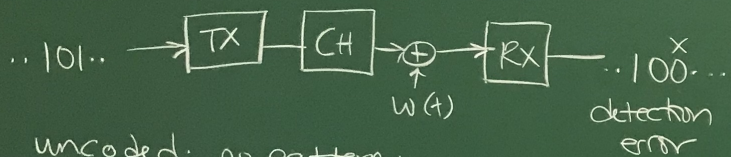


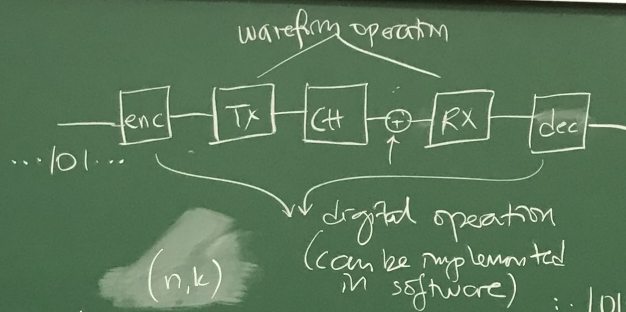
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Error Control Coding = Channel Coding  
 Un-coded, coded



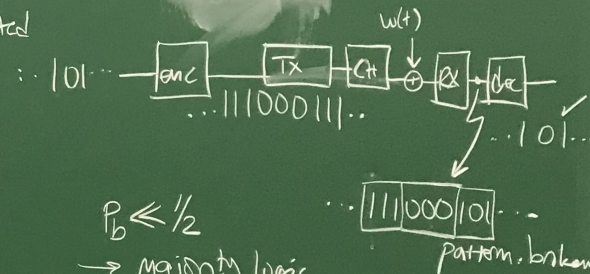
uncoded: no pattern in the tx'd sequence

coding: pattern including at the expense of redundancy  
 trade-off between good patterns and ↑ least amount of redundancy



- $n \geq k$  (equality: uncoded)
- code rate:  $r = \frac{k}{n}$  ( $r=1$  uncoded)
- good codes (BER ↓)
  - \*  $r \downarrow$  (penalty: BW)
  - \*  $k \uparrow$  (penalty: complexity = signal processing delay)

Ex 1: Repetition coding (3,1)



$P_b \ll 1/2$   
 → majority logic  
 $r = \frac{1}{3}$  (1M)

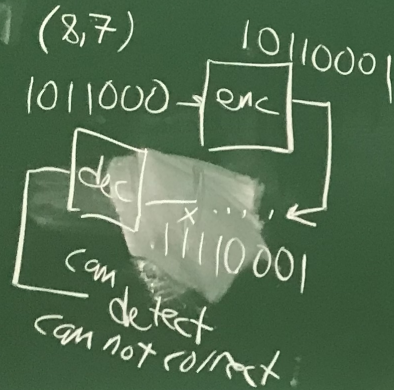
detects error  
 corrects error  
 [FEC: forward error correction]

Ex: 2 Parity-check code  
even parity check

$$k \xrightarrow{\text{enc}} n = k+1$$

$$r = \frac{k}{k+1} \text{ (close to 1)}$$

In the block of  $n$  bits, the # of 1's should be even



Optims

1) Discard

2) ARQ

automatic  
repeat  
request

penalty: delay

(delay-sensitive X)

5G: EMBB (rate)

5G: mMTC (IoT)

URLLC

ultra-reliable  
low-latency comm

LLC: cannot support  
ARQ

ARQ: time diversity  
selective

diversity only when  
there is a need

• Diversity

\* Dumb  
(always)

\* Smart  
(selective)  
(when needed)

History of channel coding

• Shannon, 1948

• convolutional codes, 1950s  
(decoding complexity)

Viterbi decoding, 1967  
Forney

• Turbo codes, 1993

• LDPC (Gallager,  
reinvented 2000s)

• Polar codes (Arikam, 2008)

4G LTE: turbo codes, LDPC

5G: LDPC, polar codes  
payload control channel

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# Channel Capacity

Hartley-Nyquist-Shannon

$$R_{\max} : C \quad (\text{SISO})$$

$$R \leq C = B \log_2(1 + \text{SNR})$$

with arbitrarily high reliability ( $P_e \rightarrow 0$ )

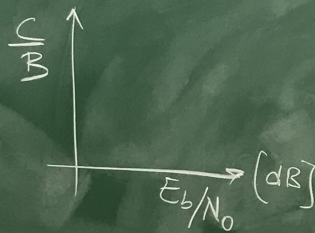
$$\text{SNR} = \frac{P_{\text{rx}}}{B N_0} = \frac{E_b C}{N_0 B}$$

$$(E = P T)$$

$$\frac{C}{B} = \log_2 \left( 1 + \frac{E_b}{N_0} \left( \frac{C}{B} \right) \right)$$

$$\frac{2^{C/B} - 1}{C/B} = \frac{E_b}{N_0}$$

$$\frac{C}{B} : SE_{\max} \quad (\text{bits/sec/Hz})$$



$C/B$	$E_b/N_0$	$\frac{\partial \left( 2^{C/B} - 1 \right)}{\partial C/B}$	$\left. \frac{\partial \left( 2^{C/B} - 1 \right)}{\partial C/B} \right _{C/B=0}$
0	$\ln 2 = 0.69 = -1.59 \text{ dB}$		
1	$1 = 0 \text{ dB}$	$\frac{\partial}{\partial C/B} \left( \frac{C}{B} \right)$	
2	$\frac{3}{2} = 1.5 = 1.76 \text{ dB}$	L'Hospital's rule	
3	$\frac{7}{3} = 3.68 \text{ dB}$		
4	$\frac{15}{4} = 5.74 \text{ dB}$	$\frac{C/B}{2 \cdot \ln 2}$	$\left. \frac{C/B}{2 \cdot \ln 2} \right _{C/B=0} = \ln 2$
6	$\frac{63}{6} = 10.21 \text{ dB}$	1	
8	$\frac{255}{8} = 15.03 \text{ dB}$		$\frac{C}{B} \quad E_b/N_0$
16	$\frac{2^{16} - 1}{16} = 36.12 \text{ dB}$		$\frac{1}{2} \quad -0.82 \text{ dB}$
			$\frac{1}{4} \quad -1.21 \text{ dB}$
			$\frac{1}{8} \quad -1.4 \text{ dB}$

