无线通信.

一、Antennas and Propagation.

1. **Antenna**: Coverts electrical signals into radio waves, vice versa.

Transmission line: connect the radio transmitter or receiver to the antenna.

2. 一些参数及重点.

1) Radiation Pattern: radiation properties of the antenna as a function of space coordinates.

2) Field Regions: Reactive near-field / Radiating near-field / Far-field

3) Isotropic Antenna: Radiate equal amount of energy in all directions

Omnidirectional Antenna: horizontal plane 等向能量辐射

但 vertical plane 有限辐射.

4) Gain (某方向上增益): $\boxed{G\,(\mathrm{dBi}) = e_{tot}(\mathrm{dB}) + D\,(\mathrm{dBi})}$.

$e_{tot} \in [0,1]$, in dB ⇒ $10\log_{10} e_{tot}$.

where D is Directivity, 在某方向的能量集中能力.

5). Reflection Coefficient: $\boxed{\Gamma = \frac{Z_L - Z_0}{Z_L + Z_0}}$ Z_0 默认 50Ω.

Return loss: $\boxed{RL(\mathrm{dB}) = -20\log_{10}|\Gamma|}$.

6) 两种天线
- Half-wave Dipole Antenna: $\boxed{L = \frac{\lambda}{2},\ arm = \frac{L}{2}}$
- Microstrip Antenna.

7) Friis transmission equation:

$$\boxed{P_r = P_t G_t G_r \left(\frac{\lambda}{4\pi d}\right)^2}$$

8) Satellite communication
- space segment: Receive → Transponder → Transmitting
- Ground segment: Parabolic Reflector Antenna.
  (curved ~~surf~~ surface with cross-sectional shape of a parabola to direct the radio waves)

3. 5G Antenna and techniques.

1) MIMO
- model: $Y = HX + W$, where $X \in \mathbb{R}^{m\times 1}$, $Y \in \mathbb{R}^{N\times 1}$
- Techniques
  - Spatial Diversity: 由多条路径数量获得分集增益. $m \times N$.
  - Spatial multiplexing: 由空间复用数量获得复用增益.

2) Massive MIMO: BS上有大量 antenna elements.

3) Beamforming: concentrating signals in a particular directi

将时信相位叠加在一起以加强信号.

4) Multiple Acess Techique
- Orthogonal FDMA (OFDMA).
- Beam Division Multiple Access (BDMA

5) Beam Steering: 动态调整主波束方向.

⇓

Smart / Phased Array Antenna

二、Massive MIMO System.

1. Channel Capacity / Spectral efficiency.

Def 每个复数值样本能够可靠传输的 bit 数量.

$$\boxed{C = B\log_2(1 + SNR)}$$

⇒ 默认为1.

Note 在多数简单分析时, PPT会选择省略 B, 很适天的行为.

1) SISO: $y[l] = g\cdot x[l] + n[l]$, $C = \log_2\left(1 + \frac{|g|^2\rho}{N_0}\right)$, $x \sim CN(0, \rho$

2) SIMO: $\vec{y} = \vec{g}x + \vec{n}$, $C = \log_2\left(1 + \frac{\|\vec{g}\|^2\cdot\rho}{N_0}\right)$.

3) MISO: $y = \vec{g}^T\vec{x} + n$, $C = \log_2\left(1 + \frac{\|\vec{g}\|^2\cdot\rho}{N_0}\right)$.

4) Point-to-Point MIMO：$\vec{y} = G\vec{x} + \vec{n}$.

分析：SVD - $G = U\Sigma V^H$, where $\mathrm{Rank}(\Sigma) = S$.

Let $\vec{x} = V\tilde{x}$, $\tilde{y} = U^H\vec{y}$. 酉变换.

$$\tilde{y} = U^H(U\Sigma V^H V\tilde{x} + \vec{n}) \triangleq \Sigma\tilde{x} + \tilde{n}.$$

$$= \begin{bmatrix} s_1 & & & \\ & \ddots & & \\ & & s_S & \\ & & & 0 \ddots 0 \end{bmatrix}\tilde{x} + \tilde{n}$$

$$\Rightarrow \tilde{y}_k = \begin{cases} s_k\tilde{x}_k + \tilde{n}_k, & k \in [1, S]_{IN} \\ \tilde{n}_k, & \text{otherwise}. \end{cases}$$

由信道容量定义. $C = \max\limits_{\substack{q_1, \dots q_S \\ q_1 + \dots + q_S = q}} \sum\limits_{k=1}^{S} \log_2\left(1 + \frac{s_k^2 q_k}{N_0}\right)$

$$\Rightarrow \boxed{q_k^* = \max\left(\mu - \frac{N_0}{s_k^2}, 0\right), \text{waterfilling}}.$$

特殊情况

① Low SNR.

所有功率分配给增益最高的信道，$q_1 = q$.

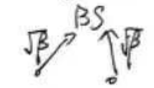
$$C = \log_2\left(1 + \frac{q}{N_0}s_1^2\right).$$

② High SNR.

几乎近似于平均分配，$q_i = \frac{q}{S}$,

$$C = \sum_{k=1}^{S}\log_2\left(1 + \frac{q}{N_0}\frac{s_k^2}{S}\right).$$

2. Orthogonal Multiple Access



占用不同带宽，若为 2B，则

$$C = 2B\log_2\left(1 + \frac{\beta q}{2BN_0}\right)$$

所以 OMA 面临对频带的取舍.

3. Uplink Multi-User MIMO（完全不懂[illegible]讲这个的逻辑在哪）.

Model $\vec{y} = \sqrt{\rho_{ul}}G\vec{x} + \vec{w}$, where $\begin{cases} g_k^1, \dots g_k^m \sim CN(0, \beta_k) \\ w \sim CN(0, I_m). \end{cases}$

$$\boxed{\rho_{ul} = \frac{\text{Uplink radiated Power} \times \text{Antenna gains}}{BN_0}}.$$

$\Rightarrow$ 则 $\boxed{\text{Max SNR} = \rho_{ul}\beta_k}$ 第K个用户.

4. 信道估计.

1) 理论依据：信道可估计.

在由 Coherence Time T_c 和 Coherence Bandwidth 所构成的 Channel Coherence Interval 中，信道特性类似 LTI系统且存在频率不变性，由采样定理，则由 $\boxed{\tau_c = B_c T_c}$ 个样本完全确定.

Where $\boxed{T_c \triangleq \frac{\lambda}{2v}, \quad B_c \triangleq \frac{c}{|d_{max} - d_{min}|}}$

2) Uplink / Downlink Channel Estimation.（设 M个天线，K个用户）.

上行链路，需要 K个 pilot Signal 以估计信道.

下行链路，需要 M个 pilot Signal（每个天线发出）以估计信道，并需要一个长度为 M 的反馈信息告知 BS.

Channel Estimation 的目的是 BS 得到 estimator.

3) 两种 Channel State Information (CSI) Acquisition.

① Time-division duplex (TDD).

同频测量. UL/DL 信道互易，则用 Uplink 即可，K个 pilots.

② Frequency-division duplex (FDD).

不同频测量，UL/DL 信道不一样.

用户测信道：M Downlink pilots + M Uplink feedback.

BS测信道：K Uplink pilots.（测两次，UL/DL 不互易）.

测量总数为 $M + \frac{K}{2}$ 个 symbols. 在 massive MIMO 情况下，TDD 适用.

信道在相干时间内才能完成信息的解码，每个 Interval 里载 τ_c 个 symbols，则设用于测量信道用的 pilots + feedback = K symbols 个，用于传送 payload 的符号数量为 $\tau_c - K$.

三. Fading and Communication Fundamentals.

- Fading Types
  - Large Scale Fading
    - Path loss
    - Shadowing
  - Small Scale Fading
    - Doppler Spread
      - Fast Fading
      - Slow Fading
    - Multipath
      - Flat Fading
      - Frequency Selective Fading

1. Doppler Spread: Moving changes frequency.

model Doppler frequency $f_D = \frac{v}{\lambda}\cos\theta \triangleq f_m \cos\alpha$

Doppler spread $\boxed{B_D = f_m = \frac{v}{\lambda}}$ $(T_0 \propto \frac{1}{B_D})$

使信号的带宽有 ± B_D 的扩展.

若信号 $B_S \gg B_D$, 影响不大 ⇒ Slow fading, 反之, fast Fading.

2. Multipath

Cause time dispersion and results in InterSymbol Interference

一般会给功率延迟曲线 $P(\tau)-\tau$, τ为 excess delay.

侧重于求由于多径带来的平坦频率区间.

$$\mathbb{E}\tau = \frac{\sum_i P(\tau_i)\tau_i}{\sum_i P(\tau_i)}, \quad Var(\tau) = \sigma_\tau^2 = \mathbb{E}\tau^2 - (\mathbb{E}\tau)^2.$$

⇒ 50% coherence bandwith $\boxed{B_c = \frac{1}{5\sigma_\tau}}$

考虑信号脉冲时间 T_s, 带宽 B_s.

一般选择这种 ↗ 若 $B_s \ll B_c$, 则为 Narrowband Channel, flat fading, 影响小.

若 $B_s \gg B_c$, 则为 Wide band channel, frequency selective fading, 需要由均衡器作用.

3. Resolving mutipaths.

若 pulse duration < delay spread, 即 $T_s < \tau$, 则信道为 frequency selective channel, 此时, 可设置多径通道数.

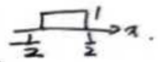
$$\boxed{\text{Number of resolvable paths} = \lfloor \frac{\tau}{T_s} \rfloor + 1}.$$

即脉冲时间短, 即使有延迟也不会混叠.

4. Others.

$n(t) = n_c \cos(2\pi f_c t) - n_s(t)\sin(2\pi f_c t) = \sqrt{n_c^2(t) + n_s^2(t)}\cos(2\pi f_c t + \phi(t))$

$PSD_{n_c}(f) = PSD_{n_s}(f) = N_0 \,\mathrm{rect}\{\frac{f}{B}\}$., rect(x):



$P_{n_c} = P_{n_s} = P_n = N_0 B$, Gaussian 分布不变.

Gaussian Tail function, $Pr(x(t) > A) \triangleq T\{\frac{|A-\mu_x|}{\sigma_x}\}$.

正交基底: $f_1(t) = \sqrt{\frac{2}{T}}\cos(2\pi f_c t)$, $f_2(t) = -\sqrt{\frac{2}{T}}\sin(2\pi f_c t)$.

2PSK, ~~QPSK~~ QPSK, M-QAM, 若有M个星座, 则每个 symbol 传输 $\log_2 M$ 个 bit 数.

四. Cooperative Communications & Multicarrier.

A. Cooperative Communications.

1. Why Cooperative Communications?

quality
~~Improve communication quality, meaning capacity or diversity~~.

Broader coverage and increased capacity, add diversity

2. Self Backhauling

$$BS \xrightarrow{\text{Backhaul link}} RS \xrightarrow{\text{Access link}} UE.$$

两个link 用相同的频率为 in-band relay, 不同为 out-of band relay

一般半双工.

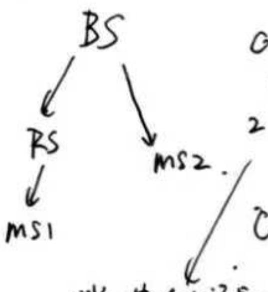
3. Two-Way Relaying.

BS 和 RS 都是广播所有信息, 接收方根据已有信息解码.

$$\begin{tikzcd} x_2 & UE1 \arrow[l, Rightarrow] \arrow[r, "x_1"] & RS \arrow[l, "x_1+x_2"'] \arrow[r, "x_1+x_2"'] & UES \arrow[l, "x_2"'] \arrow[r, Rightarrow] & x_1 \end{tikzcd}$$

4. Two-Way Relay 的应用：CDR.

Coordinated Direct and Relay Transmission.



CDR1：解决 relayed DL - direct UL.

↑ 2 slots ↓

1) BS 发下行

2) MS2 发上行同时 RS 广播，MS1 正常，BS 可由 1) 信息恢复.

CDR2：解决 relayed UL - direct DL

1) BS发下行，同时 MS1 上行

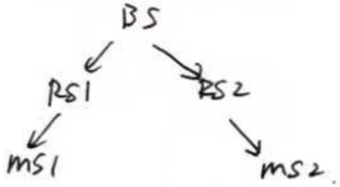
2) RS 广播，BS可恢复.

传统策略的话是 3 slots.

其实都是一种贪婪的思想.

5. Four-way Relaying.

并没有讲清楚，只讲了 coupling 版本的.



BS, MS1, MS2 同时发所有要发的信息

全部收到后都减掉已知信息.

共 24 slots.

6. Relaying Protocols

Decode-and-Forward (DF)：解调，解码再编码后转发.

Amplify-and-Forward (AF)：放大后转发.

B. Multicarrier and OFDM.

Motivation 很多系统由多径衰落影响，$B > B_c$，会有频率选择.

若频分复用多载波令 $\boxed{\frac{B}{N} \ll B_c}$，可享受 flat fading 且无ISI.

本章节中，令 T_m 表示 delay spread，且 $B_c = \frac{1}{T_m}$.

1. 若 Nonoverlapping Subchannels.

$\boxed{B = \frac{N(1+\beta+\epsilon)}{T_N}}$，$T_N$ 是符号周期.

直接带通 filter 可"解调"，但有缺陷，可以见得子载波并不严格 $\frac{B}{N}$ 带宽，且需要大量 filter

2. Overlapping Subchannels, method 1.

有重叠，开头结尾~~多余频率~~多出 $\frac{\beta+\epsilon}{N}$.

$$\boxed{B = \frac{N}{T_N} + 2\cdot\frac{1}{2}\frac{\beta+\epsilon}{N} = \frac{N+\beta+\epsilon}{N}}$$

用匹配 filter 接受，依然硬件开销大.

3. Overlapping Subchannels, OFDM.

1) DFT/IDFT.

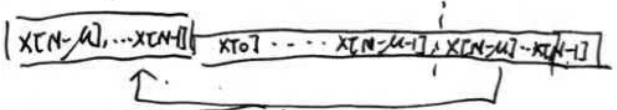
$$\mathrm{DFT}\{x[n]\} = X[i] \triangleq \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} x[n] e^{-j2\pi\frac{n}{N}i}.$$

$$\mathrm{IDFT}\{X[i]\} = x[n] \triangleq \frac{1}{\sqrt{N}} \sum_{i=0}^{N-1} X[i] e^{j2\pi\frac{n}{N}i}$$

DFT和IDFT代替了匹配滤波器的作用

并且IFFT可完成对星座产生的频分

2) Cyclic Prefix，循环前缀.



前缀长度 $\boxed{\mu+1 = \frac{T_m}{T_s}}$，实际 $\mu+1 > \frac{T_m}{T_s}$ 保证无ISI. Sampling time

两种好处，用 DFT 恢复 x[n]（圆卷积），无ISI.

OFDM系统接受 y[n] 时，只要有 μ 前缀的，直接去掉前缀就能消除 ISI.

3) others.

OFDM Symbol 传输总时长 $= \underline{(N+\mu)T_s}$. Symbol time.

$$\text{data rate} = \frac{\log_2 M \times N}{\text{OFDM传输时长}}.$$

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bit → 调制 → IFFT → D/A → ⊗ → 发送.

对星座点　　　　$\cos(2\pi f_c t)$.

接收 → ⊗ → A/D → FFT → 解调/判决 → output.

$\cos(2\pi f_c t)$