Chapter 15 移动通信中的无线电传播

Radio propagation in mobile communications

一、多径效应和衰落 (Multipath effect and fading)

由于障碍物的存在，实际上接收到的电磁波来源有两类：

(1) 直接接收到的电磁波

(2) 通过障碍物和地面反射接收到的电磁波

1. 衰落的分类

(1) 长期衰落：在传播中的小变化通过时间积累后被放大。

(2) 短期衰落：传播过程中多次反射引起多径效应造成的衰落。

2. 传播环境

path loss: $L = 32.4 + 20\log(r) + 20\log(f)$

↑ 大尺度衰落，接收功率随距离衰减

Rayleigh distribution：对于非直射路径 (NLOS) 的传播，即时接收的信号电平具有瑞利分布。

3. 位置可变性

在一个 100–200 米的正方形区域来测量位置变化。这意味着在这个区域内，移动设备的位置会发生变化，因此需要对信号强度进行测量和分析。

在城市区域的信号电平分布几乎为对数正态分布。

接收位置的场强 E_i (dBμV/m) 表示：

$$E_i = E_m + Q_i \sigma_L$$

E_m：该点场强的中值，

Q_i：指定信号需覆盖 $i\%$ 的衰落余量 (Fade margin) 所对应的指数分布系数，

σ_L (dB) 表：标准差。

4. 衰落余量 (fade margin)

$$FM = Q_i \sigma_L$$

↓ 概率　↘ 标准差

衰落余量是指在无线电通信中，为了保证通信质量，需要在接收端增加的一定的接收信号的强度余量。

[例1]:

Signal level in 50% of locations within an area equal to $200 \times 200\ m^2$ is acceptable. Assuming 1W transmitter, $G_L = 8dB$, and ignoring the time ~~de~~ variability, obtain the following parameters:

1. Fade margin (FM) for received signal level in acceptable conditions for at least 90% of locations.
2. For 97% locations coverge, what is the new required transmitter power?

解:

1. $Q_i(90\%) = 1.282$

$FM = Q_i G_L = 10.256\ dB$.

2. $\because 97\% > 90\%$

$Q_i(97\%) = 1.881$

$FM' = Q_i(97\%) \cdot G_L = 15.048\ dB$.

$10\log(\frac{P_t'}{P_t}) = FM' - FM = 4.792\ dB$

$P_t' = P_t \times 10^{\frac{4.792}{10}} \approx 1.5W$

5. 分集技术

分集技术是用来补偿多径衰落的一种有效方法。分集技术用来补偿衰落信道损耗。通常用两个或多个接收天线来实现。

具体包括:

1. 空间分集 (Space diversity): Multiple antenna at different position to receive signals

2. 角度分集 (Angular diversity):

Using multi-beam antenna at different receiving angle

3. 频率分集 (frequency diversity)

Using various frequency to receive signals.

4. 极化分集 (~~polari~~ polarization diversity):

Using cross-polarization to receive signals.

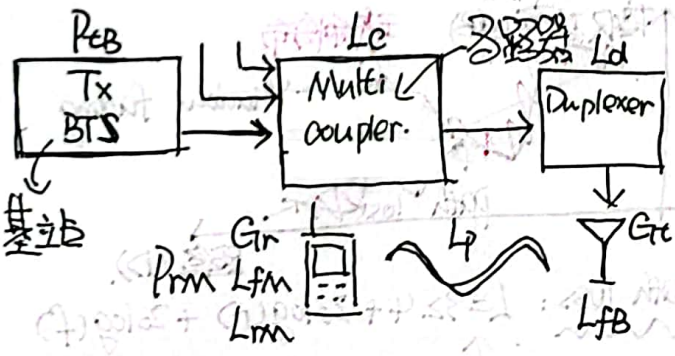
5. 时间分集

Retransmit the same signals multiple times in different time intervals.

二. 大规模路径损耗

- 链路功率预算方程

1. 下行链路 (downlink):



下行链路需要用多路器把多个用户信息进行整合。此外会有传输损失 Lc.

$P_{rm} = P_{tB} - L_c - L_d - L_{fB} - L_p - L_{fM} + G_t + G_r$

~~L_{fB}: 馈线损耗 (feeder losses)~~

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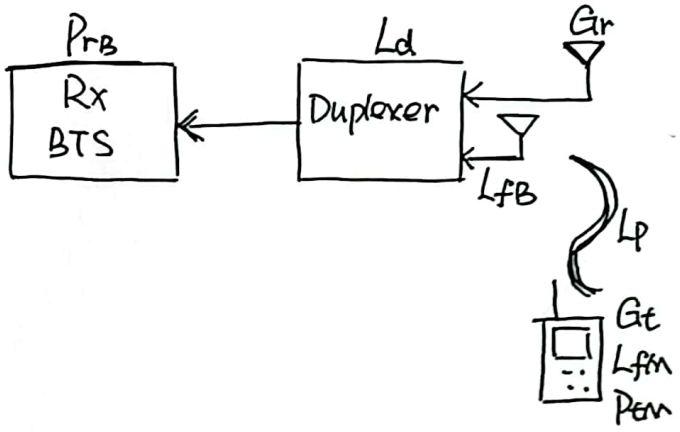
2、上行链路(uplink)



$P_{RB} = P_{EM} - L_d - L_p - L_{fM} - L_{fB} + G_t + G_r$

- 公式中一些参数解释：

P_{RM}: Received signal power at the mobile terminal in dBm.

P_{EB}: BTS Tx power in dBm.

L_c. L_d: Coupler and duplex losses in dB.

L_{fB}. L_{fM}: transmitter and terminal feeder losses in dB. (馈线损耗)

L_p: Path loss in dB.

G_t. G_r: BTS Tx and Rx (terminal) antenna gain in dBi

3、downlink 和 uplink 的关系

Down: $P_{RM} = P_{EB} - C - L_c$

Uplink: $P_{RB} = P_{RM} - C$

$\Rightarrow P_{EM} - P_{RB} = P_{EB} - P_{RM} - L_c$

[例3]: Find the BTS transmitter power with the following assumptions. (假设)

- Coupler loss: 6dB
- Pathlength: 15km.
- Duplexer loss: 1dB
- Path loss: 138dB
- Receiver sensitivity: -106dBm.
- Terminal feeder loss: 0.5dB
- BTS feeder loss: 0.5dB
- Fade margin: 8dB.
- BTS antenna gain: 12dBi
- Terminal antenna gain: 2dBi

解:

$P_{RM} = P_{RS} + FM = -106\,dBm + 8dB = -98dBm$

$P_{RM} = P_{EB} - L_c - L_d - L_{fB} - L_p + G_t + G_r$ (其中 $-L_{fM}$)

$= P_{EB} - 6 - 1 - 0.5 - 138 + 12 + 2$ (-6.5)

$= P_{EB} - 138$

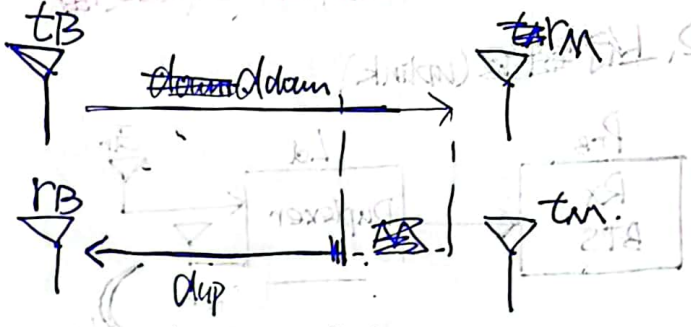
$\therefore P_{EB} = P_{RM} + 138 = 40dBm = 10W$

$dBm = 10 \cdot \log\left(\frac{P}{1mW}\right)$

[例3]

In a mobile link, the BTS and mobile terminal transmitter power are 25W and 2W, respectively. The receiver sensitivities are equal to -110 dBm and -105 dBm, and the correction factor of receiver antenna space diversity in the BTS is 3dB (L_C=5dB).

1. Is the system balanced or not?
2. Which of the downlink or uplink coverage is greater?



上下链路不平衡

上行链路的裕量大于下行链路，所以上行链路可以传播的更远，最终的覆盖区域由下行链路决定

(So the system is unbalanced and the uplink is in a better condition, so the final coverage is determined based on the downlink)

解：

1. $P_{EB} = 10\log(25\times10^3) = 44dBm$.

$P_{EM} = 10\log(2\times10^3) = 33dBm$

~~$P_{TM} = P_{RS1}$~~

$P_{RB} = P_{RS1} + FM_{up} = -110dBm + FM_{up}$

$P_{RM} = P_{RS2} + FM_{down} = -105dBm + FM_{down}$

~~$P_{EM} = P_{EB} - C$~~

$P_{RM} = P_{EB} - C - L_C$

$P_{RB} = P_{EM} - C + G_D$ 其中 G_D=3dB.

$\therefore P_{RS2} = P_{EB} - FM_{down} - C - L_C$ ——(1)

$P_{RS1} = P_{EM} - FM_{up} - C + G_D$ ——(2).

(1)-(2)得.

$P_{RS2} - P_{RS1} = P_{EB} - P_{EM} + (FM_{up} - FM_{down}) - L_C - G_D$

$\therefore FM_{up} - FM_{down} = 至少\ 2dB$