Introduction to LAN/WAN

Data Link Layer (Part II)

Topics

- Introduction 
- Errors 
- Protocols ←
  - simple
  - sliding window
- Modeling **?**
- Examples **?**

Protocols Purpose

- Agreed means of communication between sender and receiver
- Handle reliability
- Handle flow control
- We'll move through basic to complex

Data Link Protocols

- Machine *A* wants stream of data to *B*
  - assume reliable, 1-way, connection-oriented
- Physical, Data Link, Network are all *processes*
- Assume:
  - **`to_physical_layer()`** to send frame
  - **`from_physical_layer()`** to receive frame
  - both do checksum
  - **`from_physical_layer()`** reports *success* or *failure*

Frame

- first 3 are control (*frame header*)
- *info* is data
- *kind*: tells if data, some are just control
- *seq*: sequence number
- *ack*: acknowledgements
- Network has *packet*, put in frame's *info*
- Header is not passed up to network layer

Tanenbaum's Protocol Definitions

```
#define MAX_PKT 1024                                    /* determines packet size in bytes */

typedef enum {false, true} boolean;                     /* boolean type */
typedef unsigned int seq_nr;                            /* sequence or ack numbers */
typedef struct {unsigned char data[MAX_PKT];} packet;/*    packet definition */
typedef enum {data, ack, nak} frame_kind;               /* frame_kind definition */

typedef struct {                                        /* frames are transported in this layer */
  frame_kind kind;                                      /* what kind of a frame is it? */
  seq_nr seq;                                           /* sequence number */
  seq_nr ack;                                           /* acknowledgement number */
  packet info;                                          /* the network layer packet */
} frame;
```

Continued →

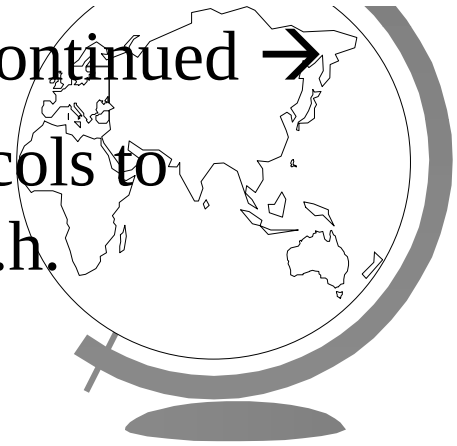


Figure 3-9. Some definitions needed in the protocols to follow. These are located in the file protocol.h.

Unrestricted Simplex Protocol

- Simple, simple, simple
- One-way data transmission (simplex)
- Network layers always ready
  - infinitely fast
- Communication channel error free
- “Utopia”

Figure 3-10

Unrestricted Simplex Protocol

```
/* Protocol 1 (utopia) provides for data transmission in one direction only, from
   sender to receiver.  The communication channel is assumed to be error free,
   and the receiver is assumed to be able to process all the input infinitely quickly.
   Consequently, the sender just sits in a loop pumping data out onto the line as
   fast as it can. */

typedef enum {frame_arrival} event_type;
#include "protocol.h"

void sender1(void)
{
  frame s;                              /* buffer for an outbound frame */
  packet buffer;                        /* buffer for an outbound packet */

  while (true) {
      from_network_layer(&buffer);      /* go get something to send */
      s.info = buffer;                  /* copy it into s for transmission */
      to_physical_layer(&s);            /* send it on its way */
  }                                      /* Tomorrow, and tomorrow, and tomorrow,
                                          Creeps in this petty pace from day to day
                                          To the last syllable of recorded time
                                              - Macbeth, V, v */
}

void receiver1(void)
{
  frame r;
  event_type event;                     /* filled in by wait, but not used here */

  while (true) {
      wait_for_event(&event);           /* only possibility is frame_arrival */
      from_physical_layer(&r);          /* go get the inbound frame */
      to_network_layer(&r.info);        /* pass the data to the network layer */
  }
}
```

Simplex Stop-and-Wait Protocol

- One-way data transmission (simplex)
- Communication channel error free
- Remove assumption that network layers are always ready
  - (or that receiver has infinite buffers)
- Could add timer so won't send too fast?
  - Why is this a bad idea?
- What else can we do?

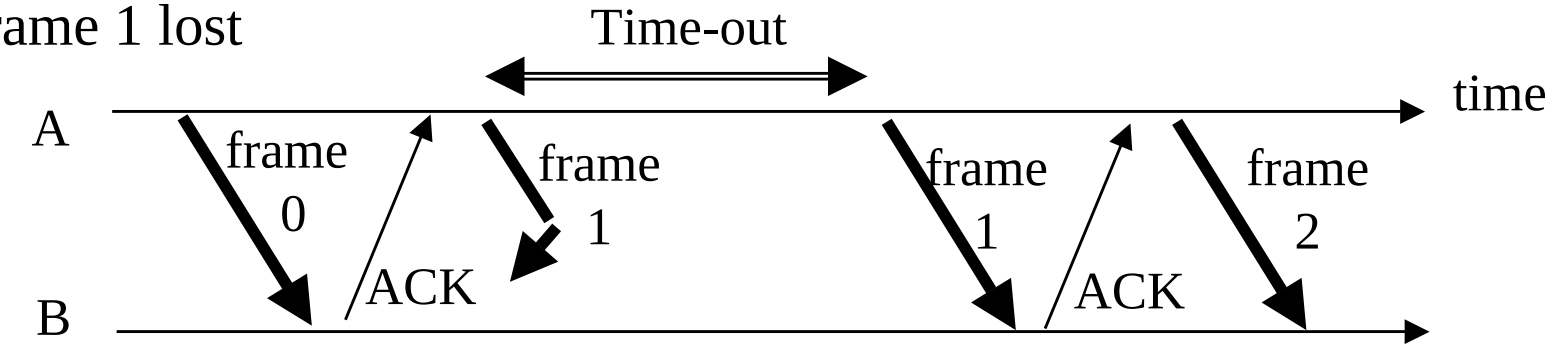
Figure 3-11

Simplex Stop-and-Wait Protocol

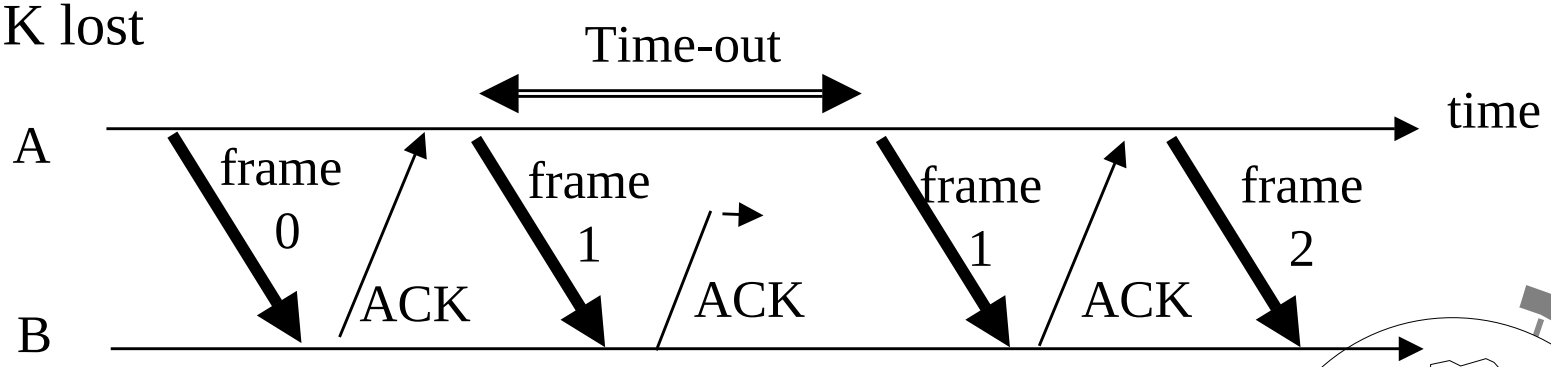
```
/* Protocol 2 (stop-and-wait) also provides for a one-directional flow of data from
   sender to receiver. The communication channel is once again assumed to be error
   free, as in protocol 1. However, this time, the receiver has only a finite buffer
   capacity and a finite processing speed, so the protocol must explicitly prevent
   the sender from flooding the receiver with data faster than it can be handled. */

typedef enum {frame_arrival} event_type;
#include "protocol.h"

void sender2(void)
{
  frame s;                              /* buffer for an outbound frame */
  packet buffer;                        /* buffer for an outbound packet */
  event_type event;                     /* frame_arrival is the only possibility */

  while (true) {
      from_network_layer(&buffer);      /* go get something to send */
      s.info = buffer;                  /* copy it into s for transmission */
      to_physical_layer(&s);            /* bye bye little frame */
      wait_for_event(&event);           /* do not proceed until given the go ahead */
  }
}

void receiver2(void)
{
  frame r, s;                           /* buffers for frames */
  event_type event;                     /* frame_arrival is the only possibility */
  while (true) {
      wait_for_event(&event);           /* only possibility is frame_arrival */
      from_physical_layer(&r);          /* go get the inbound frame */
      to_network_layer(&r.info);        /* pass the data to the network layer */
      to_physical_layer(&s);            /* send a dummy frame to awaken sender */
  }
}
```

Ambiguities with Stop-and-Wait [unnumbered frames]

(a) Frame 1 lost



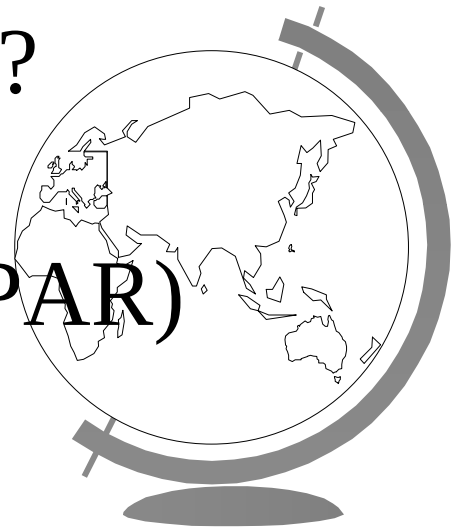
(b) ACK lost



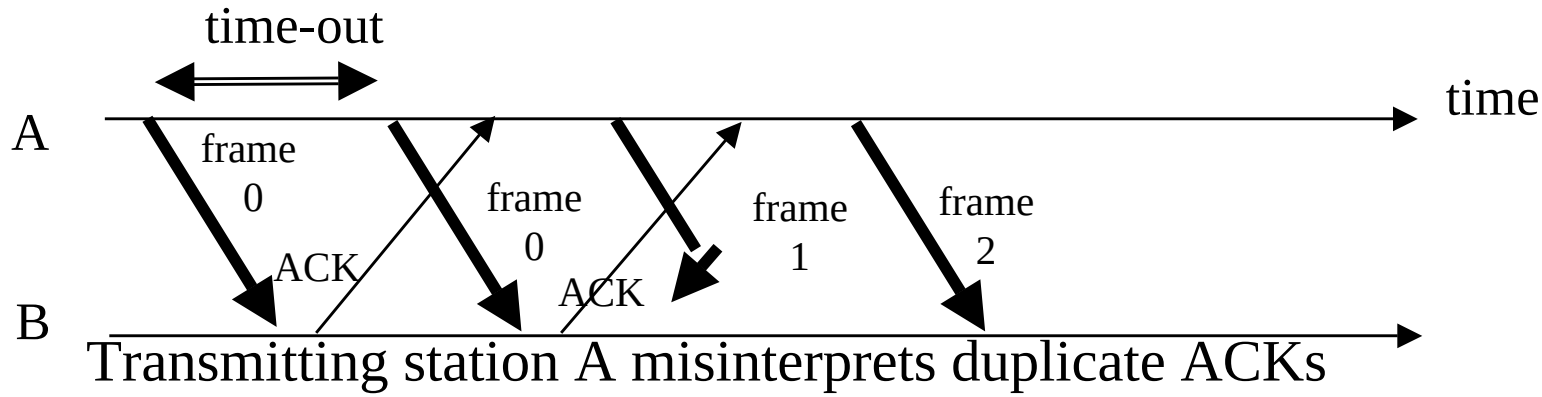
In parts (a) and (b) transmitting station A acts the same way, but part (b) receiving station B accepts frame 1 twice.

Simplex Protocol for Noisy Channel

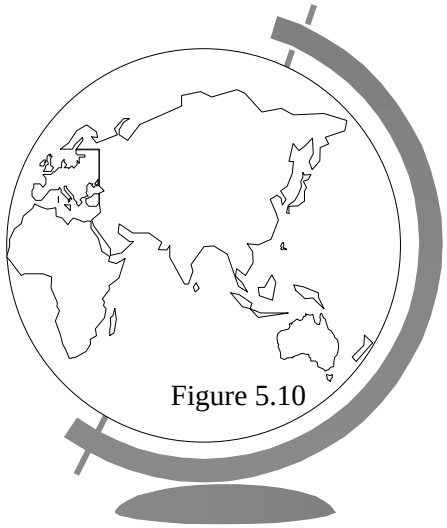
- One-way data transmission (simplex)
- Remove assumption that communication channel error free
  - frames lost or damaged
- Damaged frames not acknowledged
  - look as if lost
- Can we just add a timer in the sender?
  - Why not? (Hint: think of acks)
- Positive Ack with Retransmissions (PAR)



ACKs must ALSO be numbered!!
PAR problem:
Ambiguities when ACKs are not numbered



Transmitting station A misinterprets duplicate ACKs



PAR

Simplex Protocol for a Noisy Channel

```
/* Protocol 3 (par) allows unidirectional data flow over an unreliable channel. */

#define MAX_SEQ 1                                   /* must be 1 for protocol 3 */
typedef enum  {frame_arrival, cksum_err, timeout} event_type;
#include "protocol.h"

void sender3(void)
{
  seq_nr next_frame_to_send;                        /* seq number of next outgoing frame */
  frame s;                                          /* scratch variable */
  packet buffer;                                    /* buffer for an outbound packet */
  event_type event;

  next_frame_to_send = 0;                           /* initialize outbound sequence numbers */
  from_network_layer(&buffer);                      /* fetch first packet */
  while (true) {
      s.info = buffer;                              /* construct a frame for transmission */
      s.seq = next_frame_to_send;                   /* insert sequence number in frame */
      to_physical_layer(&s);                        /* send it on its way */
      start_timer(s.seq);                           /* if answer takes too long, time out */
      wait_for_event(&event);                       /* frame_arrival, cksum_err, timeout */
      if (event == frame_arrival) {
          from_physical_layer(&s);                  /* get the acknowledgement */
          if (s.ack == next_frame_to_send) {
              stop_timer(s.ack);                    /* turn the timer off */
              from_network_layer(&buffer);          /* get the next one to send */
              inc(next_frame_to_send);              /* invert next_frame_to_send */
          }
      }
  }
}
```

Figure 3-12.A **P**ositive **A**cknowledgement with **R**etransmission protocol.

Continued →

A Simplex Protocol for a Noisy Channel

```
void receiver3(void)
{
  seq_nr frame_expected;
  frame r, s;
  event_type event;

  frame_expected = 0;
  while (true) {
       wait_for_event(&event);                  /* possibilities: frame_arrival, cksum_err */
       if (event == frame_arrival) {            /* a valid frame has arrived. */
            from_physical_layer(&r);            /* go get the newly arrived frame */
            if (r.seq == frame  expected) {     /* this is what we have been waiting for. */
                 to_network_layer(&r.info);     /* pass the data to the network layer */
                 inc(frame_expected);           /* next time expect the other sequence nr */
            }
            s.ack = 1 – frame_expected;         /* tell which frame is being acked */
            to_physical_layer(&s);              /* send acknowledgement */
       }
  }
}
```

Figure 3-12.A positive acknowledgement with retransmission protocol.

Sliding Window Protocols

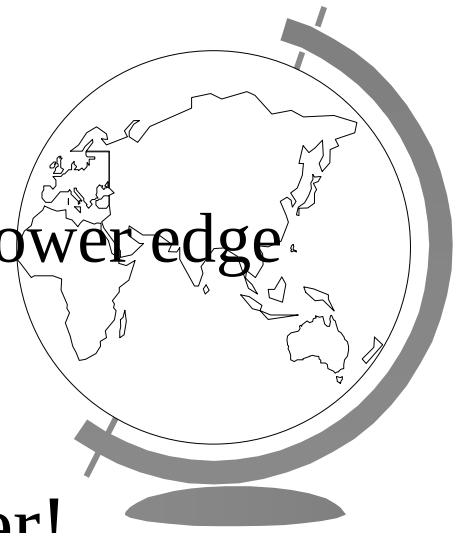
- Remove assumption that one-way data transmission
  - duplex
- Error prone channel
- Finite speed (and buffer) network layer

Two-Way Communication

- Seems efficient since acks already
- Have two kinds of frames (kind field)
  - Data
  - Ack (seq num of last correct frame)
- May want *data* with ack
  - delay a bit before sending data
  - *piggybacking* - add acks to data frames going other way
- How long to wait before just ack?

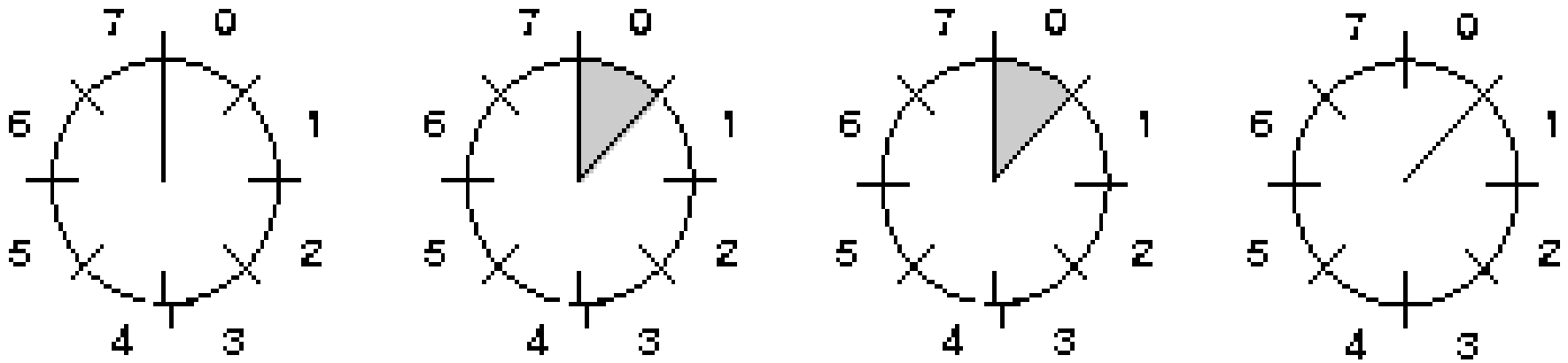
Sliding Window Protocols

- More than just 1 outstanding packet
  - "Window" of frames that are outstanding
- Sequence number is *n* bits, 2^{n-1}
- Sender has sending window
  - frames it can send (can change size): sent but no ACK
  - new packets from the Host cause the upper edge inside window to be incremented.
- Receiver has receiving window
  - frames it can receive (always same size)
  - ACKed frames from the receiver cause the lower edge inside window to be incremented
- Window sizes can differ
- Note, still passed to network layer in order!

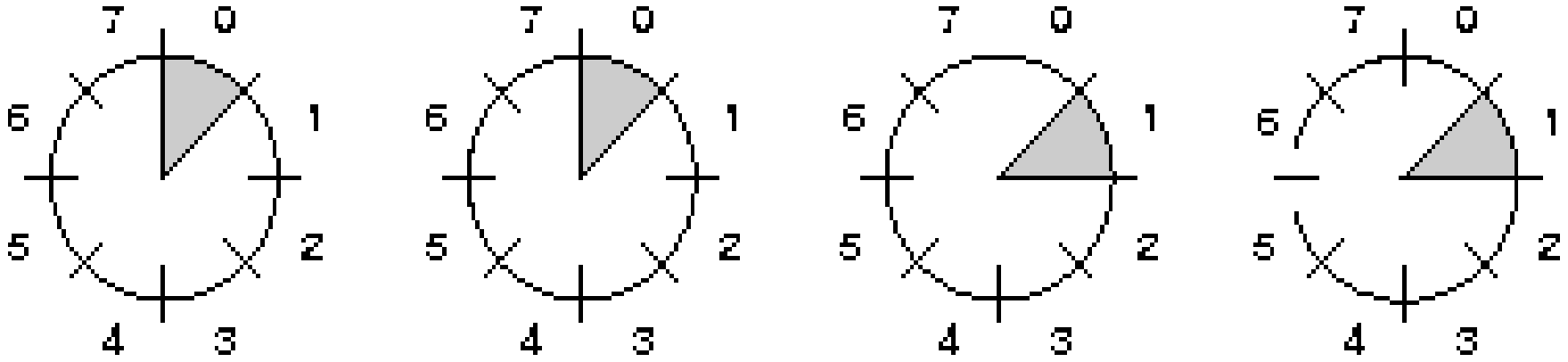


Sliding Window, Size 1

Sender



Receiver

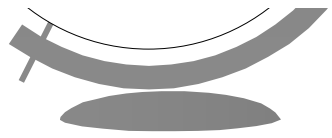


(a) (b) (c) (d)

1-Bit Sliding Window Protocol

```
void protocol4 (void)
{
  seq_nr next_frame_to_send;          /* 0 or 1 only */
  seq_nr frame_expected;              /* 0 or 1 only */
  frame r, s;                         /* scratch variables */
  packet buffer;                      /* current packet being sent */
  event_type event;

  next_frame_to_send = 0;             /* next frame on the outbound stream */
  frame_expected = 0;                 /* number of frame arriving frame expected */
  from_network_layer(&buffer);        /* fetch a packet from the network layer */
  s.info = buffer;                    /* prepare to send the initial frame */
  s.seq = next_frame_to_send;         /* insert sequence number into frame */
  s.ack = 1 – frame_expected;         /* piggybacked ack */
  to_physical_layer(&s);              /* transmit the frame */
  start_timer(s.seq);                 /* start the timer running */
```

(initialization)



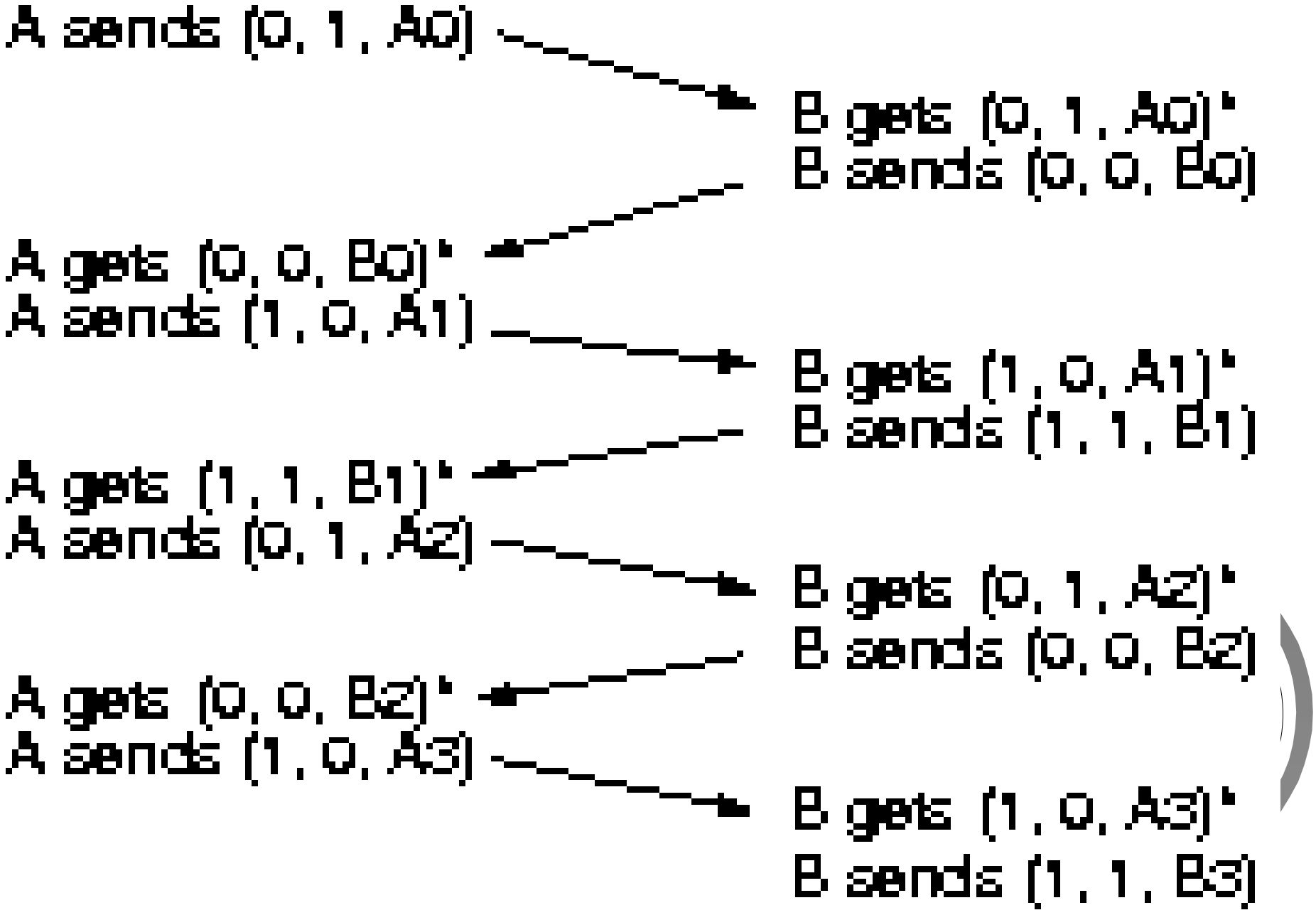
1-Bit Sliding Window Protocol

```
while (true) {
    wait_for_event(&event);              /* frame_arrival, cksum_err, or timeout */
    if (event == frame_arrival) { /* a frame has arrived undamaged. */
        from_physical_layer(&r);         /* go get it */

        if (r.seq == frame_expected) {
            /* Handle inbound frame stream. */
            to_network_layer(&r.info);   /* pass packet to network layer */
            inc(frame_expected);         /* invert sequence number expected next */
        }

        if (r.ack == next_frame_to_send) { /* handle outbound frame stream. */
            from_network_layer(&buffer);        /* fetch new pkt from network layer */
            inc(next_frame_to_send);     /* invert sender's sequence number */
        }
    }
    s.info = buffer;                     /* construct outbound frame */
    s.seq = next_frame_to_send;          /* insert sequence number into it */
    s.ack = 1 – frame_expected;          /* seq number of last received frame */
    to_physical_layer(&s);               /* transmit a frame */
    start_timer(s.seq);                  /* start the timer running */
}
```

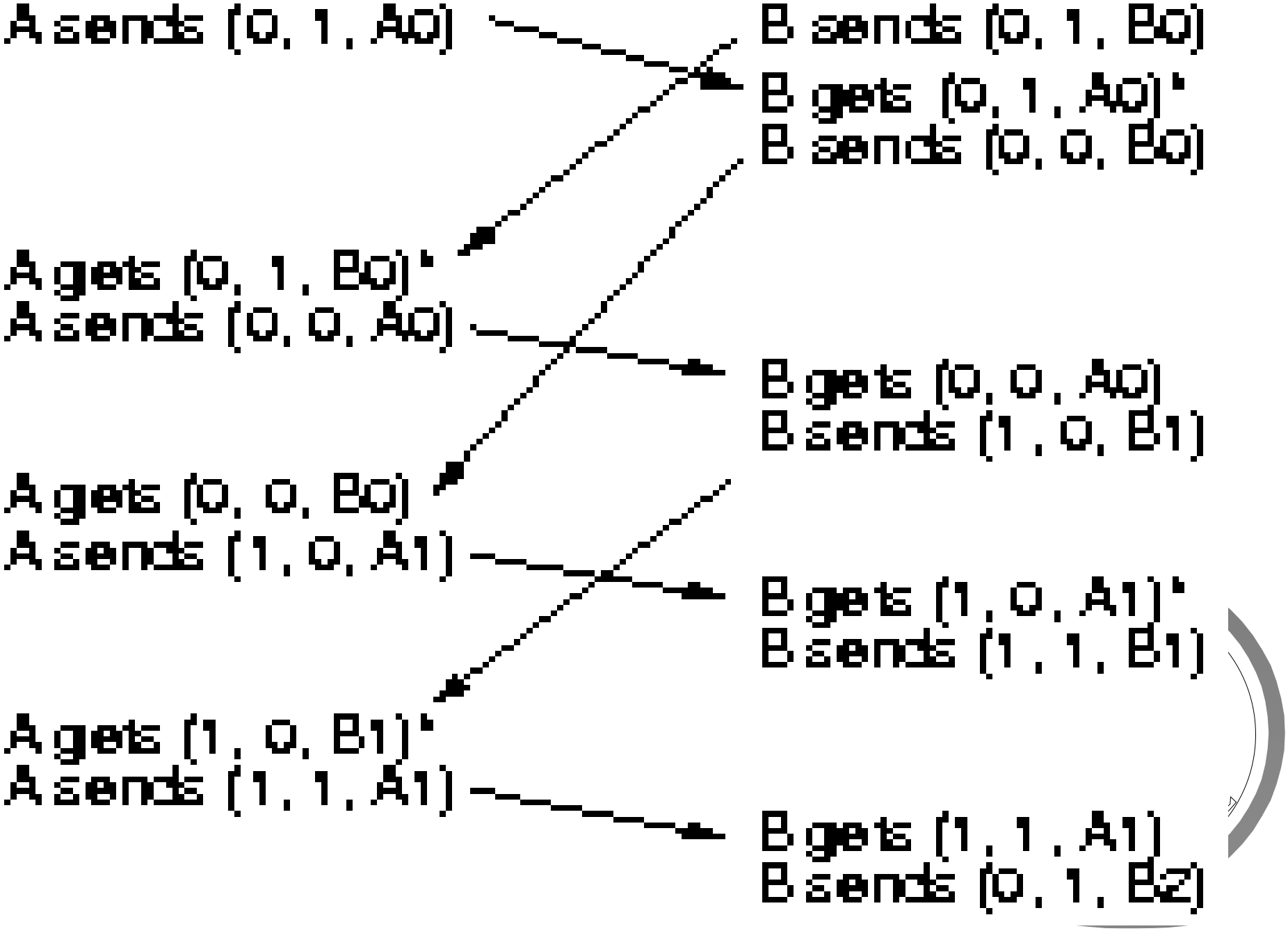
Does it Work?

- Consider A with a too-short time-out
- A sends: seq=0, ack = 1 over and over
- B gets 0, sets *frame_expected* to 1
  - will reject all 0 frames
- B sends A frame with seq=0, ack=0
  - eventually one makes it to A
- A gets ack, sets *next_frame_to_send* to 1
- Above scenario similar for lost/damaged frames or acknowledgements
- But … what about startup?

Normal Startup

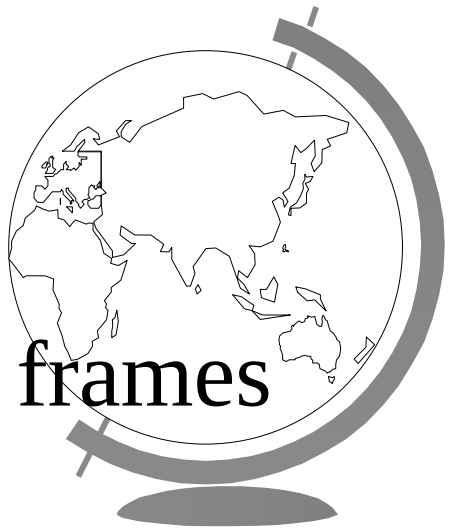


Abnormal Startup



Transmission Factors

- Assume a satellite channel, 500 msec rt delay
  - super small ack's
- 50 kbps, sending 1000-bit frames
- t = 0, sending starts
- t = 20 msec frame sent
- t = 270 frame arrives
- t = 520 ack back at sender
- 20 / 520 about 4% utilization!
- All of: long delay, high bwidth, small frames
- Solution?

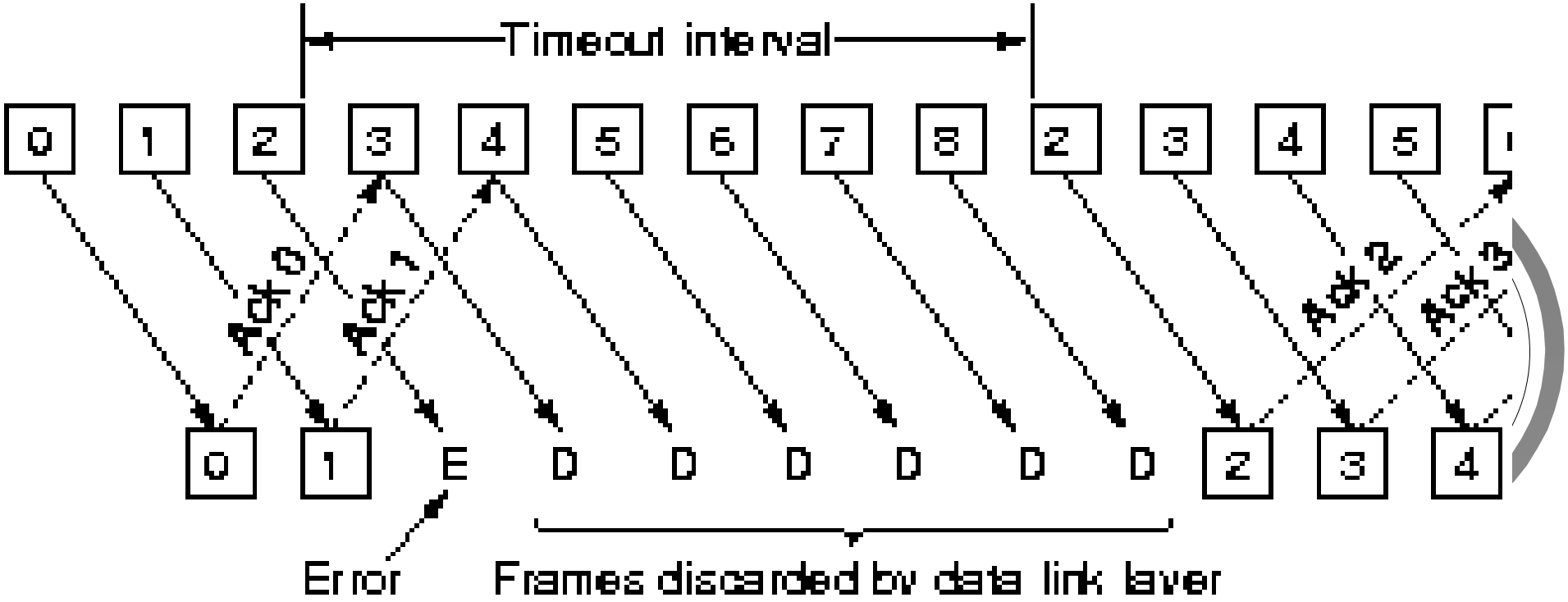


Allow Larger Window

- Satellite channel, 500 msec rt delay
- 50 kbps, sending 1000-bit frames
- Each frame takes 20 msec
  - 25 frames outstanding before first ack arrives
- Make window size 25
- Called *pipelining*
- (See p.216, protocol 5)
  - added enable/disable network layer
  - MAX_SEQ - 1 outstanding
  - - timer per frame
- Frame in the middle is damaged?

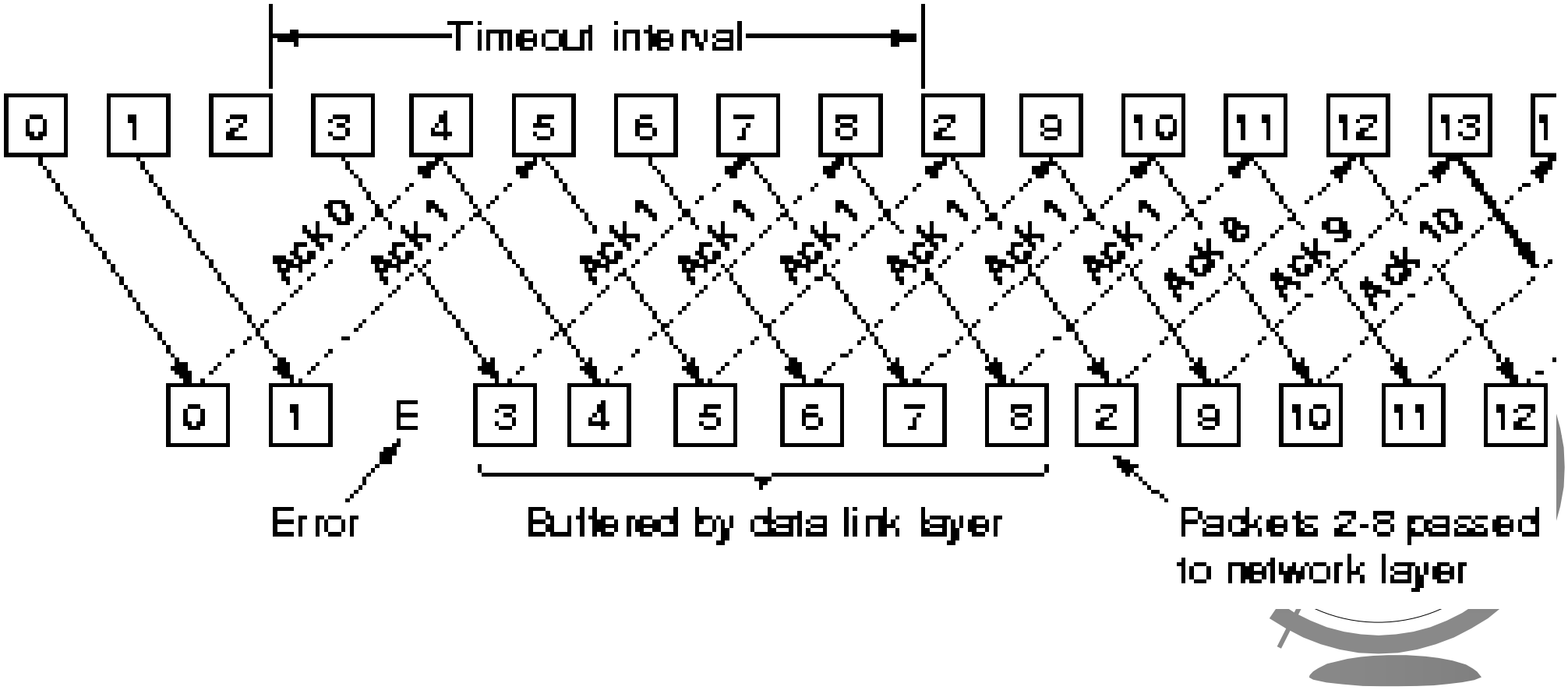
Go Back N

- Arbitrary window size:
  - send *w* frames (not 1) before blocking
- If error, receiver discards all addtl frames
- Sender window fills, pipeline empties
- Sender times out, retransmits
- Waste of bandwidth if many errors



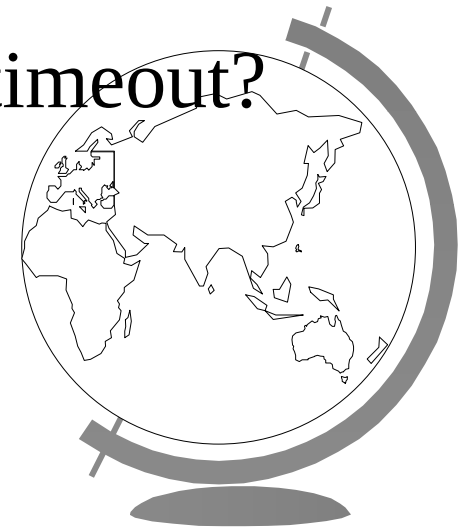
Selective Repeat

- Receiver stores all frames, waits for incorrect one
- Window size greater than 1

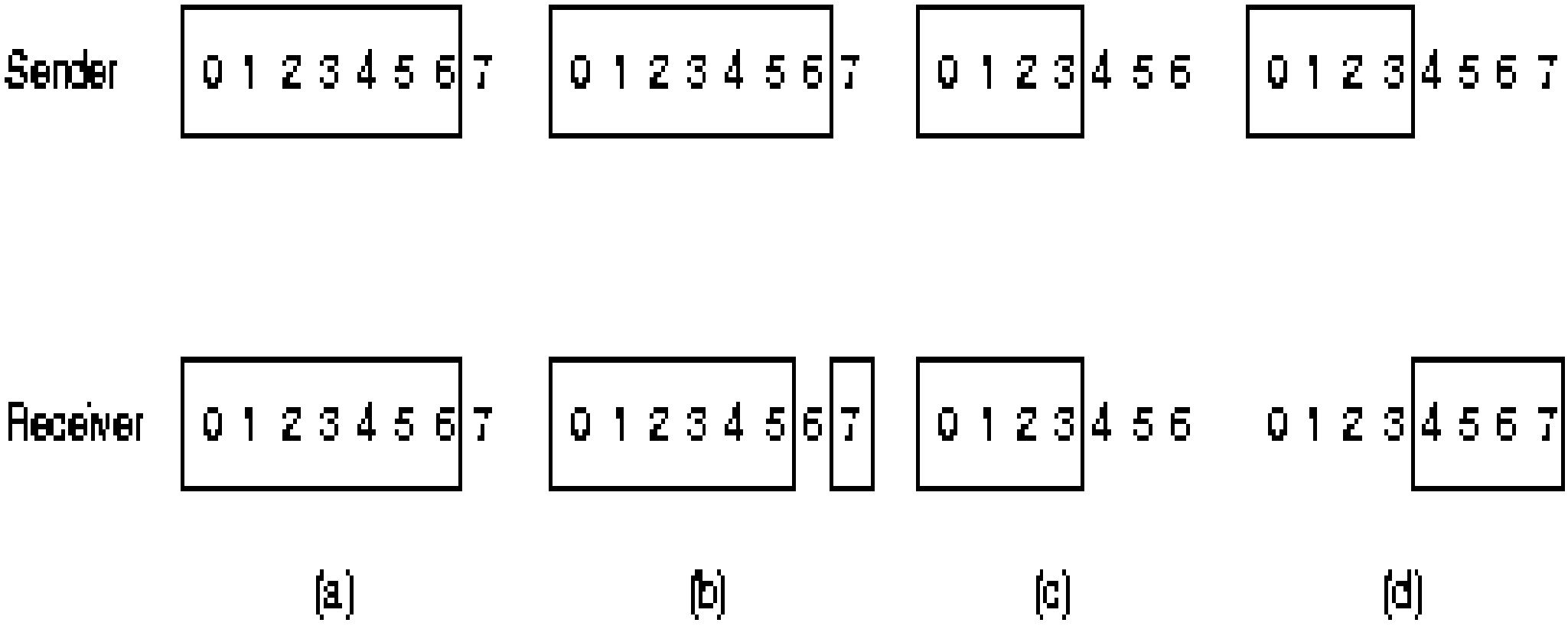


Latest and Greatest: Non-Sequential Receive

- Tanenbaum, Protocol 6
- Ack latest packet in sequence received
- Acks not always piggybacked
  - Protocol 5 will block until return data available
  - *start_ack_timer*
  - How long ack timeout relative to date timeout?
- Negative acknowledgement (NAK)
  - damaged frame arrives
  - non-expected frame arrives



Problem?



- Window size (MAX_SEQ) / 2
- How many buffers are needed? MAX_SEQ?

Closing Thoughts...

- If constant round-trip propagation delay
  - set timer just slightly higher than delay
- If variable round-trip propagation delay
  - small timer has unnecessary retransmissions
  - large has many periods of idle network
  - same is true of variable *processing* delay
- Constant, then “tight” timer
- Variable, then “loose” timer
  - NAKs can really help bandwidth efficiency

Topics

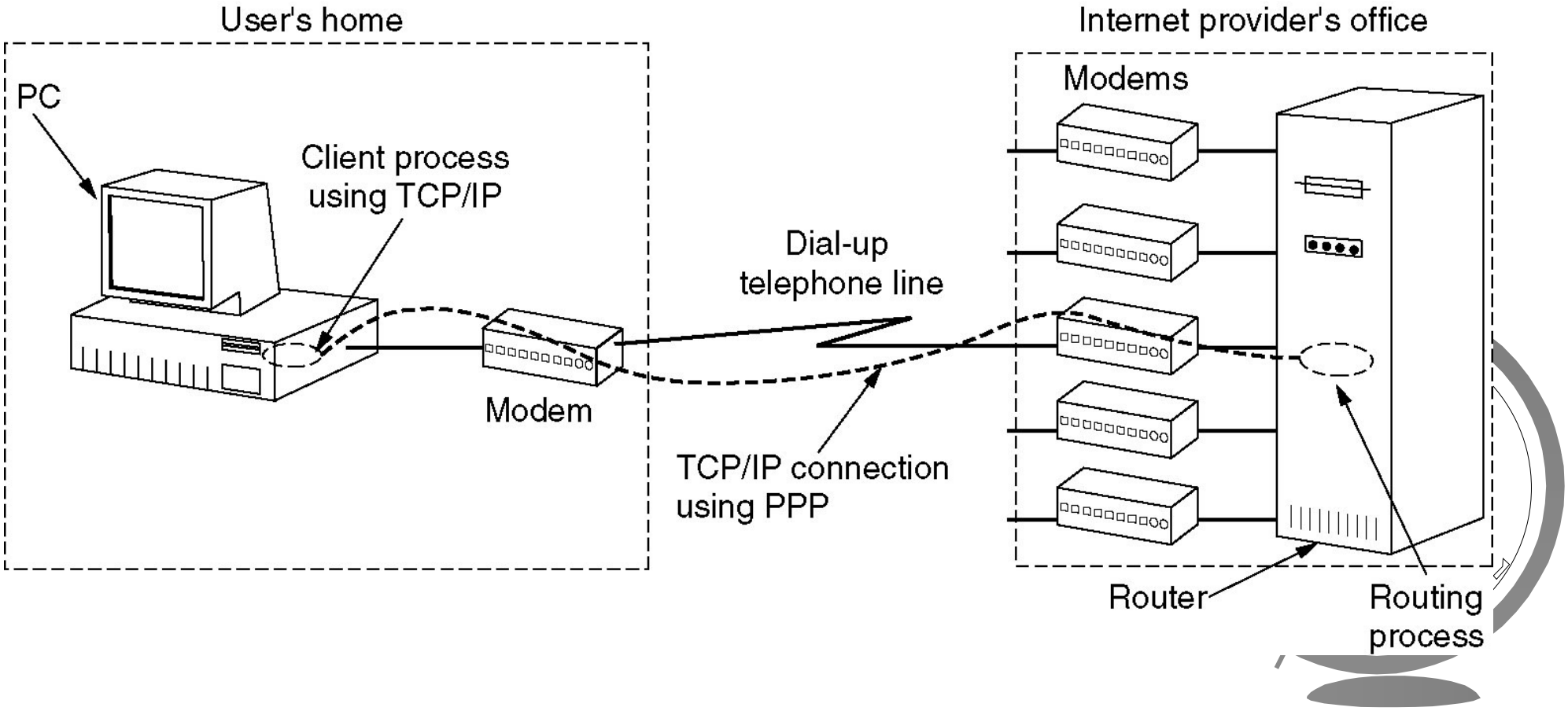
- Introduction 
- Errors 
- Protocols 
- Modeling 
  - complex specification and verification
- Examples ←

Examples

- HDLC 
  - IBM SNA
- Internet ←
  - SLIP
  - PPP
- ATM ←

The Internet

- Point-to-Point on leased lines between routers
- Home user to Internet Service Provider (ISP)
  - PPP



Point-to-Point Protocol (PPP)

- Bit-based frame
  - resorts to character based over a modem
- Line control: up, down, options
  - Link Control Protocol (LCP)
- Network control options
  - NCP (Network Control Protocol)
  - Negotiate network layer options independent of particular network layer
  - Service for: IP, IPX, AppleTalk …