Performance limitations of Laser Satellite Communication networks due to vibrations

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Location: Summer School (Brixen)

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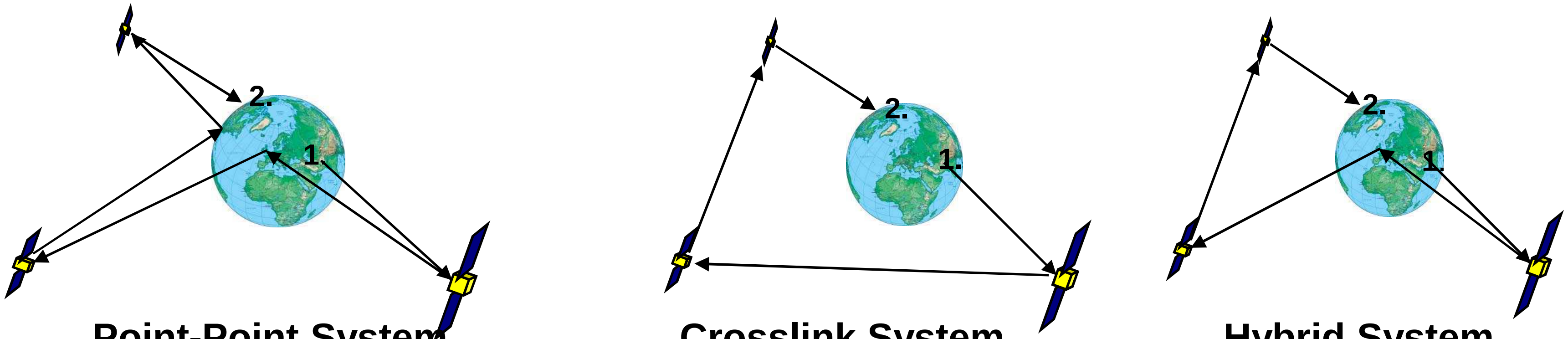
Outline

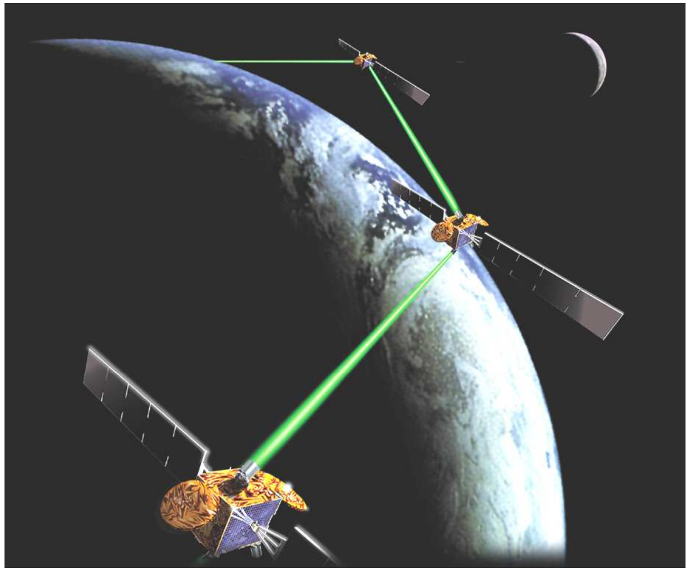
- Introduction and objective
- Inter satellite link and PAT system
- Mechanical Vibration
- Vibration statistics model
- Simulations and results
- How maximize the goodput
- Conclusion

Intersatellite Links Communication Architectures



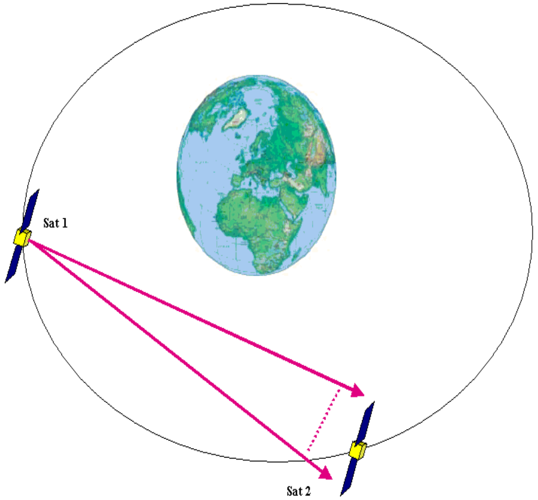
	Advantages	Disadvantages
Point-Point	■ Heritage systems ■ **Reliability and redundancy** ■ **Relatively low weight and power requirements**	■ Reliance on ground stations ■ **Frequency management issues** ■ **Atmospheric losses** ■ **Additional time delays** ■ **High probability of interception**
Crosslink	■ Very secure channels ■ **Reduced propagation delays** ■ **Reduced or no frequency management issues** ■ **Coverage flexibility**	■ Extra spacecraft bus requirements ■ **Additional payload complexity** ■ **Additional ground control requirements**

Inter Satellite Link

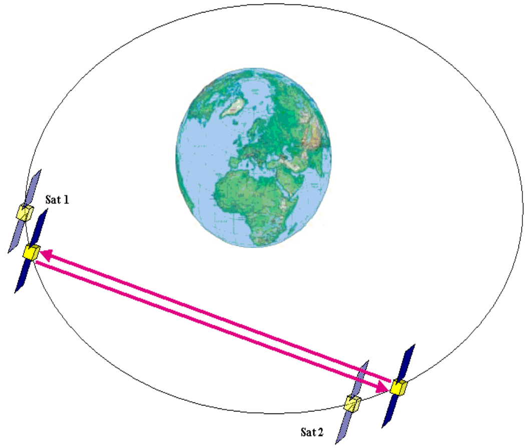


RF	LASERCOM
▪ More experience and knowledge	▪ Innovative technology (technologies without histories)
▪ **Larger wave length and mass of antenna**	▪ **Smaller size and weight of terminal**
▪ **More power consumption**	▪ **Less transmitter power**
▪ Less immunity to interference	▪ Higher immunity to interference
▪ **Bit rate <500 Mpbs**	▪ **Bit rate <= 100 Gbps**
▪ Easy PAT system	▪ **Complexity of the pointing systems (PAT)**
▪ Less dense orbit population	▪ More dense orbit population

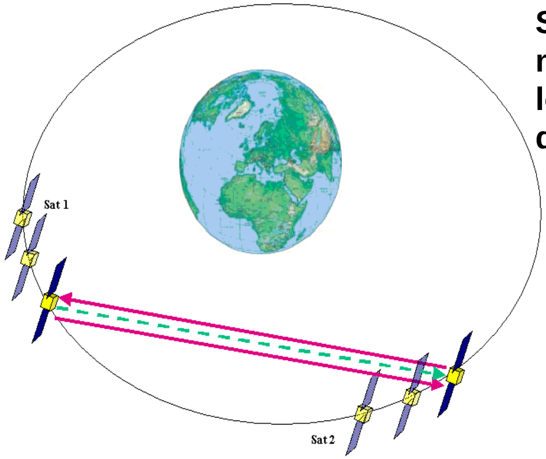
Pointing Acquisition and Tracking (PAT)



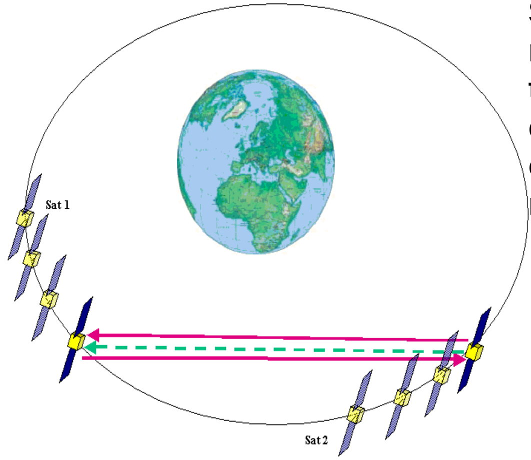
Step 1. Sat 1 scans for Sat 2 using beacon laser



Step 2. Sat 2 responds to successful acquisition with confirmation beacon. Sat 1 beacon maintains lock.



Step 3. While maintaining beacon lock, Sat 1 transmits data.



Step 4. Sat 2 replies to transmission with a confirmation code or request to retransmit.

Noise sources

- External noise
  - *Background : caused by the celestial bodies radiation as the earth, moon, stars and sun*
  - Collision with micrometeorites

- Internal noise
  - Thermal noise
  - Mechanical Vibrations
    - *Due to noise in the tracking system, antenna pointing system and navigation system*

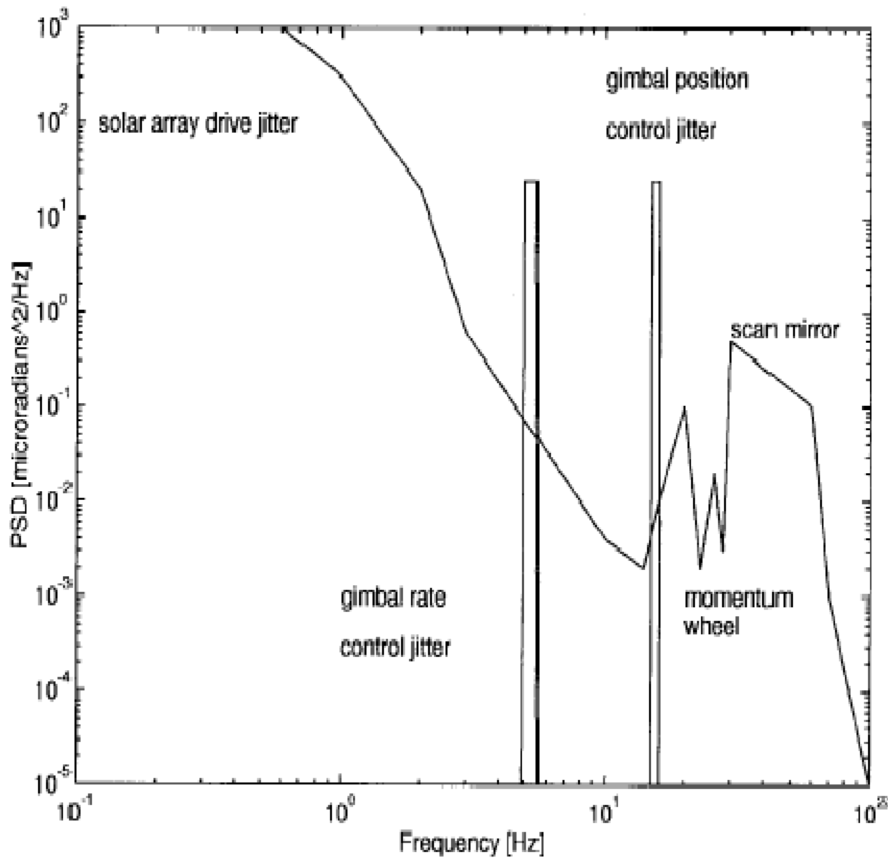
Mechanical Vibrations

Vibration Power Spectral Density:

$$S(f) = \frac{160 \mu rad^2 / Hz}{1 + \left(\frac{f}{f_0} \right)^2}$$

f_0= 1Hz

- Small vibration amplitude with high frequencies (internal satellite subsystems: base vibrations)
- Big vibration amplitude with low frequency (random vibrations)



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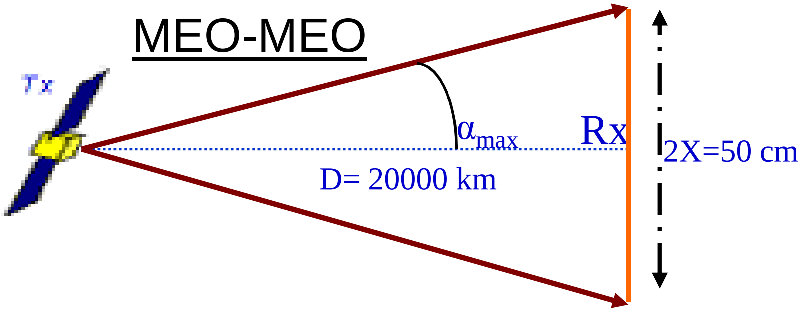
Vibration statistics model and link geometry



Max angle Tx:

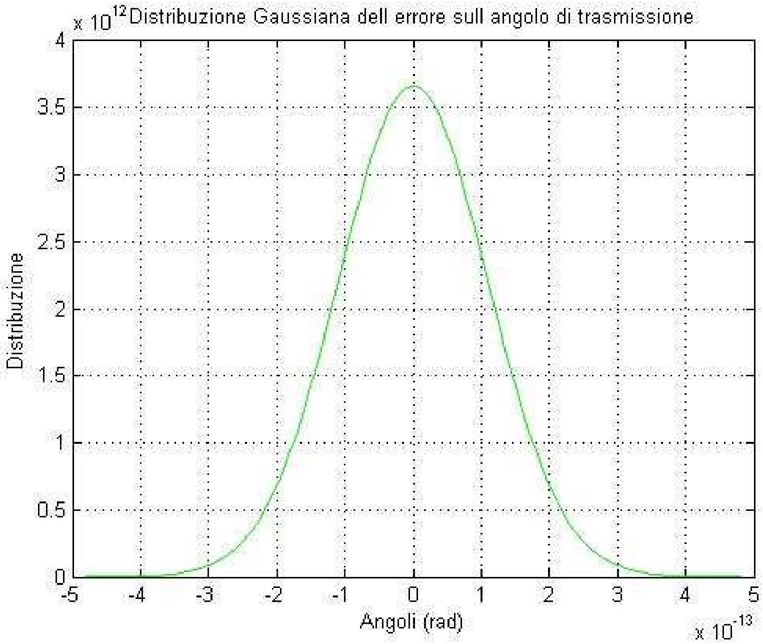
α_{max}= arctg(X/D)= arctg(0.25/2$\times$10^7)= 7.16*10^{-7} degree

Time of travel:

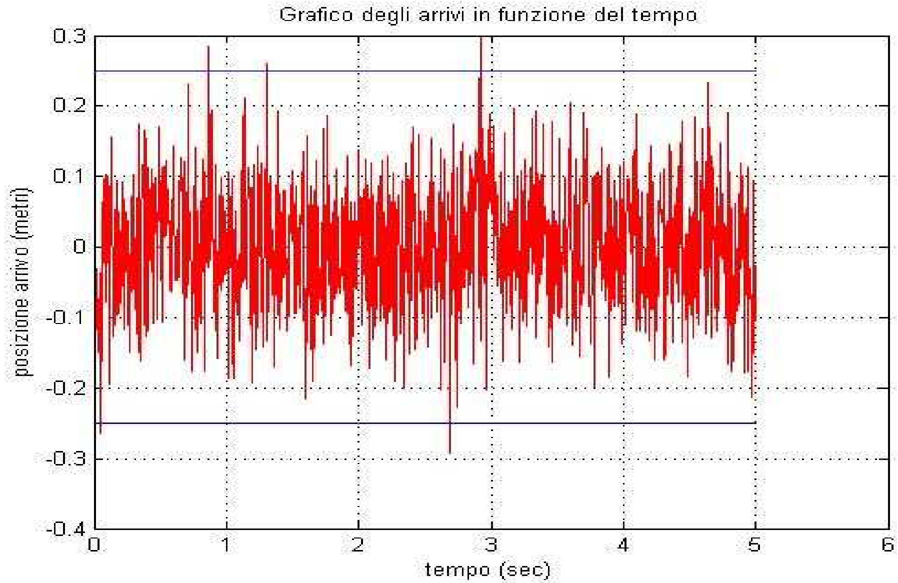
$\Delta\tau = D / c \cong 2\times10^4 / 3\times10^5 \cong 0.07$ sec

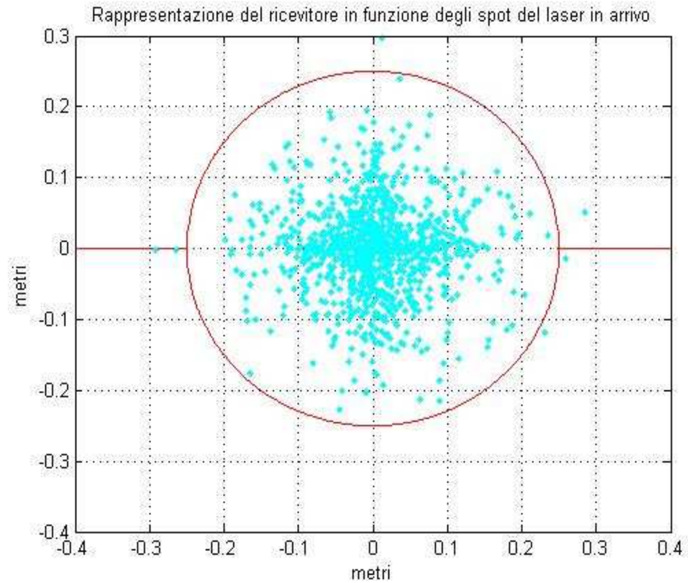
The radial pointing error angles (azimutl and zenith) are modeled by a normal distribution with probability density function (PDF):

$$f(\varphi) = \frac{1}{\sigma_v\sqrt{2\pi}} \exp\left(-\frac{(\varphi-\mu_v)^2}{2\sigma_v^2}\right)$$



Vibration statistics model (high frequency)





$$\theta_{Tx} = \theta_{in} \sin\left(2\pi \Delta f_{base} t\right)$$

θ_{in} → average = 0
variance = $0.5*10^{-13}$

Δf_{base} → average = 150 Hz
variance = 1600

Management of base vibrations → Probability Out of Service ~= (10^{-3}).

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Vibration statistics model (low frequency)

Mass → $F_m = -k \cdot x$

Damping → $F_{smorz} = -h \cdot \dot{x}$

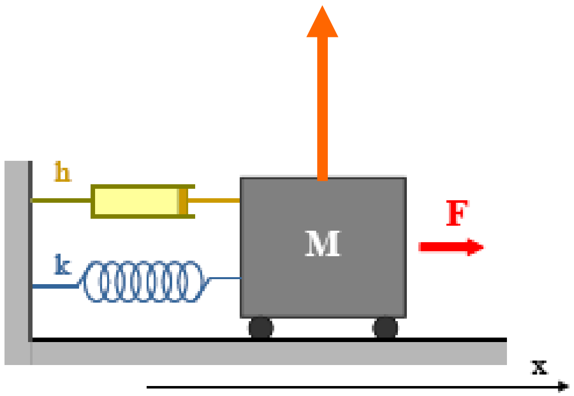
Balance forces → $M \cdot x = F + F_m + F_{smorz}$

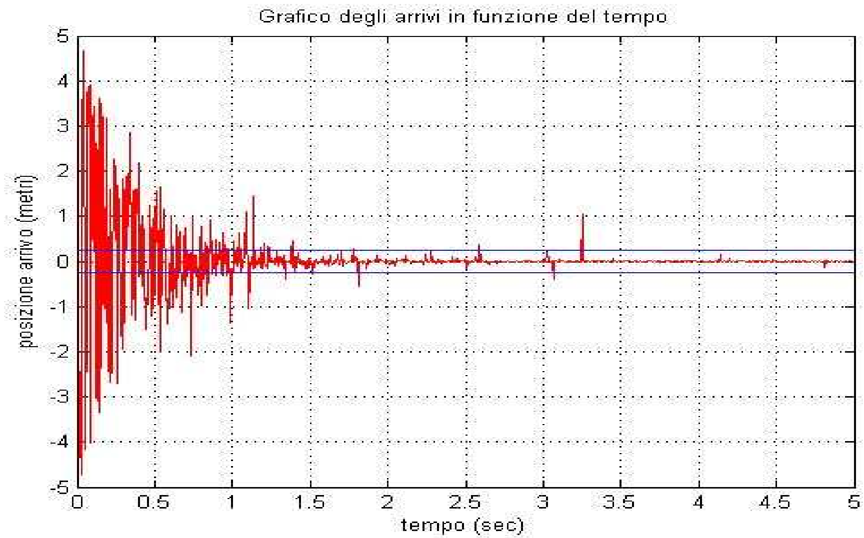
$$x(t) = Xe^{-\varsigma\omega_n t} \cos\left(\sqrt{1-\varsigma^2}\,\omega_n t - \phi\right)$$

$$\omega_n = 2\pi f_n$$

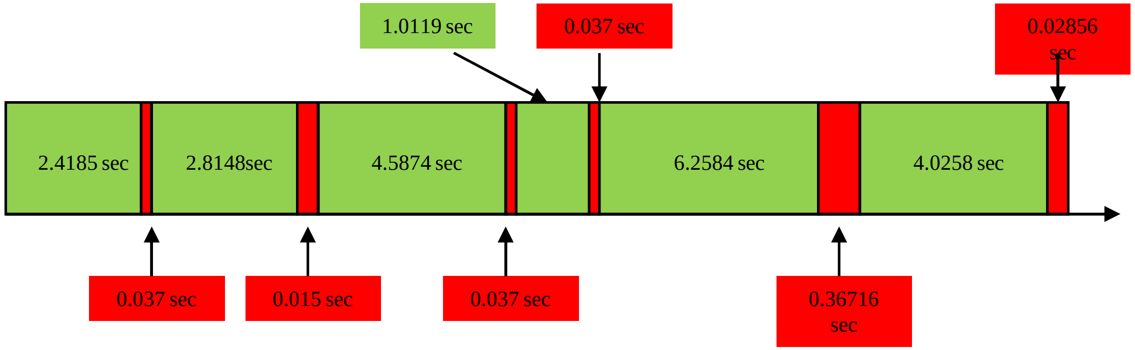
$$\varsigma = \frac{c}{2\sqrt{km}}$$

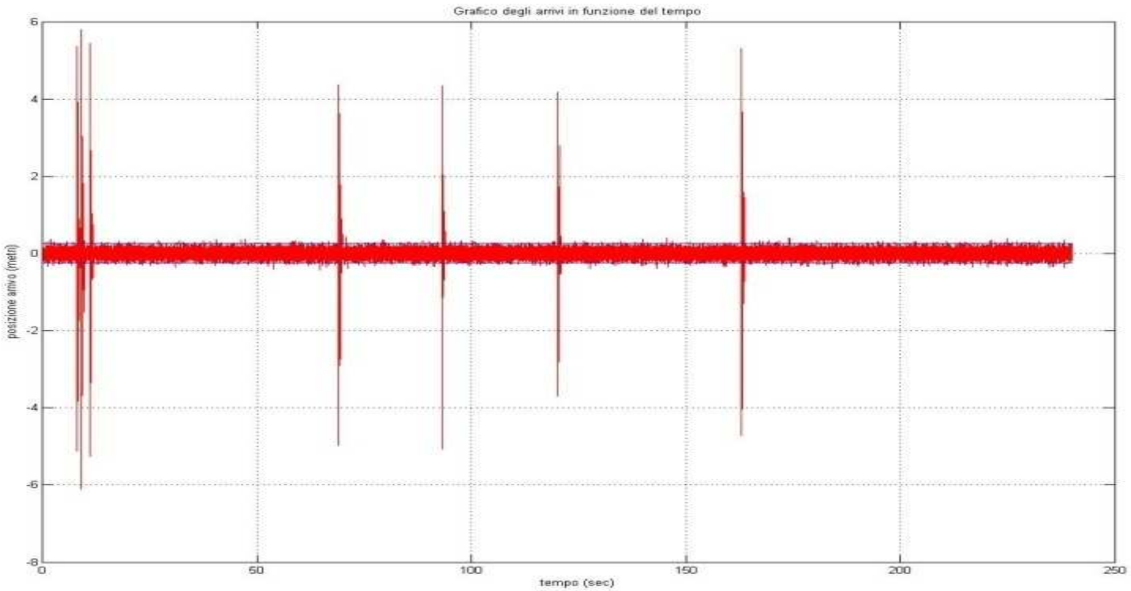
<u>mass-spring-damper model</u>

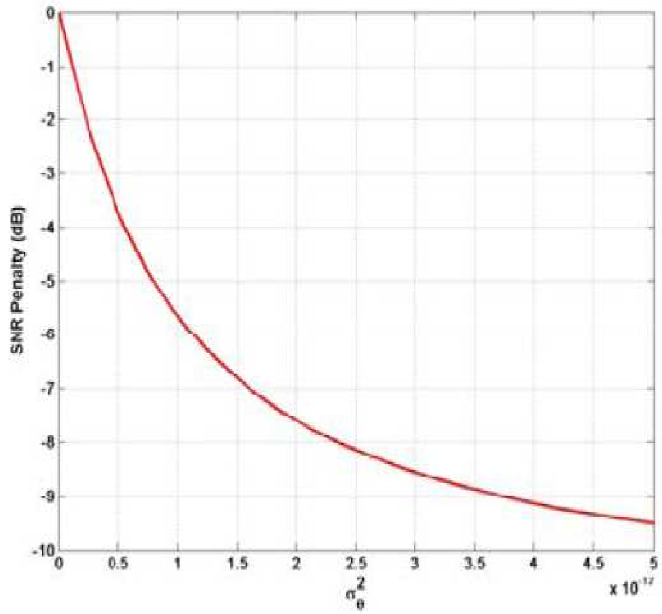




Simulations and results

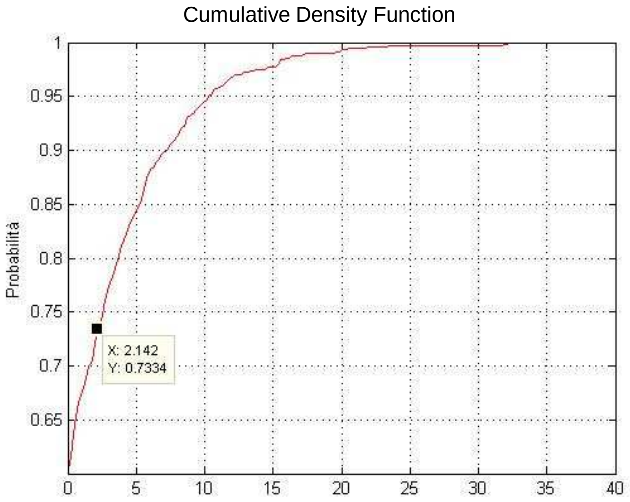


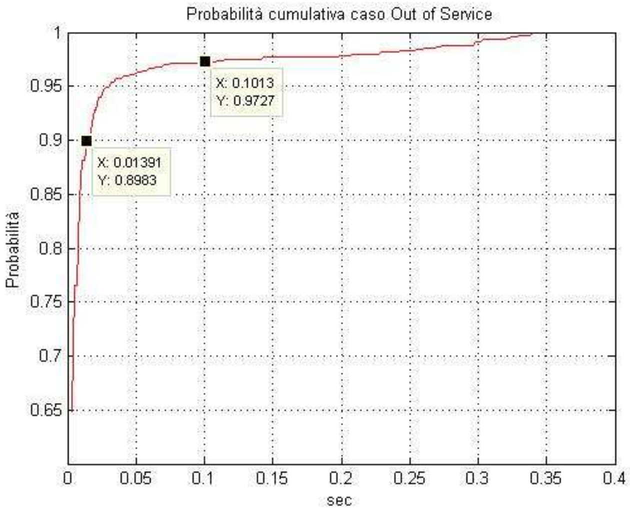




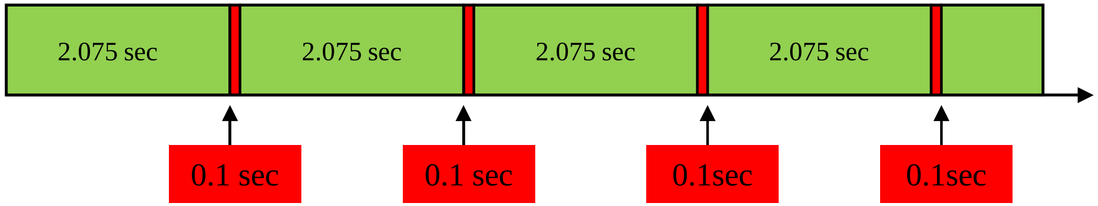
The algorithm join the two event of vibration(low and high frequencies)
The base vibrations are always present

Analysis of results





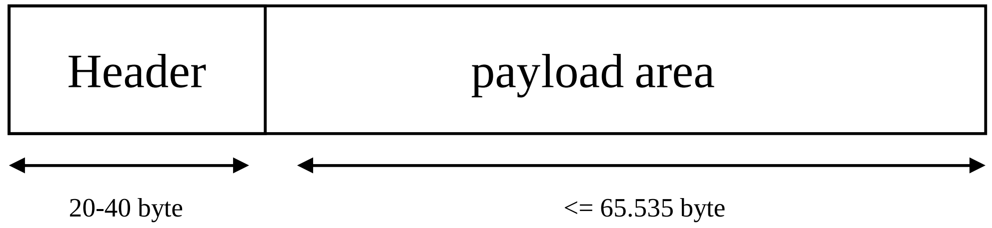
Channel with Periodic Structure

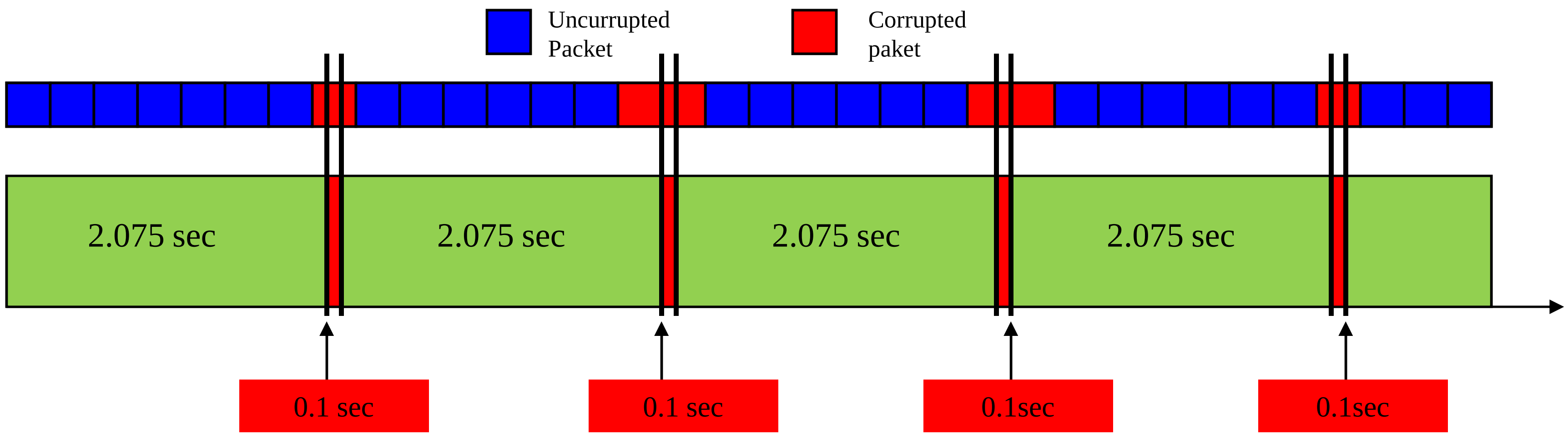


Average Time Service	= 2.075 sec	(73%)
Time Out of Service	= 0.1 sec	(97%)
Time of analysis	= 2.175 sec	

Packet IP size

<u>Channel capacity</u>: 1 ÷ 2,5 Gbps
<u>Multiplexing tipe</u>: Wavelenght Division Multiplexing (WDM)
<u>Data Flow</u> :
128 kbps
256 kbps
512 kbps



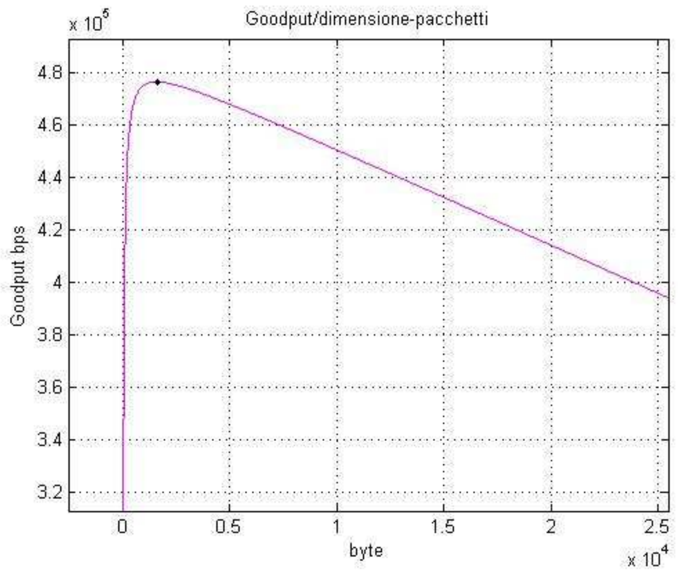


Maximize the performance of IP network

Max GoodPut function in respect of : period of analysis, payload IP, Header IP and bit-rate of data flow.

$$GoodPut = \frac{N_b \times (D - H)}{T_{analisi}}$$

N_b = all packets transmitted in service time
D = packet IP size (byte)
H = Header IP size (byte)
$T_{analysis}$ = 2,175 sec



BitRate (kbps)	Payload IP (byte)	GoodPut max (kbps)	Throughput Loss (%)		MAN FDDI (4470 byte)
128	1636	120,368	~ 6		~ 18%
256	3292	242,161	~ 5,4		~ 8,25%
512	6608	485,977	~ 5		~ 8%

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Conclusion and Future work

- The IP packet size optimization is a good alternative to improve the performance (GoodPut)
- The vibration statistics model approximates the real events and the environment of the space communication

- Future works :
  - Deeper study of the PAT system in order to produce a more accurate model
  - Introducing a system of error control for data transmission
  - Testing the performance on a IP sky/space network