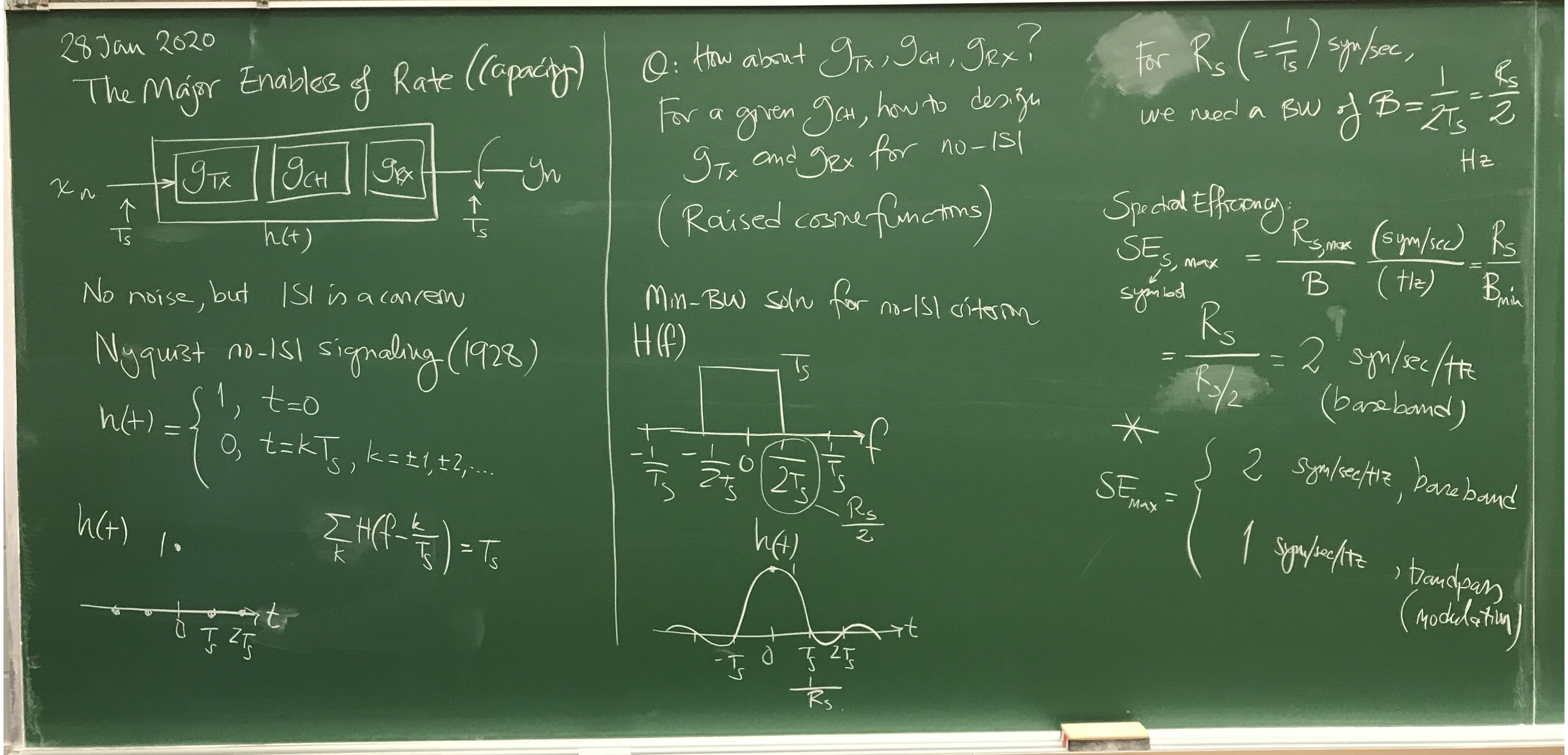


28 Jan 2020

The Major Enables of Rate (Capacity)

No noise, but ISI is a concern

Nyquist no-ISI signaling (1928)

$$h(t) = \begin{cases} 1, & t=0 \\ 0, & t=kT_s,\ k=\pm1,\pm2,\ldots \end{cases}$$

$h(t)$ 1.

$$\sum_k H\left(f-\frac{k}{T_s}\right) = T_s$$

Q: How about g_{TX}, g_{CH}, g_{RX}?

For a given g_{CH}, how to design g_{TX} and g_{RX} for no-ISI

(Raised cosine functions)

Min-BW soln for no-ISI criterion

For $R_s \left(=\frac{1}{T_s}\right)$ sym/sec,

we need a BW of $B = \frac{1}{2T_s} = \frac{R_s}{2}$ Hz

Spectral Efficiency:

$$SE_{s,\max} = \frac{R_{s,\max}}{B} \frac{(\text{sym/sec})}{(\text{Hz})} = \frac{R_s}{B_{\min}}$$

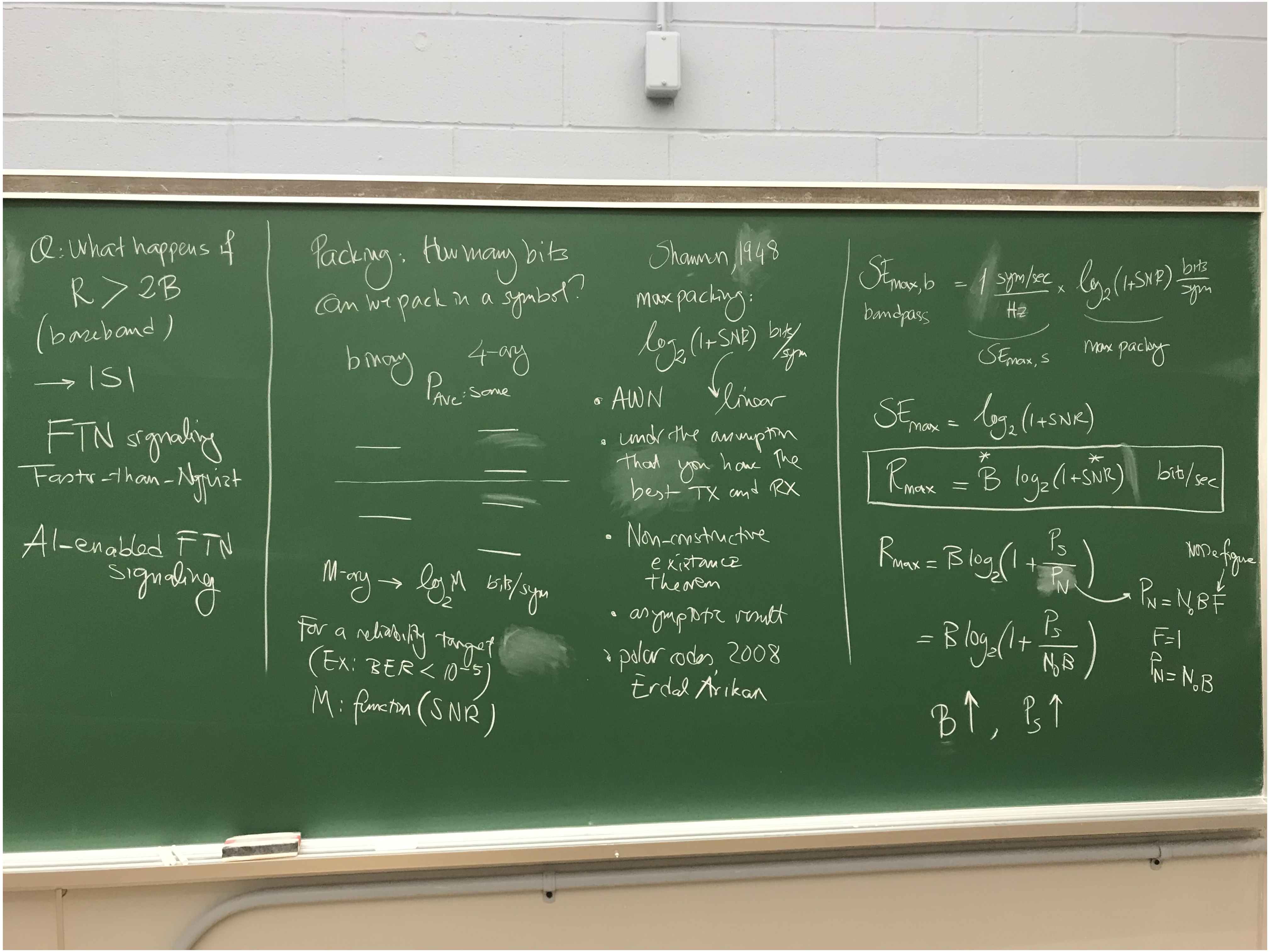
symbol

$$= \frac{R_s}{R_s/2} = 2 \text{ sym/sec/Hz}$$

(baseband)

*

$$SE_{Max} = \begin{cases} 2 \text{ sym/sec/Hz}, & \text{baseband} \\ 1 \text{ sym/sec/Hz}, & \text{bandpass (modulation)} \end{cases}$$



Q: What happens if

$R > 2B$

(baseband)

→ ISI

FTN signaling

Faster-than-Nyquist

AI-enabled FTN signaling

Packing: How many bits can we pack in a symbol?

binary

4-ary

P_{Ave}: same

M-ary → $\log_2 M$ bits/sym

For a reliability target (Ex: BER < 10^{-5})

M: function (SNR)

Shannon, 1948

max packing:

$\log_2(1+SNR)$ bits/sym

- AWN
- linear
- under the assumption that you have the best TX and RX
- Non-constructive existance theorem
- asymptotic result
- polar codes, 2008 Erdal Arikan

$$\underset{\text{bandpass}}{SE_{max,b}} = \underbrace{1\ \frac{\text{sym/sec}}{\text{Hz}}}_{SE_{max,s}} \times \underbrace{\log_2(1+SNR)}_{\text{max packing}}\ \frac{\text{bits}}{\text{sym}}$$

$$SE_{max} = \log_2(1+SNR)$$

$$\boxed{R_{max} = \overset{*}{B}\ \log_2(1+\overset{*}{SNR}) \quad \text{bit/sec}}$$

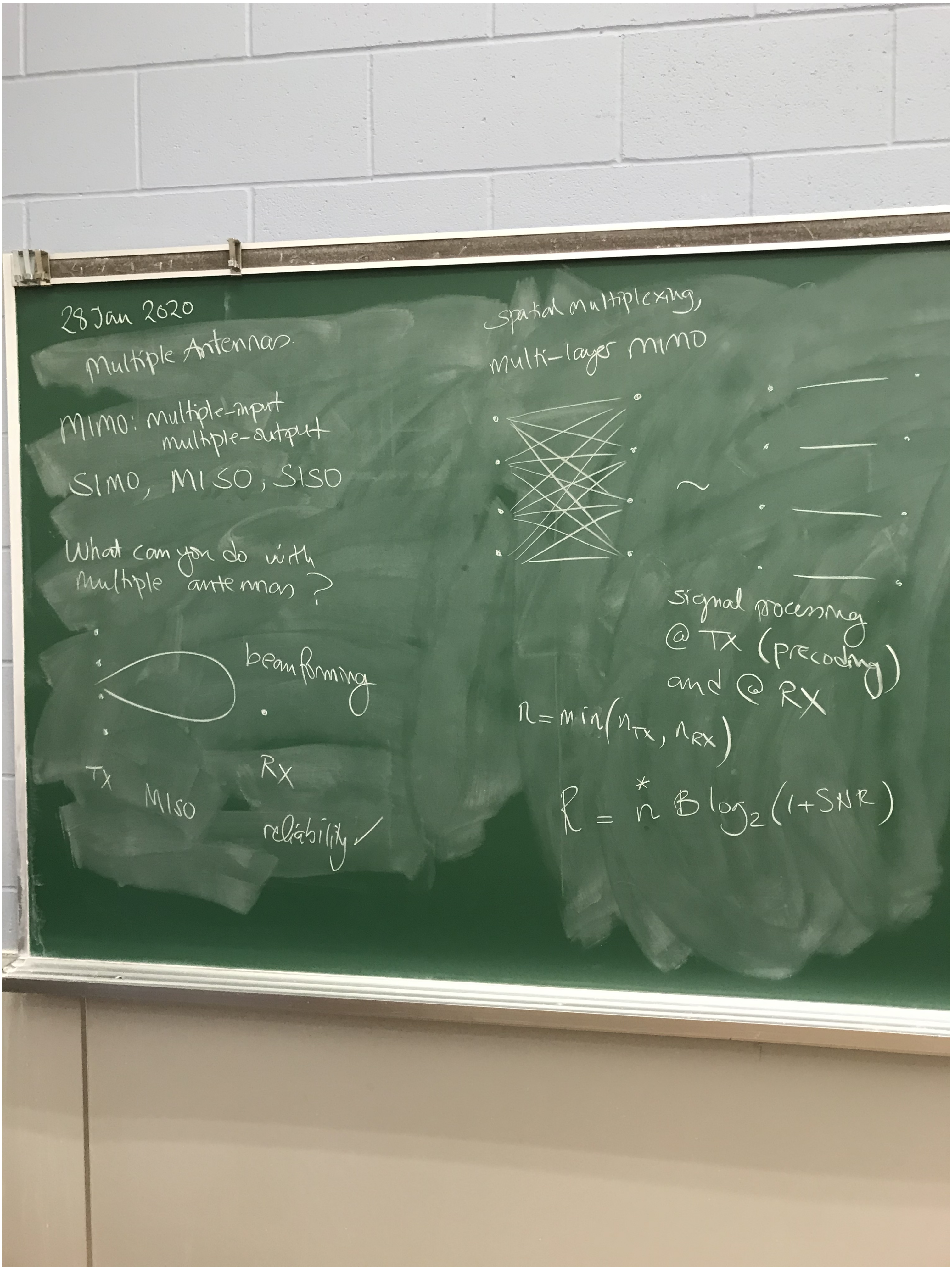
$$R_{max} = B\log_2\left(1+\frac{P_s}{P_N}\right) \longrightarrow P_N = N_0 B \overset{\text{Noise figure}}{F}$$

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

$F=1$

$P_N = N_0 B$

$B\uparrow,\ P_s\uparrow$



28 Jan 2020

Multiple Antennas.

MIMO: multiple-input
multiple-output

SIMO, MISO, SISO

What can you do with
multiple antennas?

beamforming

Tx

Rx

MISO

reliability ✓

spatial multiplexing,

multi-layer MIMO

~

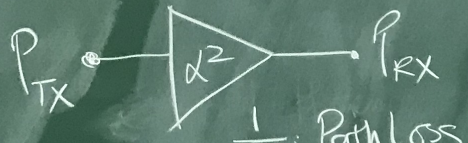
signal processing
@ TX (precoding)
and @ RX

$n = \min(n_{TX}, n_{RX})$

$R = \overset{*}{n} B \log_2(1+SNR)$

$h_{ch}(t) = \alpha\, \delta(t)$

$P_{RX} = \alpha^2 P_{TX}, \quad \alpha^2 \ll 1$



$\frac{1}{\alpha^2}$: Path Loss

$$P_{RX} = \frac{P_{TX}}{PL}$$

SISO P_{TX} • • $P_{RX} = \alpha^2 P_{TX}$

MIMO • $\frac{P_{TX}}{n_{TX}}$ • $P_{RX} = \frac{\alpha^2 P_{TX}}{n_{TX}}$

$$R = n B \log_2\left(1 + \frac{\alpha^2 P_{TX}}{n_{TX} B N_0}\right)$$

$n \hookrightarrow \min(n_{TX}, n_{RX})$

3 fundamental enablers

- * B → • mmWave, 28 GHz, 60 GHz } 5G
- * SNR (P_{RX}) → densification of RAN (radio access network), small cell
- * n → MIMO $n \leq 8$, massive MIMO $n \geq 64$

• unlicensed spectrum U-LTE) 4G

• mmWave
28 GHz
60 GHz } 5G

• Terahertz) 6G
($B < 0.1 f_c$ electronics)

* carrier aggregation) 4G
up to 5 carriers
@ 20 MHz each