Ch. 4 Homework Overview (1/4)

• P4.1: Describe a scenario showing why frame sequence numbers for the stop-and-wait protocol
  – Fig. 4.5 and Part 1 of Ch. 4 lecture notes consider why numbered ACK messages are needed
  – Sequence numbers needed for information frames as well for duplicate detection (Section 4.5.1.3)
Ch. 4 Homework Overview (2/4)

- P4.2: Go-back-$N$ ARQ protocol with $n$-bit sequence number
  - $W_{RX}$ ≡ Receive window size (at RX)
  - $W_{TX}$ ≡ Transmit window size (at TX)
  - What are $W_{TX}$ and $W_{RX}$ as functions of $n$?
    - Go-back-$N$ requires in-sequence frame delivery
    - Need to avoid frame number ambiguity

Ch. 4 Homework Overview (3/4)

- P4.3: Repeat P4.2 for selective-reject ARQ
  - Still need to avoid frame number ambiguity
  - Formulate inequality between $W_{TX}$, $W_{RX}$ and $n$
  - What if we want the RX to buffer any frame sent by the TX?
  - How does setting $W_{RX} > W_{TX}$ impact performance (e.g., $\eta$)?
Ch. 4 Homework Overview (4/4)

- P4.9: Selective-repeat (i.e., selective-reject) ARQ
  - Channel bit rate $R = 1$ Mbps
  - Frame length $L = 1000$ bits
  - Probability of unsuccessful frame transmission $p = 0.01$
  - Frame errors are independent
  - $\tau, T_F >> T_P, T_{ACK} \approx 0$

  a) Find average number of transmissions per frame ($N_{TX}$)
  b) What is the protocol efficiency $\eta$ given window size $W = 4$?

What is $\eta$ for $a = \tau / T_F = \{1, 2, 3, 4, 5, 6\}$?

See Section 4.7.2

Stop-and-Wait ARQ Efficiency (1/4)

- $T_{OUT}$ ≡ Duration of timeout interval
- $T_S$ ≡ Duration for a successful transmission interval
- $T_E$ ≡ Overhead associated with transmission error

$$T_{OUT} \geq 2 \cdot \tau + T_P + T_{ACK}$$

Figure 4.3
Stop-and-Wait ARQ Efficiency (2/4)

\[ T_S = T_F + 2 \cdot \tau + T_P + T_{ACK} \]

\[ T_E = T_F + T_{OUT} \geq T_F + 2 \cdot \tau + T_P + T_{ACK} \]

Stop-and-Wait ARQ Efficiency (3/4)

- \( P_E \equiv \text{Probability of unsuccessful transmission} \)
- \( N_{TX} \equiv \text{Number of frame transmissions required for successful receipt at the RX} \)

\[
N_{TX} = \sum_{k=1}^{\infty} k \cdot P_E^{k-1} \cdot (1 - P_E) = \frac{1}{1 - P_E} \quad \text{Eq. 4.2}
\]

\[
T_{\text{TOTAL}} = T_E \cdot (N_{TX} - 1) + T_S
\]

\[
\Rightarrow T_{\text{TOTAL}} = \frac{(T_F + T_{OUT}) \cdot P_E + 2 \cdot \tau + T_P + T_{ACK}}{1 - P_E}
\]

\[
\eta = \frac{(1 - P_E) \cdot T_F}{(T_F + T_{OUT}) \cdot P_E + (T_F + 2 \cdot \tau + T_P + T_{ACK}) \cdot (1 - P_E)} \quad \text{Eq. 4.3}
\]

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Stop-and-Wait ARQ Efficiency (4/4)

• Suppose $T_P, T_{ACK} \ll \tau, T_F$ and $P_E \approx 0$:

\[
\eta = \frac{(1 - P_E) \cdot T_F}{(T_F + T_{OUT}) \cdot P_E + (T_F + 2 \cdot \tau + T_p + T_{ACK}) \cdot (1 - P_E)} \quad \text{Eq. 4.3}
\]

\[
\Rightarrow \eta \approx \frac{T_F}{T_F + 2 \cdot \tau} = \frac{1}{1 + 2 \cdot \tau/T_F}
\]

- $\tau$ is due to propagation distance ($d$) and speed ($v$)
- $T_F$ is a function of frame length ($L_F$) and transmission rate ($R$)
- Large $d$ (e.g., satellite communications) or $R$ (e.g., Gigabit Ethernet) yields low $\eta$ for stop-and-wait

\[
\tau = d/v, \quad T_f = L_F/R \quad \Rightarrow \eta/T_F = \frac{d \cdot R}{L \cdot v}
\]

Sliding Window Efficiency (1/3)

• Assume $T_{ACK}, T_P \ll \tau, T_F$.
• Two cases to consider:
  1. $W \times T_F \geq T_F + 2 \times \tau$
  2. $W \times T_F < T_F + 2 \times \tau$
• For initial analysis, assume error free transmission:

\[
\eta = \begin{cases} 
1 & \text{if } W \cdot T_F \geq T_F + 2 \cdot \tau \\
W \cdot T_F & \text{if } W \cdot T_F < T_F + 2 \cdot \tau \\
\end{cases}
\]

\[
\Leftrightarrow \eta = \begin{cases} 
1 & \text{if } W \geq 1 + 2 \cdot \tau/T_F \\
W & \text{if } W < 1 + 2 \cdot \tau/T_F \\
\end{cases} \quad \text{Eq. 4.6}
\]
Sliding Window Efficiency (2/3)

- Under noisy channel conditions, must consider the number of transmissions ($N_{TX}$):

\[
\Rightarrow \eta = \begin{cases} 
\frac{1}{N_{TX}} & \text{if } W \geq T_F + 2 \cdot \tau / T_F \\
\frac{W}{N_{TX}} & \text{if } W < T_F + 2 \cdot \tau / T_F 
\end{cases}
\]

- For selective-reject, $N_{TX}$ is modeled as a geometric RV with parameter $1 - P_E$ (i.e., Eq. 4.2):

\[
\Rightarrow \eta_{S-R} = \begin{cases} 
\frac{1 - P_E}{W \cdot (1 - P_E)} & \text{if } W \geq 1 + 2 \cdot \tau / T_F \\
\frac{1 + 2 \cdot \tau / T_F}{1 + 2 \cdot \tau / T_F} & \text{if } W < 1 + 2 \cdot \tau / T_F 
\end{cases}
\text{ Eq. 4.8}
\]

Sliding Window Efficiency (3/3)

- For the case of go-back-$N$:

\[
N_{TX} = \sum_{k=0}^{\infty} (1 + k \cdot N) \cdot P_E^k \cdot (1 - P_E) = 1 + \frac{N \cdot P_E}{1 - P_E}
\]

- For $W \times T_F \geq T_F + 2 \times \tau$:
  - Time to get ACK or NACK is approximately $2 \times \tau$
  - $N \times T_F \approx T_F + 2 \times \tau \rightarrow N \approx 1 + 2 \times \tau / T_F$

\[
\Rightarrow N_{TX} \approx 1 + \frac{(1 + 2 \cdot \tau / T_F) \cdot P_E}{1 - P_E}
\]

- For $W \times T_F < T_F + 2 \times \tau$, $N = W$ \Rightarrow $N_{TX} = 1 + \frac{W \cdot P_E}{1 - P_E}$