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DECENTRALIZED CONTROL OF SWARM OF NANOSATELLITES WITH COMMUNICATION RESTRICTIONS USING AERODYNAMIC FORCES

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Missions Involving Plenty of Nanosatellites

Nowadays much attention is being paid to missions involving many micro- and nanosatellites

QB-50 International Project

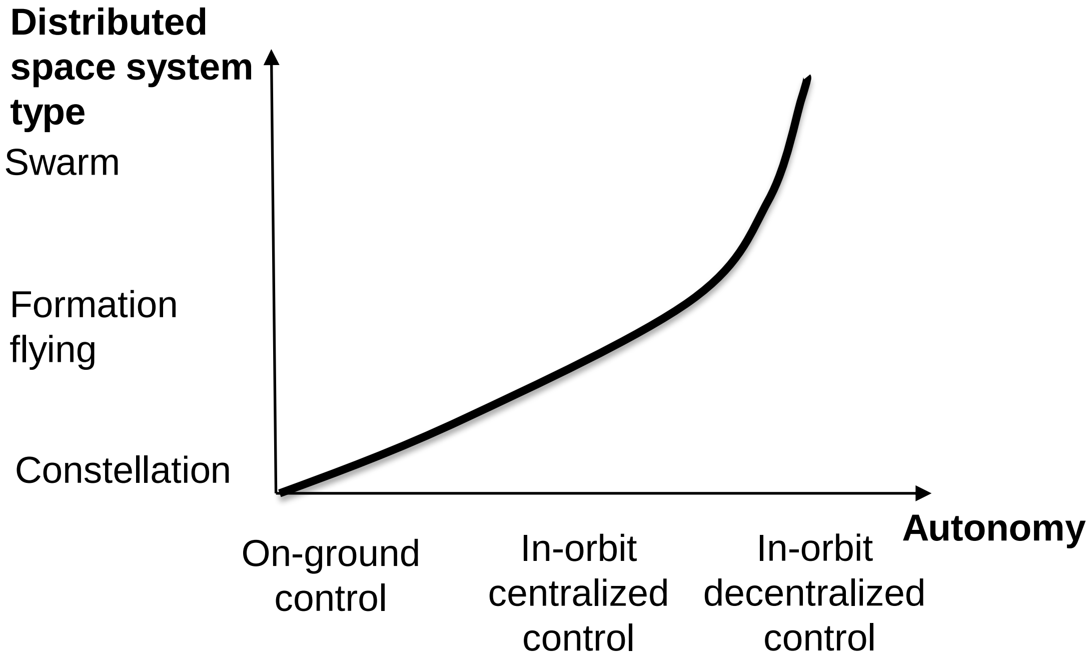
Launch of 88 3U CubeSats developed by PlanetLabs

Swarm of Nanosatellites

Swarm features

- A large number of satellites
- Decentralized control
- Communication with limited number of swarm member
- Motion along occasional trajectories:
  - Random but bounded relative trajectories

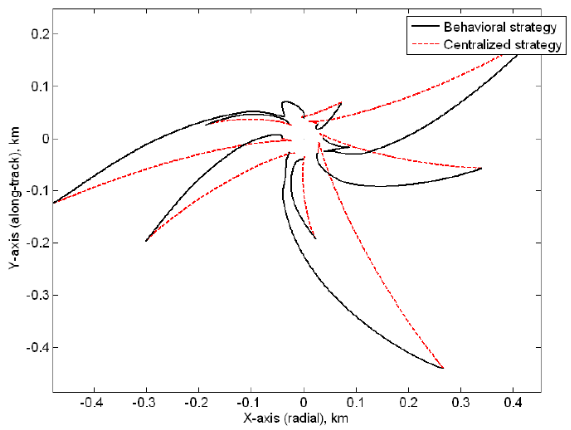
Autonomy in relative control



Previous Studies on Decentralized Control

- Comparison of the fuel consumption between centralized and decentralized control

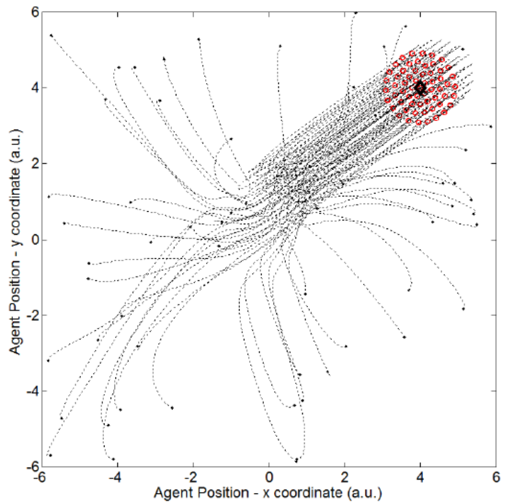
Sabatini M., Reali F., Palmerini G.B. Autonomous behavioral strategy and optimal centralized guidance for on-orbit self assembly // IEEE Aerosp. Conf. Proc. 2009. 12 p.



- Decentralized control using artificial potentials

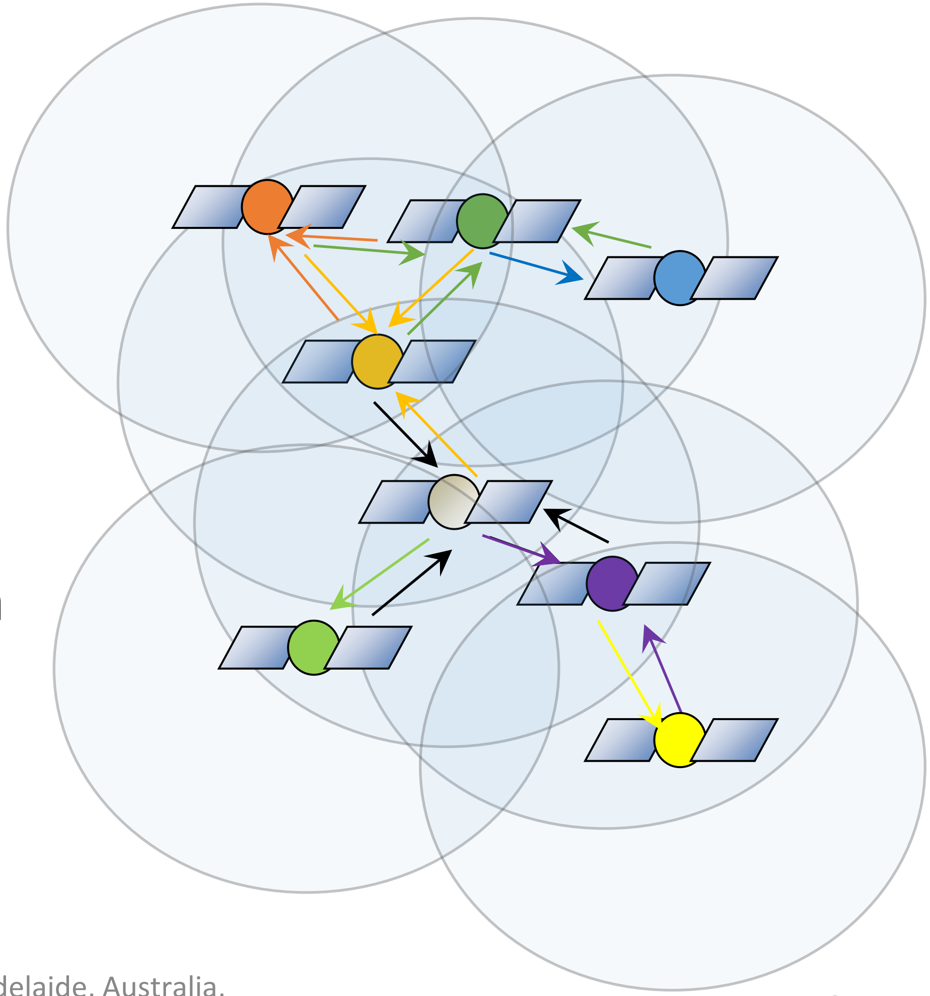
Sabatini M., Palmerini G.B., Gasbarri P. Control laws for defective swarming systems // Adv. Astronaut. Sci. 2015. Vol. 153. P. 749–768.

Chen Q. et al. Virtual Spring-Damper Mesh-Based Formation Control for Spacecraft Swarms in Potential Fields // J. Guid. Control. Dyn. 2015. Vol. 38, № 3. P. 539–546.



Decentralized Control Under Communication Restrictions

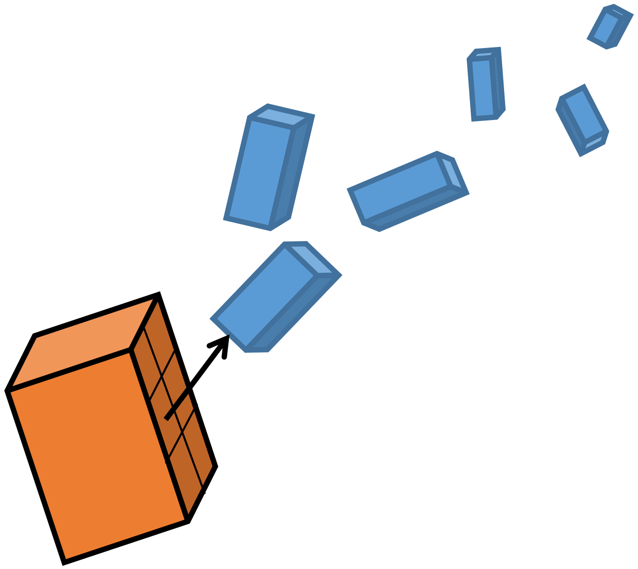
- Each satellite has a communication area in the form of sphere
- If the other satellites are inside the area theirs relative motion are known to the satellite
- The size of the communication area is determined by relative determination system parameters or by intersatellite communication link



Problem Statement

- Consider the separation the satellites from the bus launcher
- The initial conditions of the satellites after separation are random
- Without control the satellites are flying apart

- The problem of satellite swarm construction after their separation from the bus launcher is considered, i.e. the achievement of closed relative trajectories is required

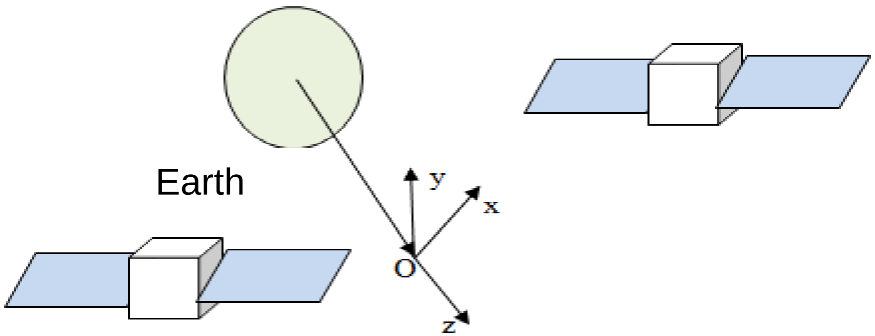


Scheme of satellites launch

Equations of Relative Motion

Clohessy-Wiltshire model is

$$\begin{cases} \ddot{x} + 2\omega\dot{z} = u_x \\ \ddot{y} + \omega^2 y = 0 \\ \ddot{z} - 2\omega\dot{x} - 3\omega^2 z = 0 \end{cases}$$



Reference frame

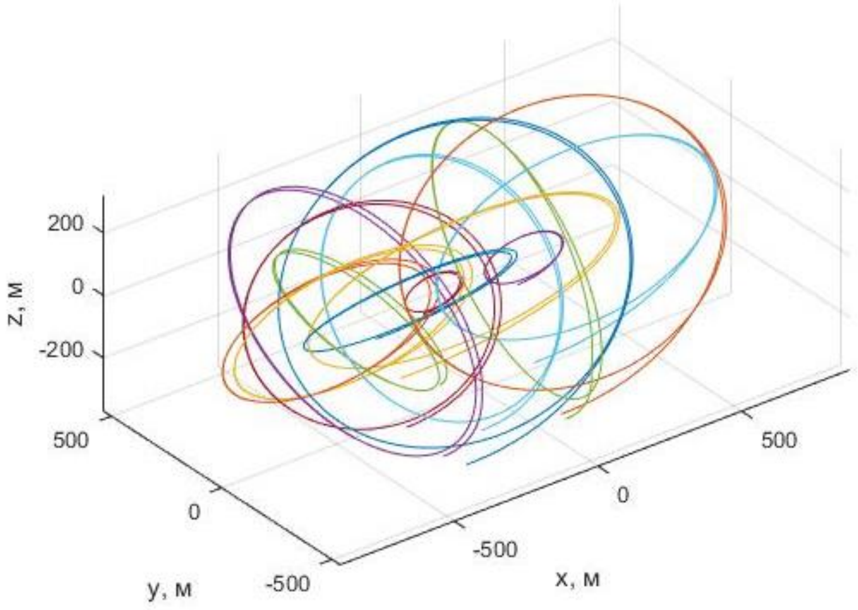
In the case $u_x = const$ solution is :

$$\begin{cases} x(t) = -3C_1\omega t + 2C_2\cos(\omega t) - 2C_3\sin(\omega t) + C_4 + 4u_x/\omega^2 - 3t^2 u_x/2, \\ y(t) = C_5\sin(\omega t) + C_6\cos(\omega t), \\ z(t) = 2C_1 + C_2\sin(\omega t) + C_3\cos(\omega t) + 2tu_x/\omega, \end{cases}$$

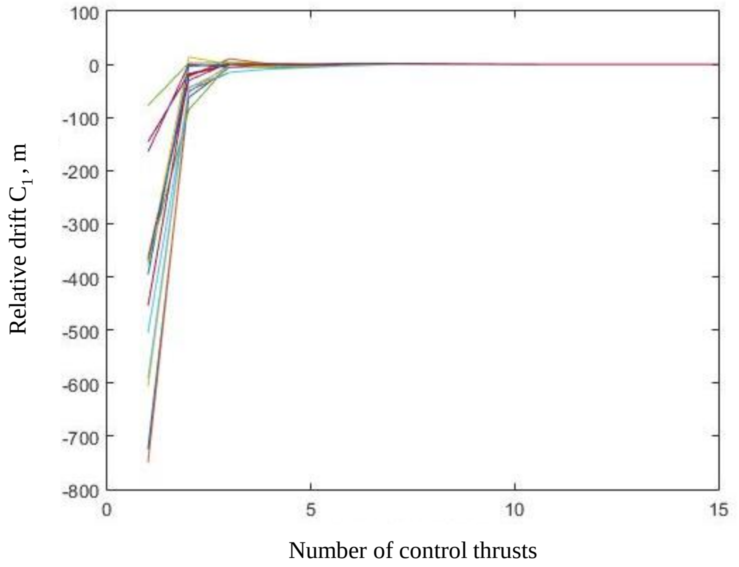
$-3C_1\omega t$ is relative drift. To set the drift to zero $u_x = \dfrac{-\omega C_1}{\Delta t}$

Piecewise-Constant Decentralized Control Using On-board Thrusters

- An example of decentralized control application
- The simulation parameters: 20 satellites are launched in orbit with altitude of 400 km, the initial velocities are random with uniform distribution

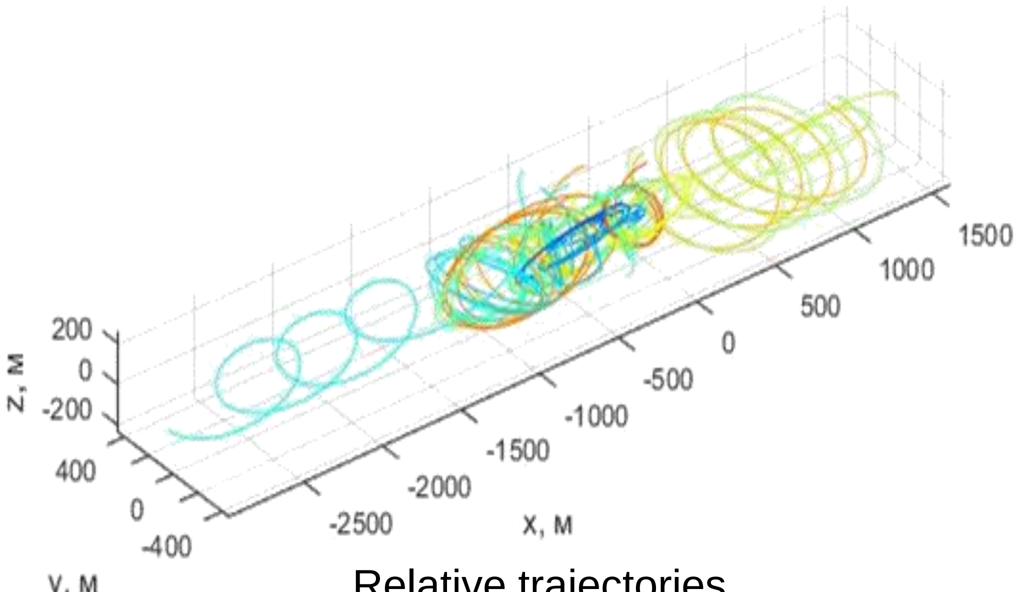


Relative trajectories



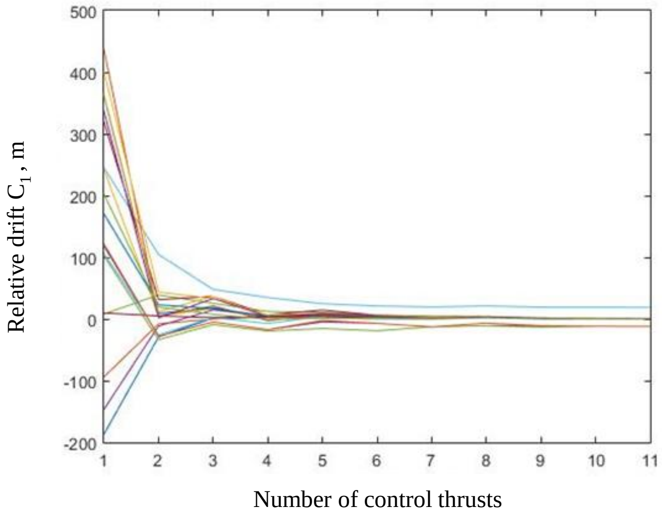
Relative drifts

Clustering Effect

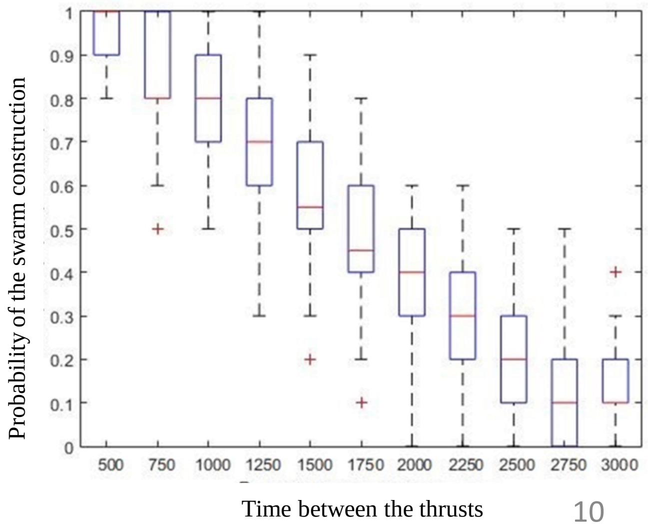


Relative trajectories

Relative drifts



Probability of swarm construction

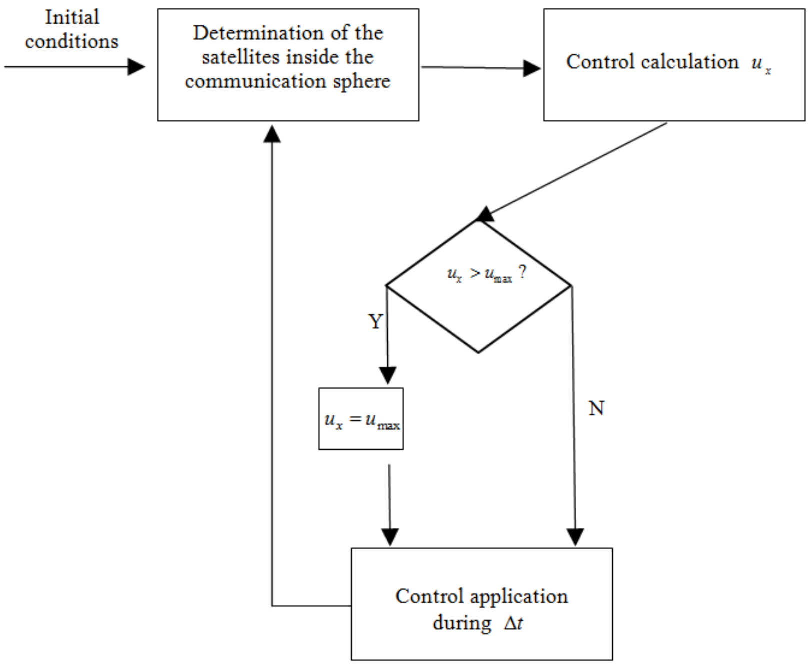


- Occasionally decentralized control with communication restriction leads to dividing the swarm into sub-groups – clustering effect
- Monte-Carlo simulations was performed to study the effect

Swarm Construction Using Aerodynamic Drag Force

- Consider 3U CubeSats launch in LEO (the same as PlanetsLabs satellites launch)
- Let the satellites be equipped with active ACS
- So, each satellite can change the aerodynamic drag force using attitude control
- The differential drag relative force model is

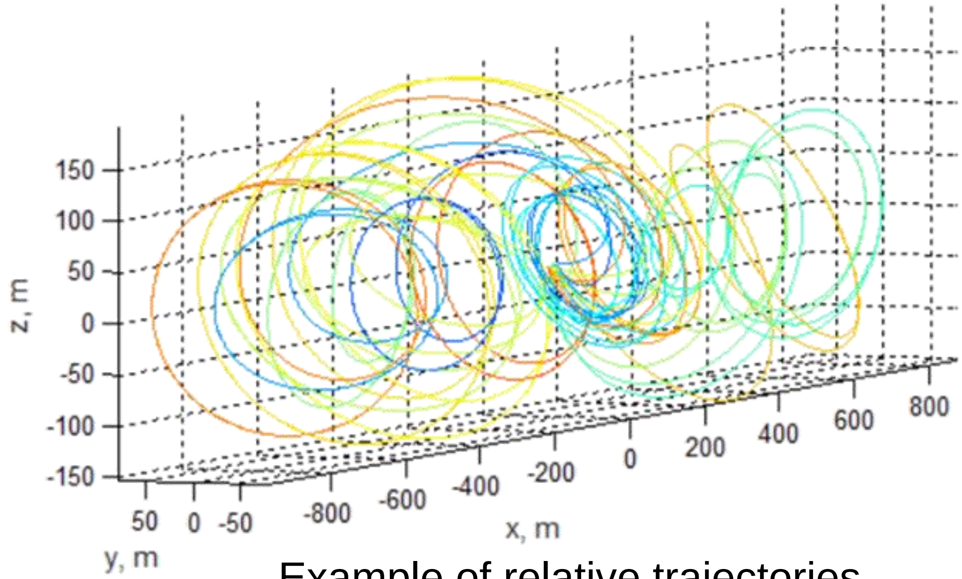
$$\Delta F = -\frac{1}{2} C \rho V^2 S (\sin\alpha_1 - \sin\alpha_2)$$



Block diagram of control of each satellite in the swarm

- The force is bounded: $\max|\Delta F| = \frac{1}{2} C \rho V^2 S \Rightarrow \max u_x = \frac{1}{2}\frac{C \rho V^2 S}{m}$

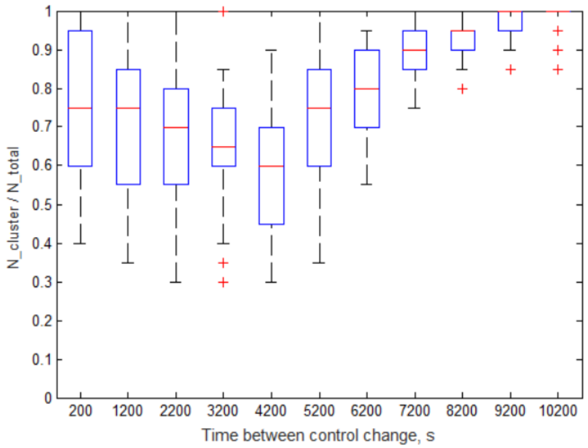
Numerical Study of Clustering Effect



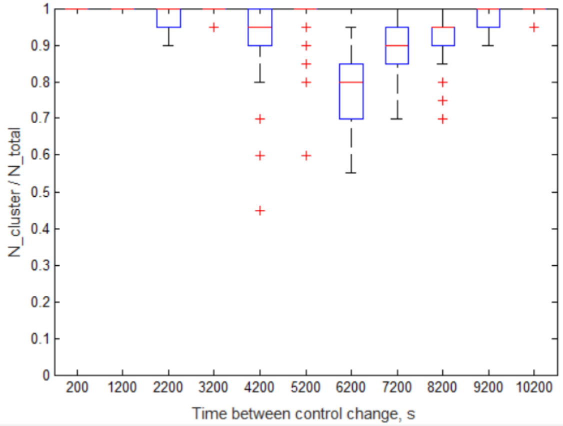
Example of relative trajectories

The ratio of the number of spacecraft in the largest group to the total number of satellites

$R_{comm} = 250\text{m}$



$R_{comm} = 1000\text{m}$

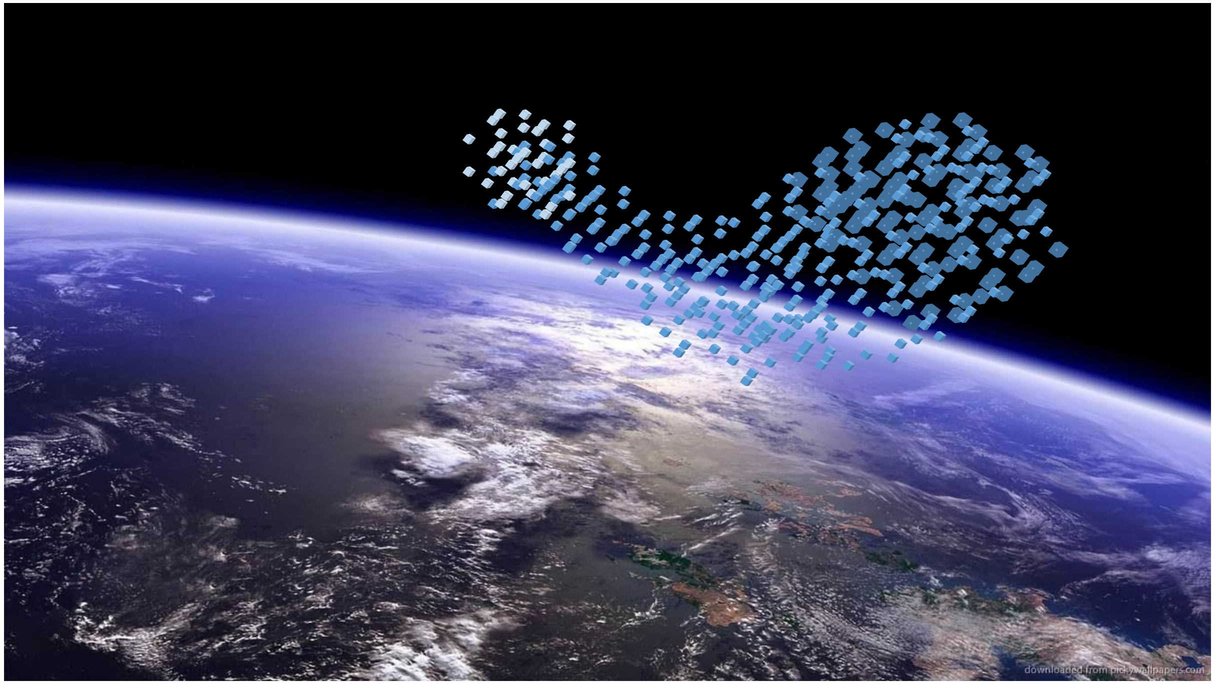


- Monte-Carlo simulations was performed to study the dependence of the clustering effect probability on communication sphere size and the time between the CubeSats attitude change

Conclusions

- Decentralized control of the swarm of satellites taking into account communication constraints makes possible to form closed relative trajectories of the satellites
- Depending on the communication area and frequency of control, there is the possibility of clustering effect in the swarm
- The paper studies the domains of control parameters under which this effect can occur when a fuelless control approach is used under an aerodynamic drag force. As the radius of the communication sphere is increased, the probability of clustering is expected to decrease

Thank you for attention!



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