

S-ARQ: A New Truncated ARQ for IP-Based Wireless Network

Youngkyu Choi, Seong-Jun Oh, and Sunghyun Choi

Abstract: Automatic Repeat reQuest (ARQ) is a very effective technique against transmission error at the medium access control (MAC) layer. An erroneous MAC protocol data unit can be typically retransmitted within a given limit. In order to improve the IP-level performance, which directly affects the user-perceived quality-of-service (QoS), we propose a new truncated ARQ strategy, called MAC service data unit-based ARQ (S-ARQ), where the finite number of opportunities for retransmissions are shared by multiple fragments out of an IP datagram. We describe how S-ARQ can be implemented in a practical system, and then propose another variant of S-ARQ employing a functionality called early detection of failure. Basically, we evaluate the performance of S-ARQ in two different manners. First, assuming i.i.d. error process, we analyze both the probability of the delivery failure and the average delay of IP datagram. Then, we assess the performance of S-ARQ via simulation over a 2-state Markov channel.

Index Terms: MAC protocol data unit (MPDU), MAC service data unit (MSDU), truncated Automatic Repeat reQuest (ARQ).

I. INTRODUCTION

In recent years, the broadband Internet experience drives the demand for the wireless access to the IP network everywhere even in the mobile environments. In order to meet such fashion, new wireless systems are emerging today [1], [2]. One of the most difficult aspects in building a wireless IP network is how to guarantee a reliable communication over the unreliable wireless medium. In order to overcome the imperfection of the wireless medium, numerous techniques such as channel coding and diversity schemes have been developed.

Automatic Repeat reQuest (ARQ) [3] has been widely employed due mainly to its simplicity. ARQ technique is classified into various types, namely, stop-and-wait (SW) ARQ, go-back-N (GBN) ARQ, and selective repeat (SR) ARQ, depending on how the packets are (re)transmitted [3]. There have been numerous research efforts related with ARQ in the literature. In [4] and [5], the delay statistics of GBN and SR ARQ are analyzed considering the effect of non-zero delay of acknowledgment, respectively. To focus on the theoretical performance achieved by

ARQ, they basically assume that the reliability is fully achieved by ARQ, i.e., unlimited retransmissions of a packet are allowed. The cross-layer ARQ performance can also be found in [6]. On the other hand, ARQ is studied to optimize the system-wide performance in conjunction with other underlying techniques, e.g., adaptive modulation, channel coding, and duplexing [7]–[10]. Even though it may compromise the average delay due to repeated transmissions of the same information, its remarkable contribution in terms of the error probability reduction makes it an indispensable part of many practical systems. Especially, hybrid ARQ (HARQ), which combines ARQ with (adaptive) channel coding, improves the reliability at the physical layer (PHY) by increasing the received signal to noise ratio (SNR) and lowering the code rate adaptively [11], [12]. In [11], the scheduling algorithm considering the HARQ operation is considered and the several performance metrics in the HARQ-based system are defined with the Markov chain in [12]. In contrast to HARQ, pure ARQ is typically used at the medium access control (MAC) layer or at the data link layer.

The transmission unit at the MAC is a MAC protocol data unit (MPDU) in the MAC's perspective, and hence the unit of retransmission is also an MPDU. Since typical ARQ schemes limit the maximum retransmission number¹ to each MPDU, if an MPDU cannot be successfully transmitted until the maximum limit is reached, then that MPDU is discarded by the MAC. The payload size within an MPDU is often much less than that of the IP datagram [14]. This observation is generally reasonable, especially, for mobile wireless IP networks since the time duration of a transmission unit should be designed as short as possible in order to mitigate the severe channel fading due to the user mobility. Inevitably, an IP datagram should be fragmented into multiple MPDUs. Apparently, there is an exceptional case, e.g., IEEE 802.11 wireless LAN (WLAN), where the whole IP datagram with size over 2,000 bytes might be transmitted without any fragmentation although it also supports the fragmentation functionality at the MAC.

All fragments from the original IP datagram should be transferred without error for the successful re-assembly at the receiver-side MAC. Otherwise, the final delivery failure of a single MPDU (after retransmissions) makes the successful deliveries of other MPDUs useless unless we consider the additional coding scheme above the MAC layer [15], [16]. In this context, we argue that the user-perceived quality-of-service (QoS) is directly affected by the performance measure at the IP level, while it is indirectly affected by that of the link layer or physical layer, assuming that the wireless part is the bottleneck along the

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¹Note that some technologies such as IEEE 802.16 [13] employ the maximum life time instead of the maximum retransmission number. The idea presented in this paper can be also easily applied to such systems.

end-to-end path. Accordingly, we propose a new ARQ strategy which offers the enhanced IP-level performance compared with the conventional ARQ strategy. Moreover, the proposed scheme can be used along with various existing ARQ protocols, e.g., SW, GBN, and SR ARQ.

The rest of the paper is organized as follows: Section II describes our proposed scheme with implementation issues. Section III illuminates the expected benefit, i.e., the robust delivery of IP packet, from the viewpoint of throughput-oriented system. The simulation results based on more realistic channel model are shown and discussed in Section IV. Finally, the paper concludes with Section V.

II. THE PROPOSED ARQ STRATEGY

Before presenting our approach, we should mention that the IP datagram will be regarded as a MAC service data unit (MSDU) by the MAC. In practical systems, an intermediate layer, e.g., IEEE 802.2 logical link control (LLC), between IP and the MAC layer may attach its own header to the IP datagram, and then forward it to the MAC.

Let us consider the retransmission opportunity as a form of resource to be used. We recognize that the conventional ARQ allocates an equal amount of resource (or equal retransmission opportunity) to each MPDU. However, an MPDU transmitted under a good channel status does not need such excessive resource any more, while other MPDUs transmitted under a poor channel status may require more resources in order to make a complete IP datagram. Therefore, we can figure out the equal resource allocation via the conventional ARQ strategy is not optimal given the total sum of resources available to the MSDU.

Our proposed ARQ strategy is to share the total retransmission opportunities among the MPDUs derived from the same MSDU. To distinguish the proposed scheme from the conventional one, let us refer to the proposed strategy as *S-ARQ* (the ARQ with the limitation on the number of MSDU transmissions) and to the conventional strategy as *P-ARQ* (the ARQ with the limitation on the number of MPDU transmissions). In P-ARQ, each MPDU can be retransmitted until a retransmission counter C_{mpdu} , which is associated with an MPDU, exceeds the limit. Similarly, in S-ARQ, we consider a retransmission counter C_{msdu} , which is associated with an MSDU. Then, the operational procedure for S-ARQ can be described as follows:

- 1) When it begins to transmit a sequence of MPDUs derived from a new MSDU, reset C_{msdu} , corresponding to the MSDU, to zero.
- 2) MPDUs are allowed to be (re)transmitted if C_{msdu} is less than the limit.
- 3) C_{msdu} is increased by one upon each (re)transmission of an MPDU.
- 4) If C_{msdu} exceeds the limit, the transmission of the corresponding MSDU is given up, and hence all the pending MPDUs belonging to the same MSDU are discarded.

In fact, we can detect whether attempting to transmit the rest of MPDUs is meaningful earlier before C_{msdu} becomes zero. That is, if the number of pending MPDUs to be transmitted is larger than C_{msdu} , the delivery of the MSDU will fail inevitably.

Therefore, we can declare the transmission failure of the IP datagram in advance without wasting the air resource. In order to supplement S-ARQ with this capability, Step 2 is modified as follows:

- 2') An MPDU is allowed to be (re)transmitted only if the number of remaining MPDUs is fewer than or equal to C_{msdu} .

Let us refer this modified scheme to as ‘S-ARQ w/ *early drop*’ or ‘S-ARQ w/ *ED*’ in short. The modified scheme is expected to reduce the amount of resource consumption without compromising other performances, e.g., goodput and average delay achieved at the IP layer. If the transmission opportunity for an MPDU is given as a form of the maximum life time, a similar statement can also be made by introducing a timer, which notifies the expiration of transmission of each MSDU. However, we will proceed to discuss in terms of the maximum transmission number throughout this paper.

For the implementation issue, our proposed scheme requires that the MAC should know which MSDU a group of MPDUs were generated from. That is, the MAC needs to access the context information of the IP layer. However, this prerequisite is not costly because such information is also required to reassembly the fragmented IP packet even at the receiver. For this reason, we argue that S-ARQ does not require any complex MAC structure or additional information.

III. PERFORMANCE ANALYSIS

For analytical simplicity, we consider a time-slotted system, where a single MPDU with fixed size is transmitted during a time slot. We assume an IP datagram is fragmented into N MPDUs, and a transmission failure occurs with probability ε independently at each time slot. For the sake of simplicity, we assume that an ACK message is returned without error, and the round trip delay is zero. Accordingly, the sender can determine if its transmission is successful or not immediately after a transmission. When the round trip delay is zero, note that SW, GBN, and SR ARQ schemes are identical [5]. Let us consider that the P-ARQ allows an MPDU to be transmitted up to M_P times including the initial trial and $(M_P - 1)$ subsequent retransmissions. In contrast, S-ARQ allows N MPDUs to share the transmission opportunities of M_S ($\geq N$). In the following, we present the error probability of an IP datagram and the average IP delay² in terms of $M_P(M_S)$, N , and ε . We denote the probabilities of a delivery failure of IP datagram achieved by P-ARQ and S-ARQ as $P_{P,f}$ and $P_{S,f}$, respectively. Similarly, the probabilities of a successful delivery of IP datagram are represented by $P_{P,s}$ and $P_{S,s}$, respectively.

In P-ARQ, the probability of a successful transmission of an MPDU can be represented by $1 - \varepsilon^{M_P}$. Accordingly, $P_{P,f}$ is given by

$$P_{P,f} = 1 - (1 - \varepsilon^{M_P})^N. \quad (1)$$

Let us denote by $P_{S,s}(i)$ the probability that N MPDUs are successfully transmitted at the i th ($i \geq N$) time slot. Accordingly,

²In this paper IP delay means only the transmission delay [3]. Queuing delay or the propagation delay is not considered.

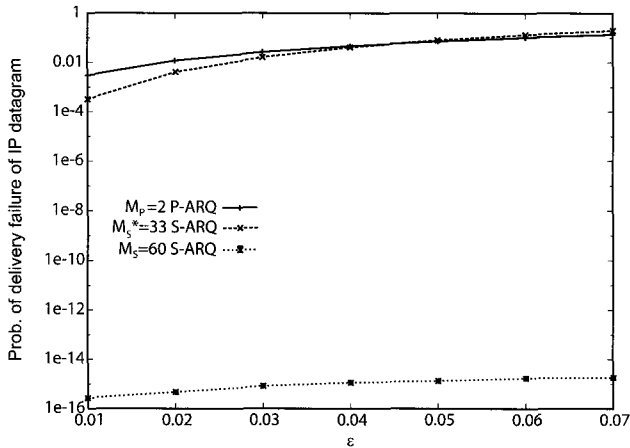


Fig. 1. The probability of a delivery failure of IP datagram vs. ϵ when $N = 30$.

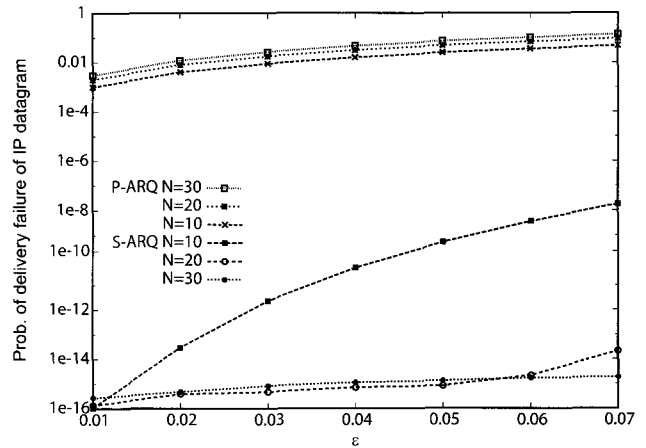


Fig. 2. The probability of a delivery failure of IP datagram vs. ϵ when $M_P = 2$ and $M_S = 2N$.

Table 1. M_S^* 's depending on M_P and N when $\epsilon = 0.03$.

$M_P \backslash N$	5	10	15	20	25	30
2	7	12	17	23	28	33
3	8	14	19	25	30	35
4	9	15	21	26	32	37

Table 2. M_P^* and M_S^* to achieve $\xi = 10^{-3}$ when $\epsilon = 0.03$.

N	5	10	15	20	25	30	35
M_P^*	3	3	3	3	3	3	3
M_S^*	8	14	19	25	30	35	41
$\frac{M_S^*}{N}$	1.6	1.4	1.27	1.25	1.2	1.17	1.17

$P_{S,s} = \sum_{i=N}^{M_S} P_{S,s}(i)$ and $P_{S,s}(i)$ can be represented by

$$P_{S,s}(i) = \binom{i-1}{N-1} (1-\epsilon)^N \epsilon^{i-N}, \text{ for } i \geq N \quad (2)$$

which is the negative binomial distribution [17]. Then, $P_{S,f}$ is determined by

$$P_{S,f} = 1 - \sum_{i=N}^{M_S} P_{S,s}(i) = 1 - \sum_{i=N}^{M_S} \binom{i-1}{N-1} (1-\epsilon)^N \epsilon^{i-N} \quad (3)$$

If an IP datagram divided into N MPDUs, it can have at most NM_P transmission opportunities (worst-case delay) in P-ARQ. Therefore, if M_S is set to NM_P , the following proposition shows that S-ARQ always outperforms P-ARQ in terms of the probability of IP datagram delivery failure.

Proposition 1: When $M_S = NM_P$, $P_{S,f}$ is always less than $P_{P,f}$.

Proof: Consider all the possible outcomes of NM_P independent transmissions, where we want to successfully transmit N MPDUs from the same IP datagram. In P-ARQ, an event of successful delivery of an MPDU should occur at least one time within M_P consecutive transmissions. On the other hand, in case of S-ARQ, it is sufficient that at least N successful transmissions occur among all NM_P transmissions. It is clear that any success in P-ARQ is a success in S-ARQ, but not vice versa. \square

Let us define M_S^* as $\min\{M_S | P_{S,f} \leq P_{P,f}, M_S \in \mathbb{Z}\}$. Then, M_S^* can be obtained numerically solving the following inequal-

ity:

$$M_S^* = \arg \min_{M_S \in \mathbb{Z}} \left\{ \sum_{k=0}^{M_S-N} \binom{k+N-1}{k} \epsilon^k \geq \left(\frac{1-\epsilon^{M_P}}{1-\epsilon} \right)^N \right\} \quad (4)$$

In Fig. 1, we compare $P_{S,f}$ with $P_{P,f}$ when $N = 30$. P-ARQ with $M_P = 2$ achieves the probability of a delivery failure of about 10^{-2} , when $\epsilon = 0.03$ whereas S-ARQ with $M_S = NM_P = 60$ yields very low probability (in order of 10^{-15}) as stated by Proposition 1. It is not until M_S is reduced to $M_S^* = 33$ that their performances become alike. In fact, this is the result of (4) and M_S^* 's corresponding to other M_P 's and N 's are shown in Table 1 as well.

At this time, Fig. 2 shows the error performances for various N values. When M_S is set to NM_P for $M_P = 2$, P-ARQ achieves lower error probability as N becomes smaller, but this trend is not valid in S-ARQ. The reason is that setting the retransmission limit of S-ARQ in proportional to N is quite excessive. In other words, it is interpreted that S-ARQ utilizes the transmission opportunities more efficiently than P-ARQ does. We can learn that the source of improvement is the statistical multiplexing gain in that MPDUs under S-ARQ share more retransmission opportunities than under P-ARQ.

Now we consider that the probability of a delivery failure of IP datagram is specified with ξ . When M_P^* is required to satisfy the requirement under P-ARQ, it is easily obtained from (1) as follows:

$$M_P^* = \left\lceil \frac{\log \left(1 - (1-\xi)^{\frac{1}{N}} \right)}{\log \epsilon} \right\rceil \quad (5)$$

Once M_P^* is determined, M_S^* from (4) by definition also enables S-ARQ to satisfy the requirement ξ . In Table 2, we enumer-

ate M_P^* and M_S^* obtained³ for given N ($N = 5, \dots, 35$) when $\varepsilon = 0.03$ and $\xi = 10^{-3}$. We see that M_S^* increases as N increases while M_P^* is fixed to 3 for all N 's. However, the relative increase of M_S^* , i.e., M_S^*/N , keeps decreasing with N . This result reconfirms that S-ARQ exploits the statistical multiplexing gain more efficiently. Afterward, it is shown that S-ARQ with M_S^* achieves a smaller average delay than P-ARQ via numerical results.

Next, we compute the average delay of IP datagram. Let us denote the average IP packet delay achieved by P-ARQ and S-ARQ as \mathcal{D}_P and \mathcal{D}_S , respectively. The average delay is defined by the expected number of time slots consumed to deliver an IP datagram successfully. Therefore, \mathcal{D}_P can be written as⁴

$$\mathcal{D}_P = \frac{\sum_{i=N}^{NM_P} iP_{P,s}(i)}{1 - P_{P,f}}. \quad (6)$$

Similarly, \mathcal{D}_S is written as

$$\mathcal{D}_S = \frac{\sum_{i=N}^{M_S} iP_{S,s}(i)}{1 - P_{S,f}}. \quad (7)$$

In order to evaluate (6) and (7), we need to derive $P_{P,s}(i)$ while $P_{S,s}(i)$ has been already obtained in (2).

Before describing how to get $P_{P,s}(i)$, we replace its notation with $P_{P,s}^N(i)$ to specify the number of MPDUs explicitly. When an IP datagram with N MPDUs is successfully delivered at the i th transmission, there exist many combinations of the time slots occupied by each individual MPDUs, respectively. We represent possible combinations by N -dimensional vector (n_1, n_2, \dots, n_N) where n_j ($1 \leq n_j \leq M_P$) is the number of time slots used to deliver the j th MPDU. Denote \mathcal{N}_i as the set of all vectors satisfying $\sum_{j=1}^N n_j = i$. Defining $S(n_j)$ as $\varepsilon^{n_j-1}(1 - \varepsilon)$, ($1 \leq n_j \leq M_P$), $P_{P,s}(i)$ can be computed as

$$P_{P,s}(i) = \sum_{(n_1, n_2, \dots, n_N) \in \mathcal{N}_i} \prod_{j=1}^N S(n_j). \quad (8)$$

(8) can be computed recursively as follows. Let us assume that it takes k time slots to transmit the N th MPDU successfully. Since $(N - 1)$ MPDUs should have been delivered during $(i - k)$ slots, k should be less than or equal to the minimum of $i - (N - 1)$ and M_P . Accordingly, $P_{P,s}^N(i)$ can be expressed using $S(k)$ and $P_{P,s}^{N-1}(i - k)$ as

$$P_{P,s}^N(i) = \sum_{k=1}^{\min\{M_P, i-(N-1)\}} S(k)P_{P,s}^{N-1}(i - k). \quad (9)$$

Using (9), we can compute the probability, $V(x, i)$ that x ($1 \leq x \leq N$) MPDUs are successfully delivered during i time slots.

³Note that the frame error rate (FER) is typically provisioned to range from 1% to 5%.

⁴We consider the average delay of successfully delivered IP datagrams without the application layer retransmission. Therefore, strictly speaking, the average delay is a conditional expectation conditioned on the successful delivery of an IP datagram. $(1 - P_{P,f})$ and $(1 - P_{S,f})$ in the denominators of (6) and (7) are the normalization factors to take the probability of an IP datagram's successful delivery into consider.

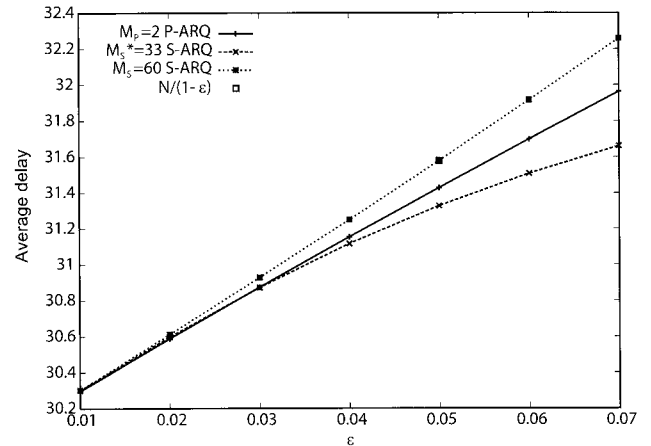


Fig. 3. The average delay of IP datagram vs. ε when $N = 30$.

$V(x, i)$ is represented by $N \times i$ matrix, and each element has the value according to

$$V(x, i) = \begin{cases} S(i), & \text{for } x = 1, 1 \leq i \leq M_P, \\ \sum_{k=1}^{\min\{M_P, i-(x-1)\}} S(k)V(x-1, i-k), & \text{for } 2 \leq x \leq N, x \leq i \leq xM_P, \\ 0, & \text{otherwise.} \end{cases} \quad (10)$$

Recursive computation using (10) yields $P_{P,s}^N(i)$ as $V(N, i)$. Finally, according to (6), \mathcal{D}_P is written by

$$\mathcal{D}_P = \frac{\sum_{i=N}^{NM_P} iP(N, i)}{(1 - \varepsilon^{M_P})^N}. \quad (11)$$

Similarly, \mathcal{D}_S is represented by using (2) and (3) as

$$\mathcal{D}_S = \frac{N \sum_{i=N}^{M_S} \binom{i}{N} \varepsilon^i}{\sum_{i=N}^{M_S} \binom{i-1}{N-1} \varepsilon^i}. \quad (12)$$

Proposition 2: When M_S is large, \mathcal{D}_S converges to $\frac{N}{1-\varepsilon}$.

Proof: Using the identity relation of $\binom{i}{N} = \binom{i-1}{N} + \binom{i-1}{N-1}$ and replacing $(i - N)$ with k , (12) is rewritten as

$$\mathcal{D}_S = \frac{\varepsilon \sum_{k=0}^{M_S-N} \binom{k+N-1}{k} k \varepsilon^{k-1}}{\sum_{k=0}^{M_S-N} \binom{k+N-1}{k} \varepsilon^k} + N. \quad (13)$$

Since $\binom{k+N-1}{k} = (-1)^k \binom{-N}{k}$, the denominator of (13) is represented as $\lambda = \sum_{k=0}^{M_S-N} \binom{-N}{k} (-\varepsilon)^k$. When $M_S - N$ is quite large, $\lambda \rightarrow (1 - \varepsilon)^{-N}$. Since $\sum_{k=0}^{M_S-N} \binom{k+N-1}{k} k \varepsilon^{k-1}$ is the same as $\frac{d\lambda}{d\varepsilon}$, $\mathcal{D}_S \rightarrow \frac{N}{1-\varepsilon}$. \square

Fig. 3 shows the average delay of IP datagram delivery under both P-ARQ and S-ARQ. While S-ARQ with $M_S = 60$ achieves very low error probability in Fig. 1, the average delay is longer than that achieved by P-ARQ. Also, the result coincides at every ε with the asymptotic delay given by Proposition 2. However, we see that S-ARQ with M_S^* accomplishes lower delay than P-ARQ. Recall that P-ARQ and S-ARQ with M_S^* yield the same performance with respect to the delivery failure probability. Indeed, M_S^* is optimal in the sense that it minimizes \mathcal{D}_S while satisfying $P_{S,f} \leq P_{P,f}$ because \mathcal{D}_S increases with M_S .

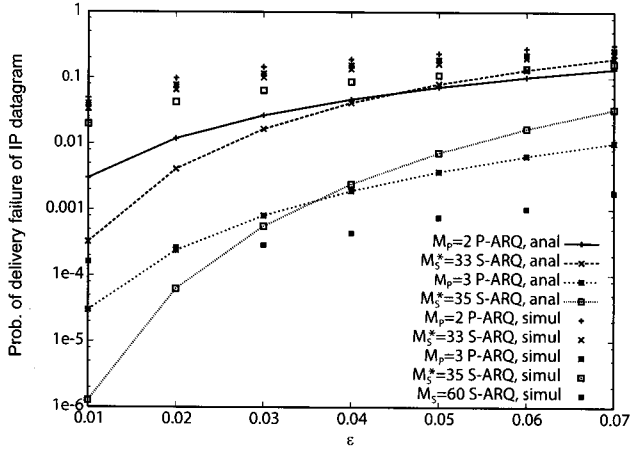


Fig. 4. The effect of retransmission limit, i.e., M_P or M_S , on the probability of delivery failure of IP datagram when $N = 30$ and $B = 5$.

IV. SIMULATION RESULTS

A. Simulation Model

So far, we have assumed that transmission failures of MPDU occur independently with probability ϵ . However, the wireless channel is characterized by bursty errors. For the wireless channel model, we consider a block fading model, known as Gilbert model [18], where the transmission is always successful at state 0 and the transmission always fails at state 1. This channel model is fully characterized by the transition matrix $\mathbf{T} = \{t_{ij}\}$, $i, j \in \{0, 1\}$. The steady state probability of transmission failure is given by $\epsilon = t_{01}/(t_{10} + t_{01})$, and $B = 1/t_{10}$ has the meaning of an average burst error length. The channel state is assumed not to vary during a time slot, but it can transit to the other state according to \mathbf{T} at a slot boundary.

The simulation scenario proceeds as follows: The sender keeps sending IP datagrams with the size of N MPDUs for 500,000 time slots. During a simulation, we keep track of three different variables:

- 1) *msdu_cnt*: Whenever the sender begins to transmit a new IP datagram, *msdu_cnt* is increased by one.
- 2) *drop_msdu*: When it fails to deliver an IP datagram, *drop_msdu* is increased by one.
- 3) *success_time*: Whenever an IP datagram is successfully delivered, accumulate the number of time slots used for the IP datagram to *success_time*.

Using these variables, we build three different metrics to assess the performance of ARQ:

- 1) The probability of a delivery failure of IP datagram: $\frac{\text{drop_msdu}}{\text{msdu_cnt}}$,
- 2) The average delay: $\frac{\text{success_time}}{\text{msdu_cnt} - \text{drop_msdu}}$,
- 3) The average goodput: $\frac{(\text{msdu_cnt} - \text{drop_msdu})N}{500,000}$.

All performance measures are obtained via averaging over more than 40 simulation runs, and for each run, the initial state of the channel is assumed to be state 0.

B. Performance Evaluation

Fig. 4 shows the probability of a delivery failure of IP datagram comparing with the analytical performance obtained in

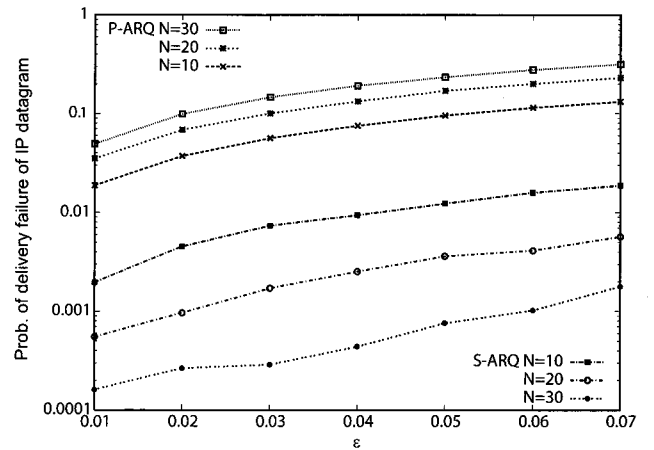


Fig. 5. The effect of N on the probability of delivery failure of IP datagram when $M_P = 2$, $M_S = 2N$ and $B = 5$.

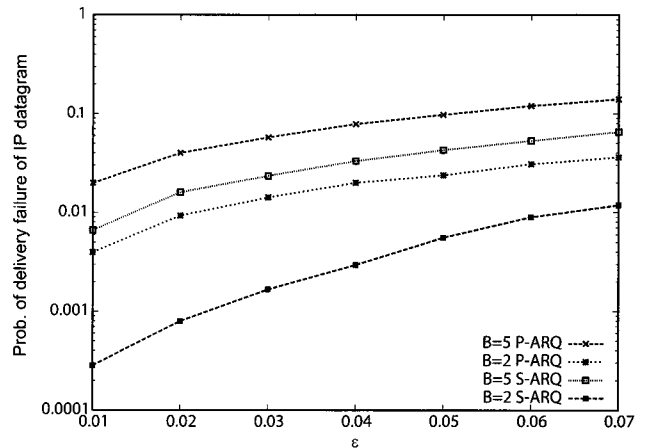


Fig. 6. The effect of B on the probability of delivery failure of IP datagram when $M_P = 6$, $M_S = 40$ and $N = 30$.

Section III. The performance of P-ARQ is obtained for $M_P = 2$ and 3 while M_S^* 's in Table 1 are used for S-ARQ. We observe that the result from simulation is worse than the analytical result due to the burst of channel errors. S-ARQ with $M_S = 60$ achieves the error probability in the order of 10^{-4} though its analytical result reaches as the order of 10^{-15} as shown in Fig. 3.

Fig. 5 shows the effect of N on the probability of delivery failure. For S-ARQ, we set M_S to $2N$ when $M_P = 2$ is used for P-ARQ. We see that as the length of IP datagram decreases, P-ARQ achieves smaller probability of delivery failure. However, this trend is reversed in S-ARQ and this is identical with the analytical result shown in Fig. 2. This means that $M_S = 2N$ is quite excessive for S-ARQ though it yields the same worst case delay as P-ARQ with $M_P = 2$.

At this time, Fig. 6 shows the impact of B . For both P-ARQ and S-ARQ, as the channel error process becomes more bursty, i.e., from $B = 2$ to $B = 5$, the probability of delivery failure increases.

Lastly, we evaluate the average goodput achieved by P-ARQ and S-ARQ, respectively. In order to compare the goodput performance achieved by each ARQ scheme, the probability of delivery failure should be made identical. However, it is quite difficult since M_S and M_P are constrained to be integer. There-

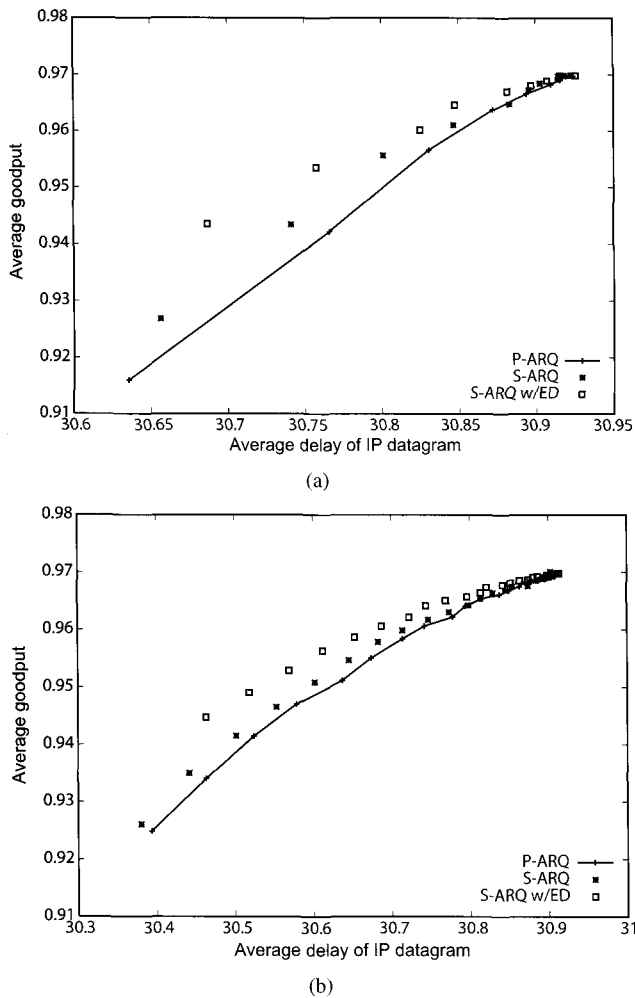


Fig. 7. The average goodput vs. the average IP packet delay when $\varepsilon = 0.03$: (a) $B = 2$ and (b) $B = 5$.

fore, we compare the achievable region consisting of the average goodput and the average IP packet delay. The average goodput vs. average IP packet delay is plotted in Fig. 7. Firstly, we observe that S-ARQ achieves a higher goodput than P-ARQ for a given average delay of IP datagram and that ARQ schemes with ED outperform schemes without ED. This is because S-ARQ yields a smaller $drop_msdu$ compared with P-ARQ while ARQ schemes with ED gives a larger $msdu_cnt$ compared with those without ED. Note that the average goodput is proportional to the difference between $msdu_cnt$ and $drop_msdu$. In addition, as the channel process becomes more bursty (from $B = 2$ to 5), the performance gaps gradually diminish.

V. CONCLUDING REMARKS

In this paper, we propose a new truncated ARQ called S-ARQ, where a finite number of opportunities for retransmissions are shared by multiple fragments out of an IP datagram. Since S-ARQ simply changes the object of interest for retransmissions from MPDU to MSDU, it does not require any complex algorithm or protocols. Via analytical study, we investigate the probability of delivery failure of IP datagram and the average delay of IP datagram based on the assumption of i.i.d. error

process. To evaluate the performance of S-ARQ in bursty error process, a 2-state Markov channel is employed for simulations. We assess the performance of S-ARQ with respect to the probability of delivery failure, the average delay of IP datagram, and the average goodput. The simulation result shows that S-ARQ achieves a better trade-off between the reliability and the average delay compared with P-ARQ, a conventional ARQ scheme.

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