Flow Control and Error Control Protocols Go-Back-N ARQ and Selective Repeat ARQ

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1 Introduction

In data communication systems, the **Data Link Layer** is responsible for reliable node-to-node delivery of frames. Two key mechanisms are used to achieve this reliability:

- **Flow Control**: Prevents the sender from overwhelming the receiver.
- **Error Control**: Detects and corrects transmission errors.

Automatic Repeat reQuest (ARQ) protocols combine both mechanisms using acknowledgments, timers, and retransmissions. This tutorial focuses on two widely used sliding window ARQ protocols:

- Go-Back-N (GBN) ARQ
- Selective Repeat (SR) ARQ

2 Stop-and-Wait vs Sliding Window

Stop-and-Wait allows only one outstanding frame, leading to poor utilization on long-delay links. Sliding window protocols improve efficiency by allowing multiple frames to be in transit simultaneously.

- Go-Back-N: Simple receiver, higher retransmission overhead
- Selective Repeat: Complex receiver, better bandwidth efficiency

3 Go-Back-N (GBN) ARQ

3.1 Operating Principle

- Sender window size = N
- Receiver window size = 1
- Frames are numbered modulo 2^k
- Receiver accepts only in-order frames

If a frame is lost or corrupted, the receiver discards that frame and all subsequent frames. The sender retransmits the errored frame and all following frames in the window.

3.2 Sequence Number Requirement

$$2^k \geq N + 1$$

This prevents ambiguity between old and new frames.

3.3 Efficiency of Go-Back-N (No Errors)

Let:

- T_f = Frame transmission time
- T_p = One-way propagation delay
- $a = \frac{T_p}{T_f}$
- N = Window size

Total time for one cycle:

$$T = T_f + 2T_p = T_f(1 + 2a)$$

Efficiency

$$\eta = \begin{cases} \frac{N}{1+2a}, & \text{if } N < 1 + 2a \\ 1, & \text{if } N \geq 1 + 2a \end{cases}$$

Full utilization condition:

$$N \geq 1 + 2a$$

3.4 Efficiency of Go-Back-N (With Frame Errors)

Let p be the probability of frame error.

$$\boxed{\eta_{GBN} = \frac{N(1-p)}{1 + 2a + (N-1)p}}$$

Observation:

- Performance degrades rapidly with increasing p
- Large window sizes amplify retransmission overhead

4 Selective Repeat (SR) ARQ

4.1 Operating Principle

- Sender window size = N
- Receiver window size = N
- Receiver buffers out-of-order frames
- Individual acknowledgments for each frame

Only the erroneous frames are retransmitted, making SR more bandwidth-efficient than GBN.

4.2 Sequence Number Requirement

$$2^k \geq 2N$$

This avoids confusion between new frames and retransmitted frames.

4.3 Efficiency of Selective Repeat (No Errors)

$$\eta_{SR} = \begin{cases} \frac{N}{1+2a}, & \text{if } N < 1 + 2a \\ 1, & \text{if } N \geq 1 + 2a \end{cases}$$

Same as GBN in error-free conditions.

4.4 Efficiency of Selective Repeat (With Errors)

$$\boxed{\eta_{SR} = \frac{N(1-p)}{1+2a}}$$

Key Advantage: Retransmission cost does not depend on window size.

5 Comparison of ARQ Protocols

Table 1: Comparison of ARQ Protocols

Parameter	**Stop-and-Wait**	**Go-Back-N**	**Selective Repeat**
Outstanding frames	1	N	N
Receiver buffering	No	No	Yes
ACK type	Individual	Cumulative	Individual
Retransmission	Single frame	Window frames	Only lost frames
Sequence space	2	$N + 1$	$2N$
Efficiency (high delay)	Very low	Medium	High
Implementation complexity	Very low	Low	High

5.1 Efficiency of Go-Back-N ARQ with Frame Errors

In practical communication systems, frame transmission is subject to errors due to noise, interference, and channel impairments. Let the probability that a transmitted frame is received in error be denoted by p. Consequently, the probability of successful frame reception is $(1 - p)$.

5.1.1 Definition of Efficiency

The efficiency of an ARQ protocol is defined as the ratio of the expected useful transmission to the expected total transmission time. In the context of Go-Back-N ARQ, useful transmission corresponds to frames that are successfully delivered to the receiver without errors.

5.1.2 System Parameters

Let:

- T_f denote the frame transmission time,
- T_p denote the one-way propagation delay,
- $a = \frac{T_p}{T_f}$ denote the normalized propagation delay,
- N denote the sender window size,
- p denote the probability of frame error.

The acknowledgment transmission time is assumed to be negligible.

5.1.3 Baseline Time without Errors

In the absence of transmission errors, the sender transmits frames continuously until the pipeline is filled and then waits for acknowledgments. The total normalized time required for one transmission cycle is given by:

$$T_{\text{baseline}} = T_f + 2T_p = T_f(1 + 2a)$$

This represents the minimum cycle time required to transmit frames and receive acknowledgments.

5.1.4 Expected Useful Transmission

In Go-Back-N ARQ, the sender transmits N frames in one window. Since each frame is successfully received with probability $(1 - p)$, the expected number of correctly delivered frames per window is:

$$\text{Expected useful frames} = N(1 - p)$$

This term represents the numerator of the efficiency expression.

5.1.5 Retransmission Overhead in Go-Back-N

A key characteristic of Go-Back-N ARQ is its retransmission behavior in the presence of errors. When a frame is received in error:

- The receiver discards the erroneous frame.
- All subsequent frames in the current window are also discarded, even if they were correctly received.
- The sender retransmits the erroneous frame along with all following frames in the window.

On average, a single frame error causes the retransmission of $(N-1)$ additional frames. Since a frame error occurs with probability p, the expected retransmission overhead per window is proportional to $(N - 1)p$.

5.1.6 Total Expected Transmission Time

Combining the baseline transmission time and the retransmission overhead, the total normalized transmission time becomes:

$$T_{\text{total}} = 1 + 2a + (N-1)p$$

5.1.7 Efficiency Expression

The efficiency of Go-Back-N ARQ in the presence of frame errors is therefore given by:

$$\boxed{\eta_{\text{GBN}} = \frac{N(1-p)}{1 + 2a + (N-1)p}}$$

5.1.8 Interpretation

The derived expression highlights the inherent limitation of Go-Back-N ARQ:

- As the frame error probability p increases, efficiency decreases rapidly.
- Larger window sizes amplify the retransmission penalty due to the $(N-1)p$ term.
- This behavior explains why Go-Back-N performs poorly in high-error or wireless environments.

5.1.9 Special Case: Error-Free Channel

When $p = 0$, the efficiency expression reduces to:

$$\eta_{\text{GBN}} = \frac{N}{1 + 2a}$$

which corresponds to the well-known efficiency of Go-Back-N ARQ in an error-free channel.

6 Real-World Implementations

- **Stop-and-Wait**: Used in simple embedded and sensor networks
- **Go-Back-N**: Used in HDLC, early data link protocols
- **Selective Repeat**: Used conceptually in TCP (with enhancements)

Modern protocols adaptively switch behavior based on network conditions.

7 Checking Protocol Behavior in Your OS

Students can observe sliding window behavior using TCP analysis.

7.1 Using Wireshark

- Capture TCP packets
- Observe sequence numbers and ACKs
- Identify cumulative acknowledgments and retransmissions

7.2 Linux Command

```
sysctl net.ipv4.tcp_window_scaling
```

7.3 Key Observation

TCP resembles Selective Repeat but uses:

- Cumulative ACKs
- Selective Acknowledgment (SACK)
- Adaptive congestion control

8 Summary

- Go-Back-N is simpler but inefficient in noisy links
- Selective Repeat offers superior efficiency at higher complexity
- Both are foundational to modern reliable transport protocols

Exam Tip: Efficiency formulas and sequence number constraints are frequently asked in GATE and interviews.