Institute for the Wireless Internet of Things
at Northeastern University

EECE 5155
Wireless Sensor Networks
(and The Internet of Things)

Prof. Francesco Restuccia
Email: f.restuccia@northeastern.edu

Link Layer Objectives

- Framing
  - Group bit sequence into packets/frames
  - Format and size are important
- Error control
  - Forward and backward error control
- Flow control
  - Ensure that a fast sender does not overrun a slow(er) receiver
- Link management
  - Discovery and manage links to neighbors
  - Do not use a neighbor at any cost, only if link is good enough **(reliable link)**

Error Control

- Objectives of error control
  - Error-free
  - In-sequence
  - Duplicate-free
  - Loss-free
- Causes of packet loss
  - Fading, Interference, loss of bit synchronization
  - Results in bit errors, often bursty
  - Bit error rates can be high (10^{-2}-10^{-4} possible)

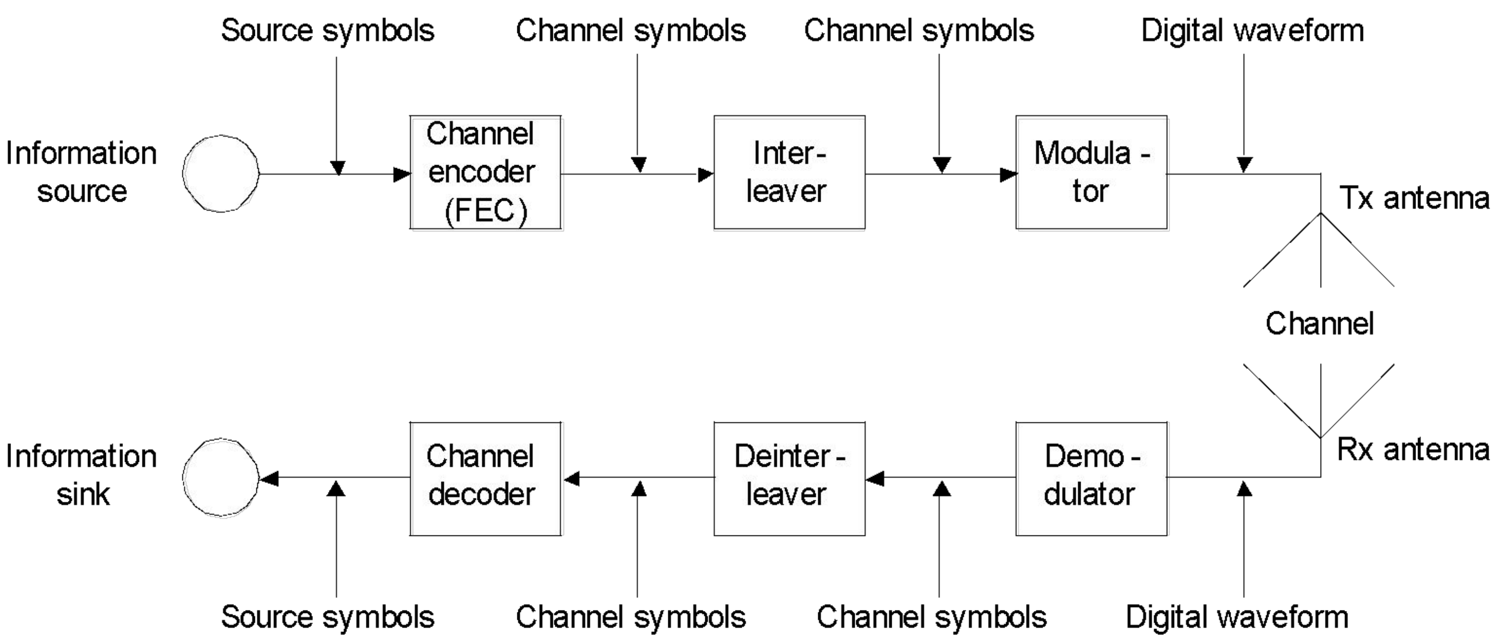
Error Control

Possible Approaches

1. Forward Error Control (FEC)
2. Automatic Repeat Request (ARQ)
   - Backward error control
3. Hybrid Schemes

Forward Error Control (FEC)

- Endow symbols in a packet with additional redundancy to withstand a limited amount of random permutations
  - Additionally: interleaving – change order of symbols to withstand burst errors



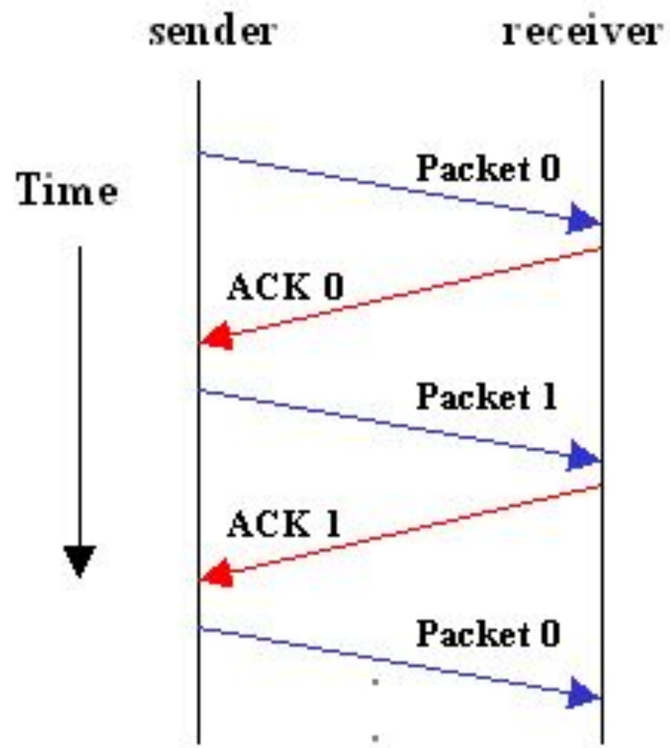
Backward Error Control – ARQ

- Basic procedure (recap)
  - Put header information around the payload
  - Compute a checksum and add it to the packet
    - Typically: **Cyclic redundancy check (CRC)**
      - Quick, low overhead, low residual error rate
  - Provide feedback from receiver to sender
    - Send ***positive*** or ***negative acknowledgement***
  - Sender uses timer to detect that acknowledgements have not arrived
    - Assumes packet has not arrived
  - If sender infers that a packet has not been received correctly, sender can retransmit it
    - What is maximum number of retransmission attempts? If bounded, at best a semi-reliable protocols results

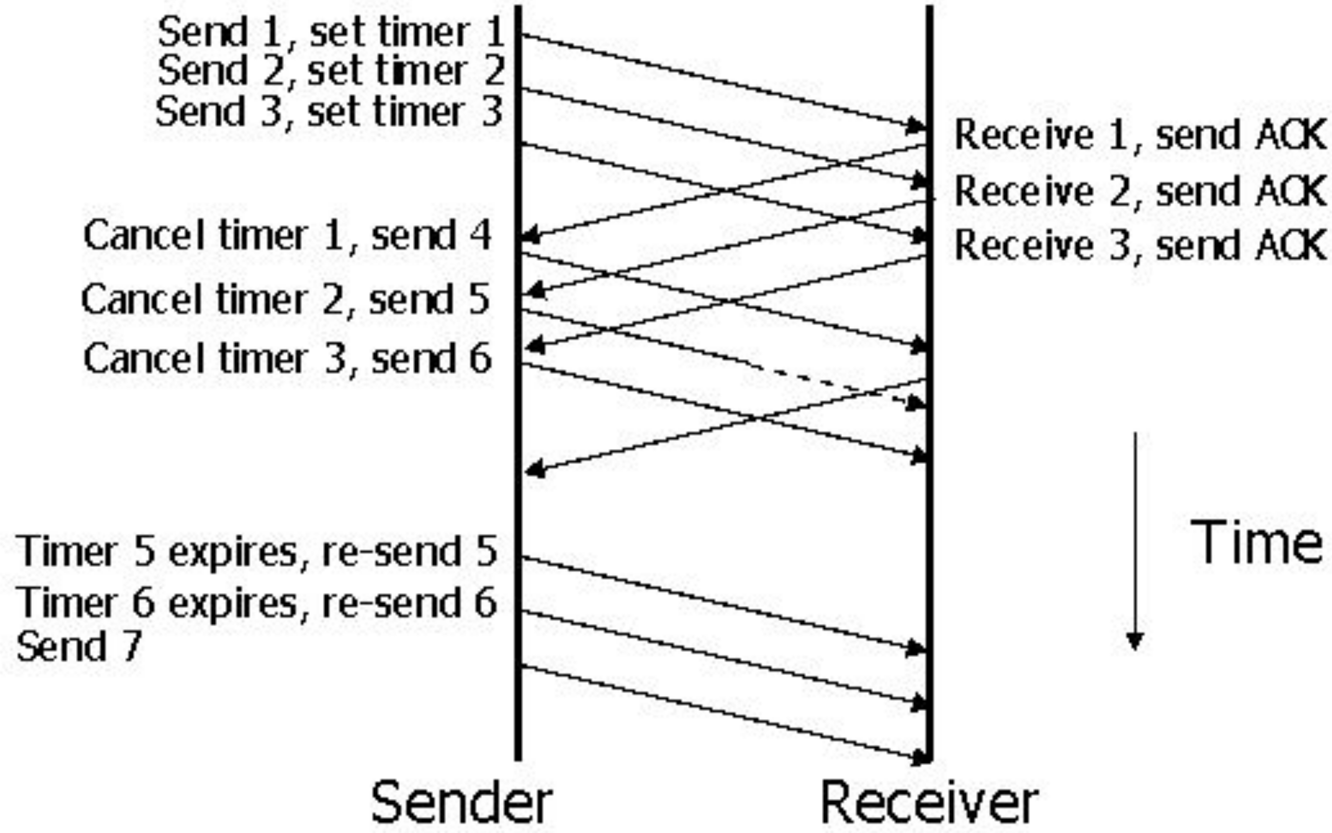
Standard ARQ Protocols

- Stop-and-Wait
  - Buffer only one packet, retransmit if no ACK before timer expires
- Go-back-N
  - Buffer N packets, send up to N packets, if a packet has not been acknowledged when timer goes off, retransmit all unacknowledged packets
- Selective Repeat
  - Buffer N packets, when timer goes off, only send unacknowledged packets

Stop-and-Wait

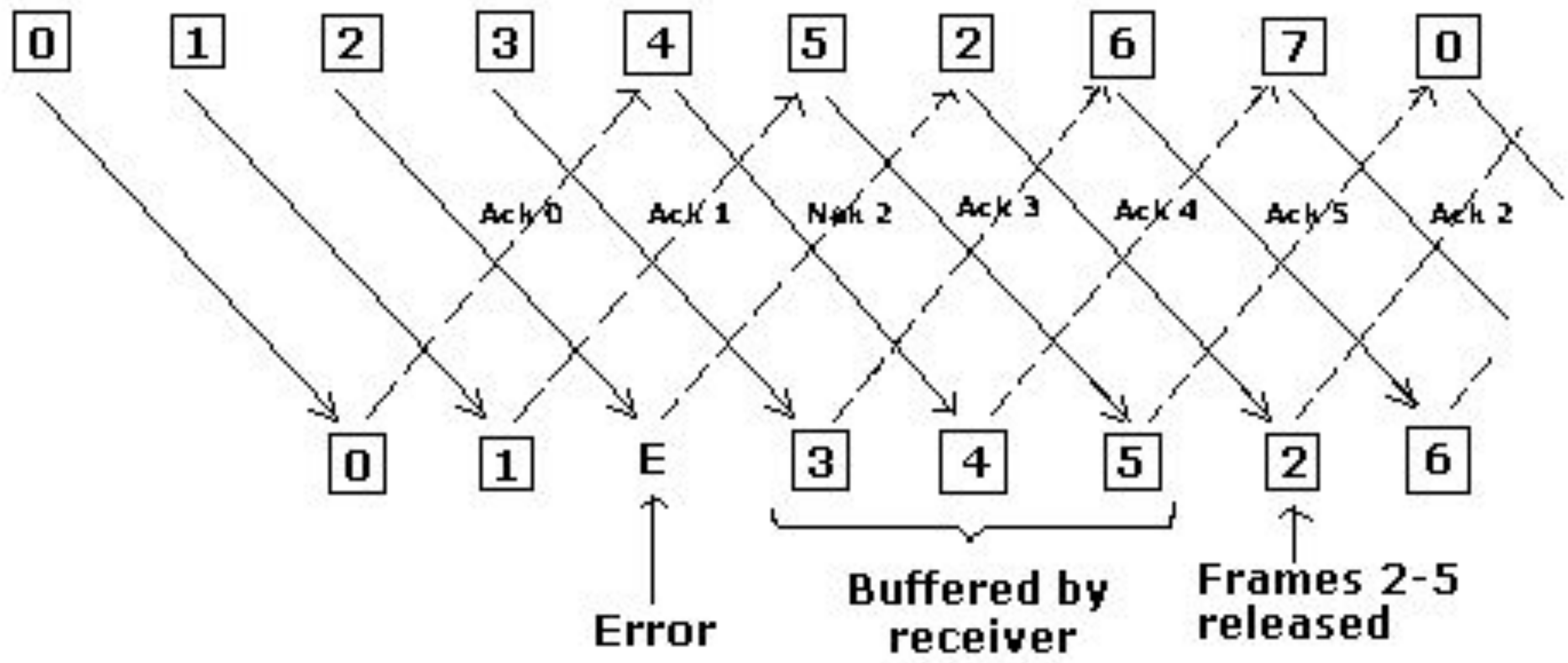


Go-back-N



Send 1, set timer 1
Send 2, set timer 2
Send 3, set timer 3
Receive 1, send ACK
Receive 2, send ACK
Receive 3, send ACK
Cancel timer 1, send 4
Cancel timer 2, send 5
Cancel timer 3, send 6
Time
Timer 5 expires, re-send 5
Timer 6 expires, re-send 6
Send 7
Sender
Receiver

Selective Repeat



Design Considerations

When To Retransmit?

- Assuming sender has decided to retransmit a packet: when do we do so?
  - In a Binary Symmetric Channel (BSC), any time is as good as any
  - In fading channels, try to avoid bad channel states – postpone transmissions
- How long to wait?
  - Example solution: **Probing protocol** (Zorzi and Rao)
  - Idea: reflect channel state by two protocol modes, “normal” and “probing”
  - When error occurs, go from normal to probing mode
  - In probing mode, periodically send short packets (acknowledged by receiver) – when successful, go to normal mode

M. Zorzi and R. R. Rao, "Error control and energy consumption in communications for nomadic computing," in *IEEE Transactions on Computers*, vol. 46, no. 3, pp. 279-289, March 1997, doi: 10.1109/12.580424.

Comparison: FEC vs. ARQ

- FEC
  - Constant overhead for each packet
  - Not (easily) possible to adapt to changing channel characteristics
- ARQ
  - Overhead only when errors occurred (expect for ACK, always needed)
- Both schemes have their uses ! ***hybrid schemes***

Optimize: Power Control On a Link Level

- Further controllable parameter: transmission power
  - Higher power, lower error rates – less FEC/ARQ necessary
  - Lower power, higher error rates – higher FEC necessary
- Tradeoff!

Optimize: Packet Size

- Small packets: low packet error rate, high packetization overhead
- Large packets: high packet error rate, low overhead
- Depends on bit error rate, energy consumption per transmitted bit

- For known bit error rate (BER), optimal frame length is easy to determine
- Problem: how to estimate BER?
  - Collect channel state information at the receiver (RSSI, FEC decoder information, …)
  - For example, use number of attempts T required to transmit the last M packets as an estimator of the packet error rate (assuming a BSC)
- Second problem: how long are observations valid/how should they be aged?
  - Only recent past is credible

Optimize: Link Management

- Decide to which neighbors (which can be *more or less* reachable) a link should be established
  - Communication quality fluctuates
  - Far neighbors can be costly to talk to, error-prone
  - Quality can only be estimated
- Establish a ***neighborhood table*** for each node
  - Partially automatically constructed by MAC protocols