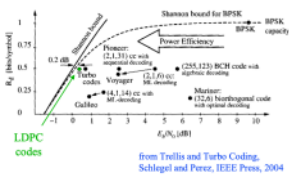
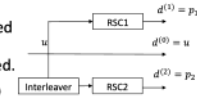


- In the channel capacity theorem, Shannon uses infinitely long codes, i.e. the code rate $R = k/n$ is fixed but $k \rightarrow \infty$ and $n \rightarrow \infty$.
- In practical system, the length of the code is limited because of the complexity of decoding: the performance of physical systems are far from Shannon theoretical limits.
- Around the turning of the century there have been two major breakthroughs:
 - Turbo codes (1993)
 - Low-density parity check codes (LDPC, 1999).

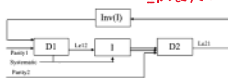


- The combination of coding and interleaving can be exploited to boost the performance of convolutional codes in general.
- *Turbo codes* are a particular example of concatenated codes, where two encoders are in parallel and the input data of the second encoder are first interleaved.
- Thanks to the interleaver, the decoder will have two independent replicas of the same data and can use both streams to decode the information sequence.
- Increase the redundancy of the transmitted information but also the *diversity* of the system.



The diagram illustrates the flow of air and exhaust gases in a turbocharger system. The compressor (top left) draws in compressor inlet air (blue arrow) and compresses it, sending it to the compressor discharge (blue arrow). The compressed air then passes through a charge air cooler (blue box) before entering the intake manifold (bottom left). The turbine (top right) is driven by exhaust gases from the exhaust manifold (bottom right). The turbine inlet (red arrow) receives exhaust gases, which then exit through the turbine exhaust (red arrow). The mechanical connection between the compressor and turbine is highlighted by a red circle. Red arrows also indicate the flow of exhaust gases from the engine to the turbine and then to the exhaust manifold.

- The turbo decoder employs the cascade of two decoders, with the output of one decoder used as prior information to the next.
- Feedback in decoding circuit allows for multiple iterations and improves bit error performance.
- The process is iterative and at each step the combination of the two decoders corrects some of the errors. $TNVS \rightarrow \text{DEINTERLEAVE}$



HOW TURING CODES WORK
Turing codes use two decoders at the receiver. With this double decoder approach, better codes anticipate all previous error correction codes.

The original data bits plus the two strings of parity bits are combined into a single block and then sent over the channel, where noise can cause errors in the transmission.

1 Data bits enter the transmitter and are added to parity bits 1 and 2. Before entering section 2, the resulting message 2 is checked and is corrected by the transmitter.

2 Each receiver generates a string of error-correction bits (parity bits) by performing a series of calculations on the data bits it receives.

3

START

0 1 0 1 0 1 0 1

0 1 1 0 1 1 0 1 1 0 1 0 1 0 1 0

DATA BITS

PARITY 1

PARITY 2

INTERLEAVE

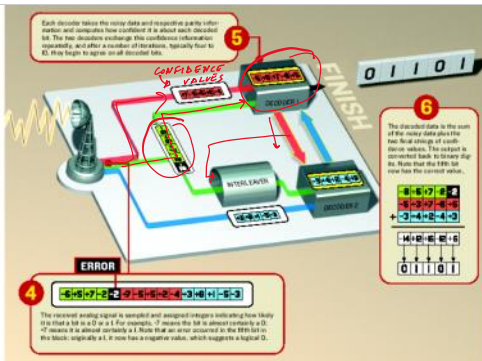
WIRELINE

RECEIVER 1

RECEIVER 2

IC

Turbo codes (© IEEE spectrum)



Turbo codes: latency

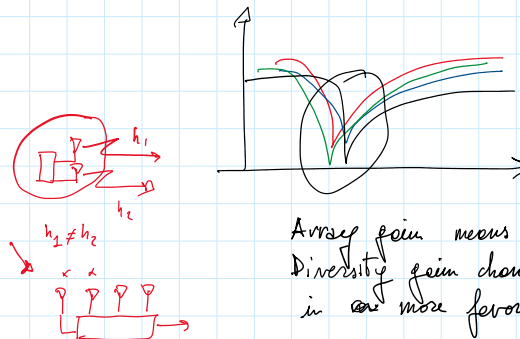
- Convolutional codes in general and turbo codes in particular have a problem with *latency* due to the presence of the interleaver and the iterative decoding process.
- At any given SNR there is a tradeoff between latency due to interleaver and QOS
 - Small block sizes (~300 bits) can be used for real time voice (medium-high BER can be tolerated).
 - Mid range block sizes (~4000 bits) used for video play back (low BER).
 - Large block sizes (~16000 bits) large latency, very low BER, useful for file transfer (very low BER).

1st source of delay is the interleaver at TRx
 2nd source of delay is " " " Rx
 3rd source of delay is the iterative process

Spatial diversity

Receive diversity

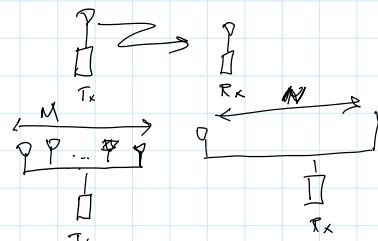
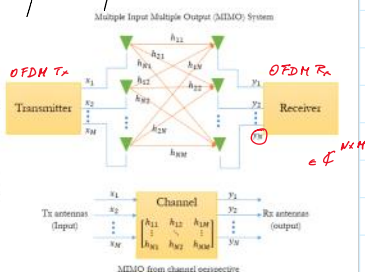
- Among the many ways to obtain diversity:
 - Frequency and time diversity require expensive resources (bandwidth or time) and do not provide array gain.
 - Space diversity by means of multiple antennas does not sacrifice bandwidth or time and may provide array gain.
- Array gain:** is the power gain achieved by using multiple antennas with respect to the single antenna case. The more correlated is the spatial channel the higher the potential array gain.
- Diversity gain:** is the power gain due to the exploitation of the diversity of the spatial channel. It is maximum when the spatial channel is uncorrelated.



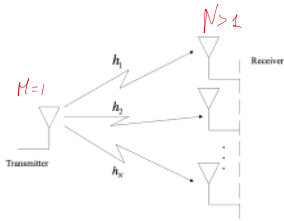
MIMO channel

Multiple input
Multiple output

- Multiple-input multiple-output systems are systems where both the transmitter and the receiver are equipped with several antennas.
- Narrowband assumption:** the channel linking the n -th receive antenna with the m -th transmit antenna is the scalar $h_{n,m}$



SIMO channel: receive diversity



- $N > 1$ antennas at the receiver, $M = 1$ at the transmitter.
- The decision variable at the i -th receive antenna is $x_i(m) = h_i c_m + n_i(m)$
- The signals received at the N antennas are combined together and the decision variable is $z(m) = w_1 x_1(m) + \dots + w_N x_N(m)$

w combining weights

$$h = \begin{bmatrix} h_1 \\ h_2 \\ \vdots \\ h_N \end{bmatrix}$$

Maximal ratio combining (MRC)

- The decision variable is

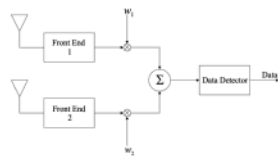
$$z(m) = \sum_{i=1}^N w_i h_i c_m + \sum_{i=1}^N w_i n_i(m)$$

- For the i -th antenna the optimal weight is

$$w_i = h_i^*$$

- In the 1x2 case, the signal-to-noise ratio is

$$SNR = (|h_1|^2 + |h_2|^2) \frac{A}{\sigma^2}$$



*Selection combining
Set to 1 the coefficient for
which the channel gain is maximum
all the other coeff.*

1x2 channel

$$z(m) = w_1 h_1 c_m + w_2 h_2 c_m + w_1 n_1(m) + w_2 n_2(m)$$

$$[opt] = (h_1^* h_1 + h_2^* h_2) c_m + h_1^* n_1(m) + h_2^* n_2(m)$$

$$= (|h_1|^2 + |h_2|^2) c_m + h_1^* n_1(m) + h_2^* n_2(m)$$

$$SNR = \frac{(|h_1|^2 + |h_2|^2)^2}{(|h_1|^2 + |h_2|^2)^2} A = \frac{(|h_1|^2 + |h_2|^2)}{\sigma^2} A$$

$$SNR_{1x1} = \frac{|h_1|^2 A}{\sigma^2}$$