Problem 3 : To code or not to code ?

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1 Statement

The work package on the lightweight image compression for the rover has now been validated by the research experts of your university, and you can now proceed with the next work package which is related to the communications between the rover and ground. To this end, the research group working on the communication payload have already paved the way for the technological choices for the rover, however, some packages are sill incomplete. Here is the corresponding work package specification.

The rover will be equipped with two Radio Frequency (RF) subsystems, each with a dedicated communication payload. The first RF subsystem is an **X-band** communication payload with a steerable High Gain Antenna (GHA) designed to communicate directly with Earth through the Deep Space Network (DSN). The second RF subsystem is an **UHF-band** payload with an omni-directional Low Gain Antenna (LGA) which allows the rover to communicate with Earth through the Mars Relay Network (MRN) satellites, for instance, MRO and MAVEN.

The rationale behind the existence of these two separate subsystems is the following. The X-band sub-systems conveys messages on a direct link Earth-Rover. This communication link suffers from a tremendous loss of the transmit power due to the very large Earth-Rover distance, thus, it requires very high gain antennas and is very sensitive to the directional pointing of both the DSN and rover antennas. Besides, due to the low power received at the destination, the communication rate achieved is very low (a few 10 kbps), and thus, the X-band subsystem serves mainly for command and telemetry messages, and scarcely for image transmissions. On the other side, the UHF sub-system conveys messages on a relay-based Rover-MRN-Earth link. The Rover-MRN link has the advantage of having a low space loss due to the short range Rover-MRN distance (400 km), and thus, it allows for low gain antennas, it is not very sensitive to the pointing of the antennas, and achieves higher data rates than the X-band subsystem (500 kbps). However, this link has the disadvantage that, for a given MRN satellite, the visibility window is quite short (8 min visibility per sol), which imposes the usage of more than one MRN satellite. This prevents as well the extensive usage of this link to transmit timely commands, and makes it best suited for image transmission.

For each of these subsystems, we carried out an extensive analysis of the possible design criteria of the digital communication chain (RF antennas, power gains, modulation schemes, ...), and are now ready to proceed with the design of the Forward Error Correction (FEC) components. We developed and coded (in python) a simplified **uncoded** communication chain (no FEC) represented in Figure 1,

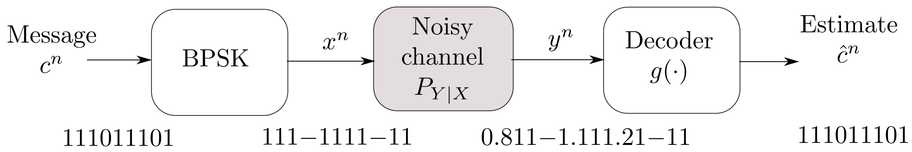

Figure 1 – Basic uncoded communication chain.

which accounts for the design choices of the rover's communication payload which are

- For each of the subsystems, the transmitted messages can be assumed to be uniformly distributed binary messages (telemetry, command messages, compressed images, ...)
- The modulation used in this chain is a Binary Phase Shift Keying (BPSK) modulation which maps every 0 into -1 and every 1 into $+1$
- For each of the subsystems, we modeled the overall possible RF impairments by an Additive White Gaussian Channel (AWGN) with respective E_b/N_0 given by : $E_b/N_0 = 0$ dB for the X-band, and $E_b/N_0 = 8$ dB for the UHF-band

We have also shortlisted 3 candidate FEC codes for the two subsystems, which are the $(7,4)$ Hamming code, the $(3,1)$ repetition code and the $(3,9)$ BKLC code (available in the documentation).

For each of the two RF subsystems, we wish, by analyzing both the curve of Bit Error Rate (BER) versus the E_b/N_0, and the curve of BLock Error Rate (BLER) versus the E_b/N_0, of the Maximum A Posteriori (MAP) sequence decoder, to be able to

- Assess if FEC coding is more beneficial than not coding
- Choose among the 3 candidate codes the most effective code

2 References

For this problem, you can rely (not exclusively) on the following references

- Textbook on Error Correction coding
- Problem Based Learning : Learners guidelines (webpage of the course)
- Nasa's similar RF payload specifications : `https://mars.nasa.gov/msl/mission/communications/#data`

3 Working material

- The python code of the basic communication chain without coding