Multiple Agile Earth Observation Satellites Scheduling Algorithm on Area Targets

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Outline of Presentation

- **Background**
- **Area Targets and the Division Method**
- **Decomposition Optimization Algorithm**
- **Numerical Simulations**
- **Summary & Conclusions**

Background

- **Satellite scheduling**
  - As a decision-making process, scheduling itself plays an important role in most manufacturing and production systems as well as transportation and distribution settings.
  - In multi-satellite multi-targets problem, we have to decide which satellite to observe which targets, while the observation time also should be determined by satellite users.

Alternative scenarios

Scenario	0	1	2	3	4	5	6	7
Comp. time (sec.)	55	26	57	63	30	59	152	56
Value (Gbit)	60980	29185	39551	43790	38905	34421	48188	33816
Taken im. num	9262	4824	7168	7643	7016	6252	8789	6189
Taken im. (%)	28.94	15.07	22.40	23.88	43.85	19.54	21.47	19.34
Access time	59:16:51	61:31:21	16:53:05	46:46:40	12:30:14	20:40:11	30:24:23	18:10:33
Transm. time	62:04:12	64:18:02	21:28:17	48:12:49	15:51:37	24:13:25	33:46:34	21:43:22
Aging	02:58:16	02:55:31	04:54:55	02:56:44	03:35:06	03:48:53	03:45:15	03:52:53
Mem. occ. (%)	37.08	29.40	86.15	44.80	70.61	68.56	81.11	82.82
Station 1 (%)	26.01	12.99	50.75	35.50	36.84	32.91	39.67	41.30
Station 2 (%)	23.36	11.28	–	32.97	32.13	28.19	35.08	35.93
Station 3 (%)	41.94	17.20	95.57	44.43	73.53	68.67	83.04	80.56
Acq. time/orbit	00:03:16	00:01:38	00:05:04	00:07:14	00:05:47	00:05:12	00:06:55	00:06:25
Set-up time/orbit	00:08:47	00:04:17	00:04:16	00:04:36	00:05:17	00:05:40	00:05:14	00:04:45

Background

- **Development of the satellite scheduling**
  - Early studies focus on the modeling establishment and description.
  - Agile Earth observing satellite (AEOS), turns the satellite selection problem into a true scheduling problem.
- **Introduction of the AEOS**
  - The AEOS has more freedom around the roll, pitch, even yaw axes.
  - The AEOS attitude maneuver strategy turns to be more difficult with longer time windows and multiple time windows constrains.

Background

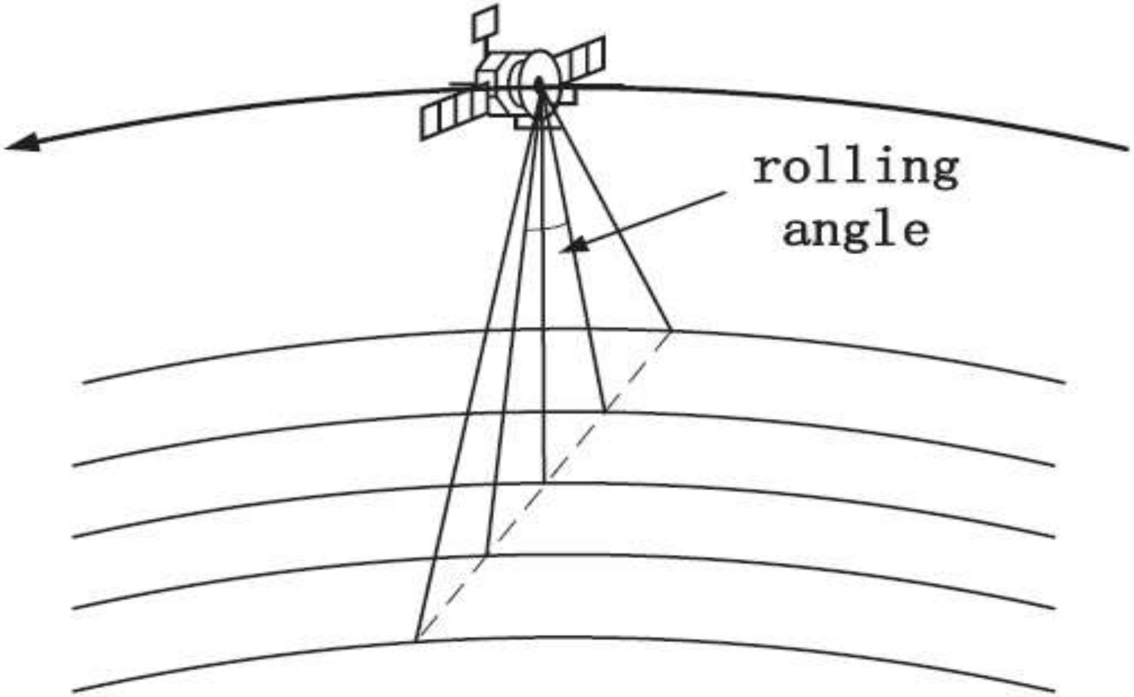
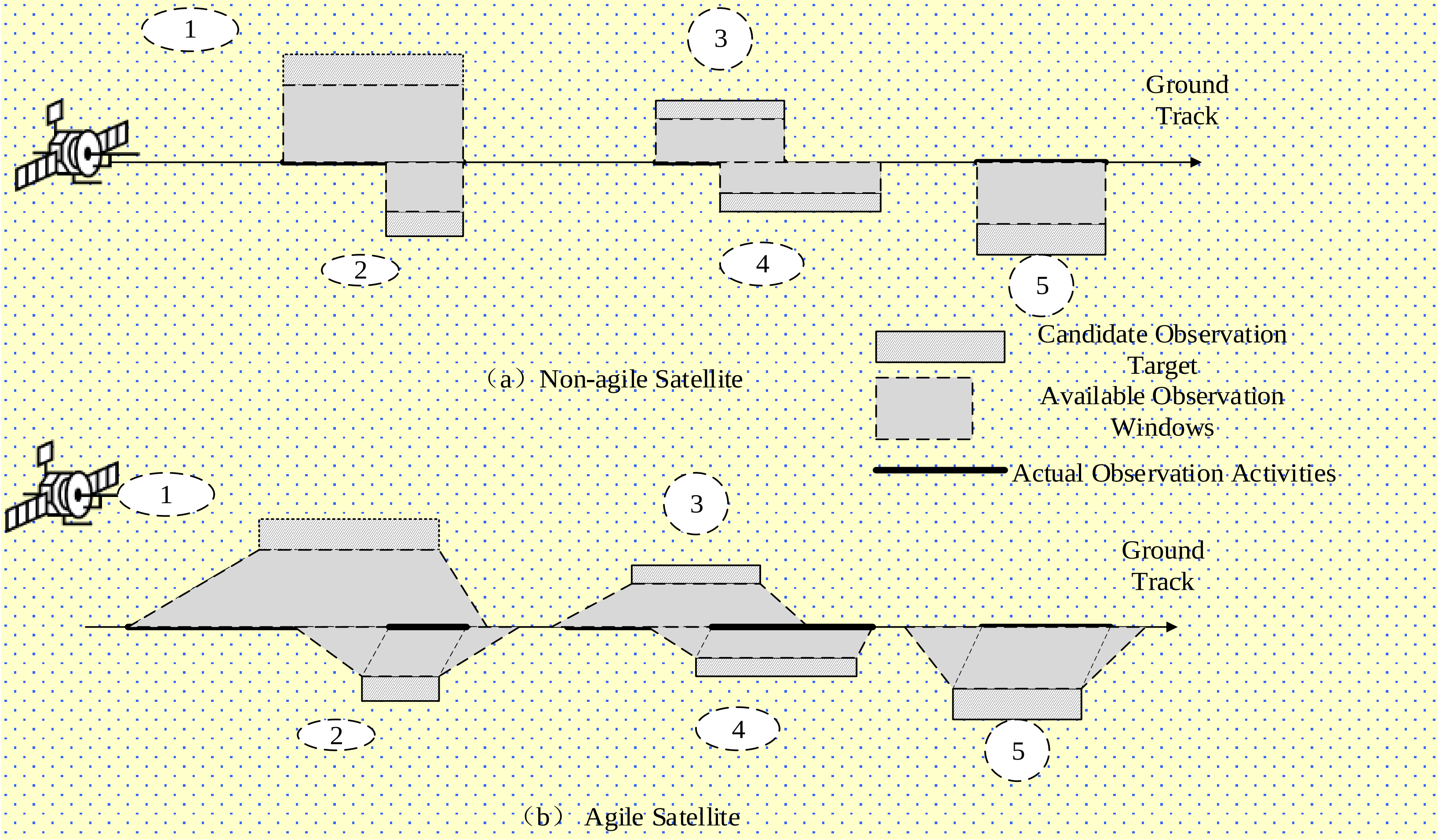


Fig. 1. Satellite attitude control capability of the roll axis. The satellite attitude control capability limits its imaging ability, and only when the satellite orbits in the specific position, the ground target could be observed. During the whole scheduling period, we only have time determined imaging opportunities for part of the ground targets.

X.-W. Wang et al. / Chaos, Solitons and Fractals 83 (2016) 125–132

Background


1
3
Ground
Track
2
4
5
Candidate Observation
Target
Available Observation
Windows
Actual Observation Activities
（a） Non-agile Satellite
1
3
Ground
Track
2
4
5
（b） Agile Satellite

Background

- **Study on the AEOS scheduling problems**
  - **Much work has been done about it. (Lemaitre and Habet, Beaumet and so on)**

    The observation objectives are point targets, and few researches consider the large scale observation targets.

    The multiple satellite assignment problems are rarely mentioned.
  - **We used a time-ordered directed acyclic graph to obtain the single AEOS attitude maneuver strategy .**

Background

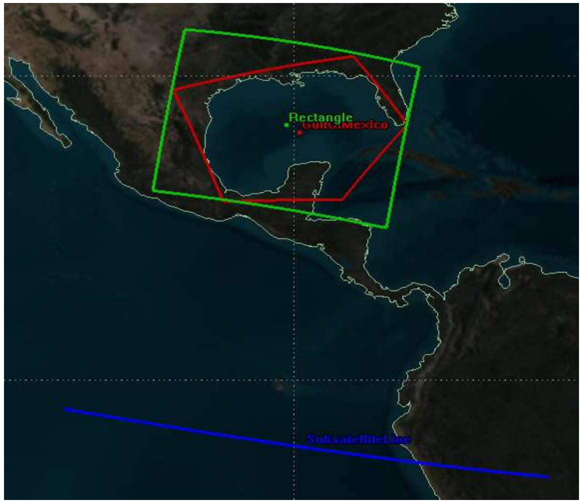
- **Our Work**
  - **The area targets are defined.**
  - **A division method of the area target is proposed.**
  - **A decomposition optimization algorithm for area targets observation mission is proposed .**
  - **Numerical simulations are conducted to demonstrate the ability of the proposed approaches.**

Area Target (1)

- **Point targets and area targets**
  - According to the relative scale between target area and imaging field of view(FOV).
- **Definitions**
  - Large scale target which could not be completely covered by a single observation scene.

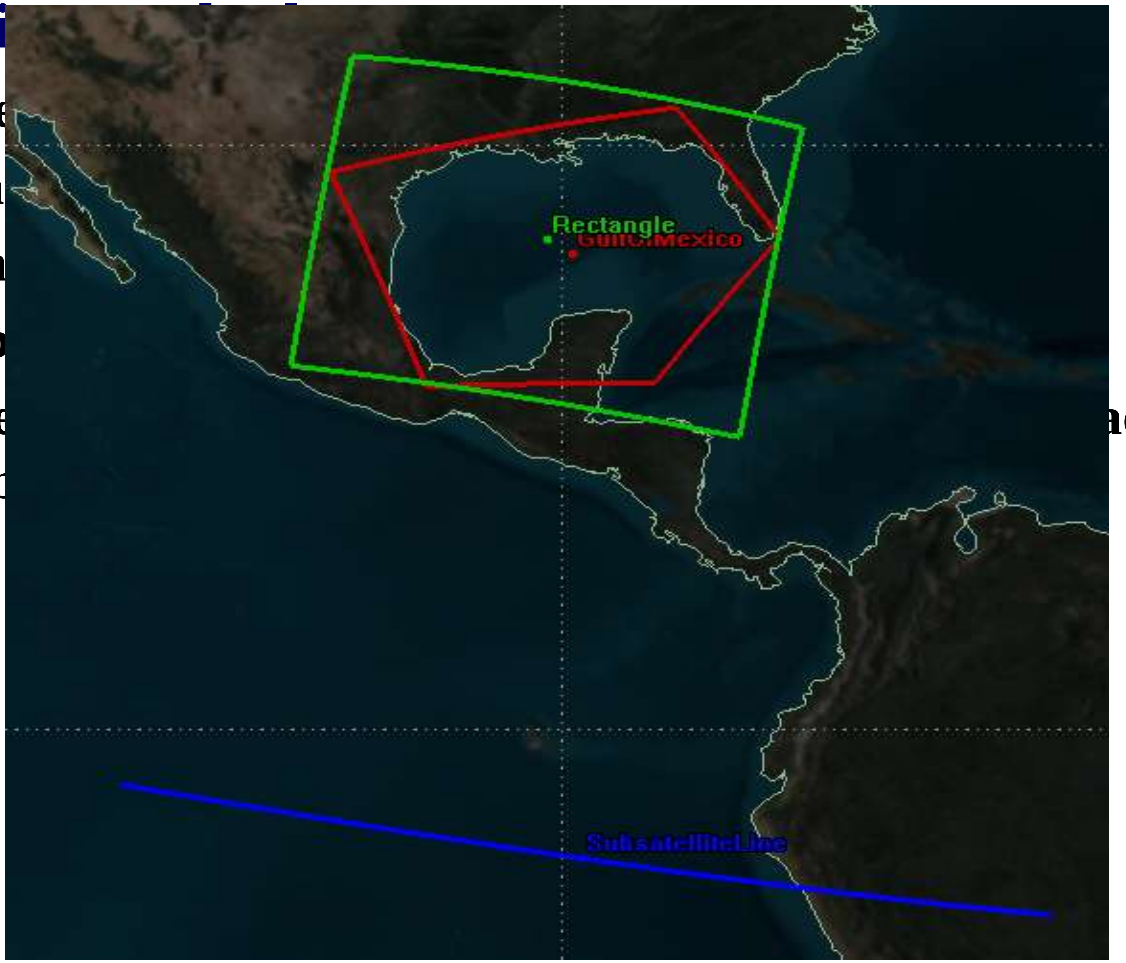
Area Target (2)

- **Division method**
  - **We take the gulf of Mexico as an example.**
  - ➢ **Calculate specified center point.**
  - ➢ **Choose the specified satellite. (EVT VD)**
  - ➢ **Obtain subsatellite line.(blue interpolation least square method)**
  - ➢ **Determine the circumscribed rectangle by the gradient of the subsatellite line.(green)**



Area Target (3)

- **Divisi**
  - **We**
  - ➢ **Ca**
  - ➢ **Ch**
  - ➢ **Ob**
  - ➢ **De** **adient of the sub**



Area Target (4)

- **Division method**
  - **Projection range**
  - ➢ **parallel projection distance (PPD)**
  - ➢ **vertical projection distance (VPD)**

  - **Rectangle target scale**
  - ➢ **parallel area distance (PAD)**
  - ➢ **vertical area distance (VAD)**

  - **Number of division area points**
  - ➢ **number of parallel (NOP)**
  - ➢ **number of vertical (NOV)**

$$NOP = \mathrm{int}(\frac{PAD}{PPD} + 0.5) + 1$$

$$NOV = \mathrm{int}(\frac{VAD}{VPD} + 0.5) + 1$$

Area Target (5)

- **Division method**
  - **we have divided the circumscribed rectangle into NOP*NOV point targets, while the specific position of every point remains unknown.**

- **the step of parallel latitude (SPLA)**
- **the step of parallel longitude (SPLO)**
- **the step of vertical latitude (SVLA)**
- **he step of vertical longitude (SPVO)**

$$SPLA = \frac{DPLA}{PAD / PPD}$$

$$SPLO = \frac{DPLO}{PAD / \mathrm{PPD}}$$

$$SVLA = \frac{DVLA}{VAD / \mathrm{VPD}}$$

$$SPVO = \frac{DPVO}{VAD / \mathrm{VPD}}$$

  - **The unit is degree.**

Area Target (6)

- **Division method**
  - **there are some divided point targets within the circumscribed rectangle, while they are far away from the original area target.**
  - **We introduce a threshold parameter named minimum distance.**

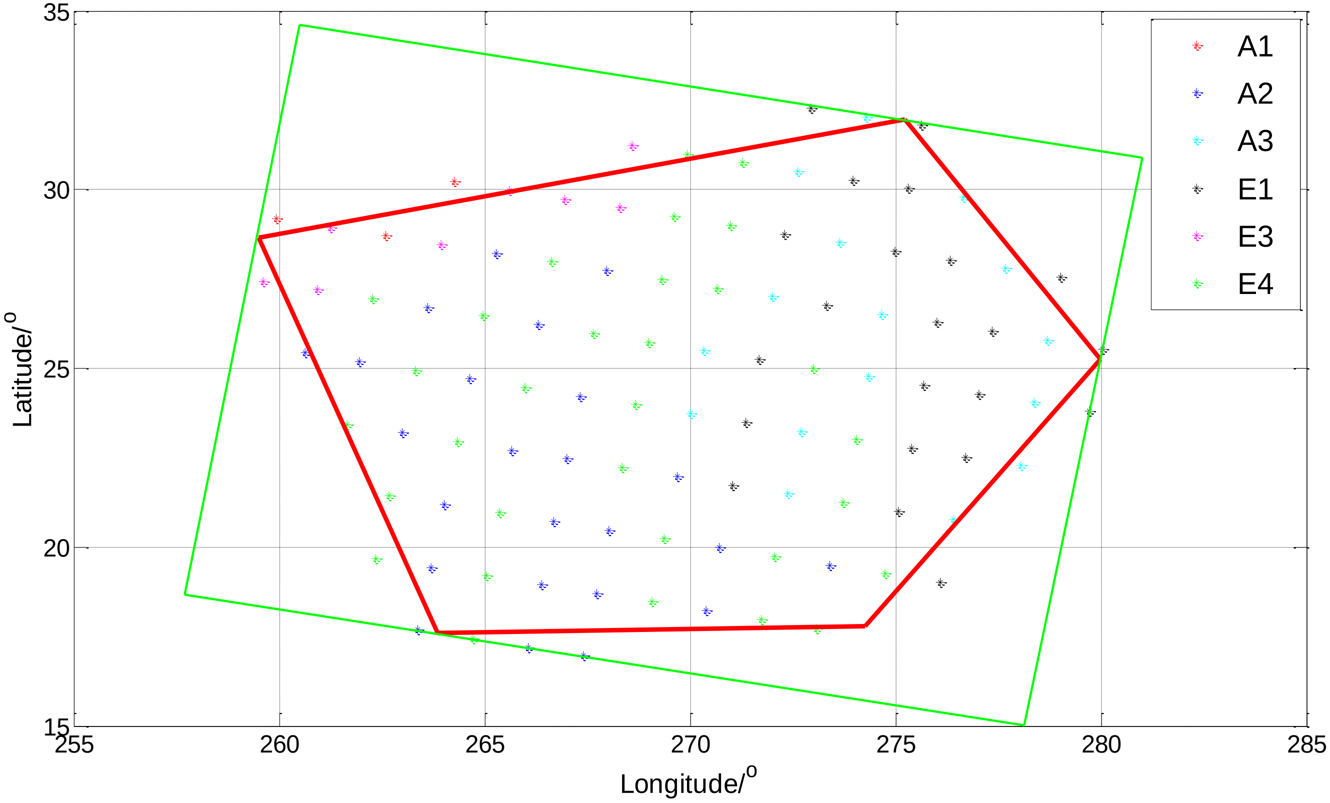
Area Target (7)

- **Division method**
  - **there are some divided point targets within the circumscribed rectangle, while they are far away from the original area target.**
  - **We introduce a threshold parameter named minimum distance.**

```
for i = 0 : NOV-1
    for j = 0 : NOP-1
            DividedTarget.Lati  = ReferencePoint.Lati + SVLA*i +SPLA*j;
            DividedTarget.Longi= ReferencePoint.Longi+ SVLO*i + SPLO*j;
                    Close = IsClose(DividedTarget,MinimumDistance);
                    Inside = IsInsideOriginalArea(DividedTarget);
                            If Inside or Close
                                    PointTargetsForObservation ← Divided Target;
                            end if
    end for
end for
Return PointTargetsForObservation;
```

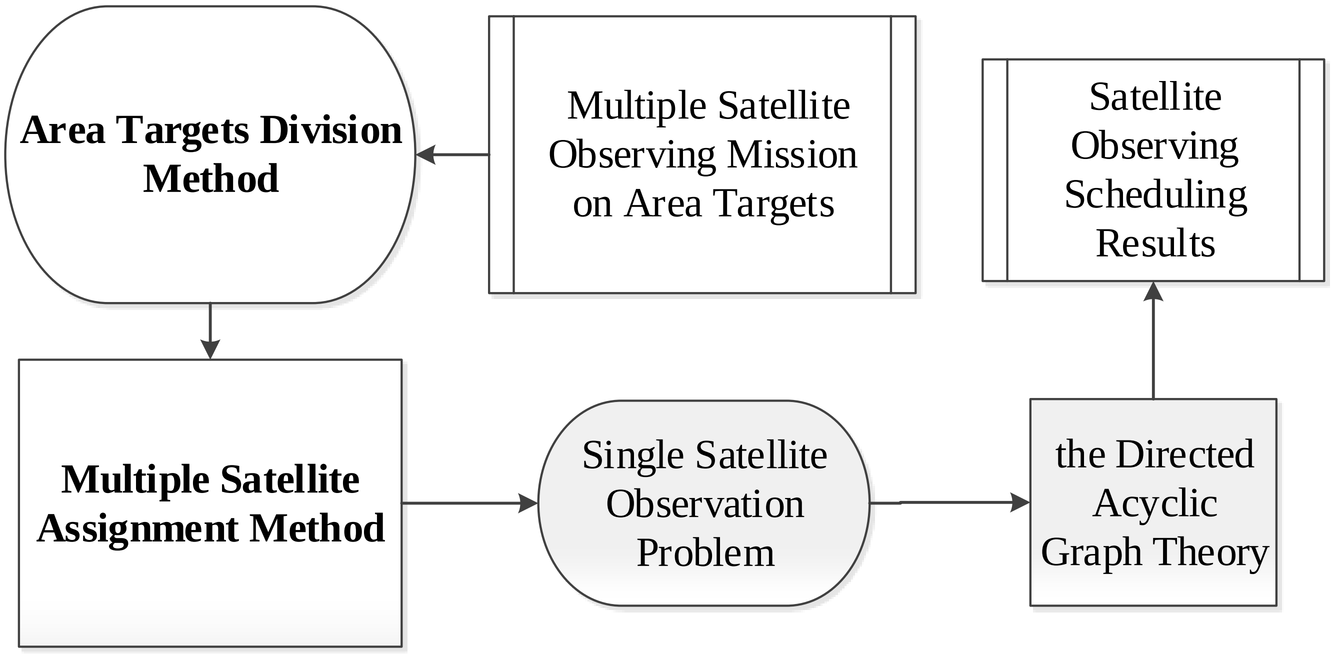
Area Target (8)

- **Division method**
  - **Results.**



Decomposition Optimization Algorithm(1)

- **Multiple Satellites Assignment Method**
- **The Directed Acyclic Graph Theory for Single Satellite**



Decomposition Optimization Algorithm(2)

- **Multiple Satellites Assignment Method**
  - **There are two important indicators to decide which satellite in the constellation to observe specified targets.**
  - ➢ **the earliest visible time (EVT)**
  - ➢ **the visible duration (VD)**
  - **We have developed some rules to solve the dispatching problem.**

Attitude Maneuver Strategy of Agile Earth Observing Satellite Constellation, 25th AAS/AIAA Space Flight Mechanics Meeting, Williamsburg, VA

Decomposition Optimization Algorithm(3)

- **Multiple Satellites Assignment Method**
  - **the rules should be revised in that the division points are too centralized.**

Step1: Find the EVT and the VD for satellite S_i (i=1,2,...,N) to every target T_j (j=1,2,...,M): t_{ij}, d_{ij}, where N equals the number of constellation satellites and M equals the number of targets. Then let $j=1$.

Step2: Compare the t_{ij} and find the satellite whose t_{ij} is the smallest for target T_j, *and* let the EVT coefficient $c_{ij}=N$. Then let the EVT coefficient of satellite whose EVT is the second smallest be equal to $N-1$. The rest satellite EVT coefficient could be done in the similar rule. There is an exception that when the satellite is invisible to the specified target, let the $c_{ij}=0$.

Step3: Compare the d_{ij} and find the largest *VD as* $d_{i,\max}$ for target T_j, and define the VD coefficient $\rho_{ij}=d_{ij}/d_{i,max}$.

Decomposition Optimization Algorithm(4)

- **Multiple Satellites Assignment Method**
  - **the rules should be revised in that the division points are too centralized.**

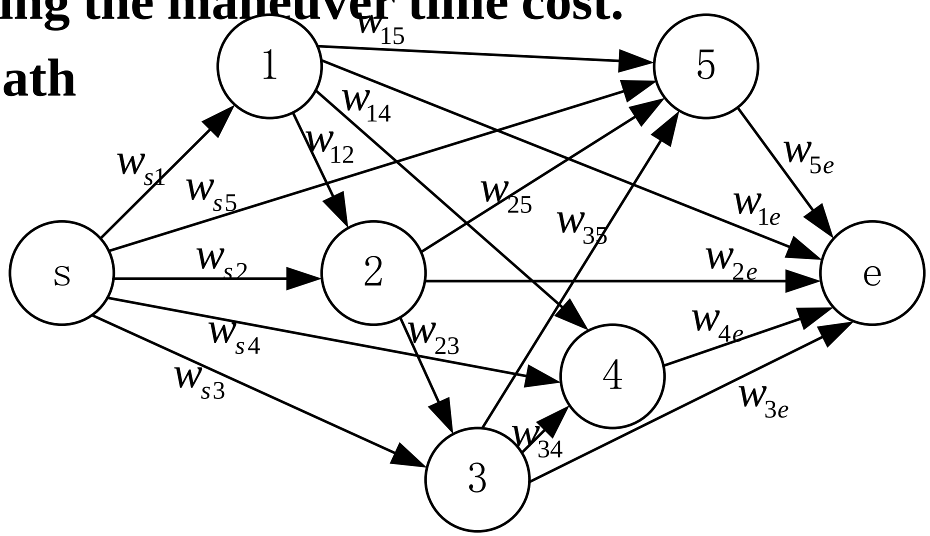
Step4: Define the satellite S_i observing ability $A_{ij} = c_{ij}\rho_{ij}$ for target T_j, and select the satellite whose observing ability is the largest for the specified target.

Step5: If j equals M, it means the dispatching problem has been solved until now. Otherwise, for the selected satellite S_k, compare the magnitude between $t_{kj} + T_c$ and t_{kj}, where $j = 1, 2, \ldots, M$. If $t_{kj} + T_c$ is greater than t_{ij}, let $t_{ij} = t_{kj} + T_c, d_{ij} = d_{ij} - T_c$. Then let $j = j + 1$, and go to step2.

Decomposition Optimization Algorithm(5)

- **The Directed Acyclic Graph Theory**
  - **Deal with the single satellite scheduling problem**

    - **It satisfies a series of constraints, such as the attitude maneuver duration and the attitude stabilization time.**
    - **the satellite scheduling would maximum the observation point targets while minimizing the maneuver time cost.**
    - **Search for a longest path**



Numerical Simulations (1)

- **The start time of all the simulations in this part is 0:00:00 on January 1, 2014, and it is set as the 0 second.**
- **Square view field of imaging instrument: 0.5 degree.**
- **Attitude maneuver range : -20 to 20 degree in pitch and roll axis.**
- **Maneuver mode: Euler angles with 213 sequences.**
- **Maneuver rate: 1 degree per second.**
- **Imaging time for division point target: 70 seconds.**
- **Attitude maneuver stabilization time: 25 seconds.**

Numerical Simulations (2)

- **The orbit parameters of the constellation satellites are shown in Table 1.**

Table 1. Orbit Parameters of Constellation Satellites.

Serial Number	$a(km)$	e	$i(^\circ)$	$\Omega(^\circ)$	$\omega(^\circ)$	$M(^\circ)$
A1	16378.0	0	10.0	180.0	0	0.0
A2	16378.0	0	10.0	180.0	0	90.0
A3	16378.0	0	10.0	180.0	0	180.0
A4	16378.0	0	10.0	180.0	0	270.0
E1	16378.0	0	0	0	0	0.0
E2	16378.0	0	0	0	0	90.0
E3	16378.0	0	0	0	0	180.0
E4	16378.0	0	0	0	0	270.0

Numerical Simulations (3)

- **The least attitude change mode**

Table 2. Boundary Points of the State of Alabama and California.

Alabama			California		
No.	Latitude (°)	Longitude (°)	No.	Latitude (°)	Longitude (°)
Area1	42.62	235.16	Area2	35.31	271.14
Area1	42.46	240.43	Area2	35.47	274.83
Area1	33.19	246.71	Area2	30.91	275.39
Area1	32.01	242.07	Area2	29.97	273.19
Area1	32.28	236.58	Area2	29.97	271.14

Table 3. Added Point Targets.

Point Targets	Latitude (°)	Longitude (°)
Hawaii	19.69	204.51
Panama	8.97	280.47
Washington	38.89	282.97
Chicago	41.85	272.35
Houston	29.76	264.64

Numerical Simulations (4)

- **The least attitude change mode**

Alabama: E4 15   California: A2 33

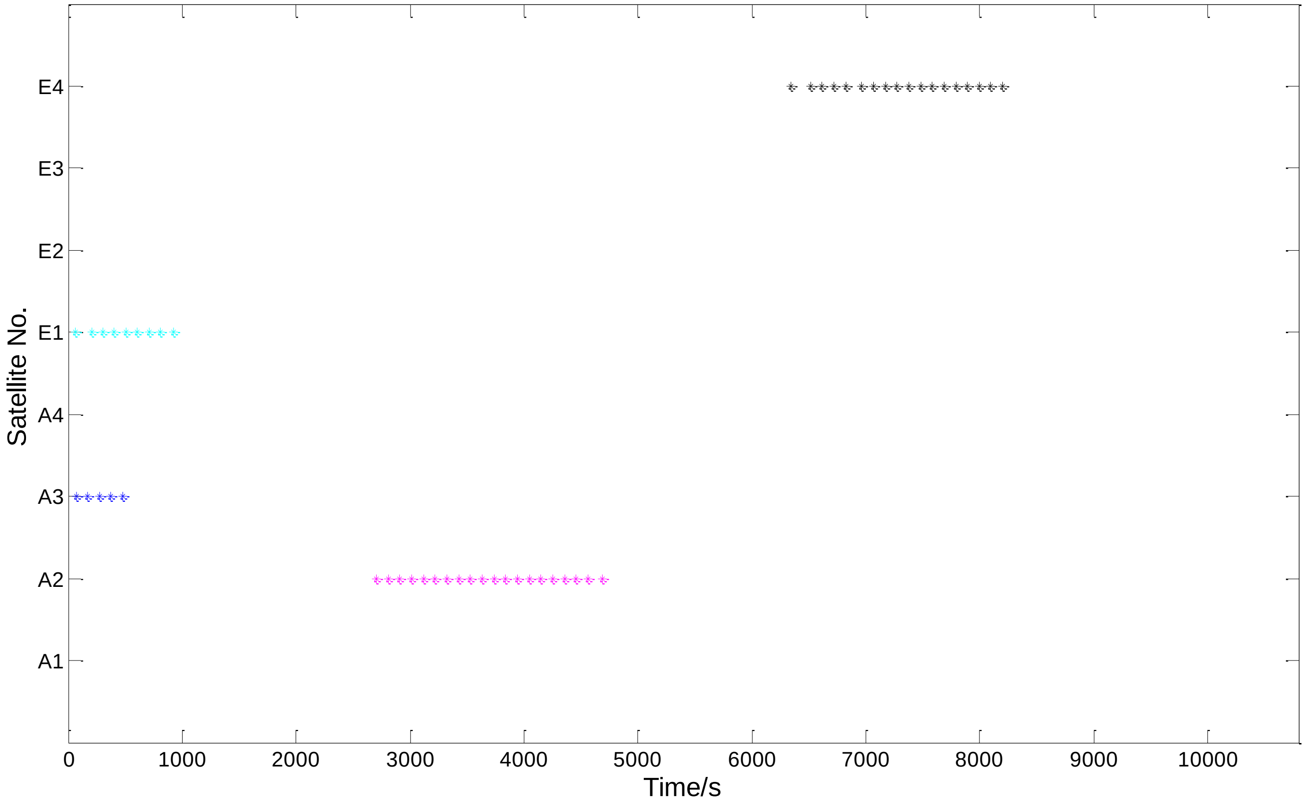
Table 4. Observing Numbers for Point Targets in Case 1.

Serial Number	Number of Observing Points	Serial Number	Number of Observation Points
A1	0	E1	9
A2	20	E2	0
A3	5	E3	0
A4	0	E4	18

Longitude/^{o}

Numerical Simulations (5)

- **The least attitude change mode**



Numerical Simulations (6)

- **The short time mode**

➢ **the Gulf of Mexico is chosen as the area target, the time duration is set as 4 hours.**

Table 5. Boundary Points of the Gulf of Mexico.

No.	Latitude (°)	Longitude (°)
Area1	17.60	263.86
Area1	17.78	274.26
Area1	5.24	279.98
Area1	31.95	275.24
Area1	28.64	259.49

Numerical Simulations (7)

- **The short time mode**

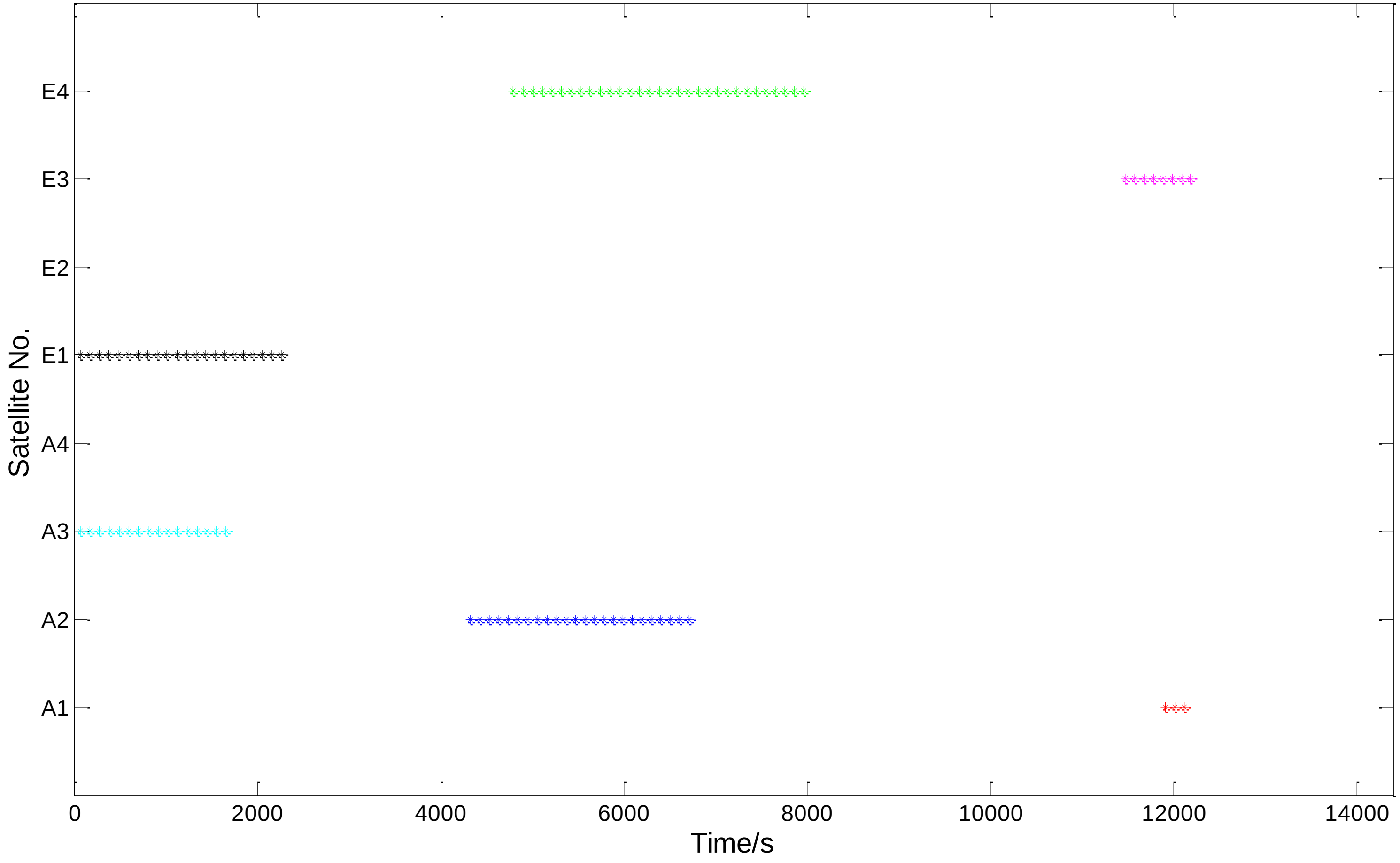
Table 6. Observing Numbers for Point Targets in Case 2.

Serial Number	Number of Observing Points	Serial Number	Number of Observation Points
A1	3	E1	22
A2	24	E2	0
A3	16	E3	8
A4	0	E4	31

A2 Divided into 104 points

Numerical Simulations (8)

- **The short time mode**



Summary & Conclusions

- The whole process of obtaining the multiple satellite observation scheduling for the area targets is derived.
- We mainly focus on the area target division method and the multiple satellite assignment algorithms.
- Then in order to verify the proposed method, two typical observing modes are defined to carry on the numerical simulations.
- The results proved the feasibility of the scheduling algorithm.

Future Work

- **Future works are as follows :**
  - **Further analysis and improvement of the area target division method.**
  - **Considering more engineering constraints into the model.**
  - **Compare the decomposition optimization algorithm with another scheduling algorithm.**

Thank You!

Q&A

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