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Analysis Model for the Transport Delay of NAK-based SR-ARQ with a Finite Retransmission

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Abstract: In this paper, we propose a simple analysis model for the transport delay of the negative acknowledgment (NAK)-based selective repeat automatic repeat request (SR-ARQ). We define the transport delay as the time from a packet's first transmission until its successful arrival at the receiver. By analyzing the transport delay, we can evaluate the efficiency of SR-ARQ's loss recovery procedures as well as its delay performance. Particularly, the model considers the traffic condition and a finite retransmission persistence of SR-ARQ as well as the packet loss rate over a wireless link. Finally, the analysis model's accuracy is verified by the simulation results.

1. Introduction

It has been shown that retransmissions by selective repeat automatic repeat request (SR-ARQ) introduce variable and, sometimes, very high packet delays that may degrade the performance of higher layer protocols [1], [2]. According to [1], transmission control protocol (TCP) may suffer performance degradation due to interaction problems and spurious timeouts caused by high packet delay variations.

The problem with the high packet delay variations may become severer with a negative acknowledgement (NAK)-based SR-ARQ protocol such as radio link protocol (RLP) [6]. If a retransmitted packet is lost again, the receiver cannot detect it until a retransmission timer is expired. It is referred to as retransmission timeout (RTO). Typically, RTO value, t_{rto}, is longer than a round-trip time (RTT), t_{rtt}, so that RTOs due to the retransmission failures may increase the overall packet transmission delay of the NAK-based SR-ARQ protocol [3]-[5]. In this paper, we evaluate the performance of the NAK-based SR-ARQ through numerical analysis and simulation results about the transport delay. The proposed analysis model derives the mean transport delay by considering the traffic condition and a finite retransmission persistence as well as packet losses over a wireless link.

2. The NAK-based SR-ARQ Protocol

We consider a SR-ARQ protocol with the following features. Every packet has a unique sequence number in the SR-ARQ protocol. The transmitter sends packets consisting of payload and header according to their sequence number. A copy of each transmitted packet is temporarily kept in a buffer for retransmissions. If packet losses are detected based on the outcome of the error detection procedure or the check on packet sequence number, the receiver side sends a NAK message requesting retransmissions of lost packets to the transmitter immediately. If a NAK message arrives, the transmitter decides whether it will permit retransmission for the packet or not, according to the retransmission persistence. The retransmission persistence is defined as the willingness of the protocol to retransmit lost packet to ensure reliable delivery of traffic across the link [1]. The SR-ARQ protocol supports in-order packet delivery for higher layer protocols. To do this, even though some packets successfully arrive at the receiver side, the SR-ARQ protocol does not forward the arriving packets to the higher layer if there are missing packets that were not recovered. The receiver side uses a resequencing queue to keep the out-of-order packets in the SR-ARQ protocol[2], [5].

When the receiver side sends a NAK message to the transmitter, it starts a timer, generally called NAK timer, to detect a retransmission failure. If a requested packet do not arrive until the NAK timer expires, the receiver side conclude that the retransmitted packet corresponding to the NAK timer is lost again. A retransmission for a corrupted packet is always prior to a transmission for new packets on a non-preemptive basis. Therefore, the transmitter cannot send a new packet until all the retransmissions are completed. In real communication system, various kinds of retransmission schemes exist and each scheme may perform differently, but we will only consider the SR-ARQ protocol that retransmit a packet once per a NAK message [5].

3. Analysis Model for the Transport Delay

In this section, we introduce a simple analysis model for the transport delay of the NAK-based SR-ARQ protocol. The transport delay is defined as the time from a packet's first transmission until its successful arrival at the receiver [2]. By analyzing the transport delay, we can evaluate the efficiency of a SR-ARQ's loss recovery procedure as well as its delay performance.

To get a simple closed-form equation for the mean transport delay of the NAK-based SR-ARQ protocol, we assume that

- The time is slotted and the slot time is fixed as s seconds and corresponds to a single packet transmission.
- The transmitter serves new arrival packets on an FCFS (First Come First Serve) basis.
- A retransmission is always prior to a transmission of a new packet.
- Packet losses on a wireless link occur following the Bernoulli process with the probability p.
- Feedback messages are error free.

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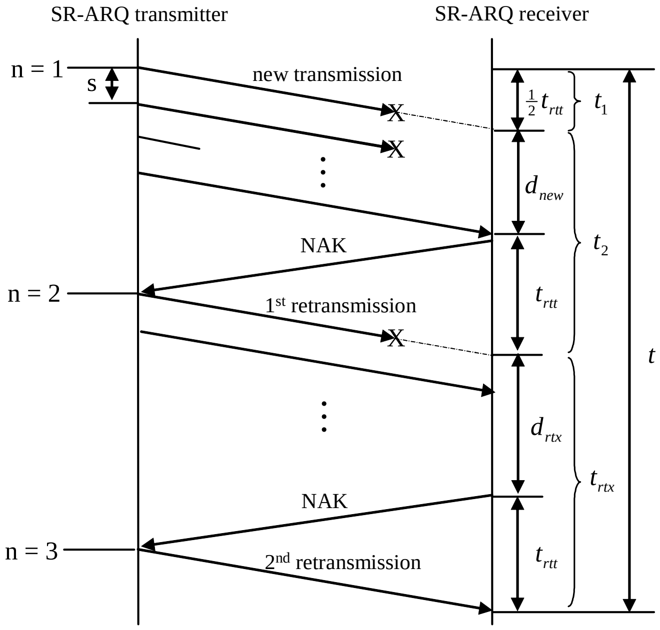

Figure 1. Delay components consisting the transport delay of SR-ARQ

- On receiving a NAK message, the transmitter immediately retransmits a requested packet.
- The one-way delay is $1/2t_{rtt}$.
- SR-ARQ has a finite retransmission persistence. The retransmission persistence is defined as the maximum number of retransmission attempts (r).

As shown in figure 1, the transport delay, t, in the NAK-based SR-ARQ protocol is composed to loss detection times and the packet transmission delay. Let n denote the number of transmission attempts for a successful packet delivery. According to n, the transport delay is expressed like this.

$$t = \sum_{k=1}^{n} t_k \tag{1}$$

where t_k denotes the time taken by the kth transmission for a packet, and is given by

$$t_k = \begin{cases} \frac{1}{2}t_{rtt} & , k = 1 \\ d_{new} + t_{rtt} & , k = 2 \\ d_{rtx} + t_{rtt} & , k = 3, \ldots, r+1 \end{cases} \tag{2}$$

where d_{new} and d_{rtx} denote the loss detection time for an original packet and a retransmitted packet, respectively. Assuming independent packet losses following the Bernoulli process, n is the random variable that has the following distribution.

$$P(n = k) = \begin{cases} (1-p)p^{k-1} & , 1 \le k \le r \\ p^r & , k = r+1 \end{cases} \tag{3}$$

The mean transport delay, $E[t]$, is derived as follows.

$$E[t] = E[E[t|n]] \tag{4}$$

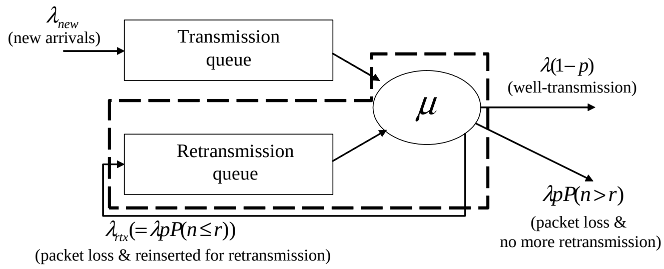

Figure 2. Network queuing model for SR-ARQ

where $E[t|n] = E[\sum_{k=1}^{n} t_k]$. If we assume that $t_3, t_4, \ldots$, and t_{r+1} are identical, then all of them can be replaced by t_{rtx}, and $E[t]$ is expressed like this.

$$E[t] = E[t_1] + E[t_2]p + E[t_{rtx}]\left(\frac{p^2 - p^{r+1}}{1-p}\right) \tag{5}$$

where

$$\begin{aligned} E[t_1] &= \frac{1}{2}t_{rtt} \\ E[t_2] &= t_{rtt} + E[d_{new}] \\ E[t_{rtx}] &= t_{rtt} + E[d_{rtx}] \end{aligned}$$

Here, $E[d_{new}]$ and $E[d_{rtx}]$ denote the mean value of d_{new} and d_{rtx}, respectively.

Now, to get the mean transport delay, we should derive the unknown terms in Equ. (8). d_{new} is defined as the time that taken by SR-ARQ receiver to detect it when a packet loss occurs. The NAK-based SR-ARQ receiver detects an original packet loss by receiving a following original packet without an error, as shown in figure 1. Assuming that packet losses occur independently, d_{new} has the geometric distribution as follows.

$$P(d_{new} = i \cdot s) = \alpha(1-\alpha)^{i-1}, \text{ i = 1, 2, 3, ...} \tag{6}$$

where α denotes the probability that there are one or more packets to transmit by the transmitter, and a given transmission is for an original packet not in error. Let be c and c_{rtx} the total number of packets in the SR-ARQ transmitter and the number of packets in the retransmission queue of the SR-ARQ transmitter, respectively. Recalling the assumption that a retransmission is always prior to a new packet transmission, α is calculated like this.

$$\alpha = P(c > 0 \text{ and } c_{rtx} = 0) \cdot (1-p) \tag{7}$$

The SR-ARQ transmitter is modeled by the network queuing model, as shown in figure 2. Let λ, λ_{new} and λ_{rtx} denote the total packet arrival rate, the new packet arrival rate, and the arrival rate of retransmitted packets, respectively. By the Jackson's theorem [7], $\lambda = \lambda_{new} + \lambda_{rtx}$, and the arrival rate of retransmitted packets is given by

$$\lambda_{rtx} = \lambda p P(n \le r) \tag{8}$$

where $P(n \leq r) = \sum_{n=1}^{r}(1-p)p^{n-1}$, recalling the assumption of random and independent packet losses. Then, the total packet arrival rate becomes

$$\lambda = \lambda_{new} + \lambda_{rtx} = \frac{\lambda_{new}}{1-p+p^{r+1}} \tag{9}$$

By the general queuing theory, $P(c > 0)$ is equal to the probability that the server is busy, which is also defined as the traffic load ($\rho = \lambda/\mu$). Therefore, form (17), $P(c > 0)$ is given by

$$P(c > 0) = \rho = \frac{\lambda_{new}}{(1-p+p^{r+1})\mu} \tag{10}$$

Also, because a retransmission is always prior to a new packet transmission and we can separate the retransmission queue from the queuing model of SR-ARQ, $P(c_{rtx} = 0)$ is calculated as follows.

$$P(c_{rtx} = 0) = 1 - \rho_{rtx} = 1 - \frac{(p-p^{r+1})\lambda_{new}}{(1-p+p^{r+1})\mu} \tag{11}$$

where $\rho_{rtx} = \lambda_{rtx}/\mu$. Consequently, if we assume that λ_{new} and p are given, $E[d_{new}]$ is expressed with all known values as follows.

$$E[d_{new}] = \frac{(1-p+p^{r+1})^2}{s(1-p)(p-p^{r+1})\lambda_{new}^2} \tag{12}$$

d_{rtx} is defined as the time from a retransmission failure to detecting it at the receiver, and $E[d_{rtx}] = t_{rto} - t_{rtt}$ because a retransmission loss can be detected by only the NAK timer's expiration.

4. Results and Discussion

The mean transport delay statistics for the NAK-based SR-ARQ protocol have been computed according to the above analysis model for various values of the packet loss rate (PLR) and the retransmission persistence. To test the accuracy, we performed simulations using the OPNET simulator [8]. For simulations, a NAK-based SR-ARQ protocol is implemented. The implementation includes three parts, a NAK-based SR-ARQ transmitter, a NAK-based SR-ARQ receiver, and a wireless link connecting the transmitter and receiver. The simulation parameters are summarized in Table I.

Figure 3 shows the mean transport delay, obtained by the analysis model, as a function of PLR in the heavy traffic load condition assuming the Poisson packet arrivals. The overall results show that every line of the transport delay increases as PLR increases. Another general observation is that larger values of r produce longer transport delays. A high value of PLR introduces a large number of retransmission failures that correspond to a large number of RTOs. On the other hand, the SR-ARQ protocol can limit the increase of the transport delay with a high PLR by using a low retransmission persistence. Figure 4 shows the effect of the retransmission persistence on the mean transport delay. When the PLR is low (0.1), the SR-ARQ protocol shows low transport delay regardless of the retransmission persistence. In case of high PLR (0.25), as the

Table 1. Simulation Parameters

parameter	value
λ_{new}	$10 \sim 80$ (packets per sec)
service rate of SR-ARQ	200 (packets per sec)
packet size of SR-ARQ	300 bytes
retransmission persistence (r)	$1 \sim 10$
the transmission queue size	infinity
the retransmission queue size	infinity
NAK timer value	200 msec
round-trip time (RTT)	50 msec
packet loss rate	$0.01 \sim 0.25$

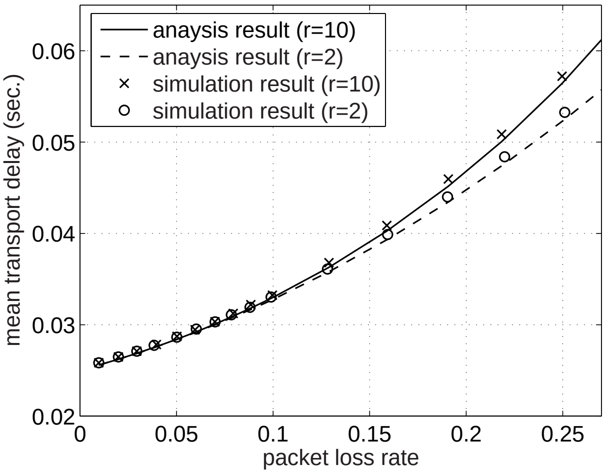

Figure 3. The mean transport delay as a function of p, for heavy traffic load ($\rho_{new} = 0.7$)

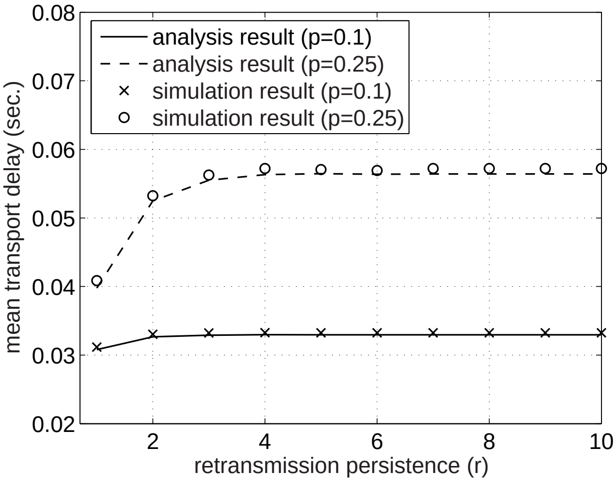

Figure 4. The mean transport delay as a function of r, for heavy traffic load ($\rho_{new} = 0.7$)

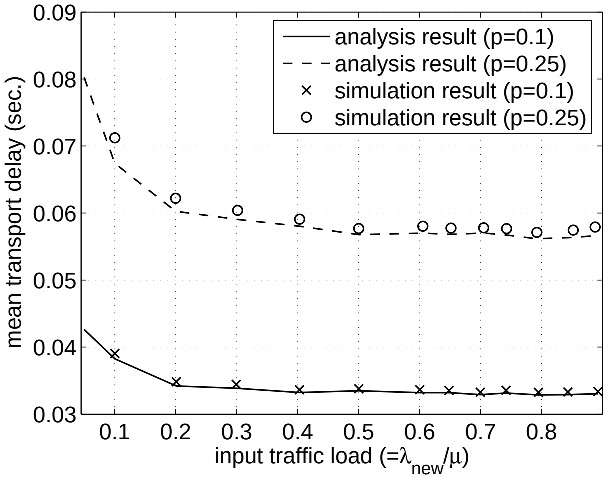

Figure 5. The mean transport delay as a function of traffic load; retransmission persistence = 10

SR-ARQ protocol allows more retransmissions, the transport delay also increases. However, when the retransmission persistence adopted by the SR-ARQ protocol is more than 4, we can confirm that the effect of the retransmission persistence on the transport is not much. The reason is that most packet losses are recovered until the number of retransmission attempts reaches the maximum number of retransmissions allowed by the SR-ARQ protocol.

Figure. 5. shows the effect of the traffic on the mean transport delay. When the traffic amount is large, the SR-ARQ protocol is able to detect a packet loss more quickly rather than when the traffic amount is small. If a packet is lost in transit, the receiver side of the SR-ARQ protocol can detect it only after receiving the following packet that is successfully delivered with no error by making a check on the sequence number. Therefore, as the transmitter sends more new packets, the receiver side has more opportunity to detect a packet loss. After all, as the traffic amount increases, the mean transport delay decreases. In case of RLP [6], the effect of the traffic on the SR-ARQ performance is minimized by using an idle control message. When there is no packet to be sent, the RLP transmitter sends an idle message to the RLP receiver with a sequence number of the following packet to be sent. By receiving the idle message, the RLP receiver can detect a packet loss with a check on the sequence number.

5. Conclusion

In this paper, we have introduced a simple analytical model for the mean transport delay of the NAK-based SR-ARQ protocol. Our analysis model showed the effects of the retransmission persistence and the traffic load on the transport delay, which can be also used to evaluate the loss recovery procedure of SR-ARQ. The simulation results have showed a good agreement with the analytical predictions. We expect that various retransmission schemes can be evaluated and compared by using the proposed analysis model.

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