DCAS
Summer Internship 2022

Data Exchange Protocol of CREME CubeSat

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29/08/22

Introduction

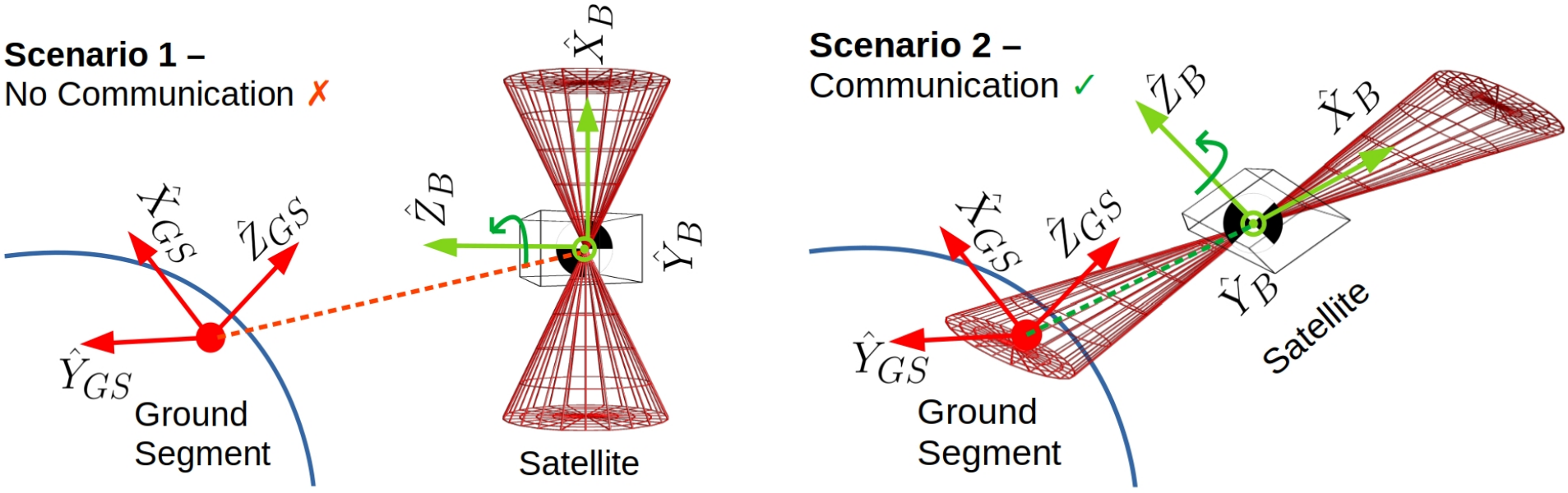


Fig 1 – Illustration of Intermittent Communication Channel

Objective → Overcome the intermittency

State of the Art

To best solve this problem, **Erasure Correcting (EC) codes** can be used.

CCSDS:
Space Packet (SP) → The useful data.
Transfer Frame (TF) → The carrier.

This research, will study the erasure of **Space Packets** and **Transfer Frames.**

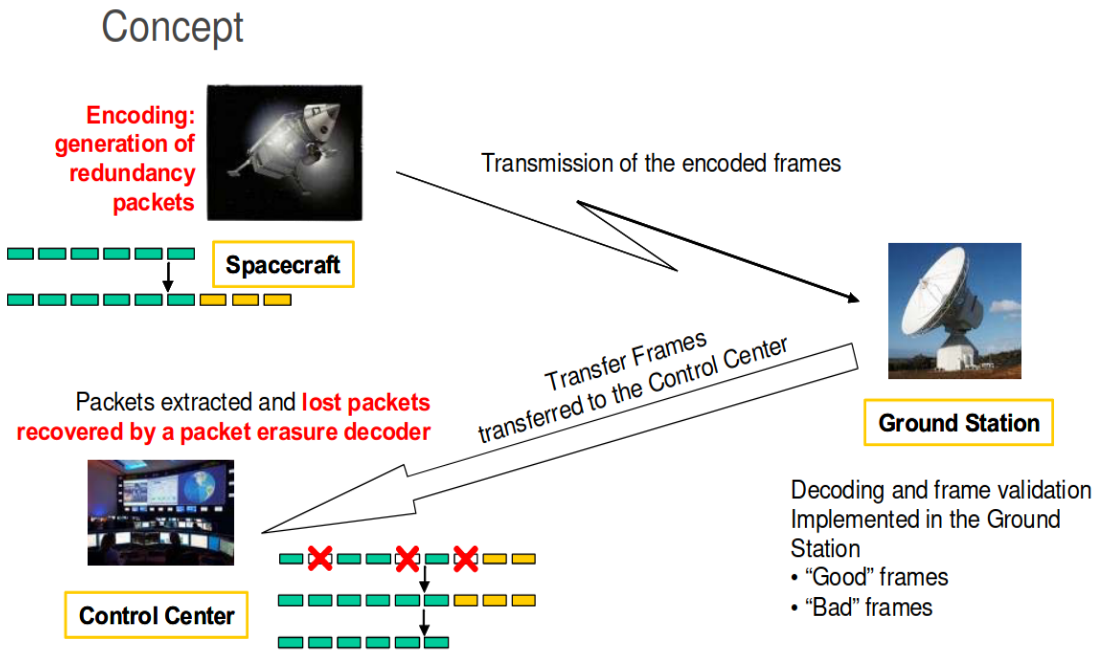


Fig 2 – Illustration of Erasure Correcting codes
https://cwe.ccsds.org/sls/docs/SLS-CandS/Meeting%20Public%20Materials/2010/201005.%20Portsmouth/SIS-LEC_v2.pdf

State of the Art

Coding Rates determine how much useful and redundant data there is.

$$R = \frac{k}{n} = \frac{k}{k+r} \begin{cases} k \rightarrow \text{Useful Data} \\ n \rightarrow \text{Total Data (Useful + Redundant)} \\ r \rightarrow \text{Redundant Data} \end{cases}$$

The following **Coding Rates** were used:

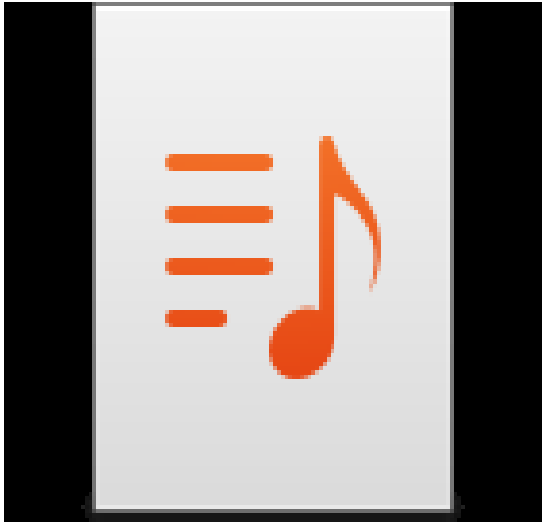
$$R = \frac{2}{3}, \frac{3}{4}, \frac{5}{6}, \frac{7}{8}$$

Candidate Code:

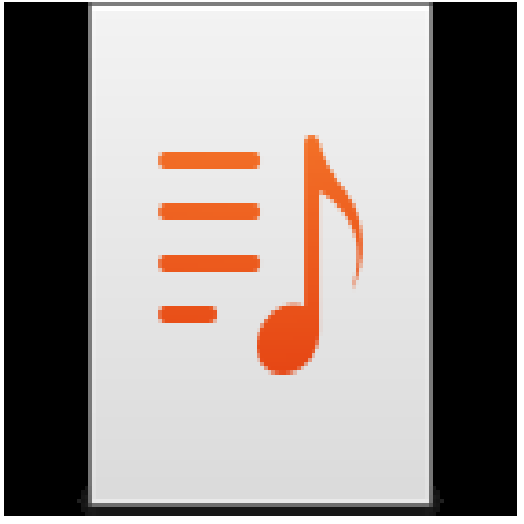
Open source *Python* EC code → zfec

Simulation of Tumbling

Clip of Satellite Tumbling



Clip of Orbit



Simulation of Tumbling

To simulate the data erasure, an **abstract Binary Erasure Channel (BEC)** is used.

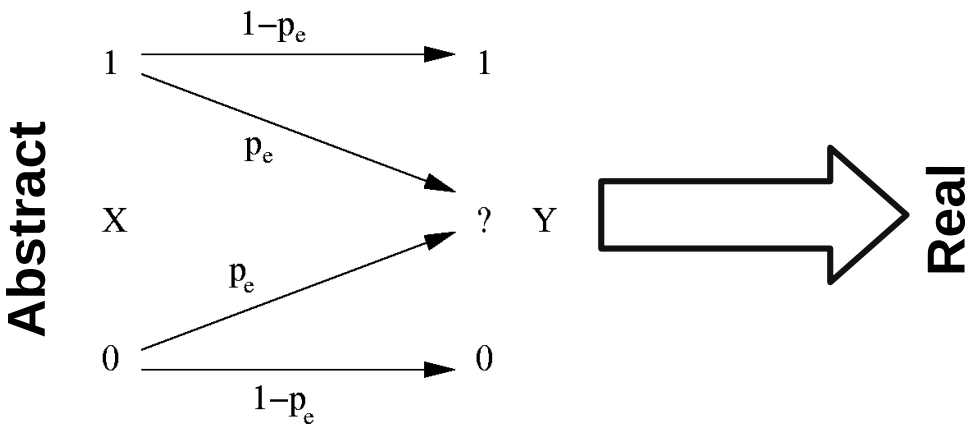


Fig 3 – BEC Schematic

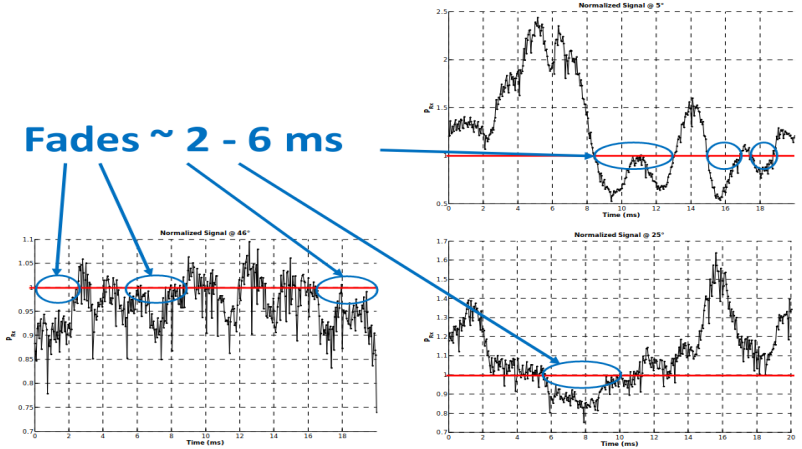


Fig 4 – Illustration of Fading Time
(CCSDS: ERASURE CORRECTING CODES FOR USE IN NEAR-EARTH AND DEEP-SPACE COMMUNICATIONS Fig 2-1)

To model the **Real Intermittency**, the **Received Power** from satellite is calculated (P_{RX}).

Simulation of Tumbling

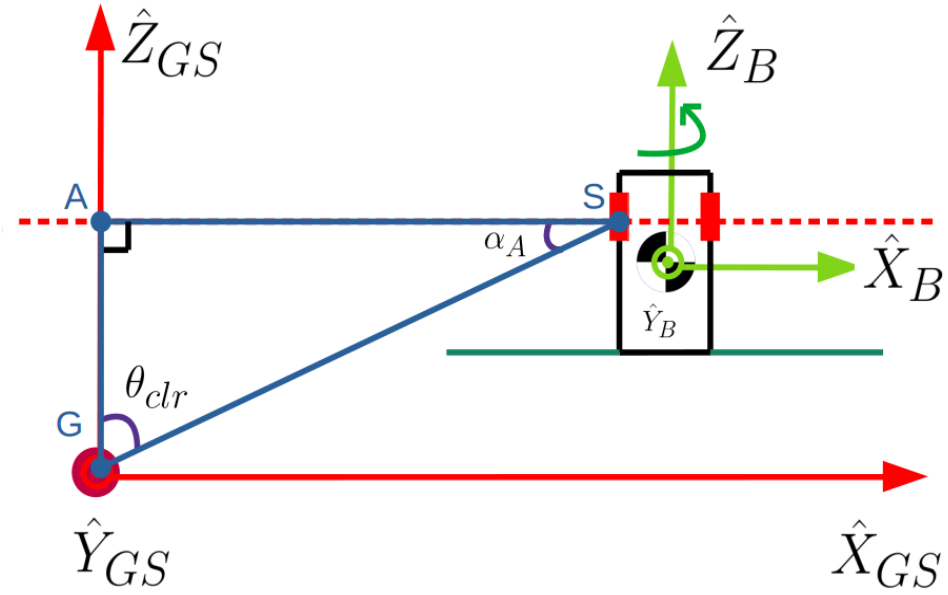


Fig 5 – Geometrical relation between Satellite and Ground Segment

Input:

- Discretized time
- Orbital Elements
- Antenna Parameters

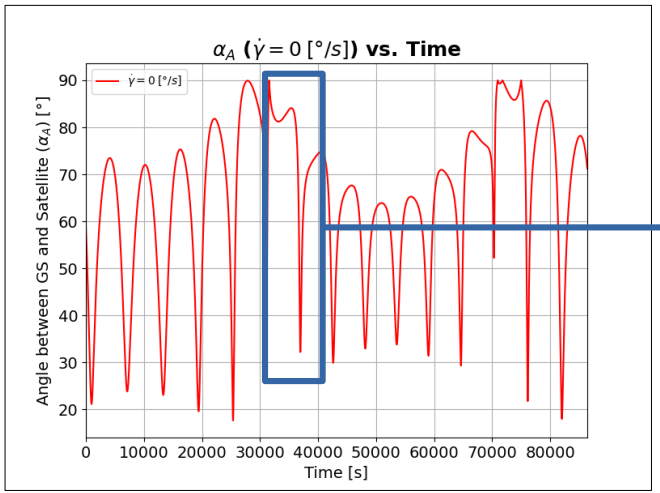
Output:

- Satellite Visibility
- Received Power

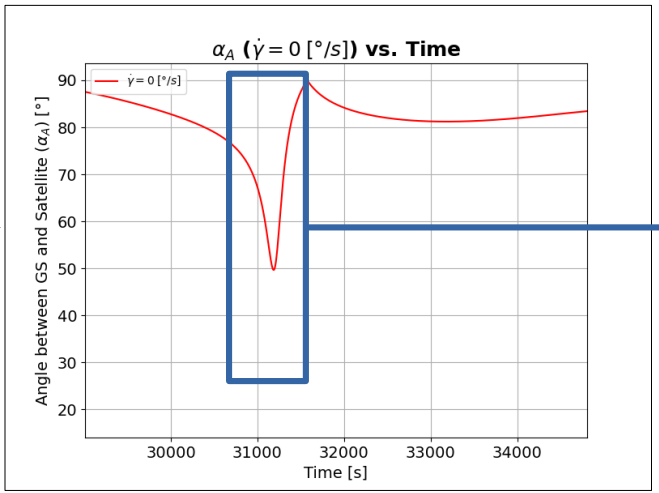
Results

Angle between Satellite and Ground Segment

1 day



5th orbit



Visibility Window in 5th orbit

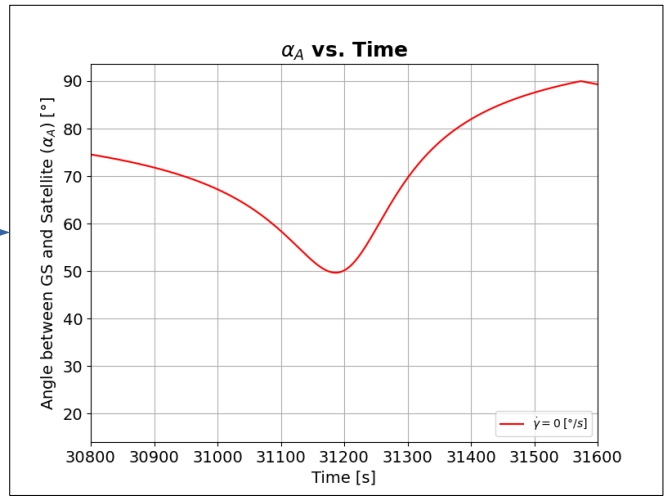
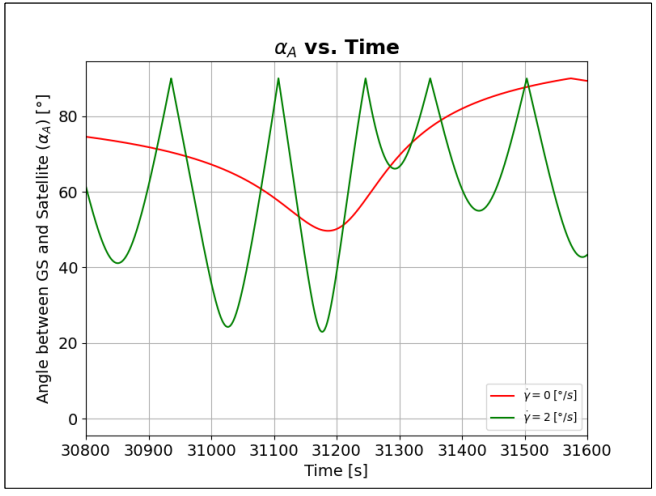


Fig 6 – Simulation of Tumbling with no spin

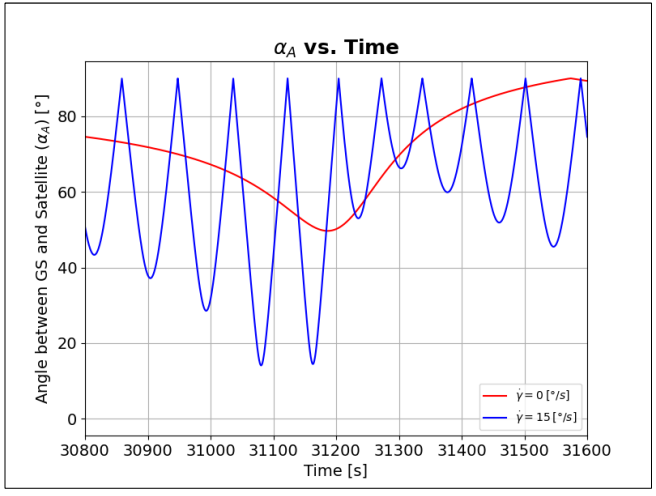
Results

Angle between Satellite and Ground Segment with different spins

Spin of 2 [°/s]



Spin of 15 [°/s]



Average from Angular Velocities

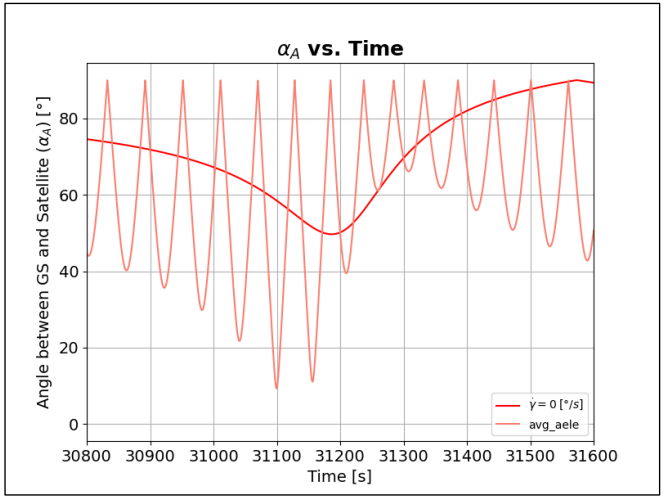
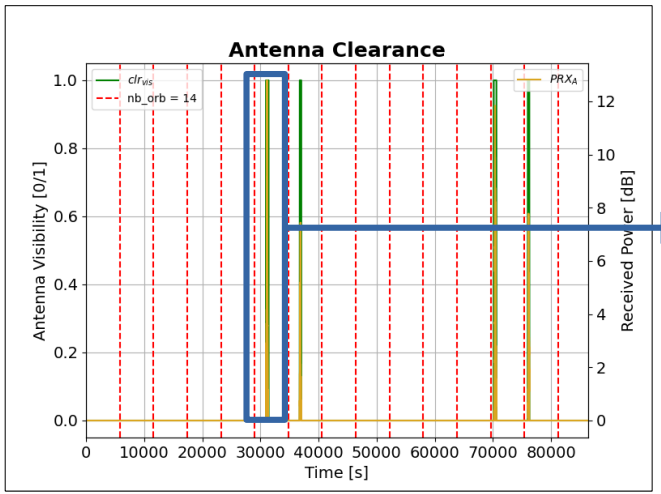


Fig 7 – Simulation of Tumbling with different spins

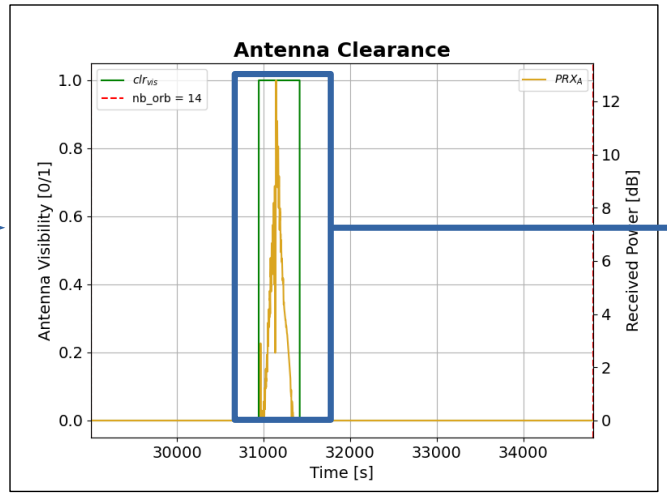
Results

Cleared Received Power from Satellite to Ground Segment

1 day



5th orbit



Visibility Window in 5th orbit

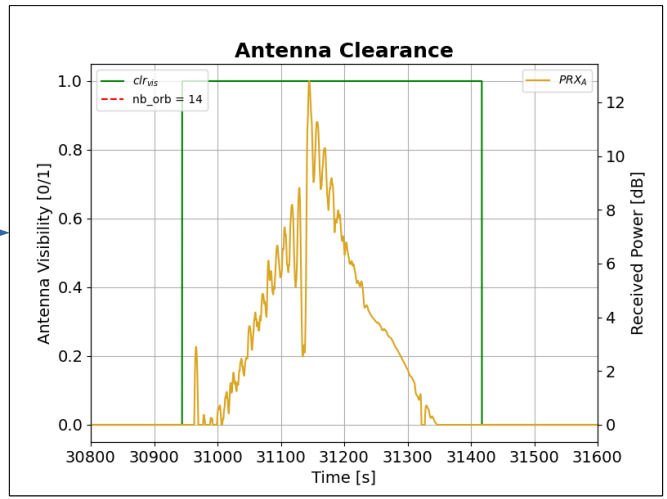
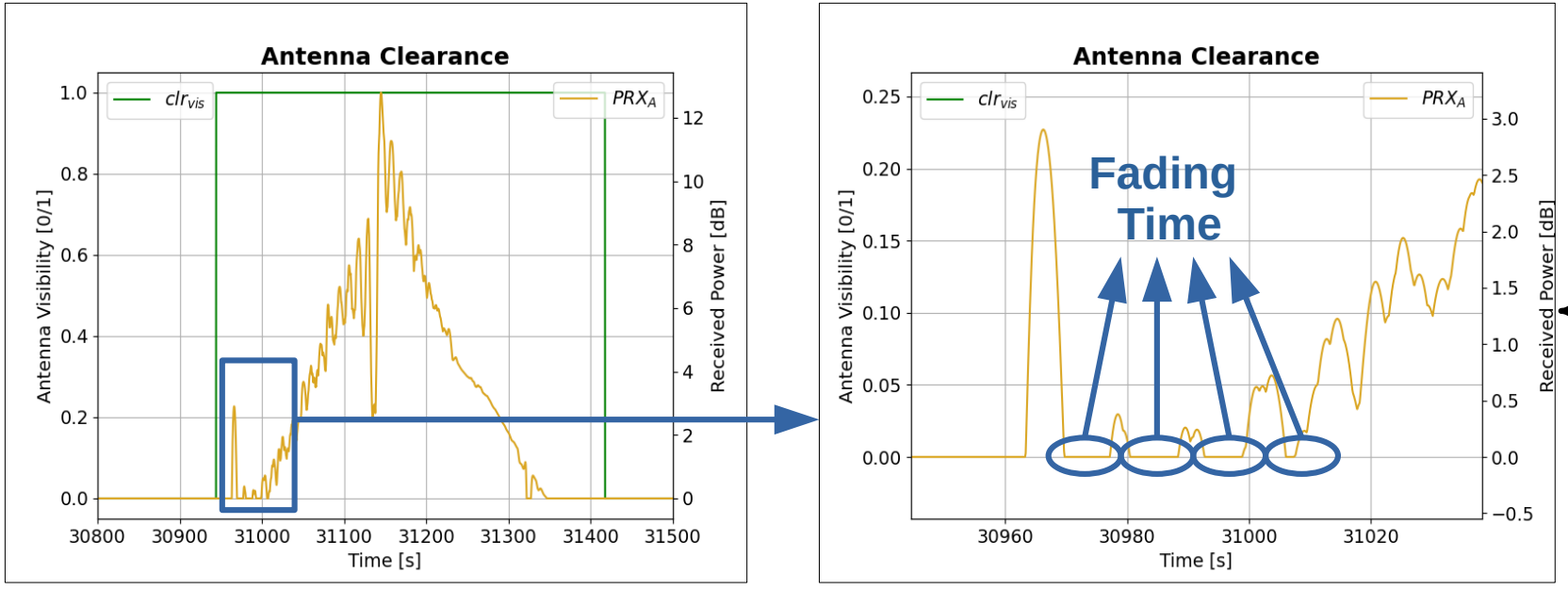


Fig 8 – Simulated Received Power with Average from Angular Velocities

Results



Mean Fading Time:

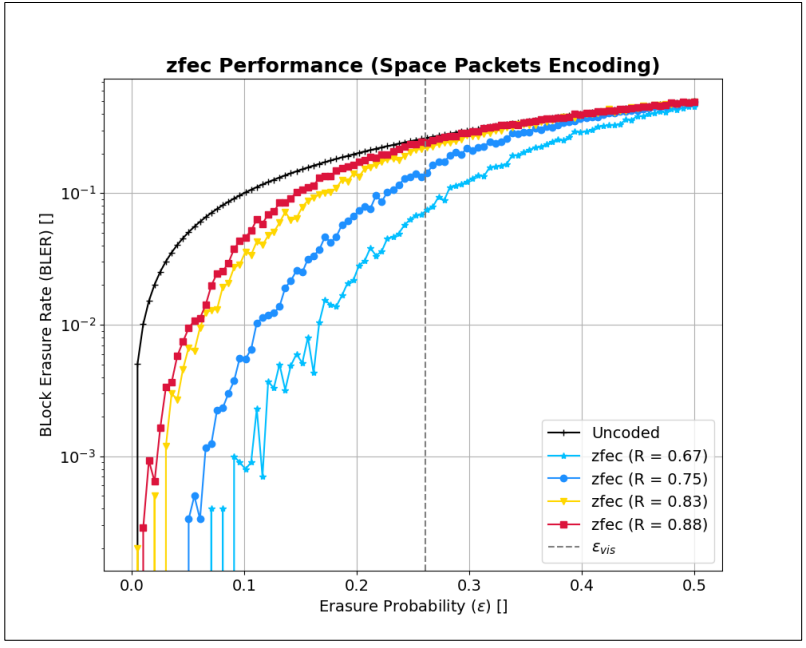
$$\bar{t}_{fad} = 6.53\ s$$

Visibility Erasure Probability:

$$\epsilon_{vis} = 0.261$$

Fig 9 – Cleared Received Power from Satellite to Ground Segment

Results



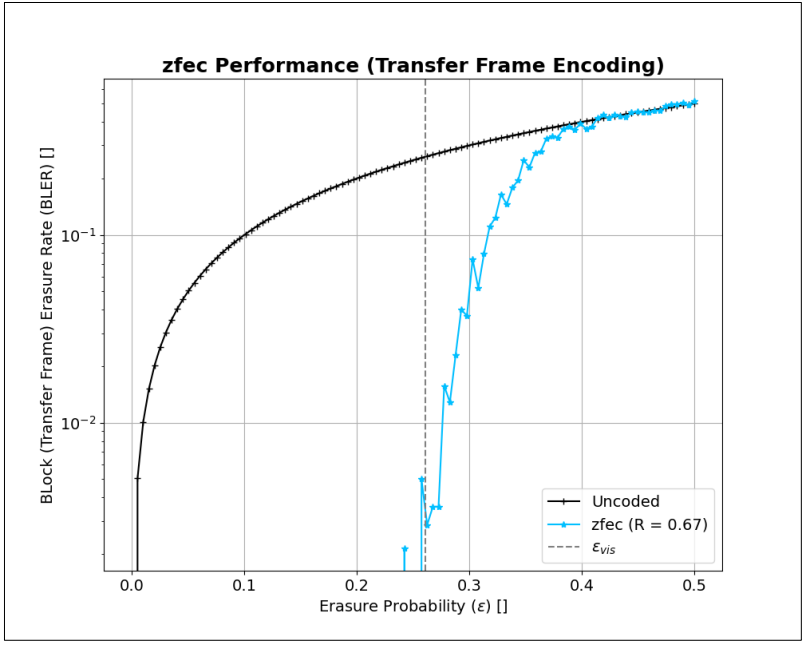


Fig 10 – zfec Performances with SP and TF Encoding

Results

zfec Performance (SP Encoding)

Coding Rate (R)	BLER ($\epsilon = 0.261$)
$2/3$	0.075
$3/4$	0.143
$5/6$	0.221
$7/8$	0.242

Table 1 – Results of SP Encoding

Mitigates fading times of a few ms.

zfec Performance (TF Encoding)

At $(\epsilon = 0.261)$, the BLER = 0.003

Mitigates fading times of a few s.

Conclusions

- **Simulation of Tumbling:**
  - Generated statistics of Tumbling with different spins
  - Mean Fading Time of 6.53 seconds
  - Visibility Erasure Probability of 0.261

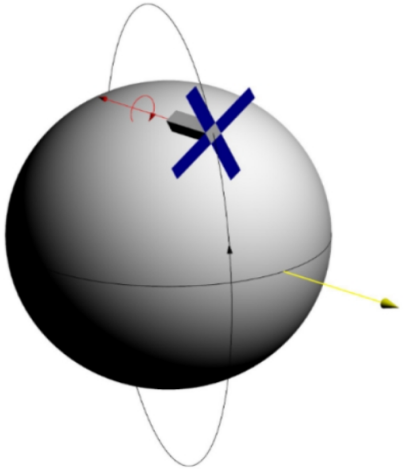
- **Erasure Correcting Code:**
  - If the fading time is in ms → encode the Space Packets
  - If the fading time is in s → encode the Transfer Frames
  - Latency for encoding must be considered

Future Developments

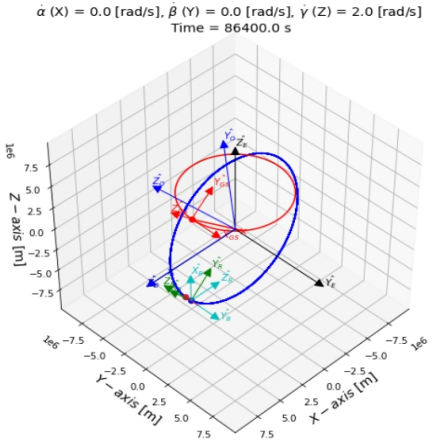
- Finalizing the **simulation model**
  - Satellite trajectories
  - Earth's Magnetic Field
  - Atmospheric disturbances to radio signals
- Studying other **EC candidate codes**:
  - OpenFEC (C language)
  - LDPC codes
  - Etc…
- Building test rig and implement the **EC code**.

ANNEXES

Simulation of Tumbling



(a) Spinning sun pointing mode illustration



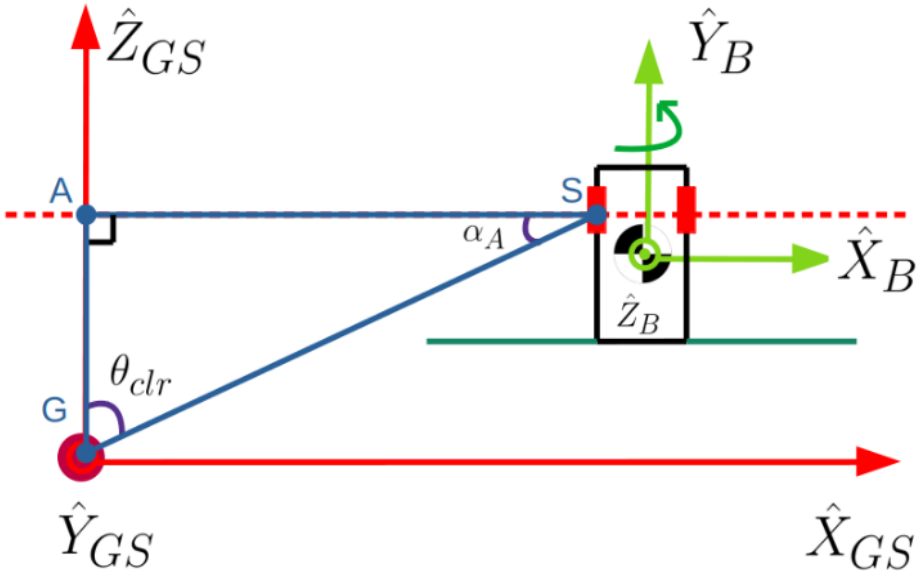
(b) Simulated orbit

Semi-major axis (a)	Eccentricity (e)	Inclination (i)	RAAN	Argument of Perigee	Mean Anomaly
6978.14 km	0	97.79°	TBD	0°	0°

$$\left(\frac{E_b}{N_0}\right)_{real} = P_{TX} - L_{TX} + G_{TX} - L_{FS} - L_{GP} + \left(\frac{G}{T}\right)_{GS} + k + BR + M_S$$

$$L_{FS} = 10 * log_{10}\left(\left(\frac{4 * \pi * d * f}{c}\right)^2\right)$$

Simulation of Tumbling



$$DGS = \vec{GS}$$

$$\alpha_A = tan^{-1}(\frac{\vec{GA}}{\vec{AS}})$$

$$L_{GP} = f(\alpha_A)$$

$$P_{RX} = \left(\frac{E_b}{N_0}\right)_{real} - \left(\frac{E_b}{N_0}\right)_{req} - M_{dwl},$$

$$\left(\frac{E_b}{N_0}\right)_{req} = 2.5\,dB, M_{dwl} = -19.09dB.$$

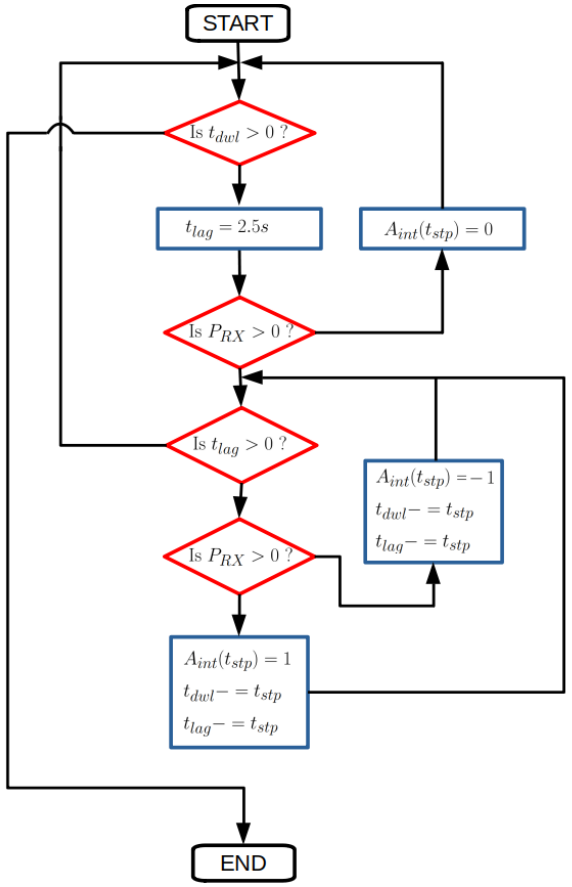
Simulation of Tumbling

Requirements for Visibility:

1. The satellite must be above the ground segment: $DGS \cdot \hat{z}_{GS} > 0$
2. The satellite must be in view of the ground segment: $\theta_{clr} > \theta_{vis}$ where $\theta_{vis} = 10°$
3. The received power must be greater than 0: $P_{RX} > 0$

Simulation of Tumbling

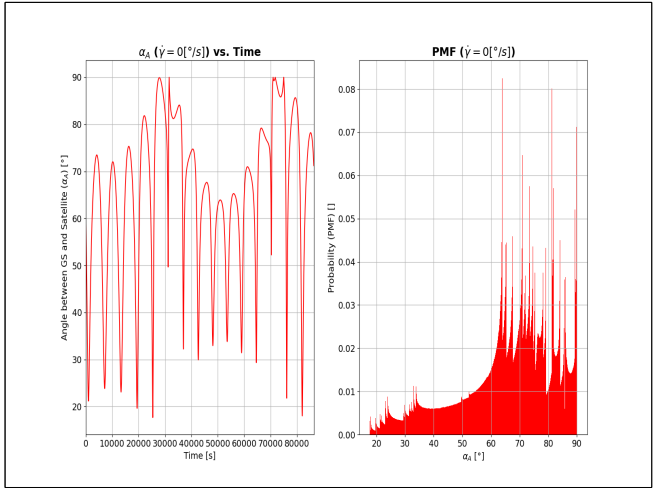
Flowchart for Antenna Intermittency



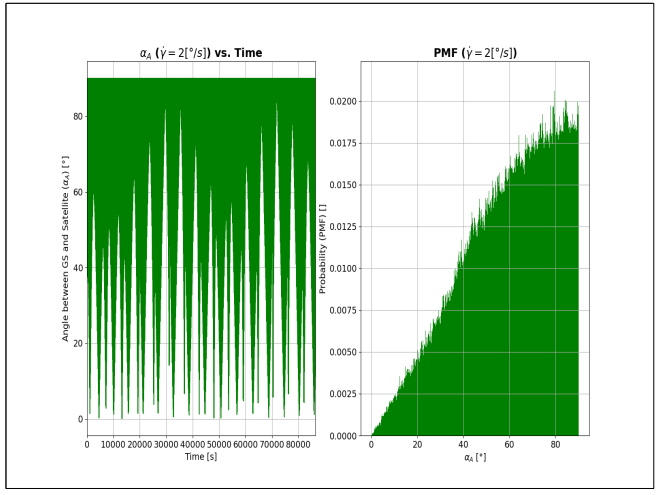
Results

Statistics

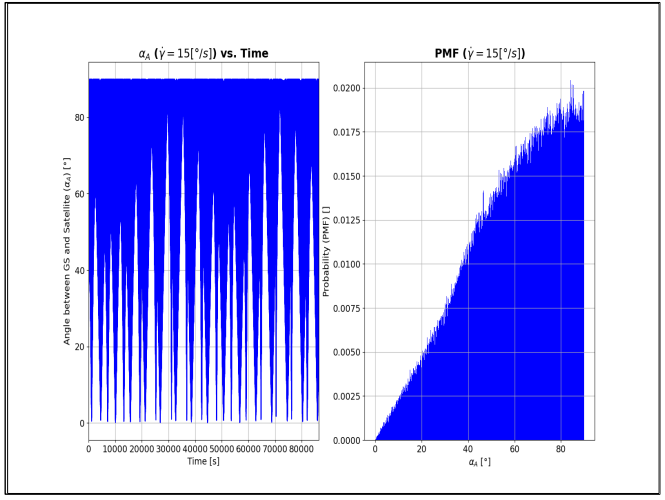
Spin of 0 [°/s]



Spin of 2 [°/s]



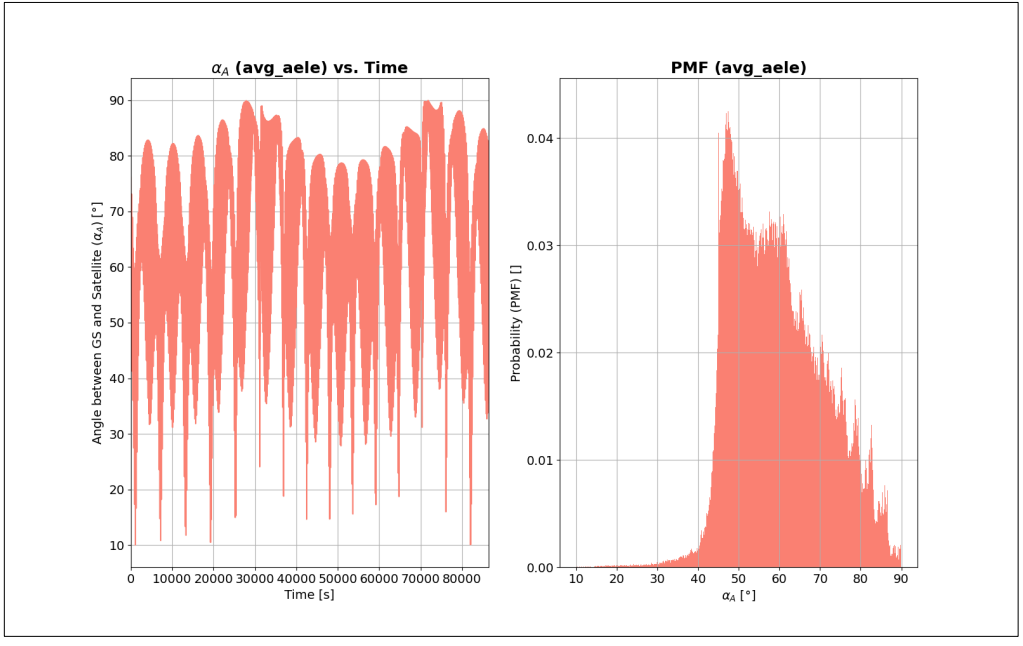
Spin of 15 [°/s]



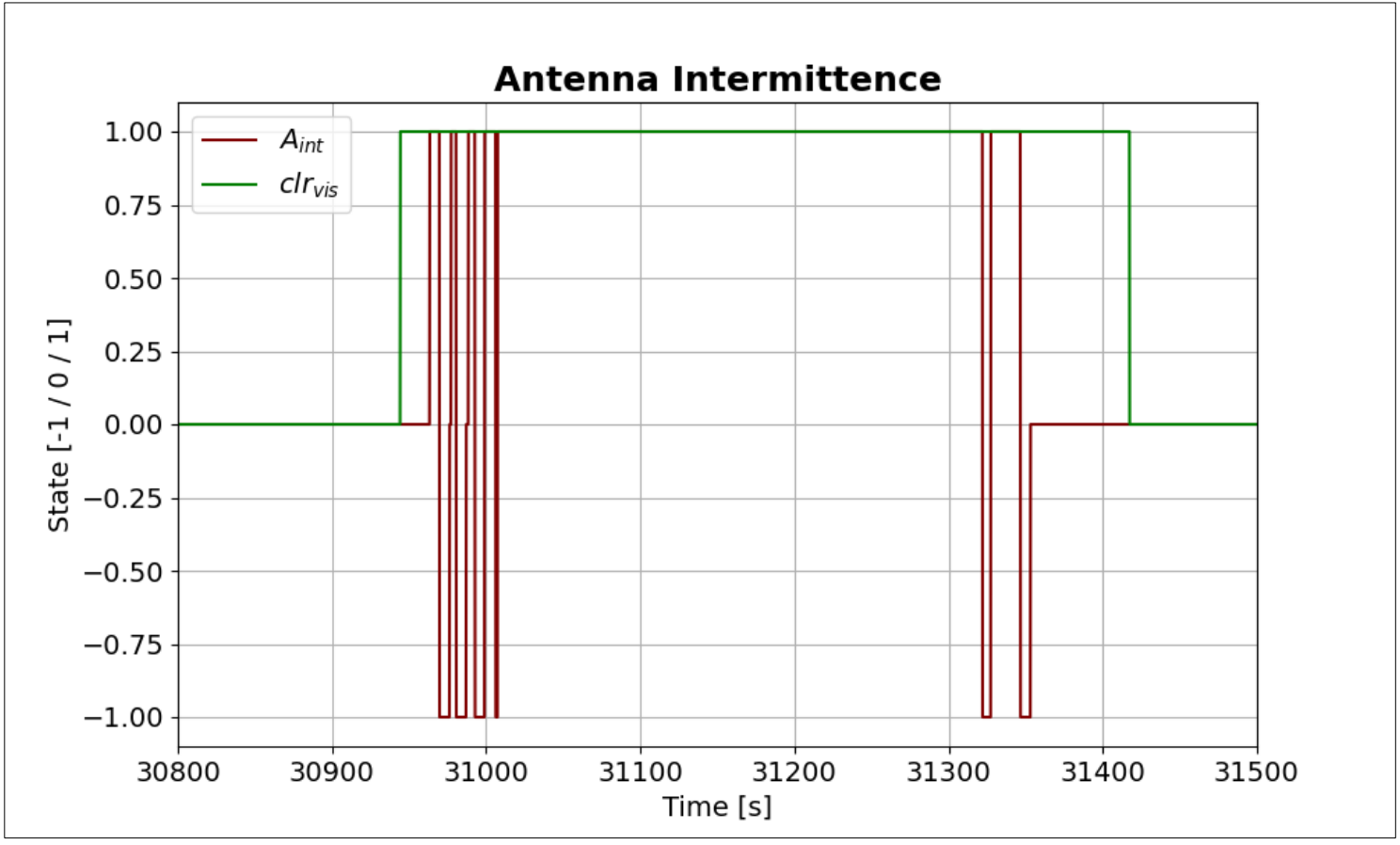
Results

Statistics

Average from Angular Velocities

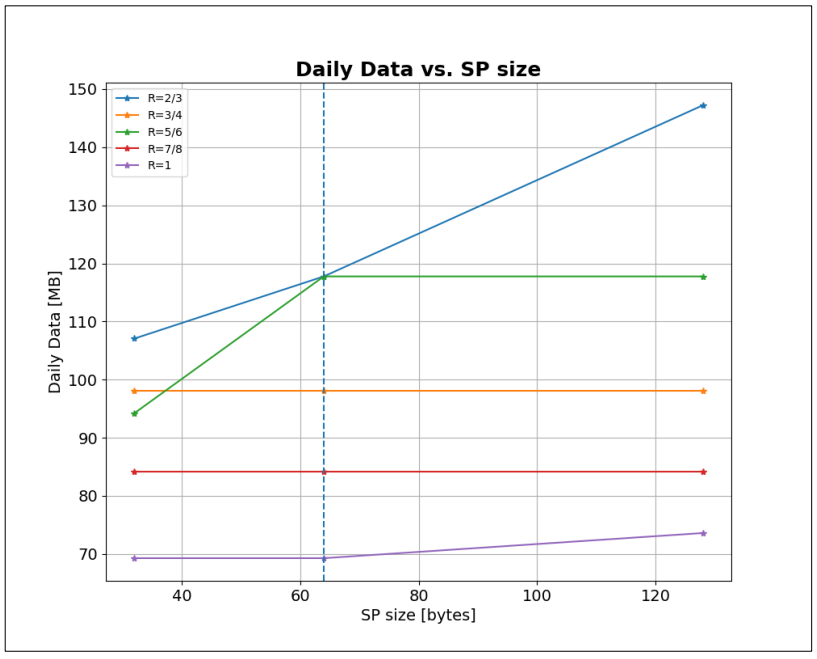


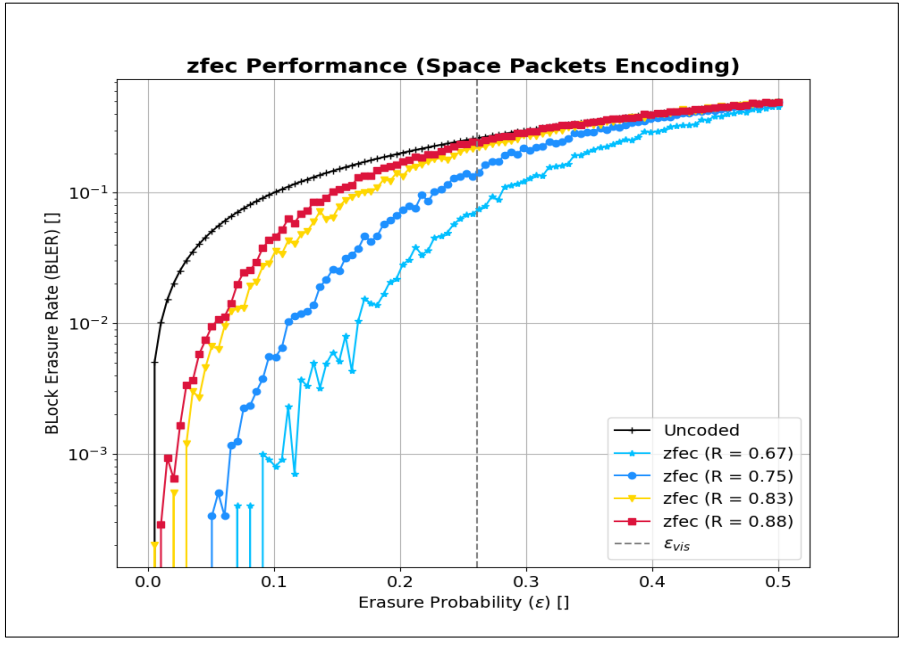
Results


Antenna Intermittence
A_{int}
clr_{vis}
1.00
0.75
0.50
0.25
0.00
−0.25
−0.50
−0.75
−1.00
State [-1 / 0 / 1]
30800
30900
31000
31100
31200
31300
31400
31500
Time [s]

Results

Space Packet Encoding Daily Data Size





	R			
	$\frac{2}{3}$	$\frac{3}{4}$	$\frac{5}{6}$	$\frac{7}{8}$
BLER ($\epsilon = 0.261$) []	0.075	0.143	0.221	0.242
$b_{daily,SP}$ [Mb]	117.771	98.147	177.771	84.126