LTE 下行MIMO簡介

2014-10

常见问题

1. 什么是MIMO？
2. LTE中为什么使用MIMO？
3. MIMO的如何理解和解释？
4. MIMO如何作用？
5. MIMO模式如何区分？
6. MIMO中的基本概念和作用过程？
7. MIMO各模式的特点如何？
8. MIMO对性能的影响如何？

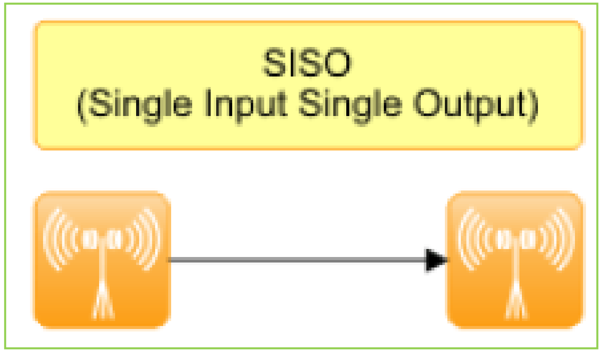
什么是MIMO？

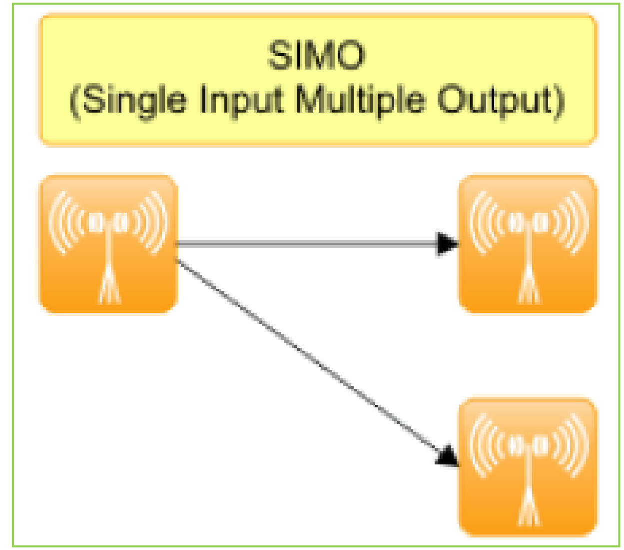
MIMO设计思路MIMO基本思想

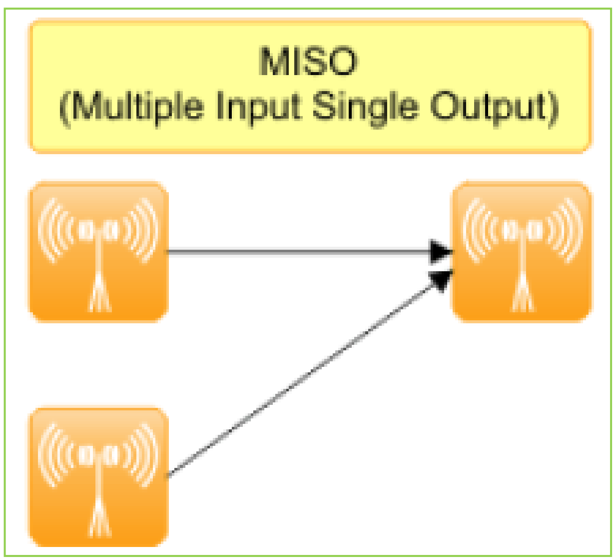
为了进一步提高频谱的复用率，研究者们想到在通信的一方或双方采用多个收发天线，主动地利用用户的空间方位信息或空间信道的冗余来提高系统的容量，这便是MIMO（多输入多输出）系统的由来。

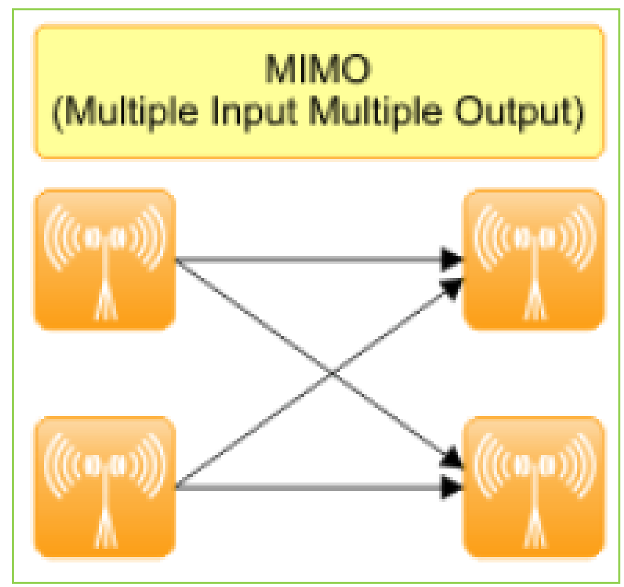
其基本思想是在收发双端采用多根天线，分别同时发射与接收，通过空时处理技术，充分利用空间资源，在无需增加频谱资源和发射功率的情况下，成倍地提升通信系统的容量与可靠性，提高频谱利用率。

根据天线数来简单区分MIMO





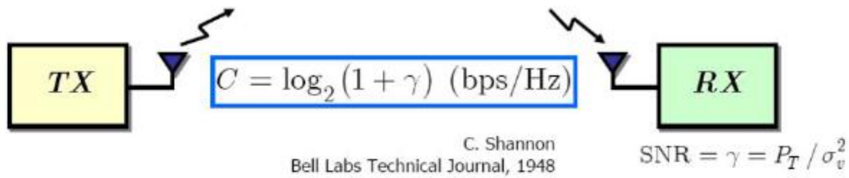




香农界限

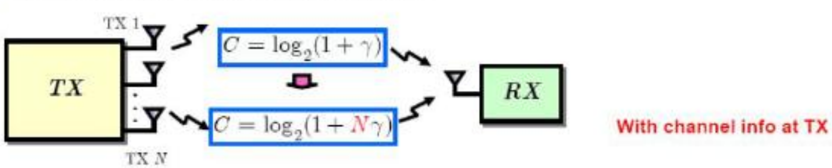
SISO的香农界限

- 根据香农定理，单天线链路的信息论容量受限于链路的信噪比

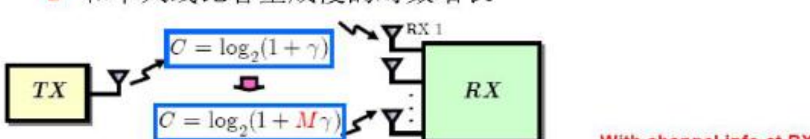


- 每个格外的bps/Hz大约需要几倍的发射功率（从1bps/Hz到11bps/Hz，发射功率必须增加大约1000倍)

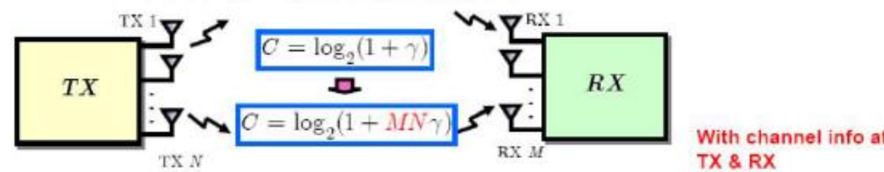
- 单TX天线组：MISO
  - 一个天线组提供发射分集对抗衰落
  - 和单天线比容量成慢的对数增长



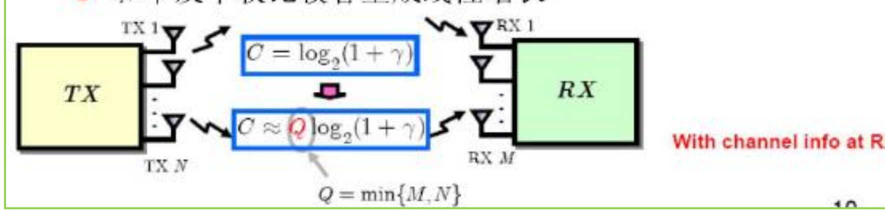
- 单Rx天线组：SIMO
  - 一个天线组提供接受分集对抗衰落
  - 和单天线比容量成慢的对数增长



- 双天线组：MIMO
  - 双天线组提供了发射和接收端的分集
  - 和单发单收比较容量成对数增长



- 双天线组：MIMO
  - 双天线组提供了并行的空间信道
  - 和单发单收比较容量成线性增长



MIMO的好处(1)

- 增强 SINR (SINR较低时)

Spectral efficiency of one channel, no diversity:

$$C=\log_2(1+SNR)\ [b/s/Hz]$$

MIMO with N Tx and M Rx antennas, unknown channel:

$$C=N\log_2(1+SNR*M/N)\ [b/s/Hz]$$

$$M=N \Rightarrow C= N\log_2(1+SNR)\ [b/s/Hz]$$

Rx & Tx diversity: N Tx and M Rx antennas, known channel:

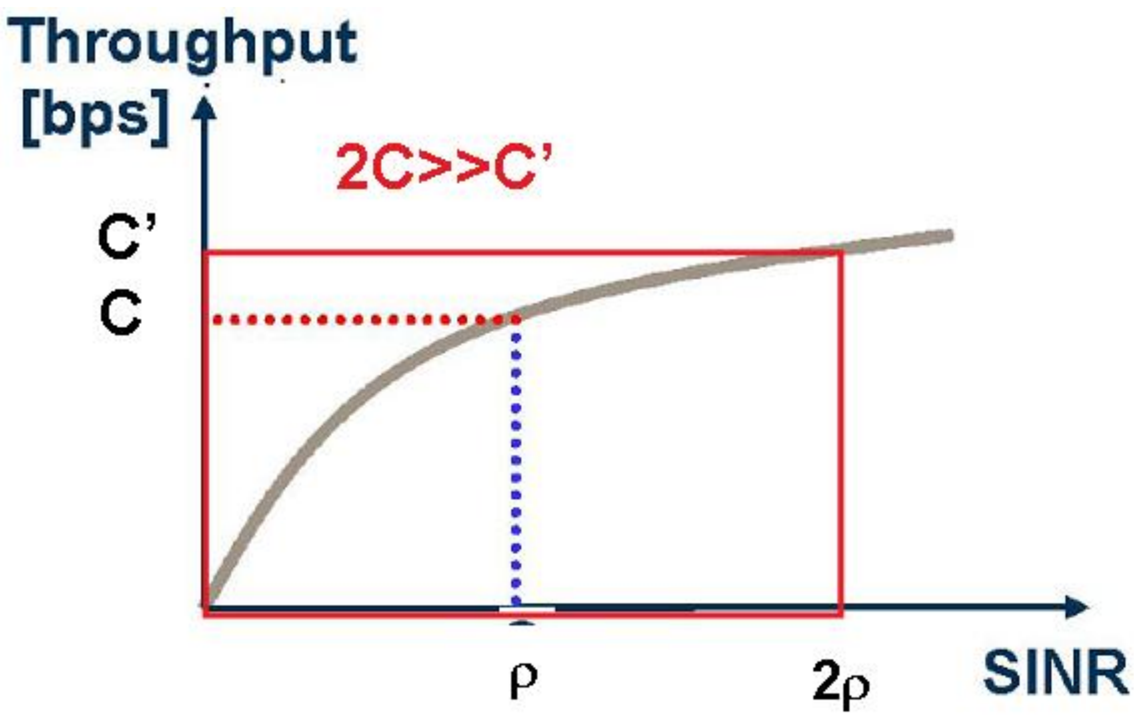
$$C=\log_2(1+SNR*M*N)\ [b/s/Hz]$$

MIMO的好处(2)

- 分享 SINR (SINR较高时)

通常，SINR越高，信道容量越大，但是SINR过高时，吞吐量的改善程度有限(存在瓶颈)。

多个天线可以看成并行的信道，每个信道都具有SINR，如果保持发射功率一定(2x2时每个数据流都降低3dB)，并且每个信道上的噪声是相同的，则相对于使用总功率的单个天线来说，MIMO模式下的SINR值约为一半。由于使用了2个数据流，因此上抵消了公共SINR值的降低。如果SINR足够高的话，吞吐量可能会加倍。



MIMO的好处(3)

- 增强容量和覆盖

$$r_{max} = \min\{N_R, N_T\}$$

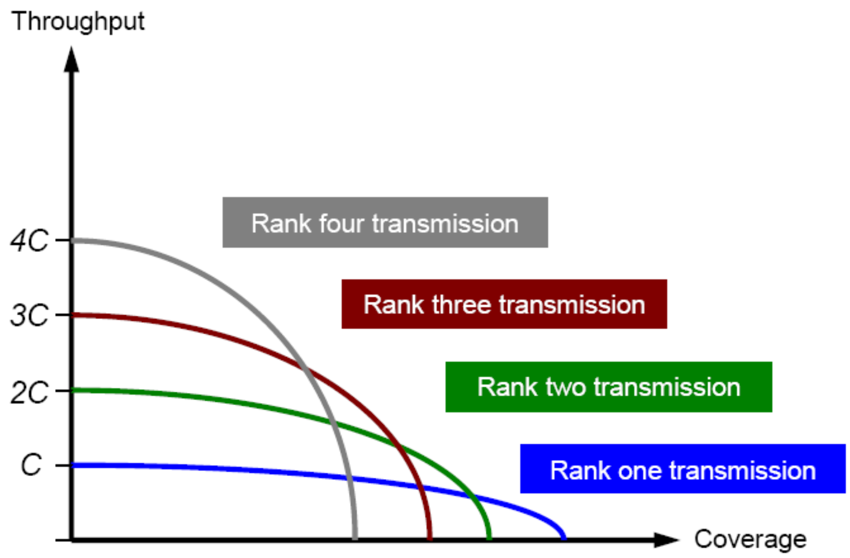


Figure 2. Throughput versus coverage (coverage for a certain minimum requirement on throughput) for a 4x4 MIMO wireless link

rank-one transmissions increase the coverage (in terms of cell edge data rates) whereas spatial multiplexing (rank larger than one) improves peak rates.

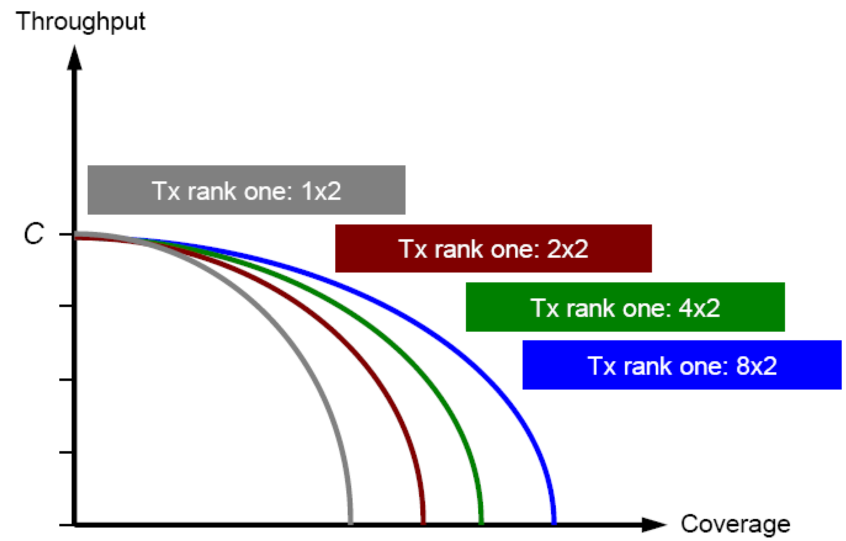
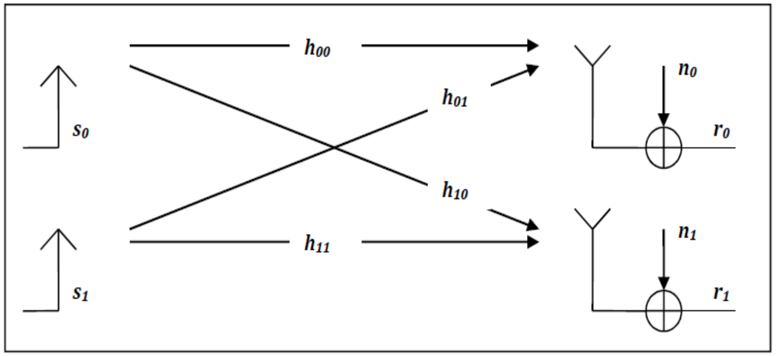


Figure 3. Throughput versus coverage curves illustrating how the array gain from the use of beamforming improves the throughput on the cell edge but not sufficiently close to the cell center

The phase adjustments are such that the signals from the different antennas add constructively at the receiver side, improving SINR and thus coverage. The achievable SINR improvement increases with the number of transmit antennas. Roughly speaking, the so-called array gain is proportional to the number of transmit antennas implying that a doubling of the number of transmit antennas allows for an up to 3 dB gain in SINR.

MIMO如何作用

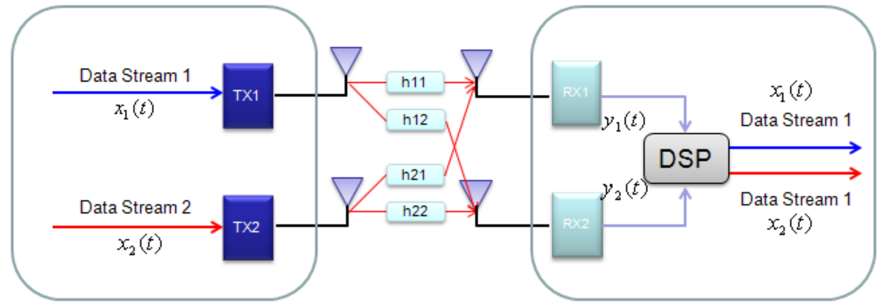
MIMO矩阵表示



$$r_0 = h_{00} \cdot s_0 + h_{01} \cdot s_1 + n_0$$
$$r_1 = h_{10} \cdot s_0 + h_{11} \cdot s_1 + n_1$$

$$\begin{pmatrix} r_0 \\ r_1 \end{pmatrix} = \begin{pmatrix} h_{00} & h_{01} \\ h_{10} & h_{11} \end{pmatrix} \cdot \begin{pmatrix} s_0 \\ s_1 \end{pmatrix} + \begin{pmatrix} n_0 \\ n_1 \end{pmatrix}$$

$$r = H \cdot s + n$$



Channel Information Matrix

Recieved data

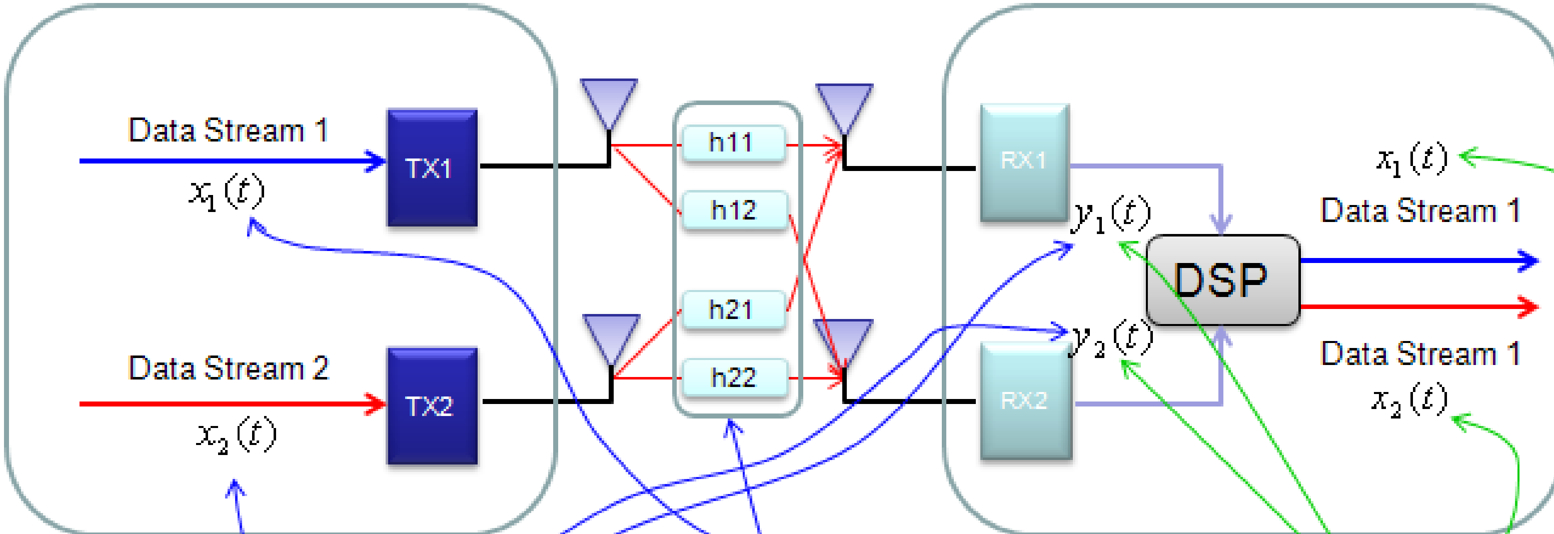
Transmitted data

$$\mathbf{y} = \mathbf{H}\mathbf{x}$$

$$\mathbf{y} = \begin{bmatrix} y_1 \\ y_2 \end{bmatrix} \qquad \mathbf{H} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} \qquad \mathbf{x} = \begin{bmatrix} x_1 \\ x_2 \end{bmatrix}$$

$$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix}$$

MIMO发射信号提取-逆矩阵



$$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix}$$

The received data is represented as the transmitted data transformed by channel information matrix

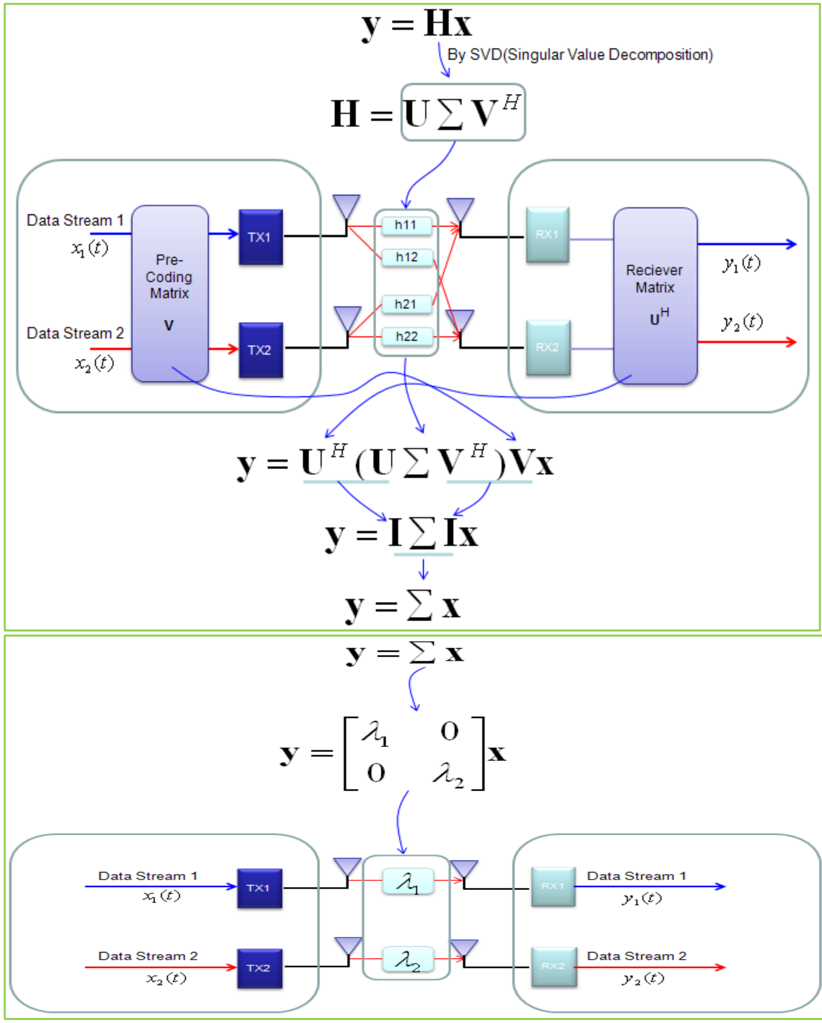
$$\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix}^{-1} \begin{bmatrix} y_1 \\ y_2 \end{bmatrix}$$

Reciever can recover the transmitted data by multiplying the channel information matrix and the received data.

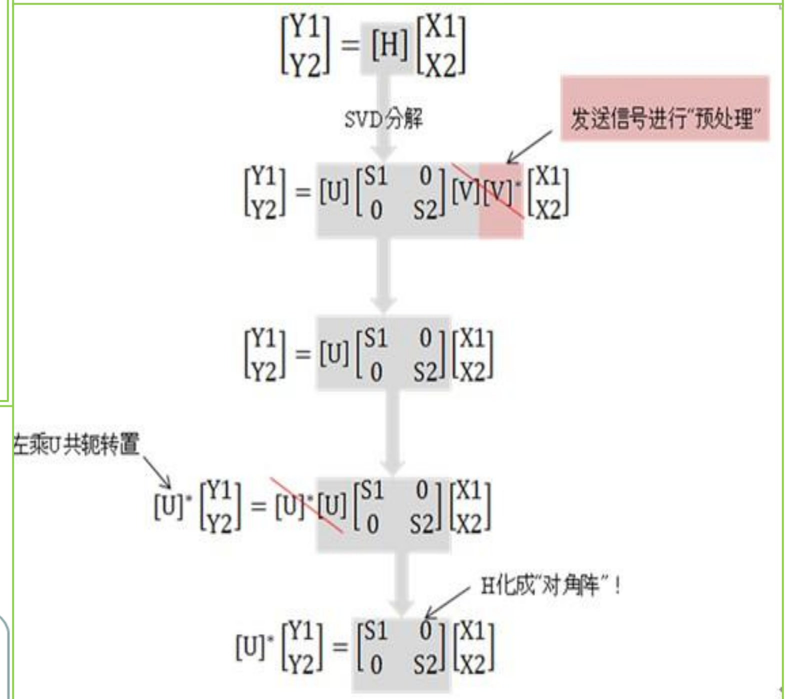
逆矩阵不好计算，且有时候不存在

MIMO发射信号提取-奇异值分解

SVD(Singular Value Decomposition)



图表 4 对 H 进行 SVD 分解



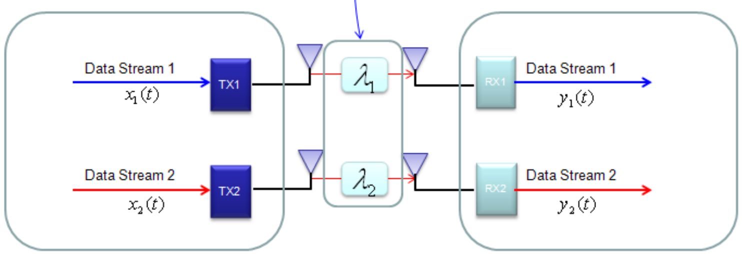
图表 5 将 H 化成对角阵的过程

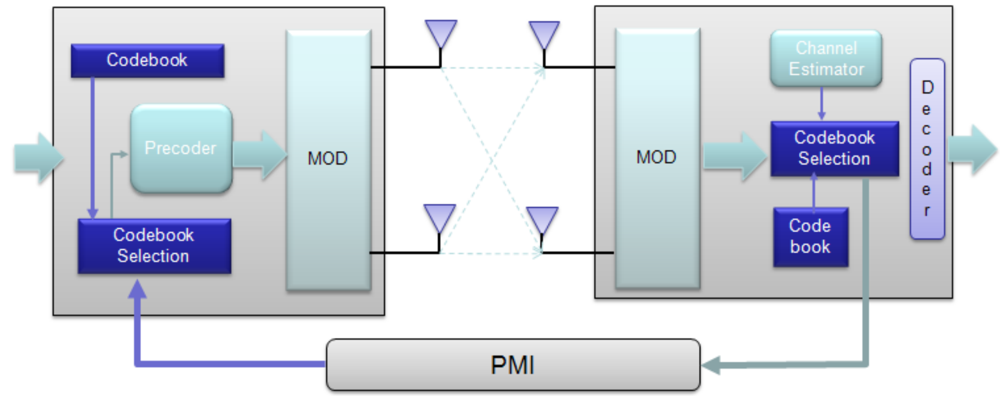
通过对传输矩阵H进行SVD分解，我们可以得到三个矩阵：左酉阵U，对角矩阵S（对角阵S中的元素s1，s2就是H矩阵的奇异值）和右酉阵V。现在，我们期望的对角阵S已经出现了，但它的左右两边又多出了两个酉阵U和V，怎么办？没关系，"酉阵"同学有一个很好的性质，它只要与自己的共轭转置相乘，就可以把自己化简掉（其实是得到了一个单位阵（））。如果我们在信号经过信道之前，首先对信号进行"预处理"，给它们乘以V的共轭转置矩阵，再让它们经过信道，右酉阵V就被化简掉了，相当于发送信号直接与对角阵S相乘！接收端的处理类似，我们对接收信号矩阵左乘酉阵U的共轭转置，就可以消掉它。这时我们惊喜的发现，拥有"对角阵"形式的传输方程又回来了，这正是我们期待的效果！

MIMO发射信号提取-将信道等价为对角阵并估算PMI

$$\mathbf{y} = \sum \mathbf{x}$$

$$\mathbf{y} = \begin{bmatrix} \lambda_1 & 0 \\ 0 & \lambda_2 \end{bmatrix} \mathbf{x}$$





Codebook Element
(Precoding Matrix)

Channel Infomation Matrix

Step 1 : Calculate $\Omega = W(H^H H)W^H$ for every elements in the code book

Step 2 : Select the codebook element which gives you the minimum value

Step 3 : Report the index of the selected codebook element (PMI) to the receiver

MIMO发射信号提取-实际应用

Reciever should know this

Transmitter should know

$$\mathbf{y} = \mathbf{U}^{H}\underbrace{(\mathbf{U}\,\Sigma\,\mathbf{V}^{H})}_{\substack{\text{This is from channel}\\ \text{(Information from Channel)}}}\mathbf{V}\mathbf{x}$$

左酉阵U　　对角阵S　　右酉阵V

$$H = \begin{bmatrix} U1 & U2 \\ U3 & U4 \end{bmatrix} \begin{bmatrix} S1 & 0 \\ 0 & S2 \end{bmatrix} \begin{bmatrix} V1 & V2 \\ V3 & V4 \end{bmatrix}$$

图表 4 对 H 进行 SVD 分解

- The three matrix at the center can be a known at least to the reciever since the reciever can estimate channel Matrix H from the received signa and calculate these matrix from H.
- The vector x is known to transmitter since it is just the data that's transmitted.
- The matrix U can be a known to the reciever since it can be derived from H.

- 对信道矩阵H进行SVD分解，得到H=U·S·V，其中S就是对角矩阵；接下来，就是用V的共轭转置V*对发送信号进行“预编码”，接收端在收到数据后，同样乘以U*，这样一来，发送的符号就像进入了独立平行的正交子信道，互不干扰。

LTE中为什么使用MIMO？

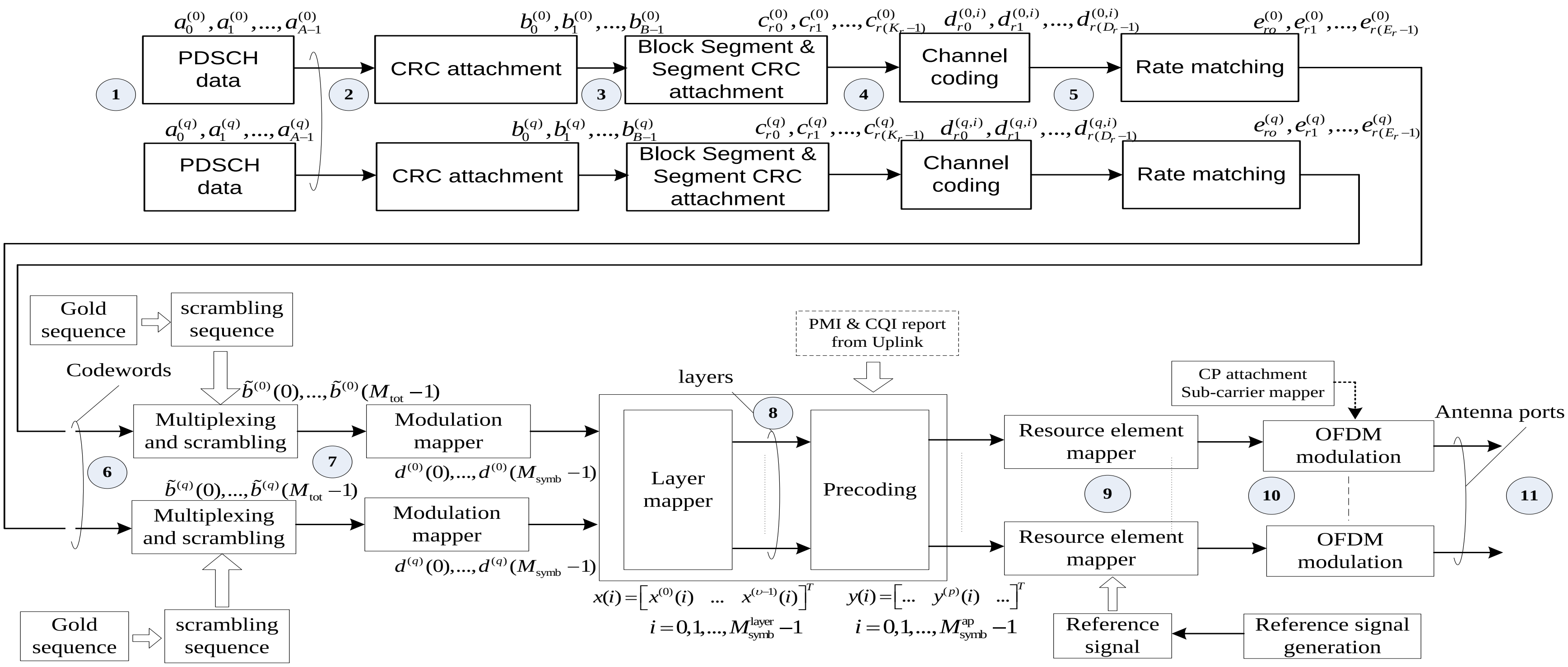
OFDM+MIMO

MIMO可以抗多径衰落，OFDM解决频率选择性衰落。

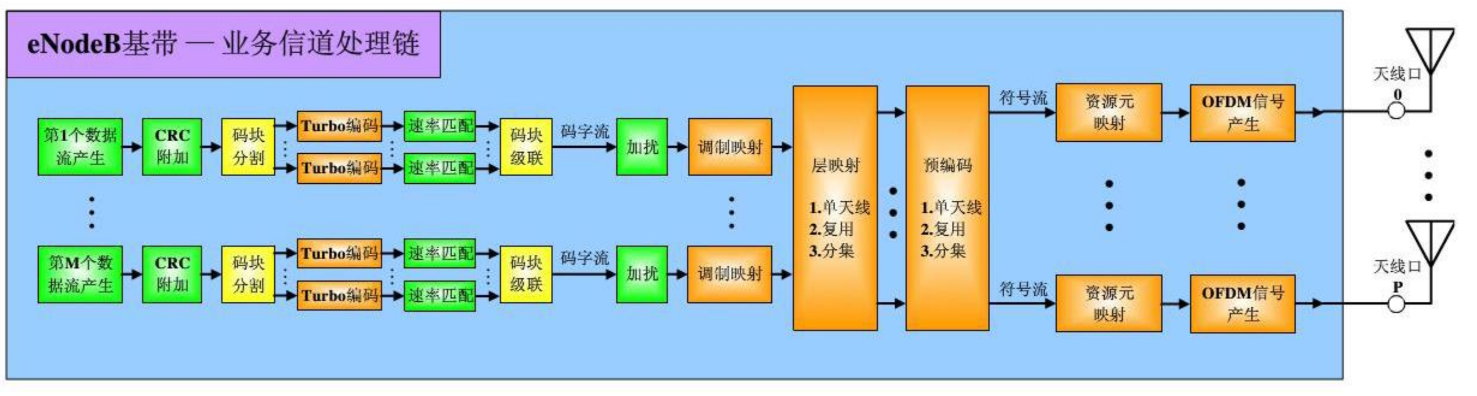
- OFDM技术实质上是一种多载波窄带调制，可以将宽带信道转化成若干个平坦的窄带子信道，每个子信道上的信号带宽小于信道的相关带宽，所以每个子信道上的频率选择性衰落可以看作是平坦性衰落。
- 而MIMO多天线技术能在不增加带宽的情况下，在每一个窄带平坦子信道上获得更大的信道容量，可以成倍地提高通信系统的容量和频谱效率，是一种利用空间资源换取频谱资源的技术。

MIMO+OFDM系统，通过在OFDM传输系统中采用天线阵列来实现空间分集，以提高信号质量，是MIMO与OFDM相结合而产生的一种新技术。它采用了时间、频率结合空间三种分集方法，使无线系统对噪声、干扰、多径的容限大大增加。

LTE发送端信号流程

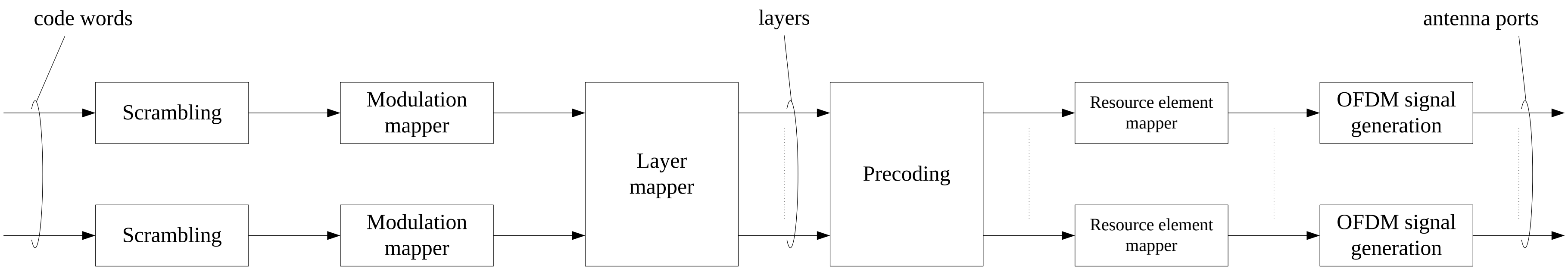


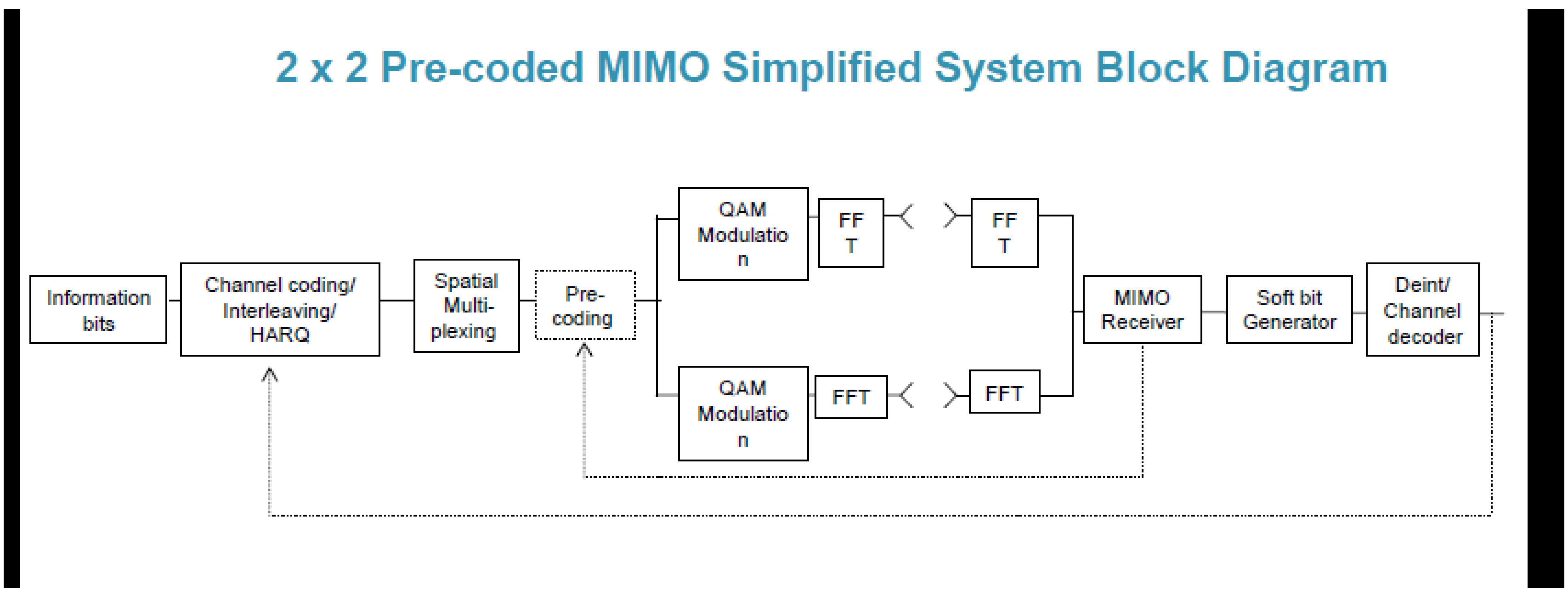
PDSCH data
CRC attachment
Block Segment & Segment CRC attachment
Channel coding
Rate matching
Gold sequence
scrambling sequence
Codewords
Multiplexing and scrambling
Modulation mapper
layers
PMI & CQI report from Uplink
Layer mapper
Precoding
Resource element mapper
CP attachment Sub-carrier mapper
OFDM modulation
Antenna ports
Reference signal
Reference signal generation



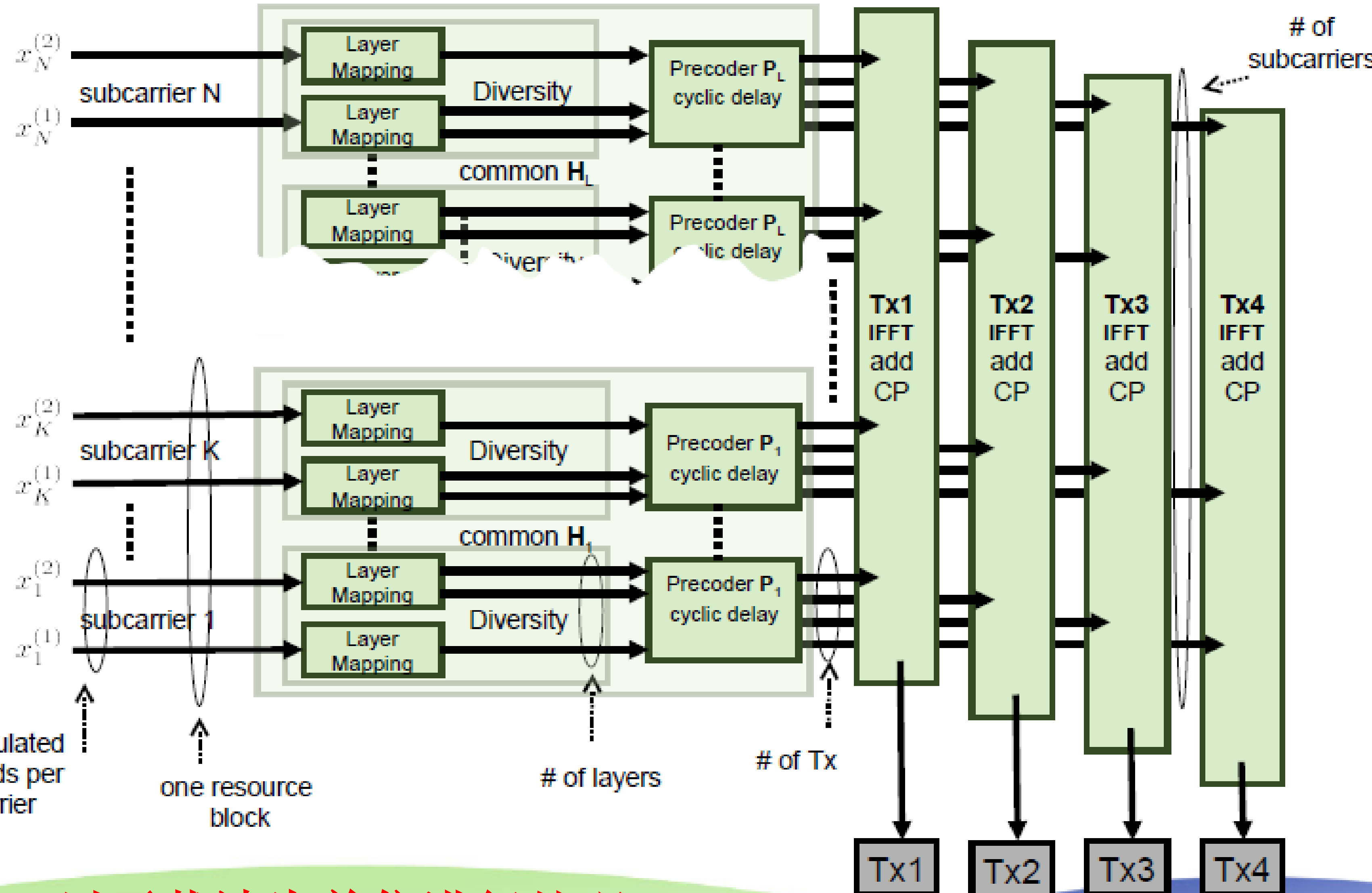
eNodeB基带 — 业务信道处理链
第1个数据流产生
第M个数据流产生
CRC附加
码块分割
Turbo编码
速率匹配
码块级联
码字流
加扰
调制映射
层映射
1.单天线
2.复用
3.分集
预编码
符号流
资源元映射
OFDM信号产生
天线口0
天线口P

LTE下行数据处理过程(TS36.211)



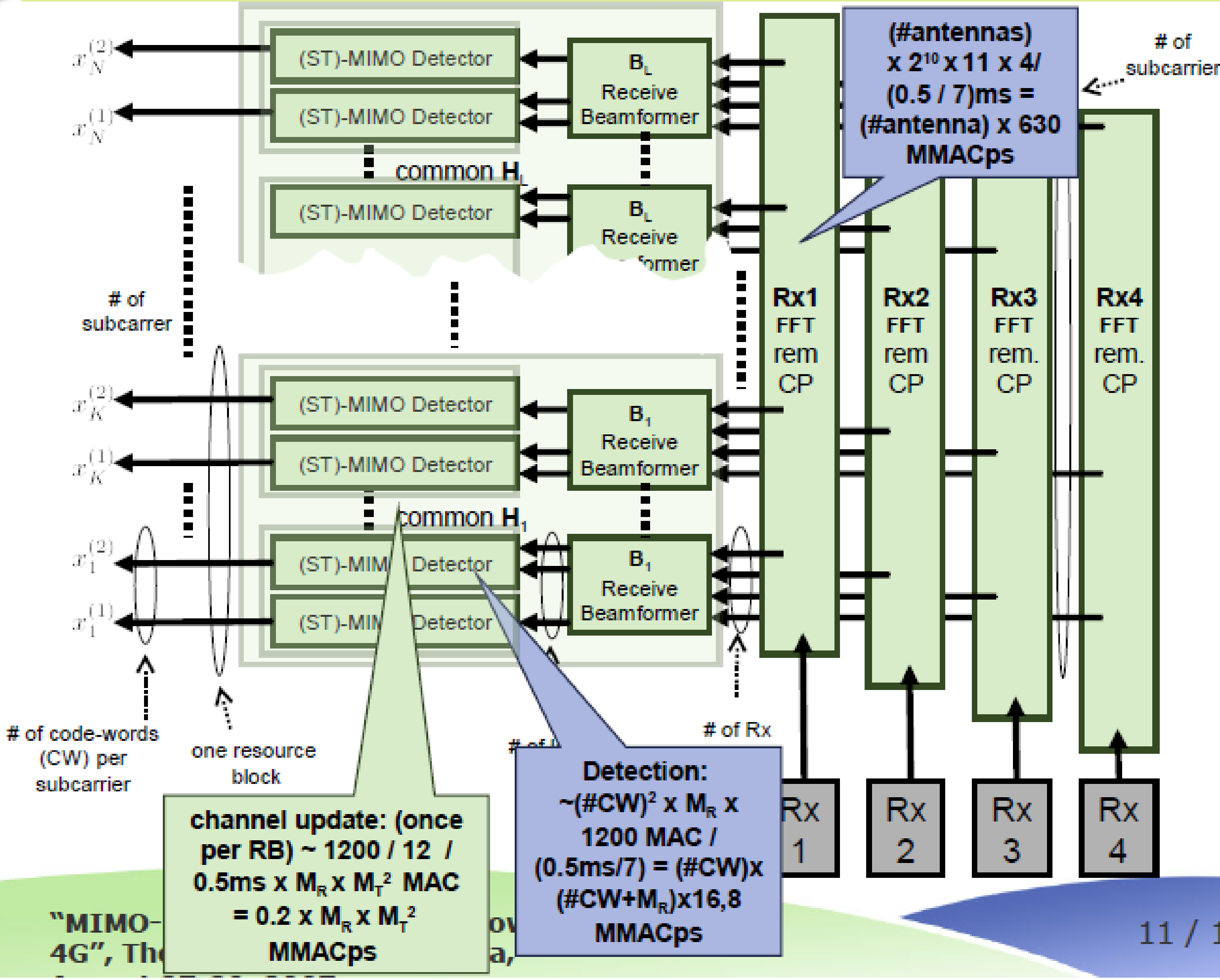


MIMO-LTE Transmitter (DL)



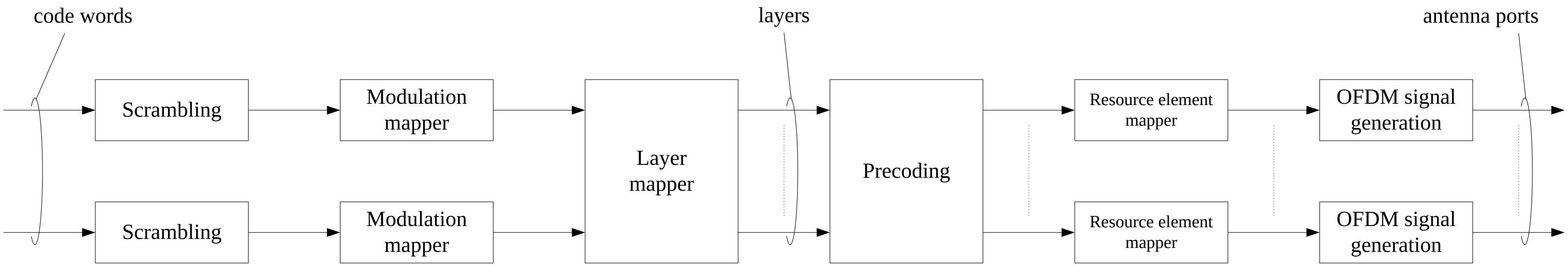
以子载波为单位进行处理。

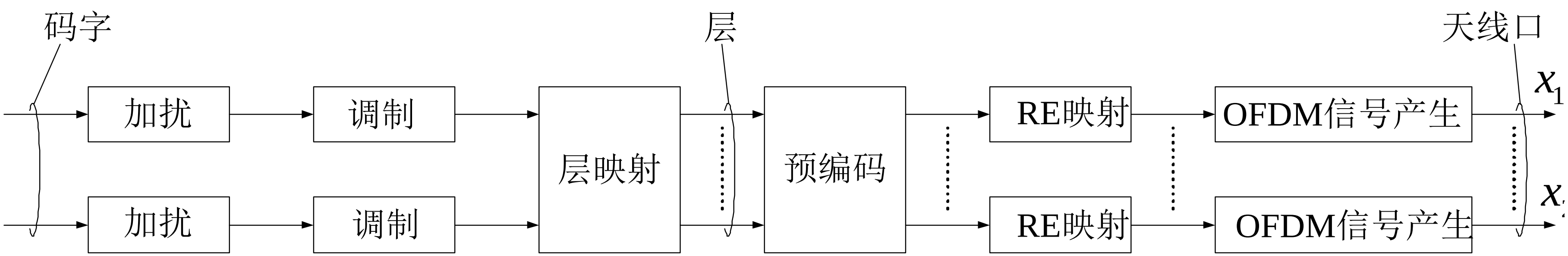
MIMO-LTE Receiver (DL)



"MIMO-
4G", Th

MIMO下行物理层处理过程(TS36.211)

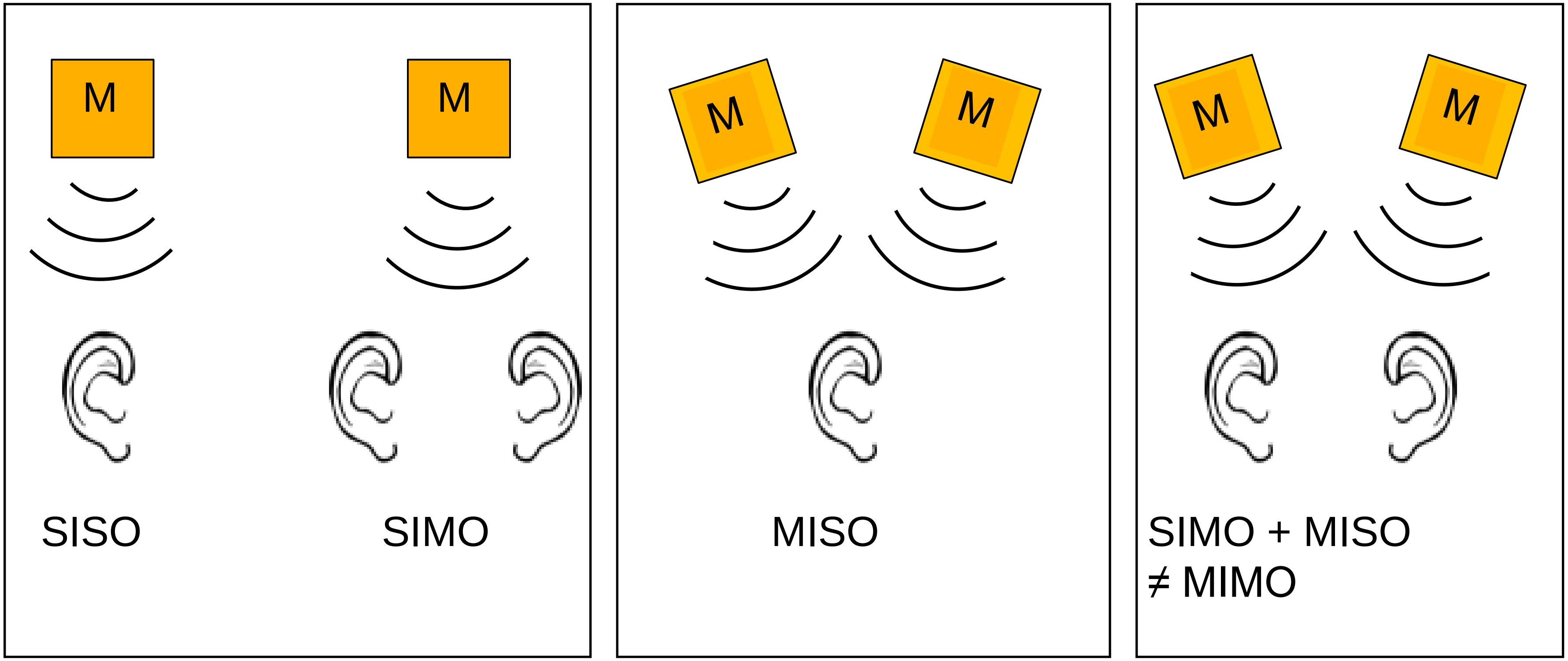




- 天线
- 天线端口
- 码字
- 秩(RI)
- 层(Layer)
- 层影射
- 预编码(PMI、码书)

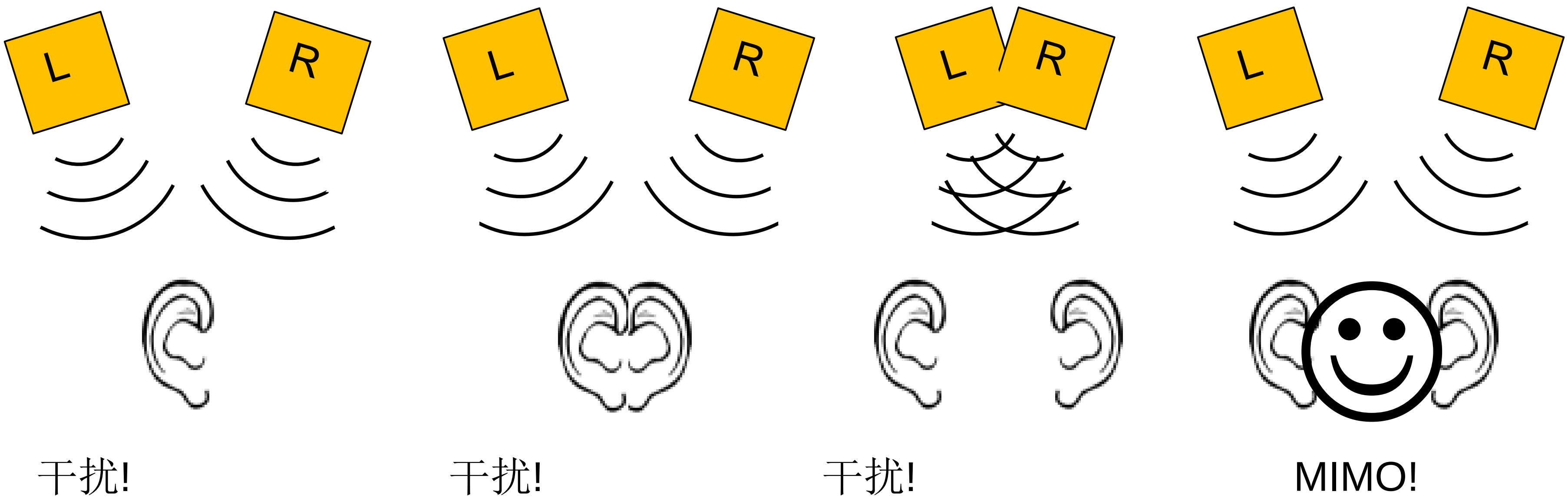
MIMO的形象理解和解释

通过声音来理解MIMO空间分集(单流/单声道)



SIMO+MISO可以增强可靠性，但是由于使用了一个数据流，所以无法提供MIMO容量增益。

通过声音来理解MIMO空间分集(双流/立体声)

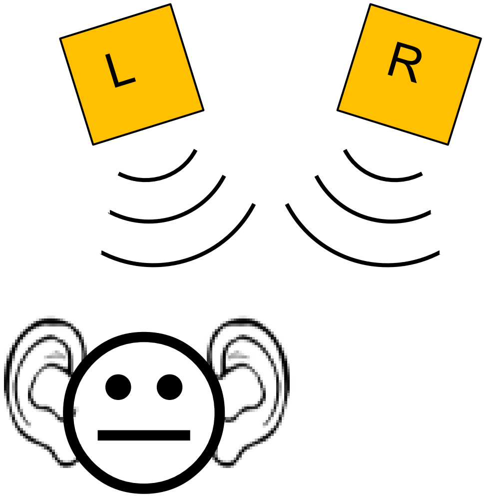


MIMO工作的前提:

- <u>流的数目至少需要大于发射机和接收机的数目</u>。
- 发送和接收天线之间必须空间隔离。
- 发射机更多时，就形成了波束赋形(+MIMO)。

通过声音来理解预编码(Precoding)

- 为了使接收机侧的不同流更加隔离，可以采用预编码码技术。
- 声音的例子中，Precoding可以看成对立体声进行”balance”
- 均衡需要Rx对Tx反馈消息。

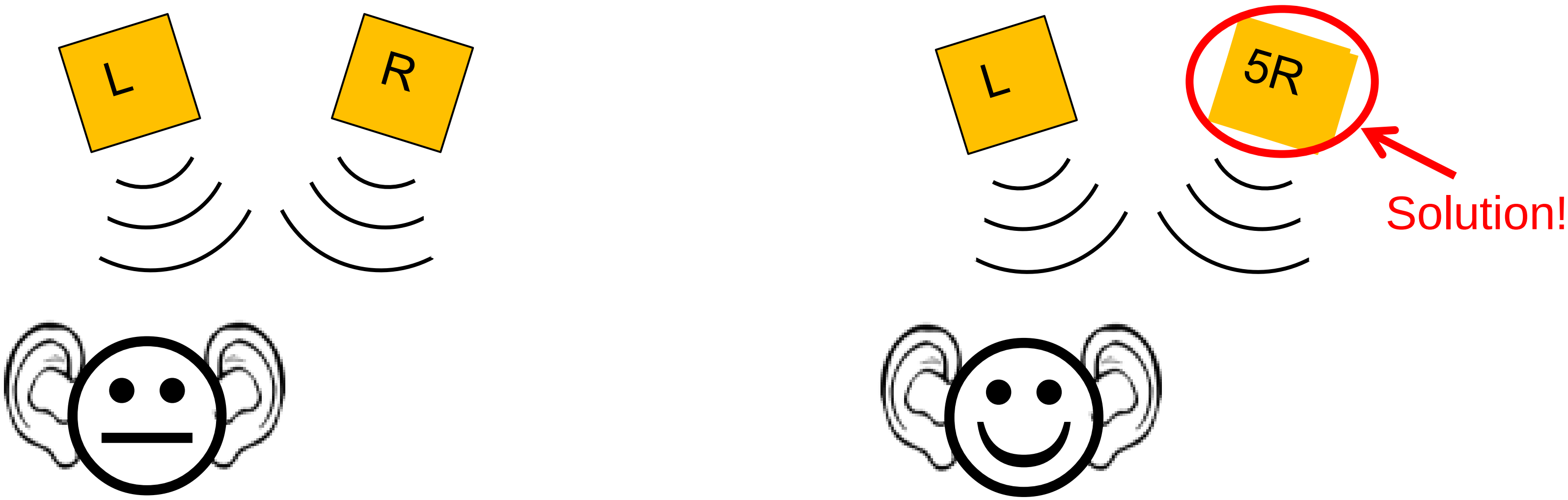


Not enough R

(右声道质量较差)

通过声音来理解预编码(Precoding)

- 如果Tx侧上报R(右声道)音量不足，Tx可以调整R的幅度，但是噪声也会随之放大，因此corrected signal 会degrade:
- Precoding the transmission as L, 5R optimizes signal recovery



$L + N_L,\ 0.2\ R + N_R$

$\rightarrow L + N_L,\ R + 5{*}N_R$

Problem!

$L + N_L,\ R + N_R$

通过声音来理解MIMO秩(Rank)的适配性

- 无线环境好时，FM立体声接收机会试图解码左声道和右声道信号(不同的数据流)。

- 如果噪声太高，则接收机转换到单声道模式，质量改善，但是立体声丢失。

- 以上为无线环境变差时流数适配的例子。

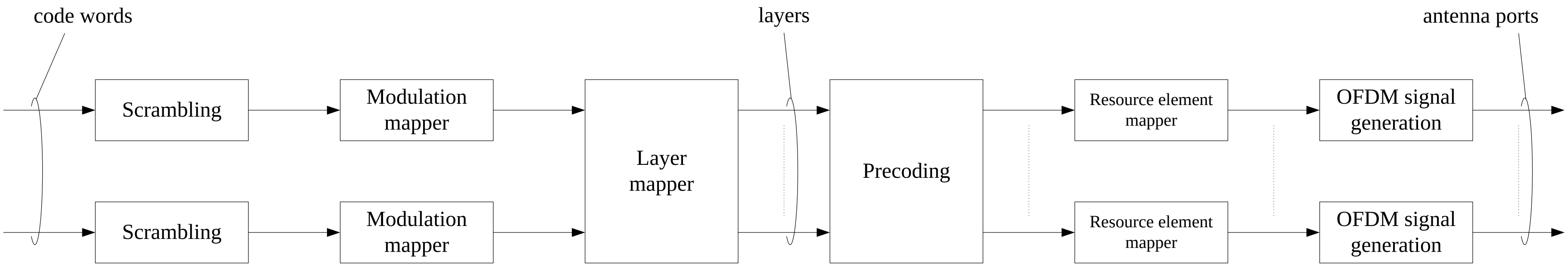
- FM立体声发射编码矩阵为：L + R, L – R
- 接收信号为：(L + R) + N_1 ，(L – R) + N_2
- 由于N_1和N_2的相关性很高，因此将2个流加在一起(最大比合并)，就可以消除大多数噪声。

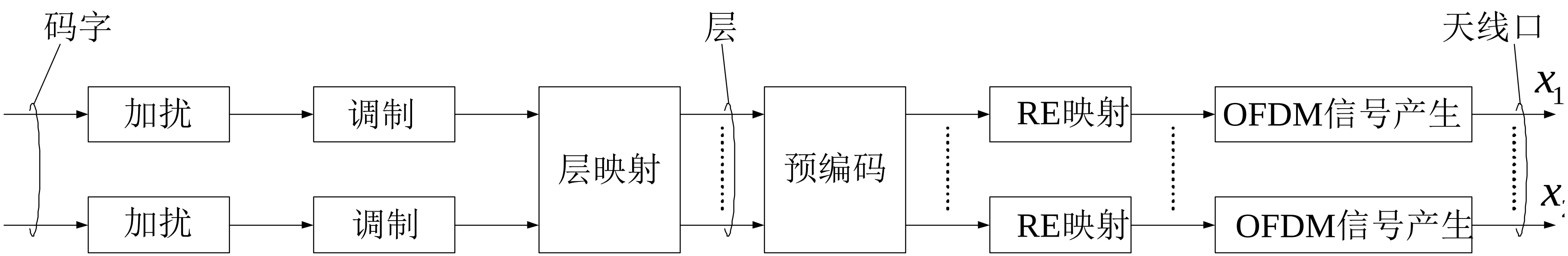
MIMO的重要实现手段

- 通过无线信道的空间复用增加容量。
- 使用Precoding来优化性能。
- 根据无线信道和噪声状况改变Rank。

MIMO中的基本概念和过程

MIMO下行物理层处理过程(TS36.211)





- 天线
- 天线端口
- 码字
- 秩(RI)
- 层(Layer)
- 层影射
- 预编码(PMI、码书)

MIMO下行物理层处理过程(TS36.211)

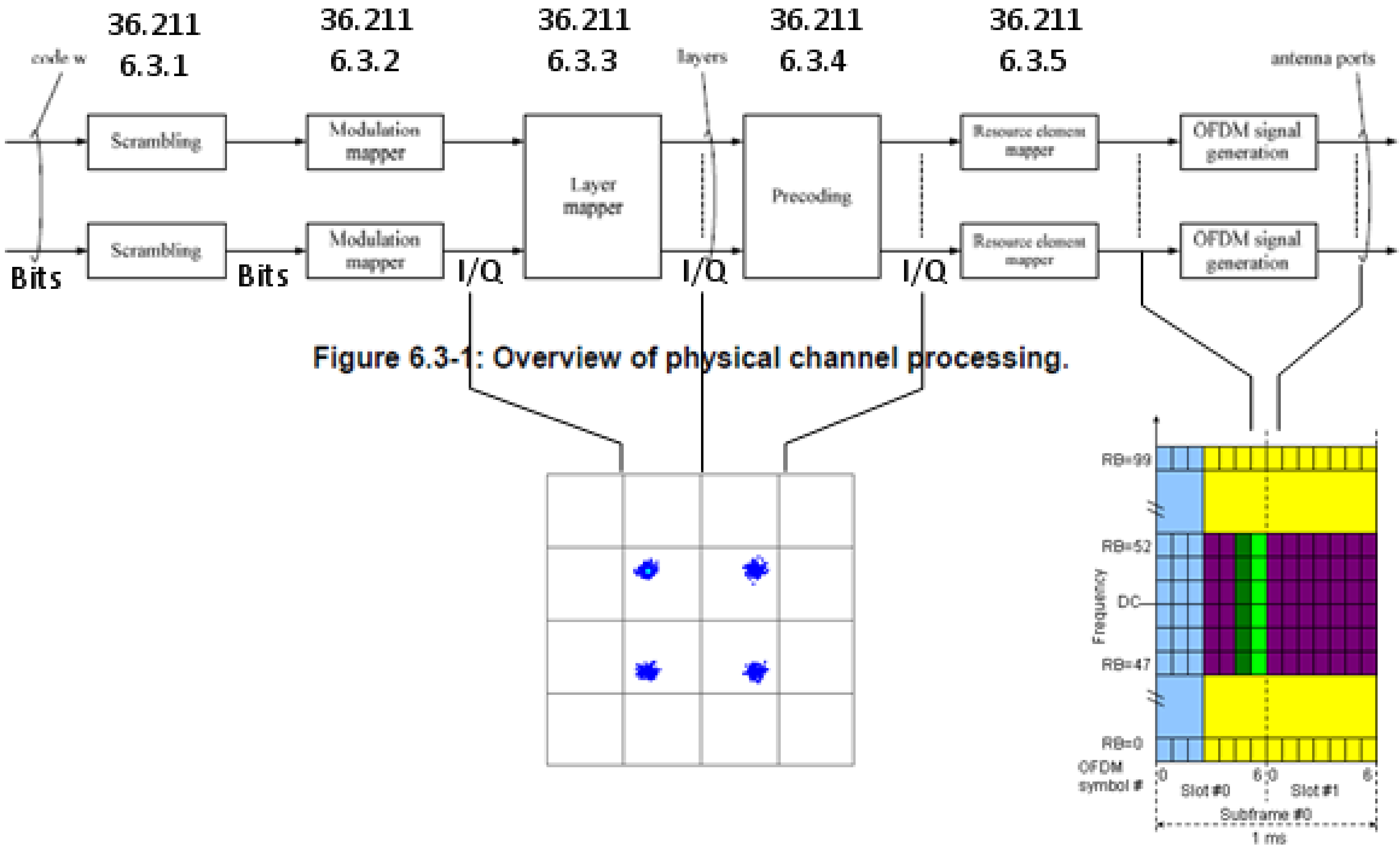
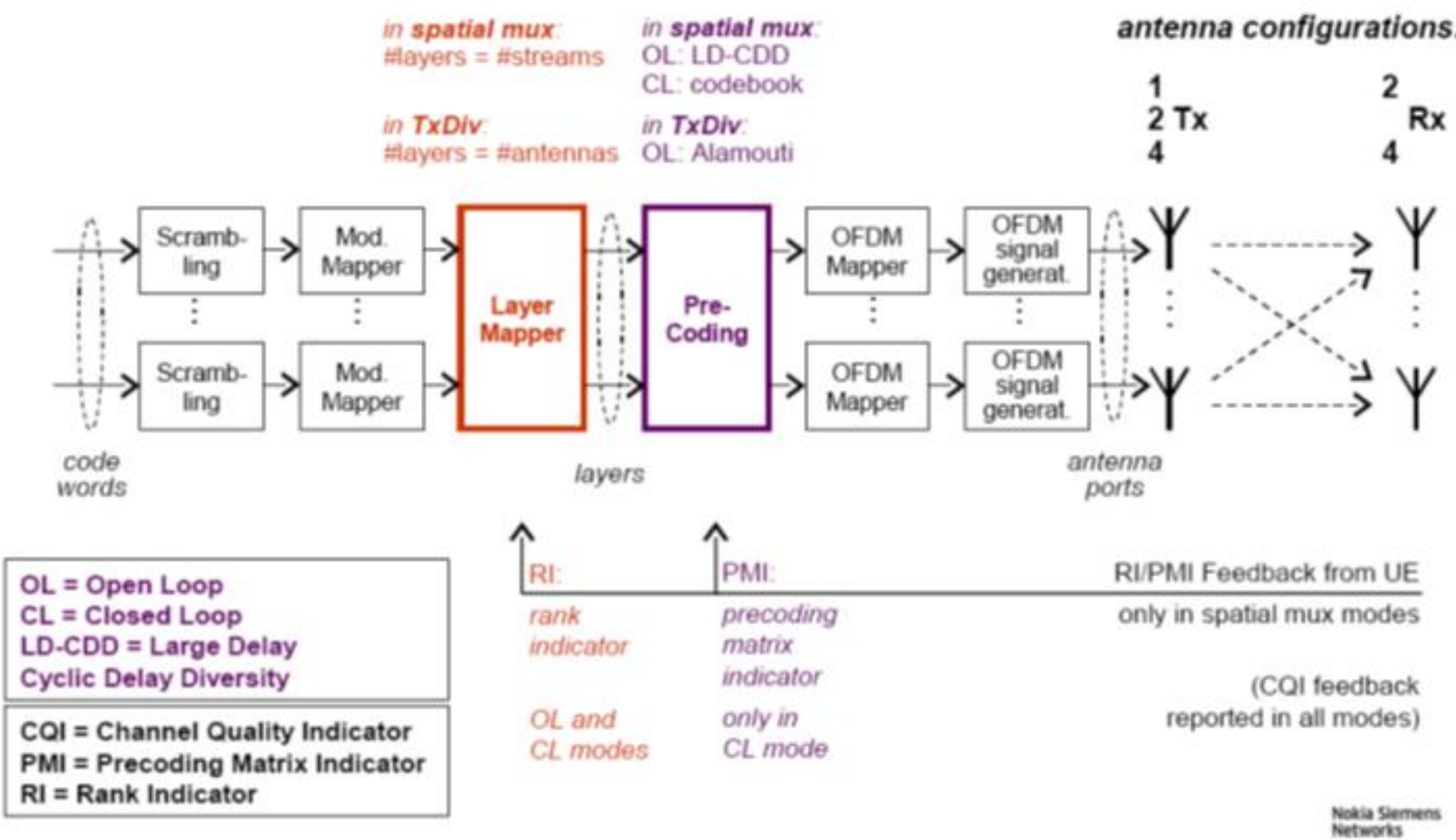


Figure 6.3-1: Overview of physical channel processing.

http://www.sharetechnote.com/html/BasicProcedure_LTE_PHY_Process.html

MIMO下行物理层处理过程

Note: in 3GPP terminology, CL TxDiv is regarded as a variant of spatial mux (single layer)



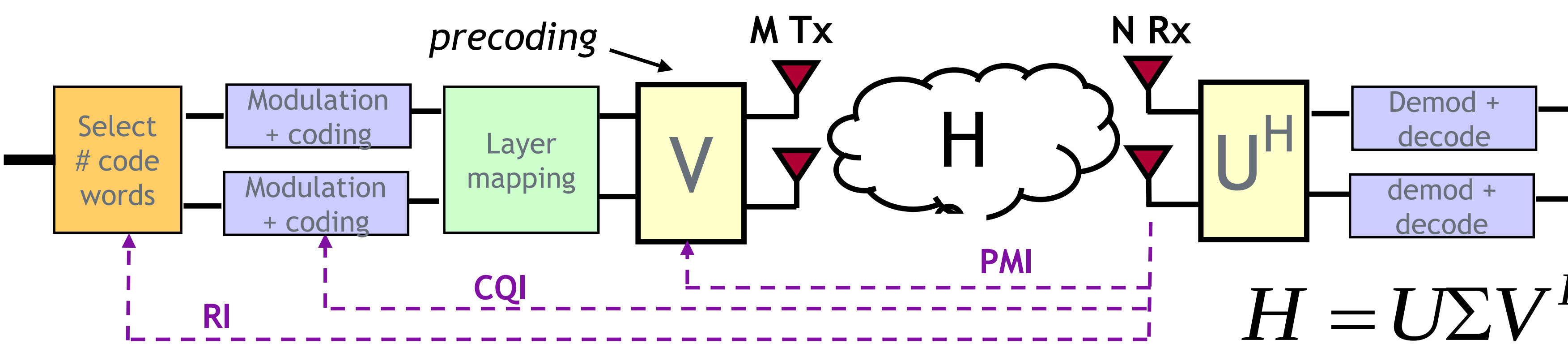
MIMO下行物理层处理过程

UE indicates best combo of CQI/PMI/RI for max throughput (i.e. high-rank/low-MCS vs. low-rank/high MCS)

Closed-loop SM is ideally suited for low speed scenarios when the CQI/PMI/RI feedback is accurate

Open-loop SM provides robustness in high speed scenarios when the feedback is not accurate

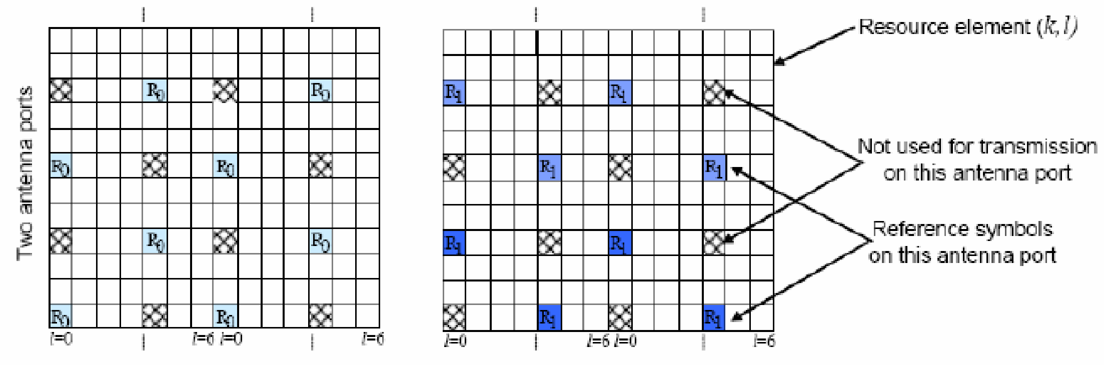
	Closed-Loop SM	Open-Loop SM
CQI	separate CQI for each codeword fed back	one value fed back applicable over all layers
PMI	PMI feedback from UE based on instantaneous channel state	no feedback from UE, fixed precoding at eNB with large delay CDD to improve robustness
RI	based on SINR and instantaneous channel matrix rank RI=1 corresponds to closed loop TxDiv (CLTD)	typically based only on SINR RI=1 corresponds to open loop TxDiv (SFBC)



$$H = U\Sigma V^H$$

天线/天线端口

- 天线端口
  - 与物理天线相对应的逻辑通道
  - 以导频符号为依据的发送通道
  - 物理资源映射的参考平面



Antenna 1　　Antenna 2

逻辑概念。分为3组：

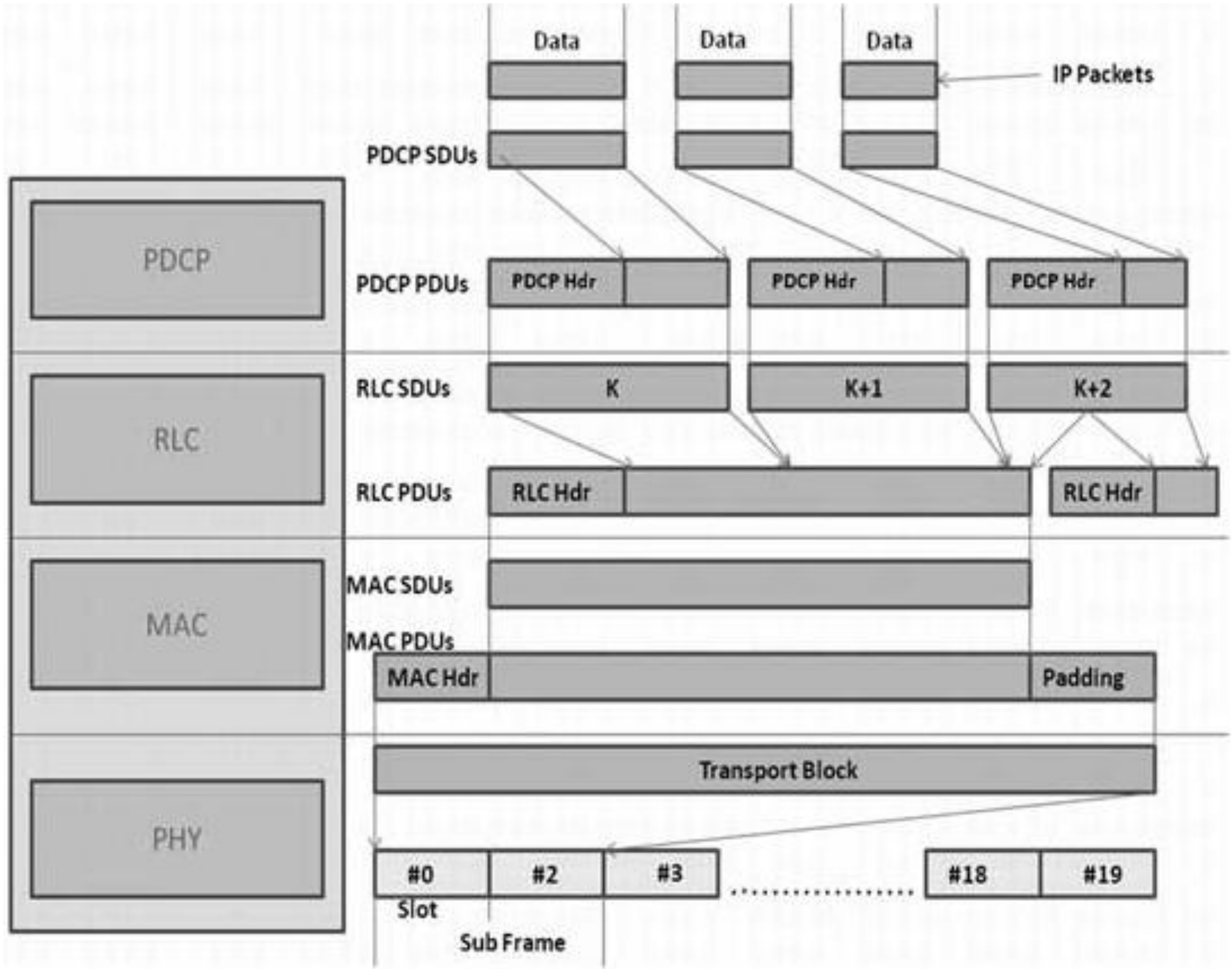
- 端口0~3　　小区专用(用于下行MIMO)
- 端口4　　MBSFN专用
- 端口5　　UE专用(用于使用所有天线对UE进行波束赋形)

- 天线数

  物理天线的数目，取值为1，2，4，8。

- Antenna port
  - Characterized by a reference signal ➨ "antenna" visible to UE
- Three types of antenna ports
  - Cell-specific reference signals
    - Antenna ports 0 – 3
    - Always present (in cells supporting unicast transmission)
  - UE-specific reference signals
    - Antenna port 5
    - Used for UE-specific beamforming
  - MBSFN reference signals
    - Antenna port 4
    - Used for MBSFN operation

码字


Data
Data
Data
IP Packets
PDCP SDUs
PDCP
PDCP PDUs
PDCP Hdr
PDCP Hdr
PDCP Hdr
RLC SDUs
K
K+1
K+2
RLC
RLC PDUs
RLC Hdr
RLC Hdr
MAC SDUs
MAC
MAC PDUs
MAC Hdr
Padding
Transport Block
PHY
#0
#2
#3
#18
#19
Slot
Sub Frame

码字

- LTE系统中，物理层所接受到来自高层的数据称为传输块(TB)，每个子帧上最多可以调度2个TB。
- 物理层对每个TB进行信道编码、速率适配、加扰、调制之后，影射到MIMO层上，再经由天线发射出去。
- 传输块TB的大小在传输信道处理过程中确定，随后就不再改变，对应于每个TB的编码比特或者调制符号称为MIMO码字(CW，即CodeWord)。
- 因此，码字CW和TB在称呼上是可以互换的。但是它们不完全一致，之间存在影射关系，见下页。

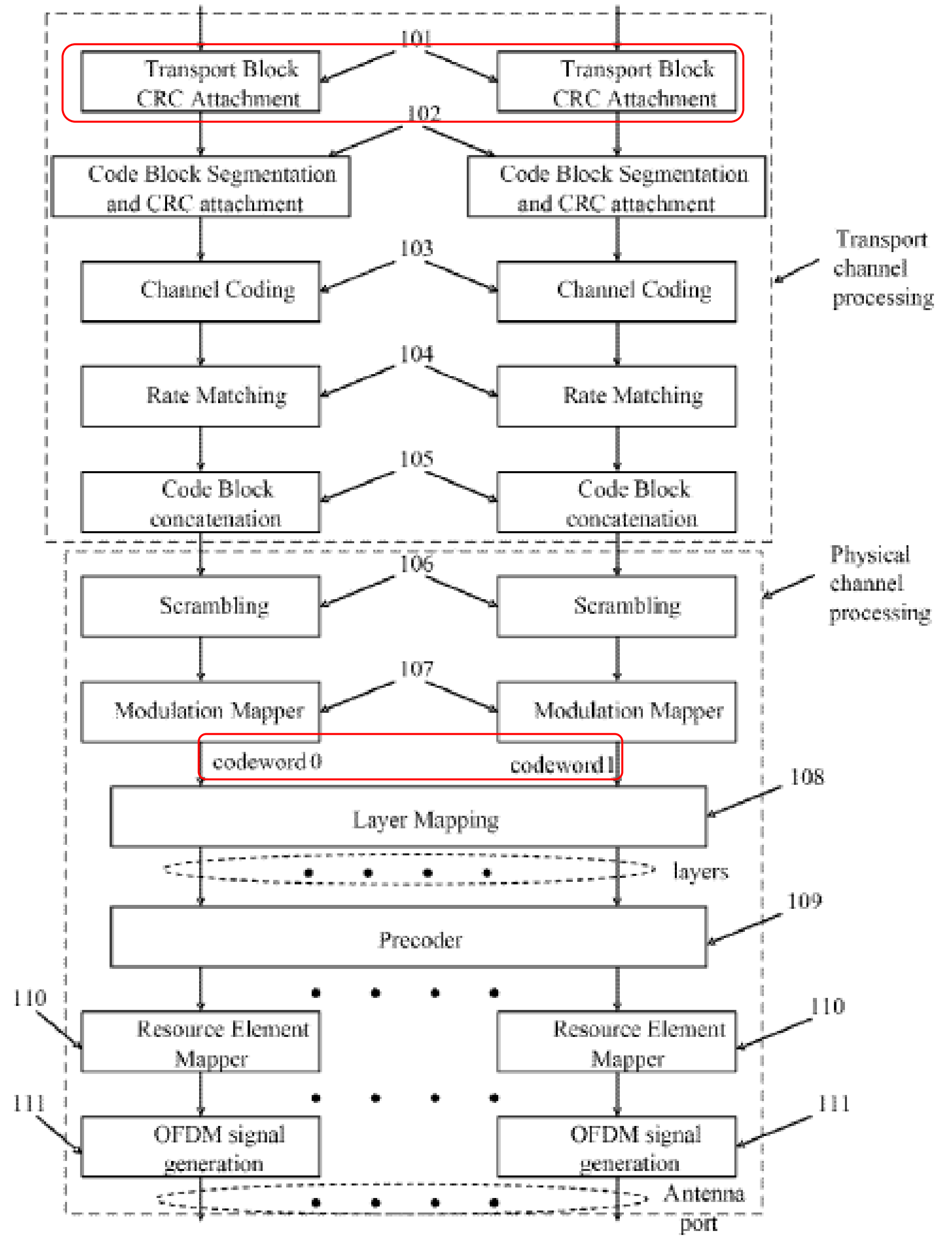


Fig. 1

码字

最多2个码字，如果只有一个，通过swap flag参数确定。

TS36.212

Table 5.3.3.1.5-1: Transport block to codeword mapping (two transport blocks enabled)

transport block to codeword swap flag value	codeword 0 (enabled)	codeword 1 (enabled)
0	transport block 1	transport block 2
1	transport block 2	transport block 1

Table 5.3.3.1.5-2: Transport block to codeword mapping (one transport block enabled)

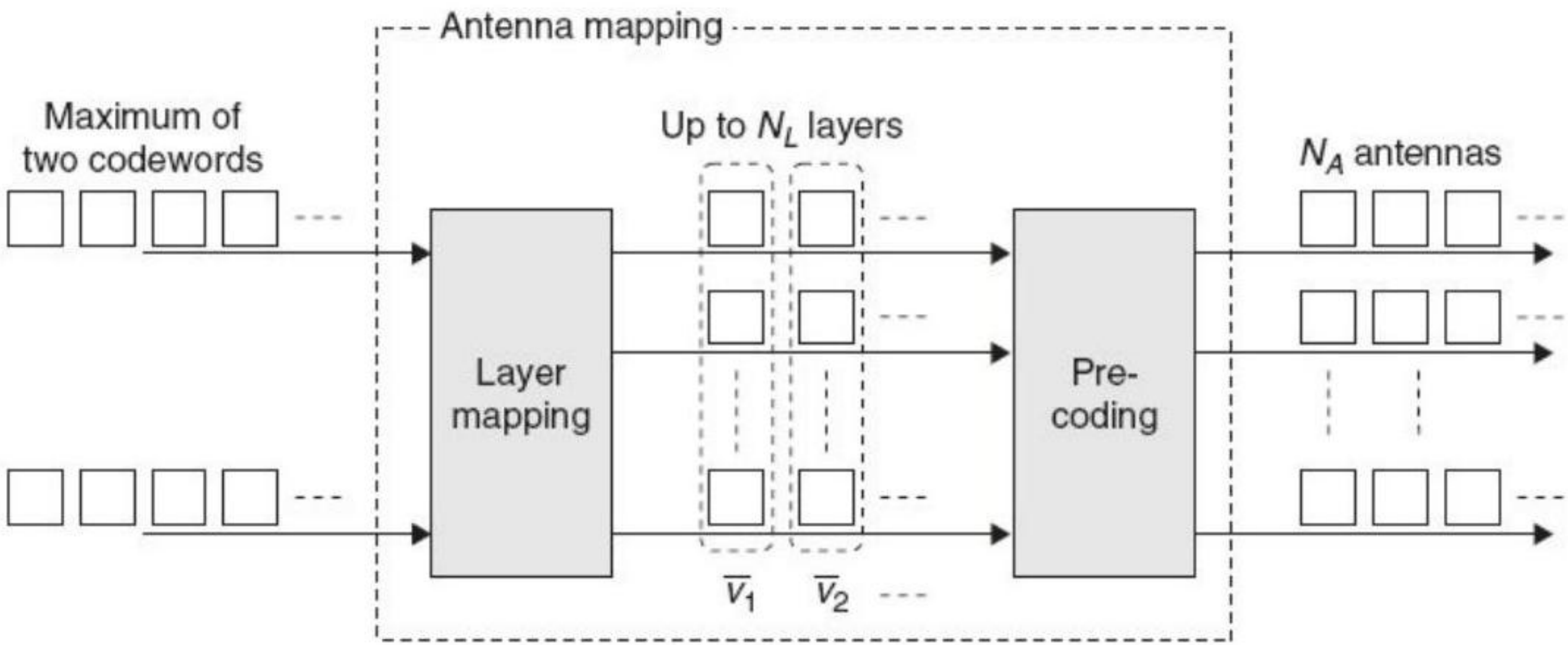
transport block 1	transport block 2	codeword 0 (enabled)	codeword 1 (disabled)
enabled	disabled	transport block 1	-
disabled	enabled	transport block 2	-

码字

- 码字与传输块
  - 传输块经过编码过程后构成码字
  - 信令中定义映射关系
  - LTE最大2码字
- LTE系统单码字/多码字并存
  - 单端口/波束赋形/传输分集：单码字
  - 空间复用：单码字/双码字并存
    - 层为1情况下，肯定是单码字
    - 层大于1的情况下，常规为双码字
      - 也允许一个传输块映射到2层
- 多个码字会对应一个HARQ进程号
- 不同码字对应不同的AMC，CQI反馈、ACK反馈

层(Layer)

1/2个码字，多个天线，或者传输信道RI=1，如何发送？

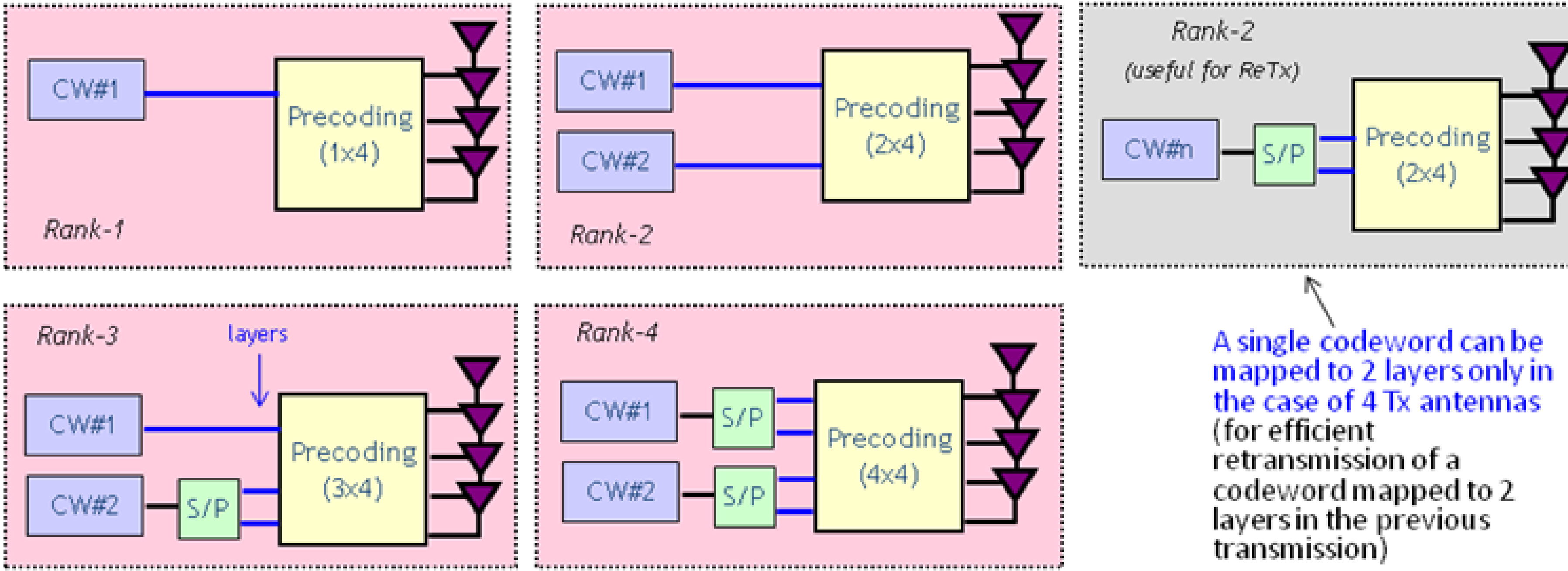


in ***spatial mux***:
#layers = #streams

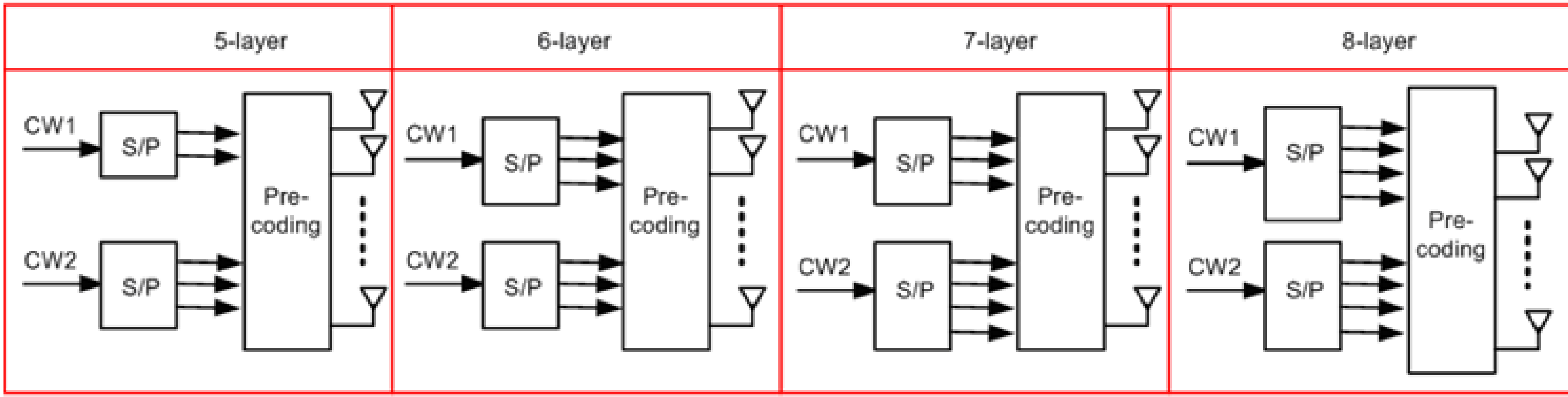
in ***TxDiv***:
#layers = #antennas

<u>发送分集下，层数 等于天线端口数P</u>
<u>空间复用下，秩指示符（RI）决定层的具体数目</u>

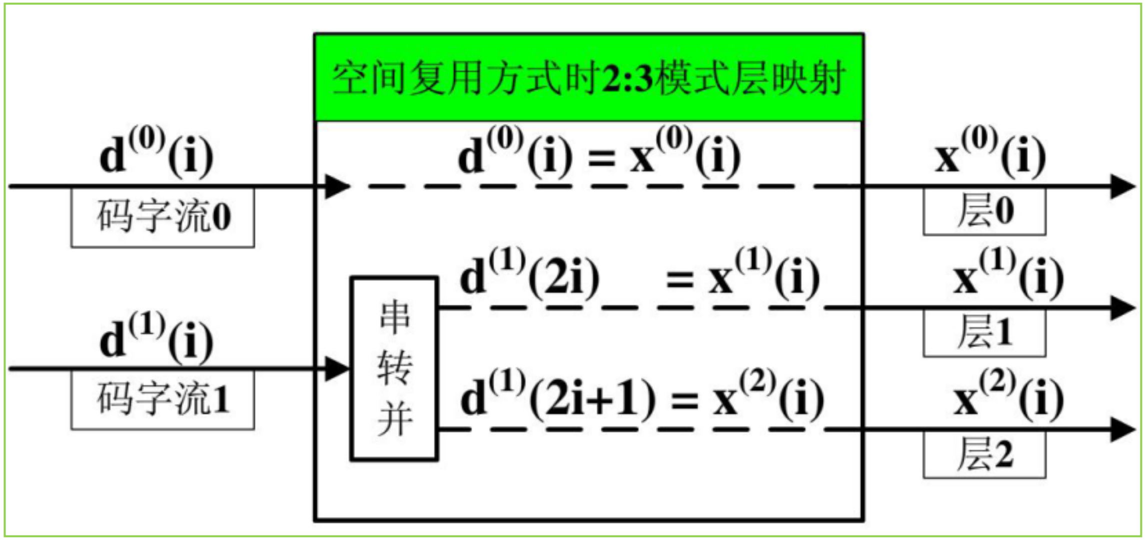
层影射

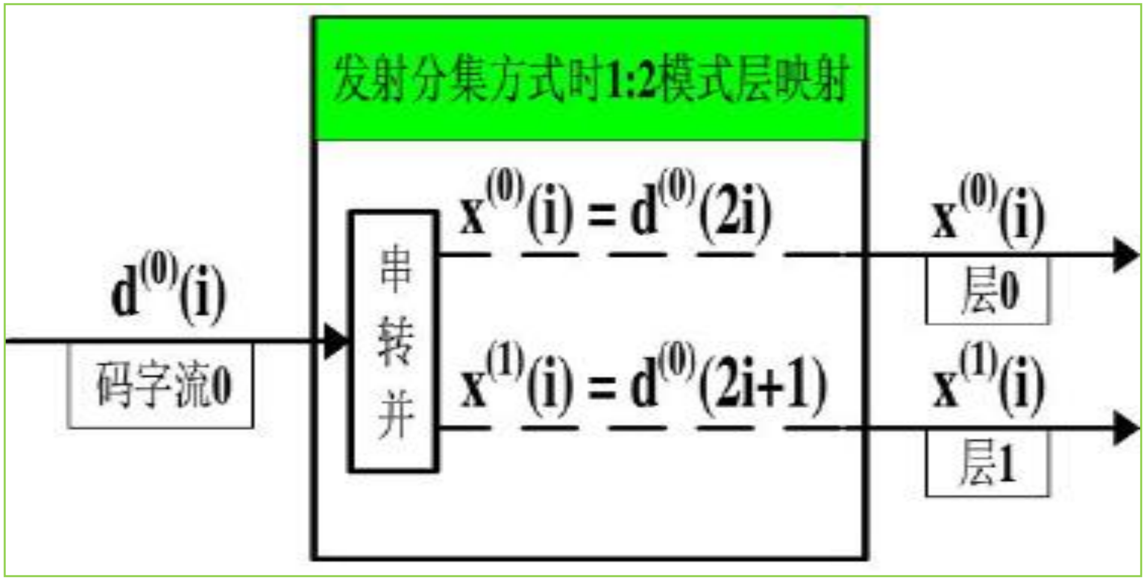


A single codeword can be mapped to 2 layers only in the case of 4 Tx antennas (for efficient retransmission of a codeword mapped to 2 layers in the previous transmission)

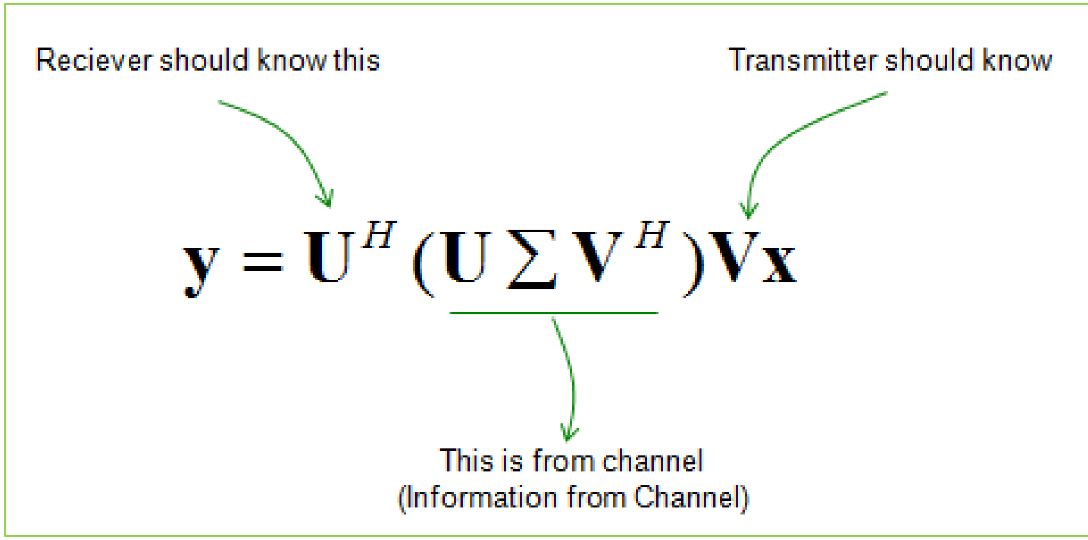


层影射举例


空间复用方式时2:3模式层映射
d(0)(i)
码字流0
d(1)(i)
码字流1
串转并
d(0)(i) = x(0)(i)
d(1)(2i) = x(1)(i)
d(1)(2i+1) = x(2)(i)
x(0)(i)
层0
x(1)(i)
层1
x(2)(i)
层2


发射分集方式时1:2模式层映射
d(0)(i)
码字流0
串转并
x(0)(i) = d(0)(2i)
x(1)(i) = d(0)(2i+1)
x(0)(i)
层0
x(1)(i)
层1

预编码

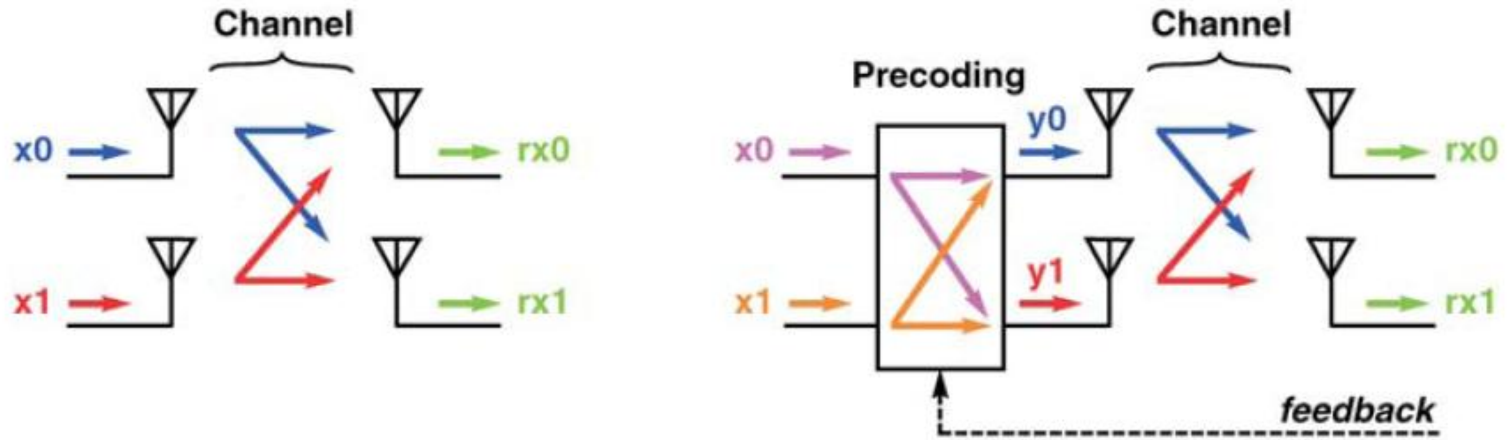


图表 4 对 H 进行 SVD 分解

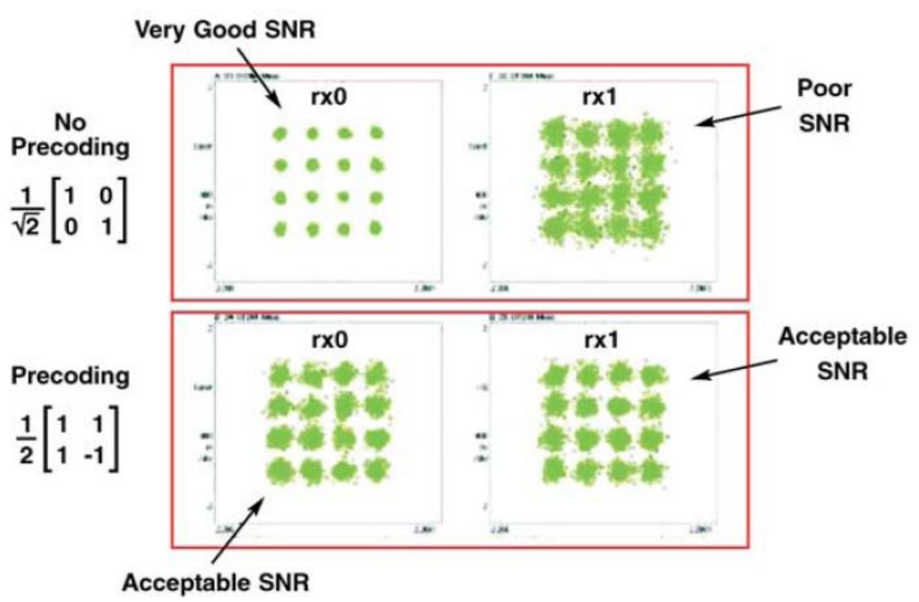
- The three matrix at the center can be a known at least to the reciever since the reciever can estimate channel Matrix H from the received signa and calculate these matrix from H.
- The vector x is known to transmitter since it is just the data that's transmitted.
- The matrix U can be a known to the reciever since it can be derived from H.

- 对信道矩阵H进行SVD分解，得到H=U·S·V，其中S就是对角矩阵；接下来，就是用V的共轭转置V*对发送信号进行“预编码”，接收端在收到数据后，同样乘以U*，这样一来，发送的符号就像进入了独立平行的正交子信道，互不干扰。

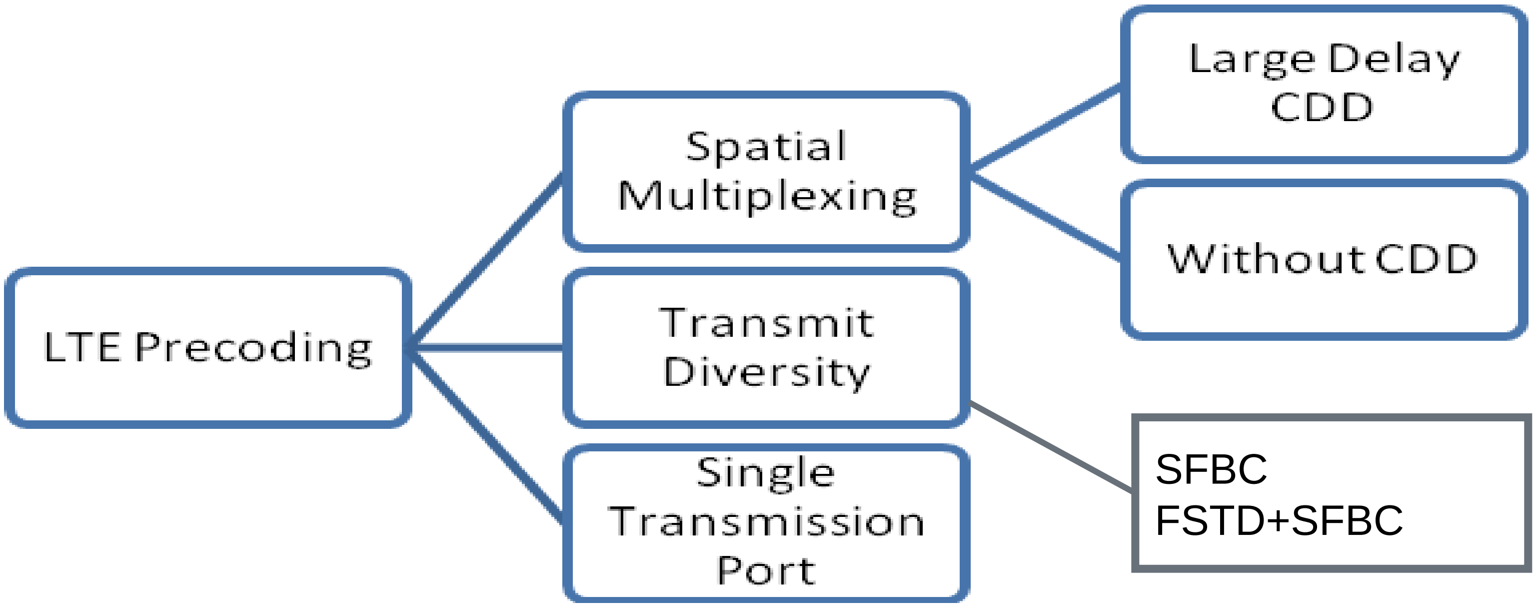
预编码



(a) MIMO (b) Precoded MIMO



预编码



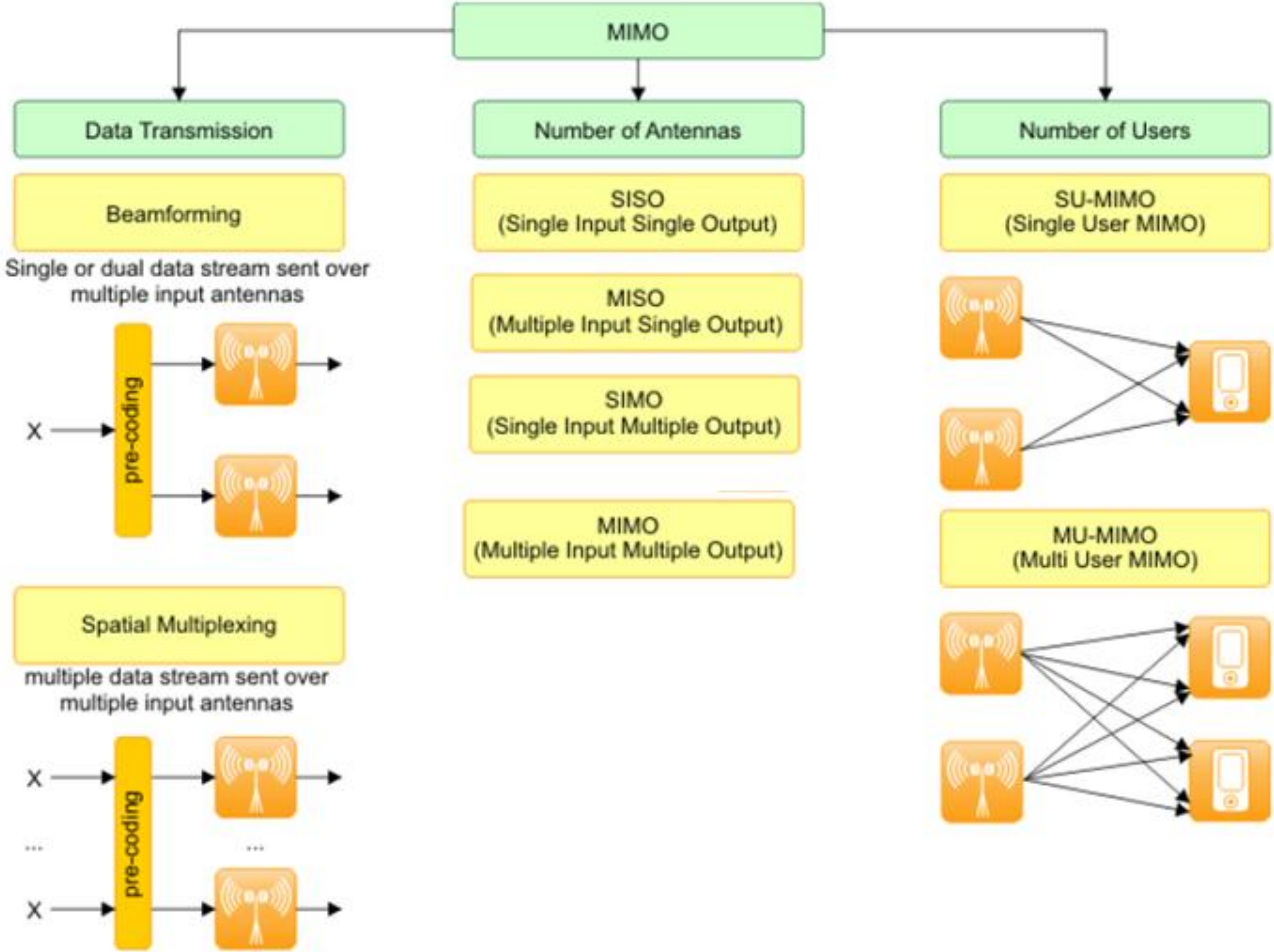
Three types of precoding are available in LTE for the PDSCH: Spatial multiplexing, transmit diversity and single antenna port transmission. Within spatial multiplexing there are two schemes;

- precoding with large delay Cyclic Delay Diversity (CDD), also known as open loop spatial multiplexing
- precoding without CDD also known as closed loop spatial multiplexing

The precoder takes a block from the layer mapper $x^{(0)}(i), x^{(1)}(i) \ldots, x^{(v-1)}(i)$ and generates a sequence for each antenna port, $y^{p}(i)$. p is the transmit antenna port number as is $\{0\}, \{0,1\}$ or $\{0,1,2,3\}$.

MIMO模式如何区分？

MIMO分类


MIMO
Data Transmission
Number of Antennas
Number of Users
Beamforming
Single or dual data stream sent over multiple input antennas
pre-coding
X
SISO (Single Input Single Output)
MISO (Multiple Input Single Output)
SIMO (Single Input Multiple Output)
MIMO (Multiple Input Multiple Output)
SU-MIMO (Single User MIMO)
MU-MIMO (Multi User MIMO)
Spatial Multiplexing
multiple data stream sent over multiple input antennas
pre-coding
X
...
X

LTE下行MIMO模式 (R8)

TS36.213
Table 7.2.3-0: PDSCH transmission scheme assumed for CQI reference resource

Transmission mode	Transmission scheme of PDSCH
1	Single-antenna port, port 0
2	Transmit diversity
3	Transmit diversity if the associated rank indicator is 1, otherwise large delay CDD
4	Closed-loop spatial multiplexing
5	Multi-user MIMO
6	Closed-loop spatial multiplexing with a single transmission layer
7	If the number of PBCH antenna ports is one, Single-antenna port, port 0; otherwise Transmit diversity

TS36.213
Table 7.1-5: PDCCH and PDSCH configured by C-RNTI

Transmission mode	DCI format	Transmission scheme of PDSCH corresponding to PDCCH
Mode 1	DCI format 1A	Single-antenna port, port 0
	DCI format 1	Single-antenna port, port 0
Mode 2	DCI format 1A	Transmit diversity
	DCI format 1	Transmit diversity
Mode 3	DCI format 1A	Transmit diversity
	DCI format 2A	Large delay CDD or Transmit diversity
Mode 4	DCI format 1A	Transmit diversity
	DCI format 2	Closed-loop spatial multiplexing (see subclause 7.1.4)or Transmit diversity
Mode 5	DCI format 1A	Transmit diversity
	DCI format 1D	Multi-user MIMO
Mode 6	DCI format 1A	Transmit diversity
	DCI format 1B	Closed-loop spatial multiplexing using a single transmission layer
Mode 7	DCI format 1A	If the number of PBCH antenna ports is one, Single-antenna port, port 0 is used , otherwise Transmit diversity
	DCI format 1	Single-antenna port; port 5

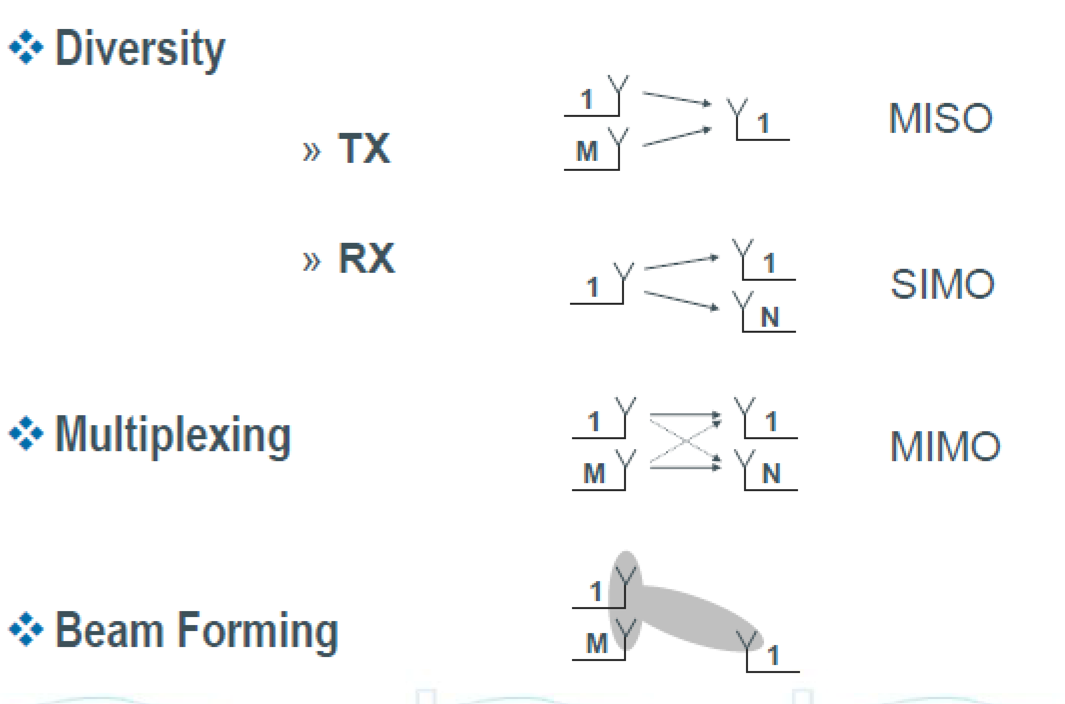
LTE下行MIMO模式

发送模式	PDSCH发送机制	多天线增益	给系统带来的好处
模式1	单天线发射，端口0	-	-
模式2	开环发送分集	分集增益	提高系统覆盖
模式3	开环空间复用	复用增益	提高系统容量
模式4	闭环空间复用	阵列增益 复用增益	提高系统容量
模式5	多用户空间复用	复用增益	提高系统容量
模式6	闭环发送分集	阵列增益	提高系统覆盖
模式7	单流波束赋形	阵列增益	提高覆盖
模式8	双流波束赋形	阵列增益 复用增益	提高系统容量

MIMO模式分类

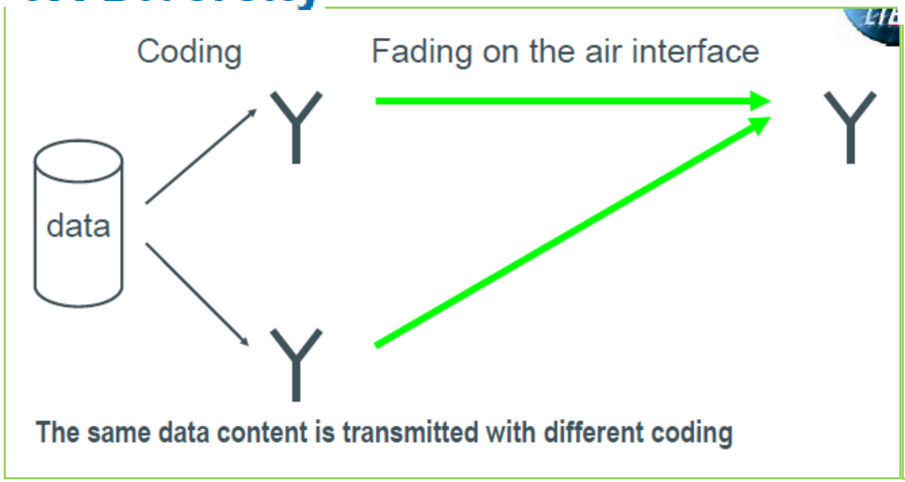
根据MIMO实现方式，可以将上述八种MIMO模式分为3大类，对应为：

- 发送分集：包括LTE MIMO模式1和2，即单天线发射和开环发送分集。
- 空间复用：包括LTE MIMO模式3、4和5，分别为开环空间复用、闭环空间复用以及多用户空间复用。
- 波束赋形：包括LTE MIMO模式6、7和8，分别为闭环发送分集、单流波束赋形和双流波束赋形。

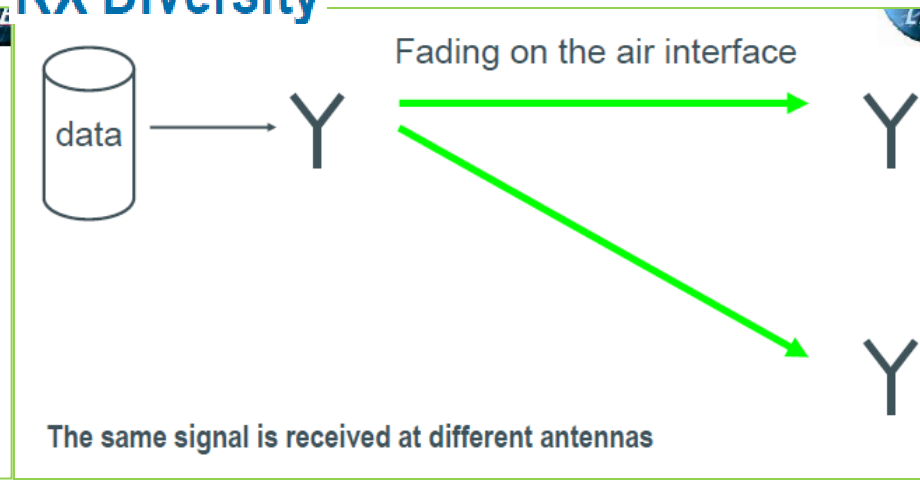


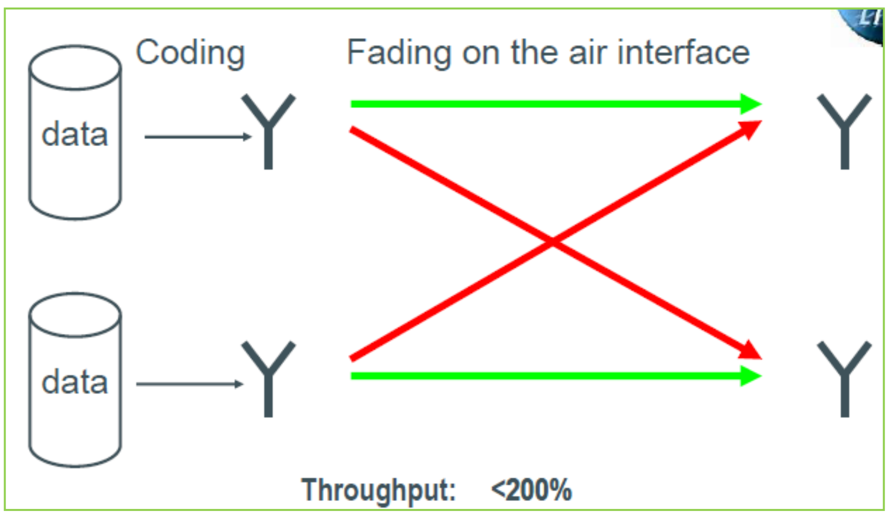
MIMO模式分类

TX Diversity

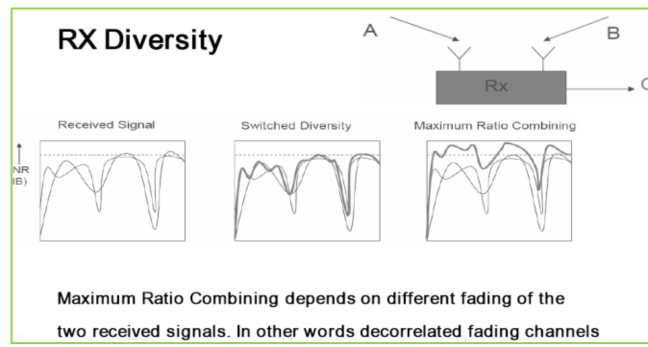


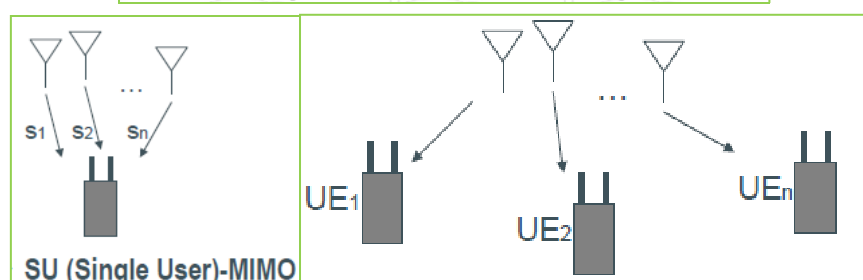
RX Diversity





Multiplexing





MIMO模式及自适应概览

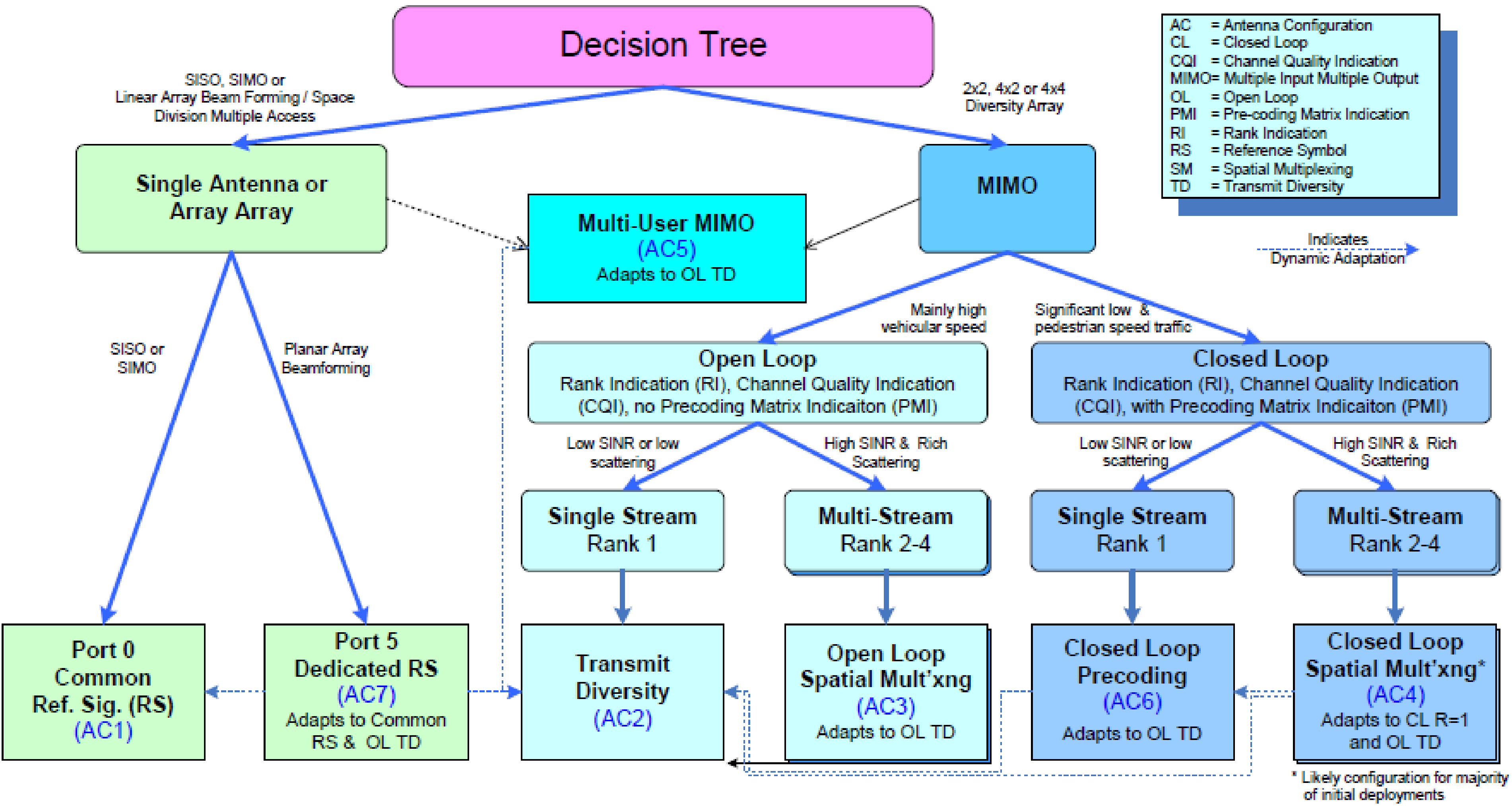
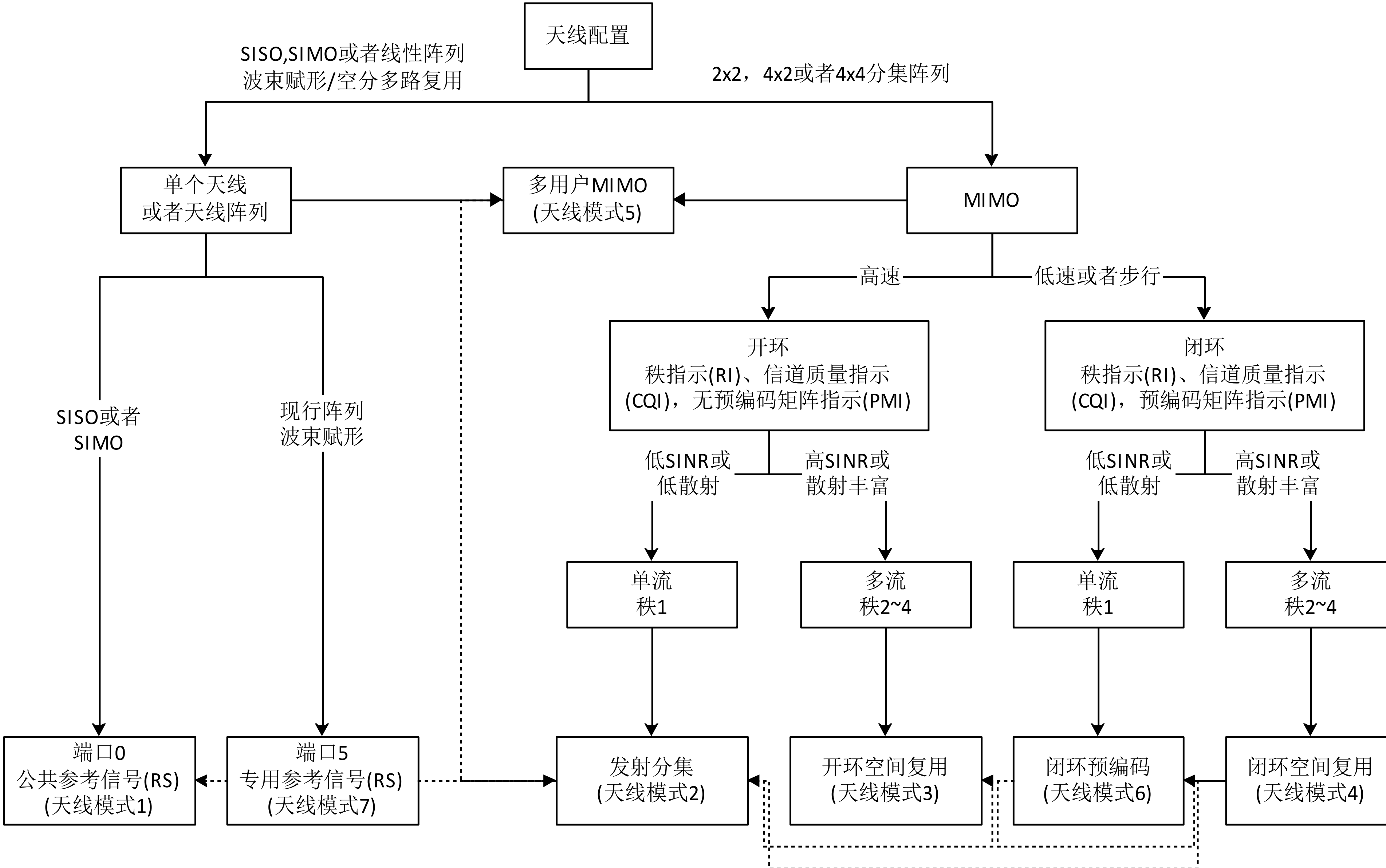


Figure 2. Taxonomy of smart antenna processing algorithms in Release 8 of the LTE standard

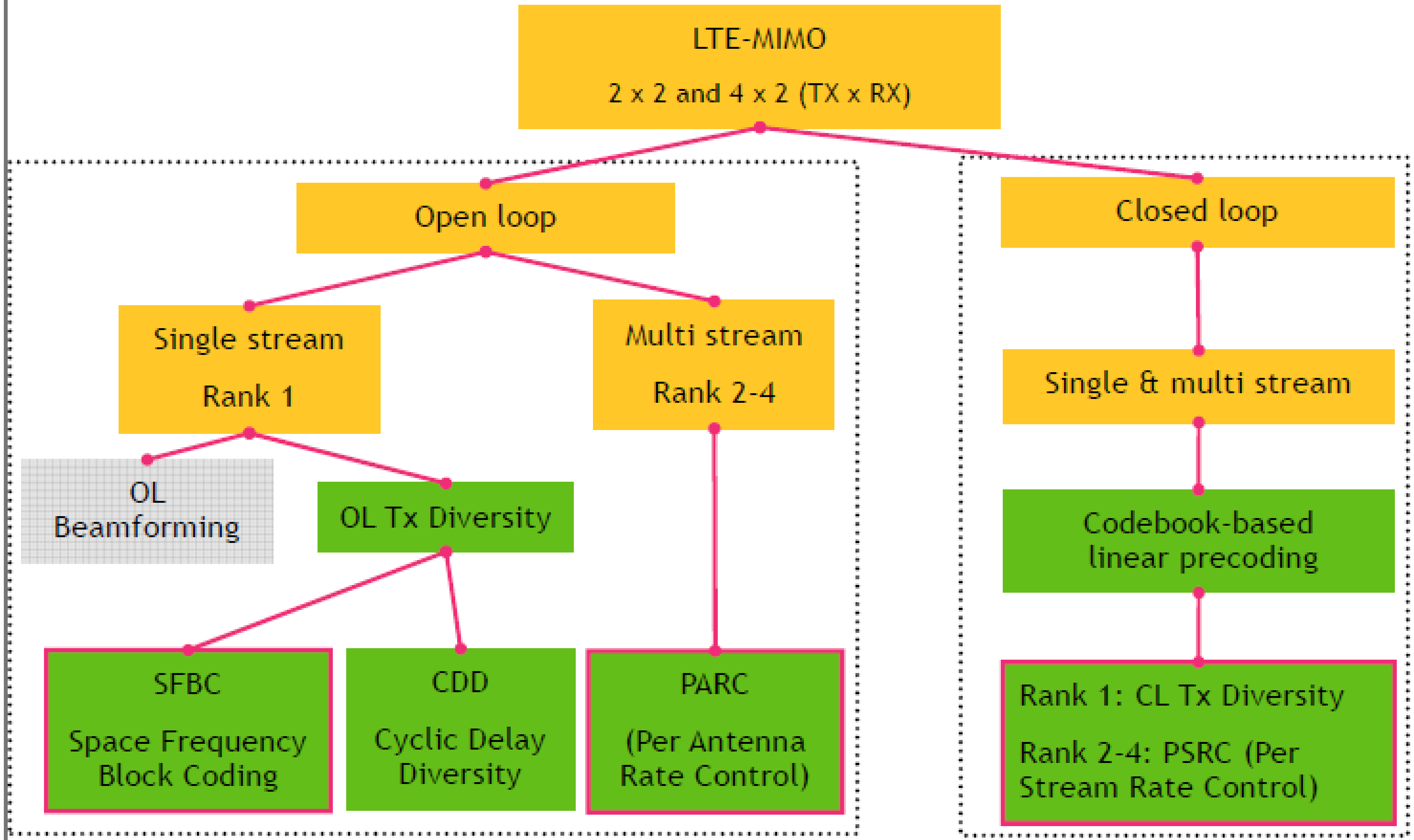
From: MIMO and Smart Antennas for 3G and 4G Wireless Systems.pdf (3G Americans,2010)

MIMO模式及自适应概览



注：虚线表示动态适配。

Downlink MIMO Modes



700277081@139.com