Digital Data Communication Techniques

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Contents

- Handling Errors
  - Types of Errors
  - Error Detection
  - Error Correction

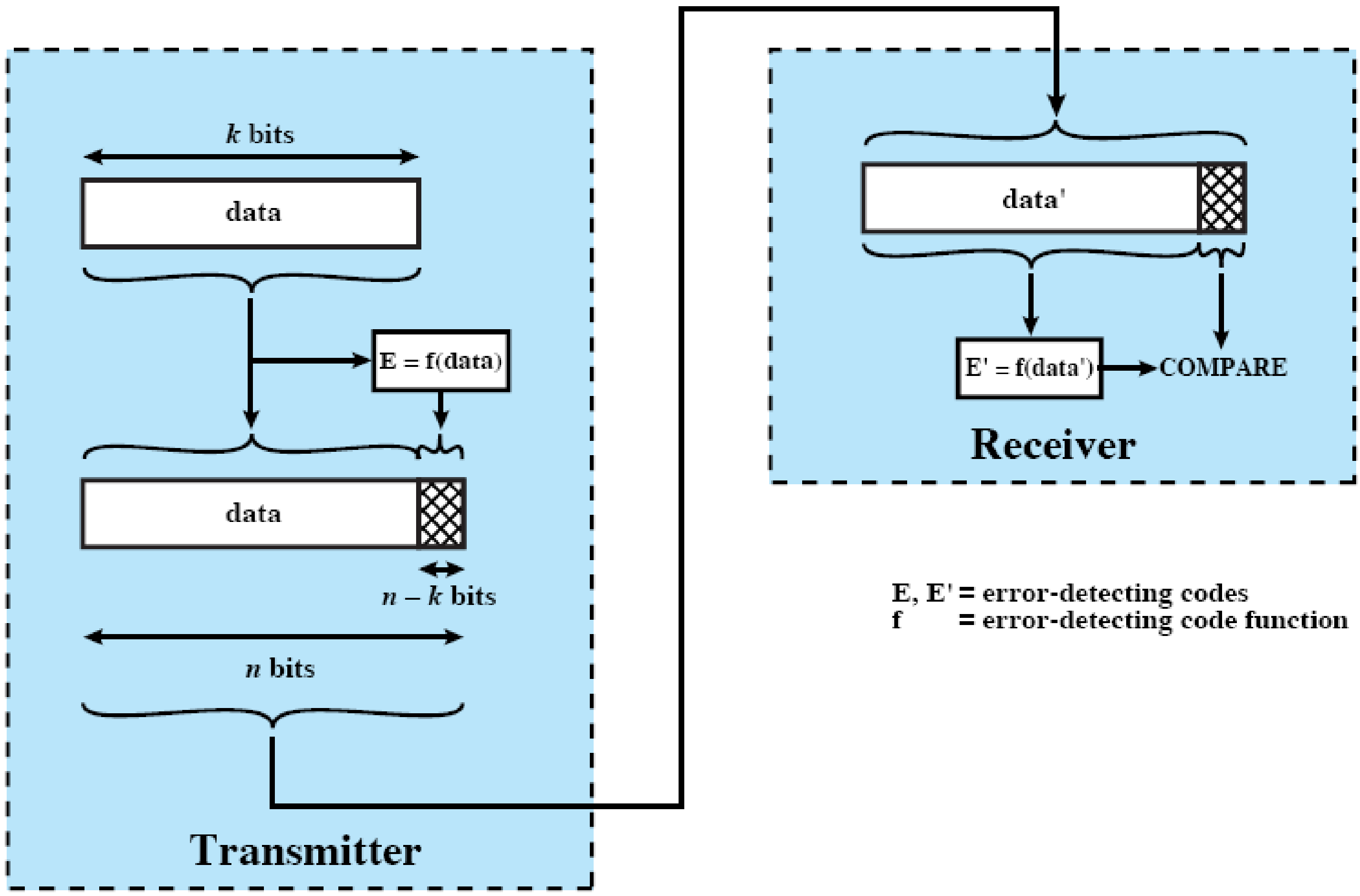
Types of Error

- An error occurs when a bit is altered between transmission and reception
  - E.g. transmitter sends a 1 but receiver thinks it is a 0
- Single bit errors
  - Only one bit altered
  - Caused by noise, the SNR is too low for receiver to determine the correct bit
- Burst errors
  - Contiguous sequence of *B* bits in which first last and any number of intermediate bits in error
  - Caused by impulse noise or by fading in wireless
  - Effect greater at higher data rates

Error Detection

- We will always have errors
- Detect the errors (so can retry or inform higher layer)
  - Transmitter adds extra information to transmitted data, i.e. an error-detecting code
  - Receiver recalculates the error-detecting code from received data, and compares to received error-detecting code
  - If the same, good. If not, then error (in data or code)
    - Still a chance that an error is not detected
- There are other forms of error detection (covered next topic)
- Simple Error Detecting Code: Parity Check
  - Single parity bit added to character to make the number of 1's even (if using even parity) or odd (if using odd parity)
    - E.g. assume odd parity is used: a 7-bit character 1110001 is sent with an eighth parity bit set to 1. Transmitted: 11110001
    - If 1 bit is in error, receiver will detect it: Receive 11100001
    - If 2 (or even number) bits in error, then not detected

General Error Detection Process



Error Detection Example: Parity Check

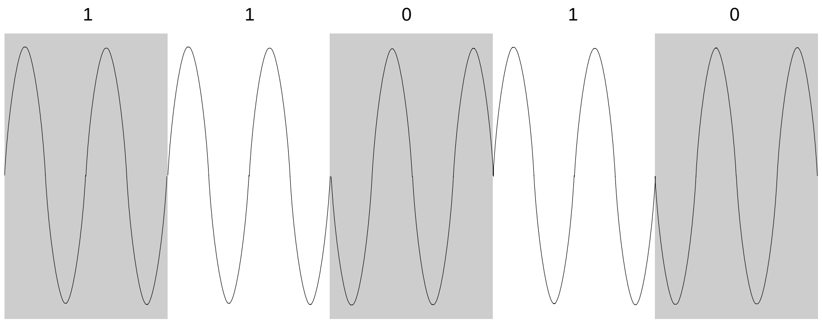
- Assume a computer wants to send the message “Steve”
- How do we represent this information as digital data?
  - Use the ASCII (or similar) character set
  - Digital data to send is:

    10100111110100110010111101101100101

Char	Dec.	Binary
S	83	1010011
t	116	1110100
e	101	1100101
v	118	1110110

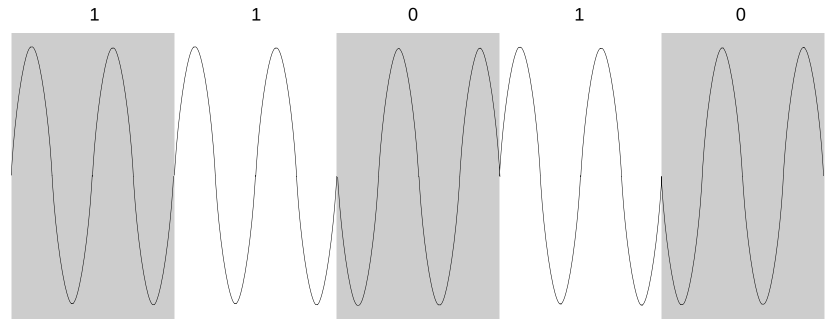
- Example of single bit odd-parity check
  - Take the 7 bits that represent each character
  - Add an extra bit (at the front) to make odd 1’s
  - Digital data to send is now:

    1101001111110100111001010111011011100101
- The digital data is now sent, lets assume as an analog signal using BPSK

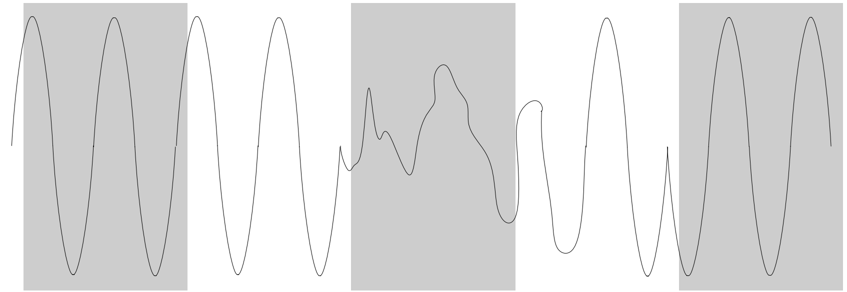


Error Detection Example: Parity Check

- Transmitted signal (first five bits)



- Received signal (due to transmission impairments)



- The receiver interprets the sequence of bits as:

1111001111110100111001010111101011100101

Error Detection Example: Parity Check

- The receiver error detector looks at each set of 8 bits and checks for errors (remember, using odd parity)
  - First 8 bits: 11110011 – there are six (even number of) 1's
    - ERROR DETECTED!
    - Upon detecting the error, the higher layer may be notified ("The character received is in error – please do something to fix it!")
    - If there is no error correction functions applied, then the character will not be sent to the higher layer
  - Second 8 bits: 11110100 – there is odd number of 1's
    - No error detected (correct)
  - Third 8 bits: 11100101 - there is odd number of 1's
    - No error detected (correct)
  - Fourth 8 bits: 01111010 – there is odd number of 1's
    - No error detected (INCORRECT!)
  - Fifth 8 bits: 11100101 - there is odd number of 1's
- What does the receiving application/user receive?
  - An error notification, and possibly the characters: "teze"

Cyclic Redundancy Check (CRC)

- One of most common and powerful checks
  - Used as a checksum for data transmission and storage
  - There are different standards, depending on the CRC length and algorithm
- For block of k bits, transmitter generates an $(n-k)$ bit frame check sequence (FCS)
- Transmits n bits which is exactly divisible by some number
  - Divisor is $n-k+1$ bits in length
- Receiver divides frame by the divisor
  - If no remainder, assume no error
  - If a remainder, then assume error

Simplified CRC Example

- An example of a simplified algorithm similar to CRC
- Lets assume we have k = 5 bits of data and a (n-k) = 3 bit frame check sequence
- Our divisor is 11. Both transmitter and receiver know this

Divisor:					1	0	1	1	11
Data:	0	1	1	0	1				13
Padded data:	0	1	1	0	1	0	0	0	104
FCS:						1	1	0	6
Tx Frame:	0	1	1	0	1	1	1	0	110

decimal

No transmission error

Rx Frame:	0	1	1	0	1	1	1	0	110
Divisor:					1	0	1	1	11
Answer:					1	0	1	0	10

No error detected, since Rx Frame is exactly divisible by 11

Simplified CRC Example

Divisor:					1	0	1	1	11
Data:	0	1	1	0	1				13
Padded data:	0	1	1	0	1	0	0	0	104
FCS:						1	1	0	6
Tx Frame:	0	1	1	0	1	1	1	0	110

2-bit transmission error

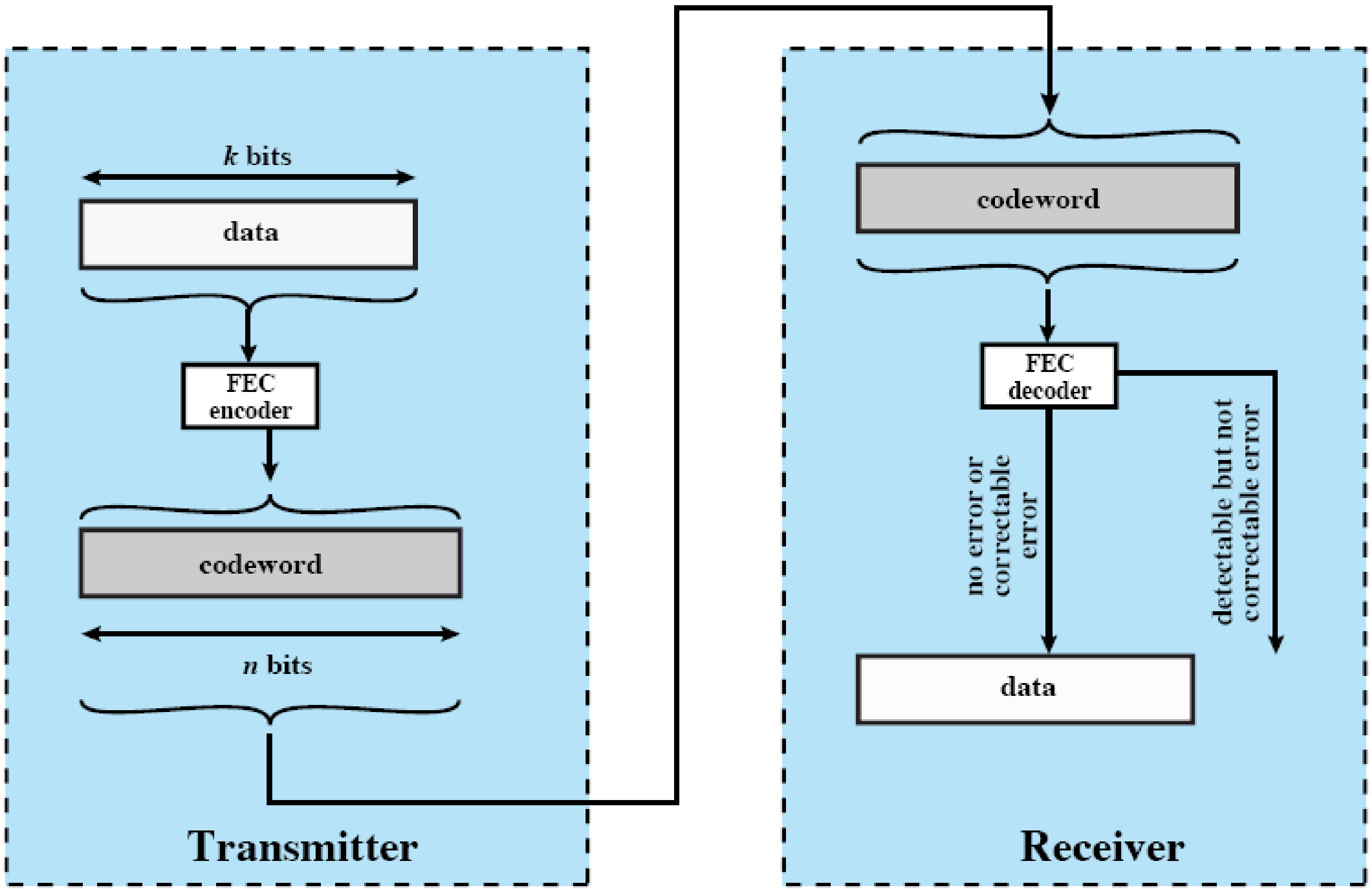
Rx Frame:	0	1	1	**1**	1	1	**0**	0	124
Divisor:					1	0	1	1	11
Answer:									Not an integer

Error detected, since Rx Frame is NOT exactly divisible by 11

Error Correction

- Correction of detected errors usually requires data block to be retransmitted (we will see techniques for this in next topic)
- Retransmissions are often not appropriate for wireless applications
  - Bit error rate is high, causing lots of retransmissions
  - When propagation delay long (satellite) compared with frame transmission time, resulting in retransmission of frame in error plus many subsequent frames
- If don't want to retransmit, then instead need to correct errors on basis of bits received
- Forward Error Correction (FEC) provides this
  - "Forward" because the transmitter sends extra data before the error occurs (before = forward of time)

Error Correction Process



How Error Correction Works

- Transmitter adds redundancy to transmitted message
- Receiver applies FEC decoder:
  - If no bit errors, input to decoder is same as original codeword, and original data is output
  - Certain error patterns, decoder will detect and correct errors (decoder outputs the original data)
  - Certain error patterns, decoder will detect (but not correct) errors
  - Certain (often rare) error patterns, decoder will not detect nor correct errors (decoder outputs data which is in error)
- Example: block error correction code
  - Map *k* bit input onto an *n* bit codeword
  - Each codeword is distinctly different
  - If get error assume codeword sent was closest to that received
- Results in reduced effective data rate
  - $(n-k)/n$ is the redundancy of the code; k/n is the code rate
  - ½ rate code uses double capacity of uncoded system

Example Error Correcting Code

- Hamming Distance
  - Number of bits of two *n*-bit sequences that disagree
    - v_1 = 011011 v_2 = 110001
    - d(v_1,v_2) = 3
- Our FEC encoder maps two bits into 5 bit codeword (k=2, n=5)

Data	Codeword (C)
00	00000
01	00111
10	11001
11	11110

- If receiver receives an invalid codeword (C_r), then assumes the codeword which is minimum Hamming distance from C_r is the transmitted codeword (C_t)
  - Only works if only 1 unique codeword with minimum distance

Error Correction Example 1

Data	Codeword
00	00000
01	00111
10	11001
11	11110

Tx Data 0 1

Tx Codeword 0 0 1 1 1

↓ No transmission error

Rx Codeword 0 0 1 1 1

Valid codeword, so no error

Rx Data 0 1

Error Correction Example 2

Data	Codeword
00	00000
01	00111
10	11001
11	11110

Tx Data 0 1

Tx Codeword 0 0 1 1 1

1-bit transmission error

Rx Codeword 0 0 **0** 1 1

Invalid codeword; min Hamming distance codeword is: 0 0 0 1 1 1

Rx Data 0 1

	0 0 0 1 1
0 0 0 0 0	2
0 0 1 1 1	1
1 1 0 0 1	3
1 1 1 1 0	4

Error Correction Example 3

Data	Codeword
00	00000
01	00111
10	11001
11	11110

Tx Data 0 1

Tx Codeword 0 0 1 1 1

2-bit transmission error

Rx Codeword **1** 0 1 **0** 1

Invalid codeword; no unique min Hamming distance codeword

Error detected, but not corrected

	1 0 1 0 1
0 0 0 0 0	3
0 0 1 1 1	2
1 1 0 0 1	2
1 1 1 1 0	3

Performance of Error Detection/Correction

- We want to detect/correct as many errors as possible
  - Because most data applications cannot tolerate errors
    - It is better for a Data Link layer protocol to perform retransmissions over a link to fix errors, then a human user having to retransmit an email
- But both error detection and correction require extra information to be sent over the transmission system
  - If k bits of useful data, send n bits of actual data
    - Efficiency of k/n
- Tradeoff: For a given data size of k bits:
  - The larger the value of n, the more errors the algorithm can detect/correct (GOOD)
  - The larger the value of n, the lower efficiency of the algorithm (BAD)
- Hence there are different approaches to error detection/correction. The best approach depends on many factors like the chance of errors, the user requirements, the protocols, …