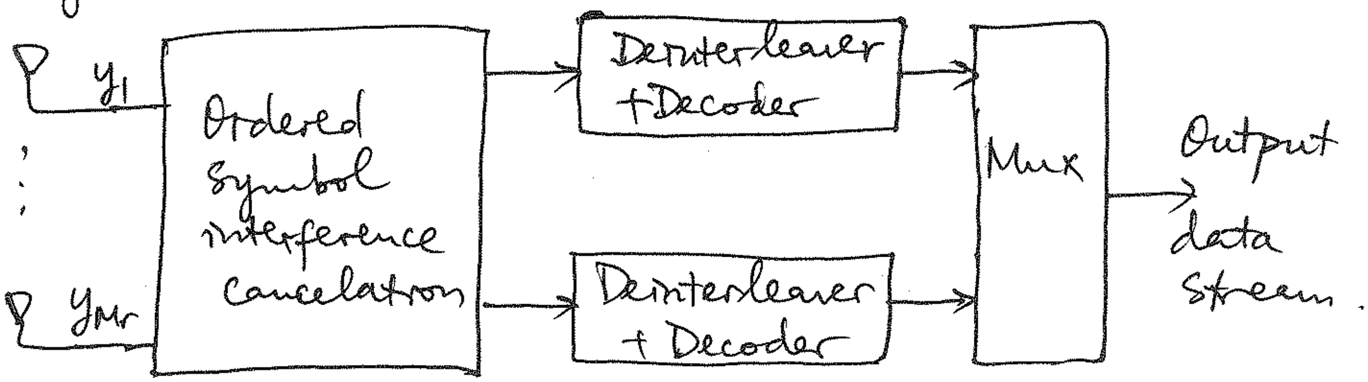
information bit is spread over all transmit antennas.

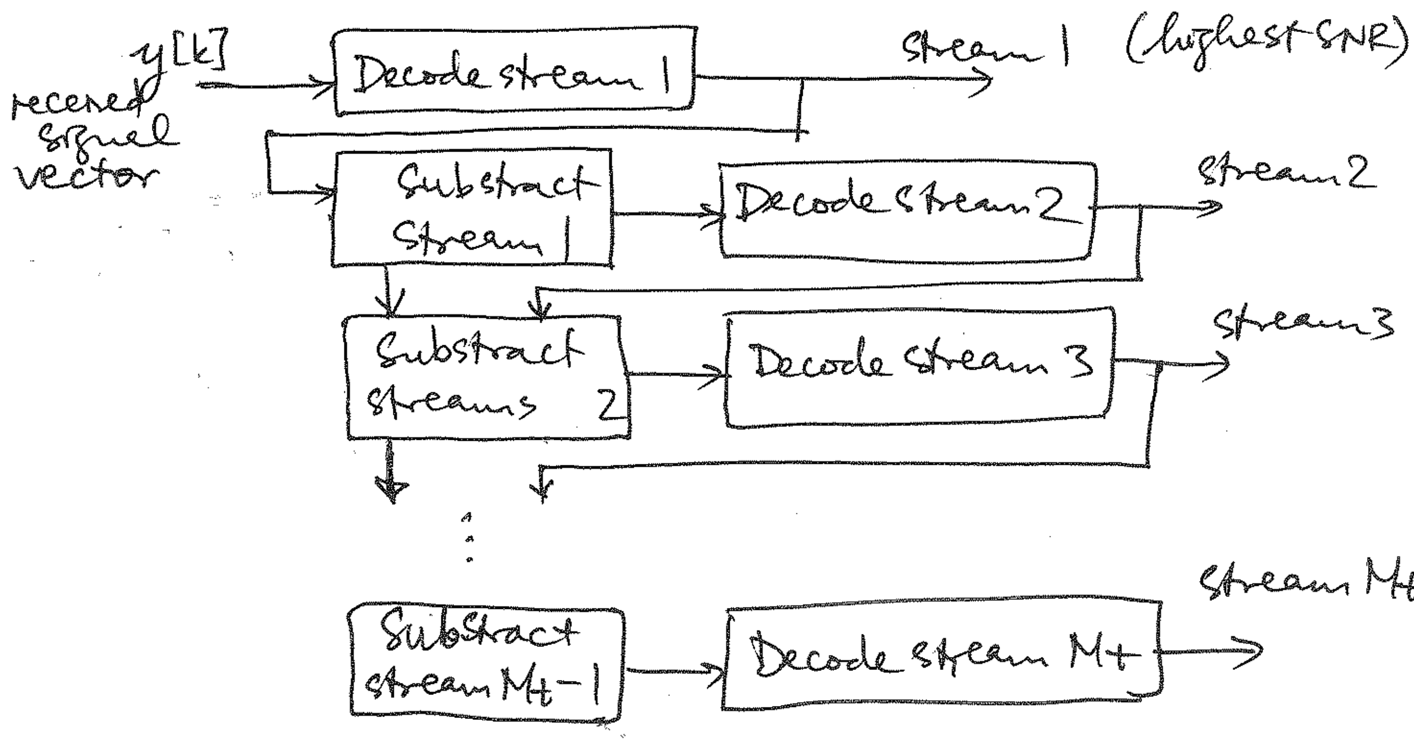
- Receiver structure is often complicated. We will look at example systems.

i) V_BLAST: Vertical Bell Labs Space-Time architecture.

- Even though the name is vertical, this structure falls into the horizontal encoding category where each data stream is coded and transmitted separately.

- Receiver is based on successive interference cancelation among the data streams based on ordered (received) SNR.





- This successive interference cancellation (SIC) structure is also called "onion peeling"

- The decoding order is from the highest SNR stream to the lowest.

- Each stream is decoded separately (after substracting the streams that are already decoded), treating the other undecoded stream as noise.

Therefore the decoding complexity is only linear in the number of streams.

- Thus V-BLAST with SIC receiver achieves the full multiplexing gain.

- However the SIC structure can reduce the diversity gain in each stream because the undecoded streams are treated as noise and hence take away some diversity.

Specifically it can be shown that the distribution of the output SNR at each stage of the SIC process is

$$SINR_k \sim \gamma_k \cdot \chi^2_{2[M_r-(M_t-k)]}$$

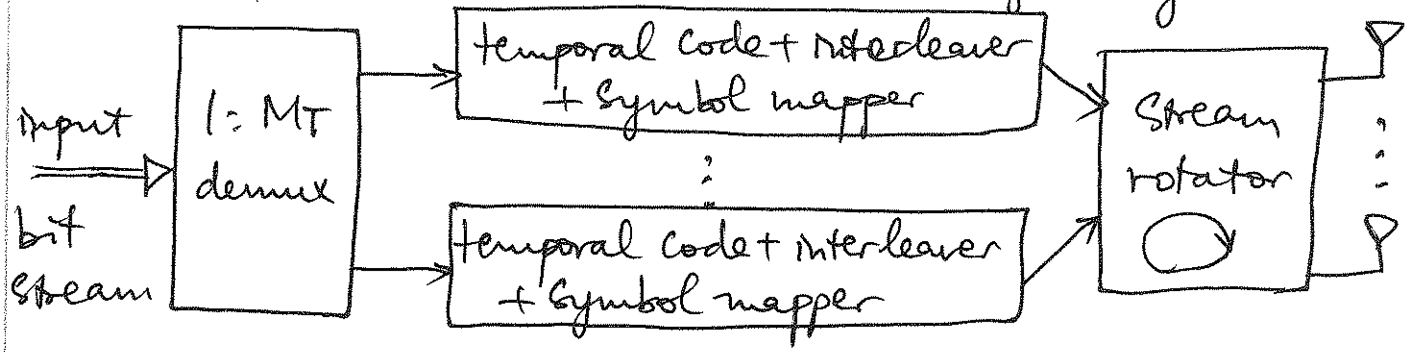
Thus the diversity order of the k^{th} stream is $M_r-(M_t-k)$, due to the M_t-k uncancelled streams.

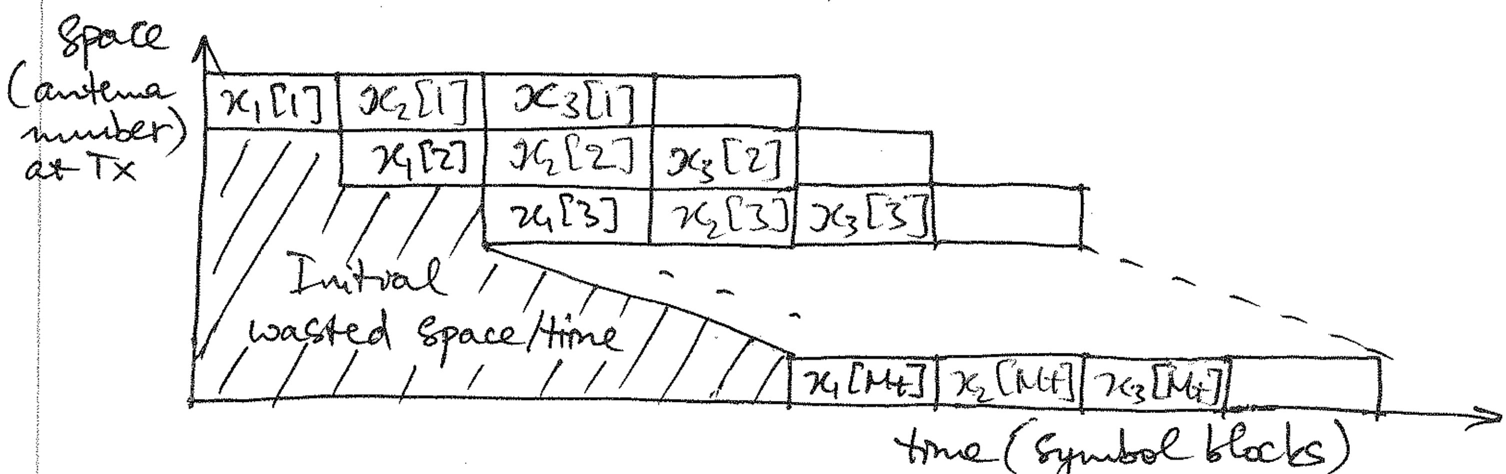
The first stream has highest SNR but worst diversity order of $M_r - M_t + 1$. Subsequent streams have diversity order increased by 1 for each successive stream.

ii) D_BLAST architecture:

- D_BLAST is a vertically encoded (or diagonally encoded) structure where each encoded stream is spread over all transmit antennas.

- The different streams are stacked diagonally.





x_1 : data stream 1 , $x_1[k]$ = symbol time k.

- Each codeword from each data stream is spread over all transmit antennas and wrap around if longer than M_t.

- Receiver operation:
  - For the received signal at the first time interval, the receiver just need to detect $x_1[1]$.
  - In the second interval, the receiver will detect $x_1[2]$ while treating $x_2[1]$ as noise. After that it substracts

$x_1[2]$ from the received signal and detect $x_2[1]$.

- This process goes on untill all symbols of each codeword from each stream are detected (for example the whole codeword x_1). Then the codeword is decoded to recover information.

- Each codeword effectively sees the parallel channels from each transmit antenna to the received antennas.

Provided an optimal channel code (temporal code) then the rate for each data stream can be written as

$$R = \log(1+\underset{\substack{\uparrow \\ \text{detecting the} \\ 1^{st}\text{ symbol}}}{SINR_1}) + \log(1+\underset{\substack{\uparrow \\ \text{detecting the} \\ 2^{nd}\text{ symbol} \\ \text{(has interference from} \\ \text{undecoded streams)}}}{SINR_2}) + \cdots$$

The above sum actually reach the information capacity of the channel.

To see this, express the capacity as

$$C = \log\det\left(I + \frac{\gamma}{M_t} HH^*\right)$$

$$= \log\det\left(I + \frac{\gamma}{M_t} h_{M_t} h_{M_t}^* + \frac{\gamma}{M_t} H_{(M_t)} H_{(M_t)}^*\right)$$

$$= \log\det\left(I + \frac{\gamma}{M_t} H_{(M_t)} H_{(M_t)}^*\right)$$

$$+ \log\left(1 + \frac{\gamma}{M_t} h_{M_t}^* \left(I + \frac{\gamma}{M_t} H_{(M_t)} H_{(M_t)}^*\right)^{-1} h_{M_t}\right)$$

Thus

$$C = \sum_{i=1}^{M_t} \log_2 \left(1 + \frac{\gamma}{M_t} h_i^* \left(I + \frac{\gamma}{M_t} H_{(i)} H_{(i)}^* \right)^{-1} h_i \right)$$

$$= \sum_{i=1}^{M_t} \log_2 (1 + \mathrm{SINR}_i)$$

where . $H_{(i)}$ is the channel matrix with all colums indexing higher than i removed, which corresponds to cancelling out the already detected streams.

SINR_i is then the SINR of the i^{th} stream which still has interference from all streams not yet detected.

- Thus with optimal channel coding then D_BLAST can reach the capacity of a MIMO channel (without CSIT) and can achieve a full multiplexing gain and full diversity gain $M_r \times M_t$ simultaneously.

This claim ignores the wasted space-time blocks initially and also assume the codeword length for the temporal code is long.

In practice there are ST blocks wasted at both the beginning and end of transmission.

- For more information see the paper handout [Foschini 96].

4) For in-between CSIT (partial CSIT), various precoding methods are used to adapt the transmission to CSIT. Precoding can be linear or nonlinear, but usually a linear (matrix) precoder is used. We will not go into details.