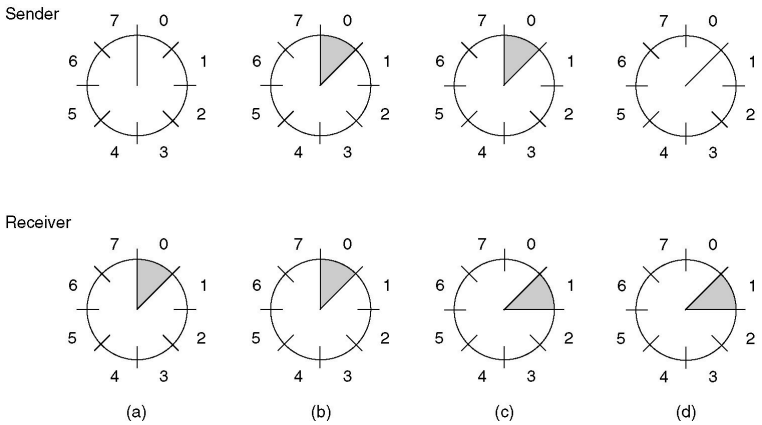
Sliding Windows Protocols

- A One-Bit Sliding Window Protocol
- A Protocol Using Go Back N
- A Protocol Using Selective Repeat

Introduction

- Full Duplex _____
- Possible to send acknowledgements by piggybacking: _____
  - Advantages: _____
  - Problem: _____
- Each frame travelling in each direction is identified using **sequence numbers**
  - Range: 0 .. 2^n-1 where _____
  - Sending window: _____
    - Keep frames _____
    - Refuse network layer _____
  - Receiving window _____
    - Pass to network layer _____

Example



One-Bit Protocol

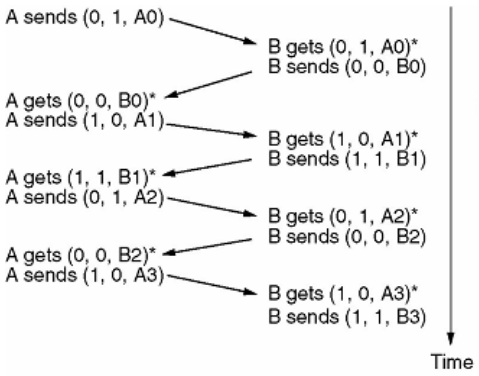

```
#define MAX_SEQ 1
typedef enum {frame_arrival, cksum_err, timeout} event_type;
#include "protocol.h"
void protocol4 (void)
{
  seq_nr next_frame_to_send = 0;
  seq_nr frame_expected = 0;
  frame r, s;
  packet buffer;
  event_type event;

  from_network_layer(&buffer);
  s.info = buffer;
  s.seq = next_frame_to_send;
  s.ack = 1 – frame_expected;
  to_physical_layer(&s);
  start_timer(s.seq);
```

Continued →

One-Bit Protocol


```
while (true) {
    wait_for_event(&event);
    if (event == frame_arrival) {
        from_physical_layer(&r);
        if (r.seq == frame_expected) {
            to_network_layer(&r.info);
            inc(frame_expected);
        }
        if (r.ack == next_frame_to_send) {
            stop_timer(r.ack);
            from_network_layer(&buffer);
            inc(next_frame_to_send);
        }
    }
    s.info = buffer;
    s.seq = next_frame_to_send;
    s.ack = 1 – frame_expected;
    to_physical_layer(&s);
    start_timer(s.seq);
  }
}
```


One-Bit Protocol



Results

Simulating Protocol 4

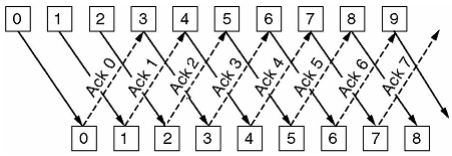
Events	100000
Timeout	30
pct_loss	20
pct_cksum	15

	Process 0	Process 1
Total data frames sent	10316	10289
Data frames lost	2073	2047
Data frames not lost	8243	8242
Frames retransmitted	2073	2045
Good ack frames rec'd	0	0
Bad ack frames rec'd	0	0
Good data frames rec'd	7008	7001
Bad data frames rec'd	1234	1242
Payloads accepted	4818	4818
Total ack frames sent	0	0
Ack frames lost	0	0
Ack frames not lost	0	0
Timeouts	2073	2045
Ack timeouts	0	0

Efficiency (payloads accepted/data pkts sent) = 46%
End of simulation. Time=100000

Pipelining

- We have been assuming that the Transmission time is negligible….
  - R _____
  - Time to send a frame = l / b _____
  - Utilisation = l / (l + b.R) _____

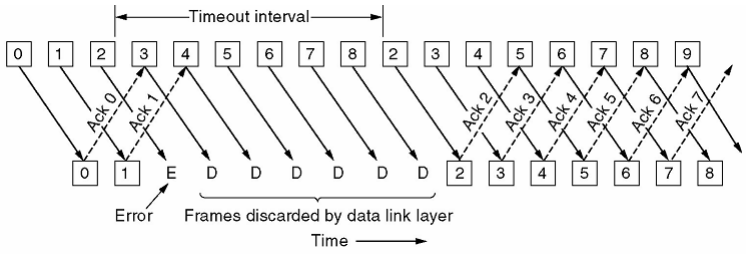


- Pipelining
  - Multiple outstanding frames _____
  - We need to consider Bandwidth * Propogation delay to _____

Pipelining – Errors

- If a frame is damaged _____
- Then retransmit, _____
- The timeout must be longer than _____

_____



Go–Back–N Protocol (1)


```
#define MAX_SEQ 7
typedef enum {frame_arrival, cksum_err, timeout, network_layer_ready} event_type;
#include "protocol.h"

static boolean between(seq_nr a, seq_nr b, seq_nr c)
{
  if (((a <= b) && (b < c)) || ((c < a) && (a <= b)) || ((b < c) && (c < a)))
      return(true);
    else
      return(false);
}

static void send_data(seq_nr frame_nr, seq_nr frame_expected, packet buffer[ ])
{
  frame s;
  s.info = buffer[frame_nr];
  s.seq = frame_nr;
  s.ack = (frame_expected + MAX_SEQ) % (MAX_SEQ + 1);
  to_physical_layer(&s);
  start_timer(frame_nr);
}
```

Continued →

Go–Back–N Protocol (2)


```
void protocol5(void)
{
  seq_nr next_frame_to_send = 0;
  seq_nr ack_expected = 0;
  seq_nr frame_expected = 0;
  frame r;
  packet buffer[MAX_SEQ + 1];
  seq_nr nbuffered = 0;
  seq_nr i;
  event_type event;

  enable_network_layer();
```

Continued →

Go–Back–N Protocol (3)


```
while (true) {
  wait_for_event(&event);

  switch(event) {
     case frame_arrival:
          from_physical_layer(&r);
          if (r.seq == frame_expected) {
               to_network_layer(&r.info);
               inc(frame_expected);
          }
          while (between(ack_expected, r.ack, next_frame_to_send)) {
               nbuffered = nbuffered – 1;
               stop_timer(ack_expected);
               inc(ack_expected);
          }
          break;
     case cksum_err:
          break;
```

Continued →

Go–Back–N Protocol (4)


```
    case network_layer_ready:
        from_network_layer(&buffer[next_frame_to_send]);
        nbuffered = nbuffered + 1;
        send_data(next_frame_to_send, frame_expected, buffer);
        inc(next_frame_to_send);
        break;
    case timeout:
        next_frame_to_send = ack_expected;
        for (i = 1; i <= nbuffered; i++) {
            send_data(next_frame_to_send, frame_expected, buffer);
            inc(next_frame_to_send);
        }
  }
  if (nbuffered < MAX_SEQ)
        enable_network_layer();
  else
        disable_network_layer();
 }
}
```


Results

Simulating Protocol 5

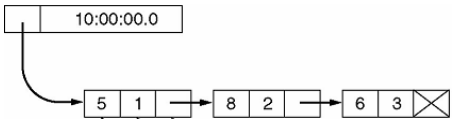
Events	100000
Timeout	30
pct_loss	20
pct_cksum	15

	Process 0	Process 1
Total data frames sent	22716	22364
Data frames lost	4570	4485
Data frames not lost	18146	17879
Frames retransmitted	17451	17143
Good ack frames rec'd	0	0
Bad ack frames rec'd	0	0
Good data frames rec'd	15178	15422
Bad data frames rec'd	2695	2724
Payloads accepted	5214	5260
Total ack frames sent	0	0
Ack frames lost	0	0
Ack frames not lost	0	0
Timeouts	2493	2449
Ack timeouts	0	0

Efficiency (payloads accepted/data pkts sent) = 23%
End of simulation. Time=100000

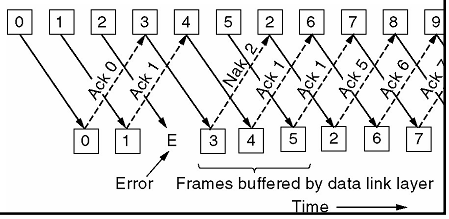
Comments

- Buffering
  - Required for all _____
  - Not needed for _____
- Assumes that acknowledgements are sent _____
  _____
- Multiple timers _____
  _____



Selective Repeat

- In the case of an error, rather than wait for a timeout send a NAK (_____). Either:
  - Go Back N: _____
  - Selective Repeat: _____
- Line utilization _____
- Buffering
  - Sent frames: _____
  - Received frames: _____



Selective Repeat Protocol (1)


```
#define MAX_SEQ 7
#define NR_BUFS ((MAX_SEQ + 1)/2)
typedef enum {frame_arrival, cksum_err, timeout, network_layer_ready, ack_timeout} event_type
#include "protocol.h"
boolean no_nak = true;
seq_nr oldest_frame = MAX- SEQ + 1;

static boolean between(seq_nr a, seq_nr b, seq_nr c)
{
  return ((a <= b) && (b < c)) || ((c < a) && (a <= b)) || ((b < c) && (c < a));
}

static void send_frame(frame_kind fk, seq_nr frame_nr, seq_nr frame_expected, packet buffer[ ])
{
  frame s;
  s.kind = fk;
  if (fk == data) s.info = buffer[frame_nr % NR_BUFS];
  s.seq = frame_nr;
  s.ack = (frame_expected + MAX_SEQ) % (MAX_SEQ + 1);
  if (fk == nak) no_nak = false;
  to_physical_layer(&s);
  if (fk == data) start_timer(frame_nr % NR_BUFS);
  stop_ack_timer();
}
```

Continued →

Selective Repeat Protocol (2)


```
void protocol6(void)
{
  seq_nr ack_expected = 0;
  seq_nr next_frame_to_send = 0;
  seq_nr frame_expected = 0;
  seq_nr too_far = NR_BUFS;
  int i;
  frame r;
  packet out_buf[NR_BUFS];
  packet in_buf[NR_BUFS];
  boolean arrived[NR_BUFS];
  seq_nr nbuffered = 0;
  event_type event;

  enable_network_layer();
  for (i = 0; i < NR_BUFS; i++) arrived[i] = false;

  while (true) {
    wait_for_event(&event);
    switch(event) {
      case network_layer_ready:
            nbuffered = nbuffered + 1;
            from_network_layer(&out_buf[next_frame_to_send % NR_BUFS]);
            send_frame(data, next_frame_to_send, frame_expected, out_buf);
            inc(next_frame_to_send);
            break;
```

Continued →

Selective Repeat Protocol (3)


```
case frame_arrival:
    from_physical_layer(&r);
    if (r.kind == data) {
        if ((r.seq != frame_expected) && no_nak)
            send_frame(nak, 0, frame_expected, out_buf); else start_ack_timer();
        if (between(frame_expected, r.seq, too_far)
                        && (arrived[r.seq%NR_BUFS] == false)) {
            arrived[r.seq % NR_BUFS] = true;
            in_buf[r.seq % NR_BUFS] = r.info;
            while (arrived[frame_expected % NR_BUFS]) {
                to_network_layer(&in_buf[frame_expected % NR_BUFS]);
                no_nak = true;
                arrived[frame_expected % NR_BUFS] = false;
                inc(frame_expected);
                inc(too_far);
                start_ack_timer();
            }
        }
    }
    if((r.kind==nak) && between(ack_expected,(r.ack+1)%(MAX_SEQ+1),next frame to send))
        send_frame(data, (r.ack+1) % (MAX_SEQ + 1), frame_expected, out_buf);
    while (between(ack_expected, r.ack, next_frame_to_send)) {
        nbuffered = nbuffered  1;
        stop_timer(ack_expected % NR_BUFS);
        inc(ack_expected);
    }
    break;
```

Continued →

Selective Repeat Protocol (4)


```
    case cksum_err:
        if (no_nak) send_frame(nak, 0, frame_expected, out_buf);
        break;
    case timeout:
        send_frame(data, oldest_frame, frame_expected, out_buf);
        break;
    case ack_timeout:
        send_frame(ack,0,frame_expected, out_buf);
  }
  if (nbuffered < NR_BUFS)  enable_network_layer(); else disable_network_layer();
 }
}
```

Results

Simulating Protocol 6

Events	100000
Timout	30
pct_loss	20
pct_cksum	15

Process 0		
Total data frames sent	15489	15237
Data frames lost	3163	3133
Data frames not lost	12326	12104
Frames retransmitted	6080	5997
Good ack frames rec'd	73	61
Bad ack frames rec'd	15	18
Good data frames rec'd	10346	10473
Bad data frames rec'd	1756	1853
Payloads accepted	7981	8086
Total ack frames sent	100	101
Ack frames lost	21	13
Ack frames not lost	79	88
Timeouts	6080	5997
Ack timeouts	100	101

Efficiency (payloads accepted/data pkts sent) = 52%
End of simulation. Time=100000

Comments

- Problem:
  - Given a 3 bit sequence number
  - Frames 0,1,2,3,4,5,6 received
  - Send an acknowledgement (of all frames up to 6)
  - What happens if the acknowledgement is lost?

    _____

    _____
- To overcome this _____

  _____
- We also need an explicit ACK in case there is no traffic in the reverse direction…
  - Timeout duration _____