Analysis of Enhanced Radio Link Control for W-CDMA Networks

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SUMMARY

Radio Link Control (RLC) is a link-layer protocol that is responsible for error recovery and flow control in UMTS 3G cellular systems. Compared to its counterpart developed for CDMA-2000 systems, *i.e.*, Radio Link Protocol (RLP), RLC is a more advanced protocol and can support different QoS requirements desired by the users. However, the setup of the RLC parameters such as transmission/receive window sizes, poll timer and poll-prohibit timer can have significant impact on the RLC throughput and delay performance, which inevitably affects the performance of the higher-layer protocols such as TCP. Although its configuration can be tweaked by trial and error, RLC still suffers from the inefficiencies inherent to its ACK/NACK reporting mechanism.

Except for minor enhancements, RLC has not been modified since its introduction in the early stages of UMTS development. In this study, we exemplify the problems associated with the ACK/NACK reporting mechanism and discuss a solution approach proposed by Qualcomm to the 3GPP RAN WG2 standardization group. The proposed approach features a new enhanced status report mechanism that can recover the lost packets faster without compromising the transmission of new packets. Naturally, a link-layer protocol with a faster and more efficient error-control mechanism enables higher-layer protocols to utilize the available resources more efficiently and perform better. In particular, High-Speed Downlink Packet Access (HSDPA) and Enhanced Uplink (EUL) systems, which will be available in the upcoming W-CDMA releases, will greatly benefit from the enhanced RLC protocol in offering substantially improved bandwidth to mobile users.

Overview of RLC:

Radio Link Control (RLC) provides error-control and flow-control functionalities at the link layer between the mobile station (MS) and the base-station controller (BSC) in W-CDMA networks. Depending on the network configuration, one-way delay between an MS and the BSC usually varies between 30 - 100 ms. Hence, RLC may operate with round-trip times as large as 200 ms. This is important since a large RTT delays the packet delivery to the other end, and further degrades the performance in case of lost packets.

When operating in Acknowledged Mode (RLC-AM), RLC receiver sends status reports to the RLC transmitter in order to control the data flow. These reports contain the sequence numbers of the received and missing packets, *i.e.*, ACKs and NACKs. A status report can be generated through any of the following:

- Periodic Status Reports: The receiver generates a report at fixed time intervals.
- Missing Protocol Data Unit (PDU): The receiver generates a report when it detects a gap in the sequence numbers of the received PDUs.
- Reception of a Poll: The receiver generates a report when a PDU with the poll bit set is received.

The poll bit resides in the RLC-AM header. The transmitter can set the poll periodically, or when it transmits the last PDU in the transmission/retransmission buffer, or when the poll timer expires and a status report has not been received, or every time a PDU is transmitted.

Naturally, when a status report is sent by the receiver, the subsequent report should not be sent before waiting for at least one RTT. This is because each status report contains the NACKs corresponding to all outstanding missing packets, and spurious retransmissions can be triggered if sufficient time is not allowed for a retransmission. To this effect, RLC employs a status-prohibit mechanism to regulate the transmission of the status reports. As a rule of thumb, the status-prohibit timer should be set to a value slightly longer than the mean RTT. This allows the RLC transmitter to perform a retransmission before a new NACK is generated.

Unfortunately, while this approach is useful in avoiding spurious retransmissions, it has two major drawbacks. First, delaying the NACK messages for the lost packets, which are identified after the last status report is sent, increases the error-recovery time. We illustrate this point in Figure 1, where the delivery of the PDU (#6) is largely affected by the deferred NACK. Clearly, it takes a certain amount of time between the detection of a lost packet and the transmission of the corresponding NACK. If we assume that packet losses occur independently and a status report is sent at every one RTT, then this certain amount of time averages half of an RTT duration. This waiting time is totally redundant and will be directly added to the error-recovery time.

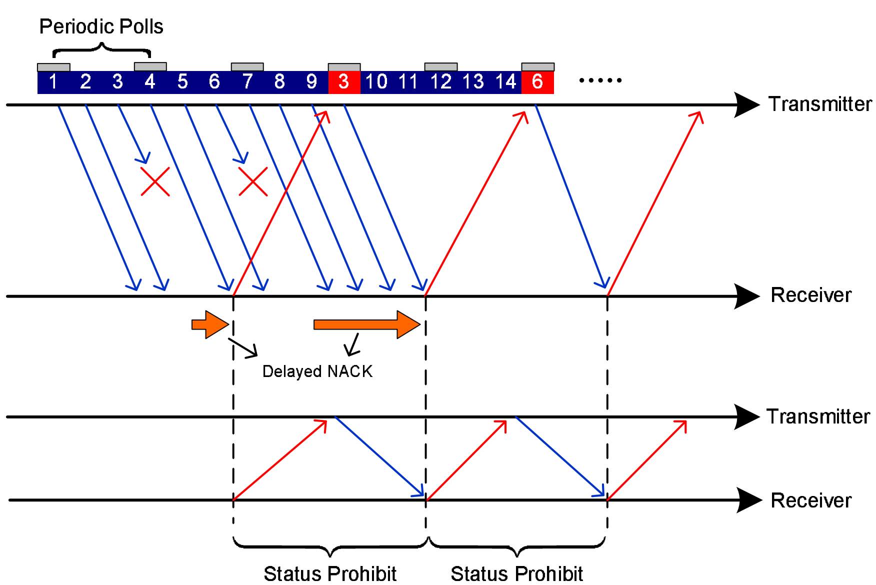

Fig. 1. Status-prohibit mechanism in RLC.

The second impact of sending a single status report per RTT is that delaying the ACK messages can stall the transmission of new PDUs. This is because of the window and flow control mechanisms used by RLC. Similar to TCP, reception of an ACK advances the transmission window and enables the transmission of new packets. If the adopted window size is large enough in the sense that it can hold several multiples of the number of bits that can be transmitted during one RTT, delaying ACK messages will not have any effect. However, for systems with high transmission rates such as HSDPA or for the systems experiencing large RTTs, the default buffers can be easily overdrawn. Subsequently, the transmission stalls until some packets are ACKed and the window is advanced.

Proposed Approach:

In an effort to solve the problems associated with the RLC status-report mechanism, Qualcomm recently submitted a proposal to the 3GPP RAN WG2 standardization group. Essentially, the main idea is to separate the ACK and NACK reports and send them as it is necessary. Whenever the receiver infers a missing PDU, it can inform the transmitter with a NACK message that includes only the sequence number of this particular PDU. In doing so, not only the error-recovery time is reduced but also any potential unnecessary retransmission for other outstanding missing PDUs is avoided. Of course, if the PDU is not recovered within a certain amount of time, which is referred to as *NACK-Prohibit Timer*, a new retransmission request is sent out. Since a separate NACK message is reported for each missing PDU, this scheme can potentially increase the feedback traffic. Fortunately, NACK reports can safely include the ACKs, which implicitly obviates the necessity of sending separate ACK messages. For example, in Figure 2 the PDU (#6) is delivered right after the PDU (#11) without incurring any additional delay. In addition, despite the increased NACK traffic, the total number of generated messages is kept the same with respect to the non-enhanced RLC.

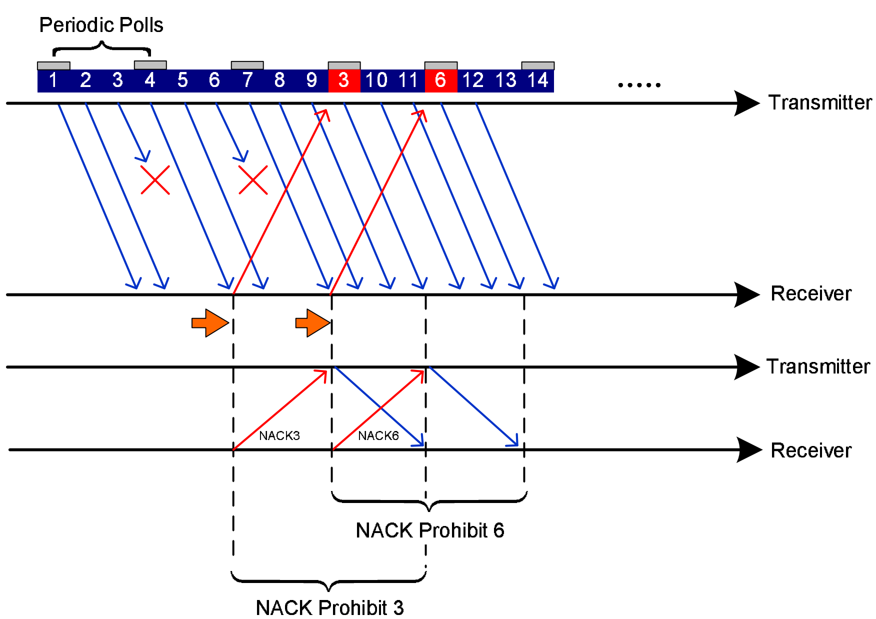

Fig. 2. Proposed NACK-prohibit mechanism for enhanced RLC.

The preliminary simulation results indicate that enhanced RLC can achieve up to 10% more throughput compared to the non-enhanced RLC. This improvement provides substantial delay reductions, particularly when the transmitted data is small relative to the bandwidth-delay product of the channel. Hence, systems featuring high bandwidth such as HSDPA and EUL will be only able to perform at their true potential with the enhanced RLC protocol. Our poster will provide a comparative performance analysis of the enhanced and non-enhanced RLC, and RLP protocols.