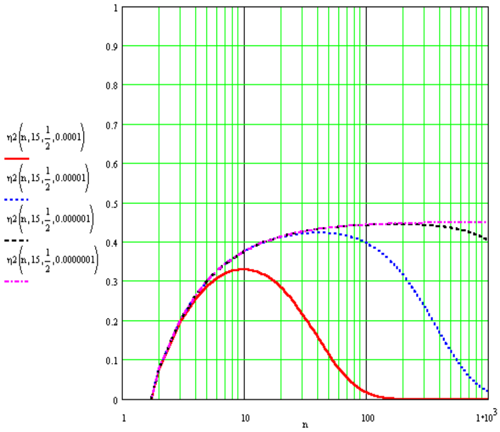
From Fig. 6, we observe the throughput efficiency of Type-I Hybrid ARQ as a function of data packet length for several values of channel BER. For any fixed value of BER, there is a definite peak or optimum value of packet size which is the best compromise between losses due to the percentage of overhead bytes and losses due to excessive retransmissions. The peak efficiency value also decreases rapidly as the BER increases for BER > 10^{-5}.

Table 1. Weight spectra of convolutional code

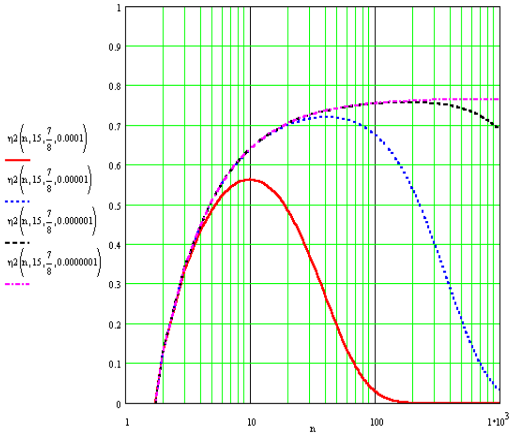
Code rate (R)	d_{free}	a_d ($d=d_{free}$, $d_{free}+1$, ..., $d_{free}+7$)
1/2	10	36, 0, 211, 0, 1404, 0, 11633, 0
2/3	6	1, 16, 48, 158, 642, 2435, 9174, 34701
3/4	5	8, 31, 160, 892, 4512, 23297, 120976, 624304
4/5	4	3, 24, 172, 1158, 7408, 48706, 319563, 2094852
5/6	4	14, 69, 654, 4996, 39677, 314973, 2503576, 19875546
6/7	3	1, 20, 223, 1961, 18084, 168982, 1573256, 14620204
7/8	3	2, 46, 499, 5291, 56137, 598557, 6371293, 67889502



(a) Type-I Hybrid ARQ
(inner code rate=1/2, b=15)



(b) Adaptive Type-I Hybrid ARQ
(inner code rate=1/2, b=15)



(c) Adaptive Type-I Hybrid ARQ
(inner code rate=7/8, b=15)

Figure 6. Throughput efficiency of Type-I Hybrid ARQ

Ⅳ. Conclusions

This paper provided optimum TCP/IP packet size that maximize the throughput efficiency of ATM traffic as a function of data packet length for several values of channel BER over wireless ATM links applying data link error control schemes to reduce error problems encountered in using wireless links. For TCP/IP nondelay-sensitive traffic requiring reliable delivery, it is necessary to adopt data link layer ARQ protocol. Both type-I Hybrid ARQ and adaptive type-I Hybrid ARQ scheme are analyzed, which ARQ is needed and FEC can be used to reduce the number of retransmissions. These schemes are effective for a variable channel condition to make the physical layer as SONET-like as possible. Finally TCP/IP traffic throughput was derived as a function of data packet length for several values of channel BER and packet size to maximize throughput was calculated. These results can be utilized for designing the practical TCP/IP architecture over wireless ATM access networks.

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