Autonomous Scheduling of Agile Spacecraft Constellations with Delay Tolerant Networking for Reactive Imaging

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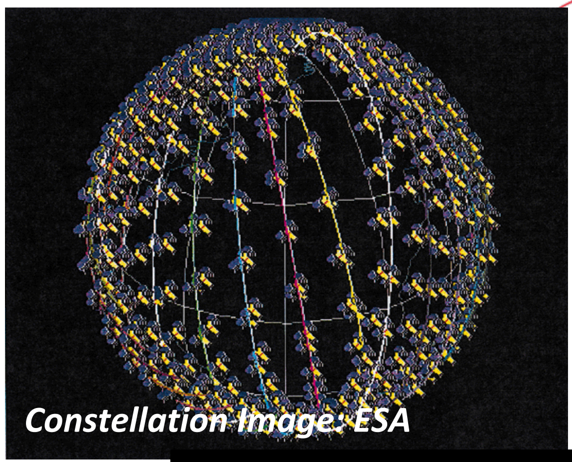
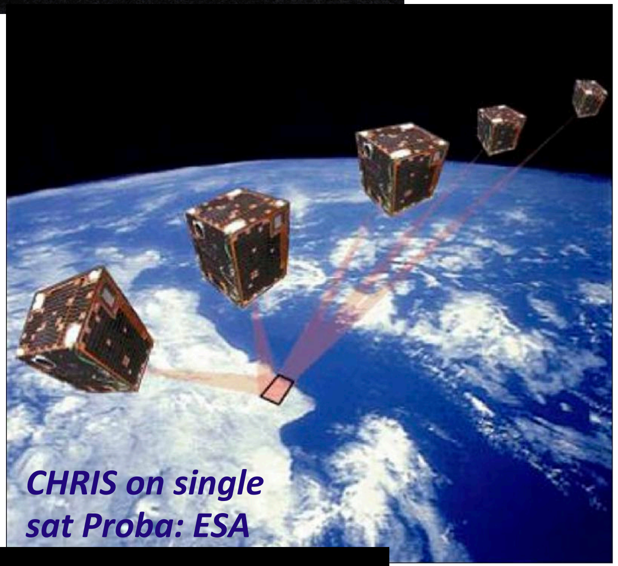
Problem Summary

- GEO satellites have 24x7 coverage but coarse resolution (SOA by NASA Earth Exchange is 2 km), LEO satellites can do finer (SOA 15m proposed by FireSat) but need 1000s of sats for 24x7.
- Lots of research on constellation design, scheduling ops for single spacecraft, downlinks for constellations, UAV path planning, and industry advances in spacecraft attitude control… however, very little on combining all of them for responsive remote sensing.
- For a 24 sat constellation with agile pointing, if one sat measures a fire, can it {process the data, predict its movement, comm. to the next sat} such that it points its payload accordingly? How do we quantify the changing value?

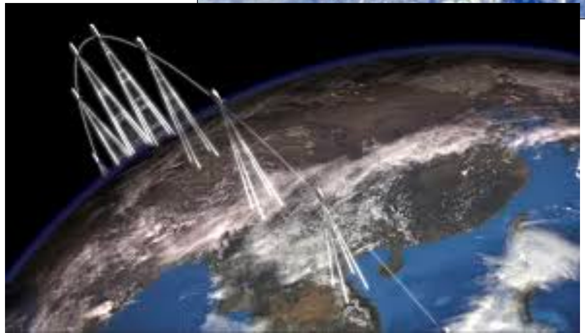


Constellation Image: ESA



CHRIS on single sat Proba: ESA

Uwash RAIN Lab

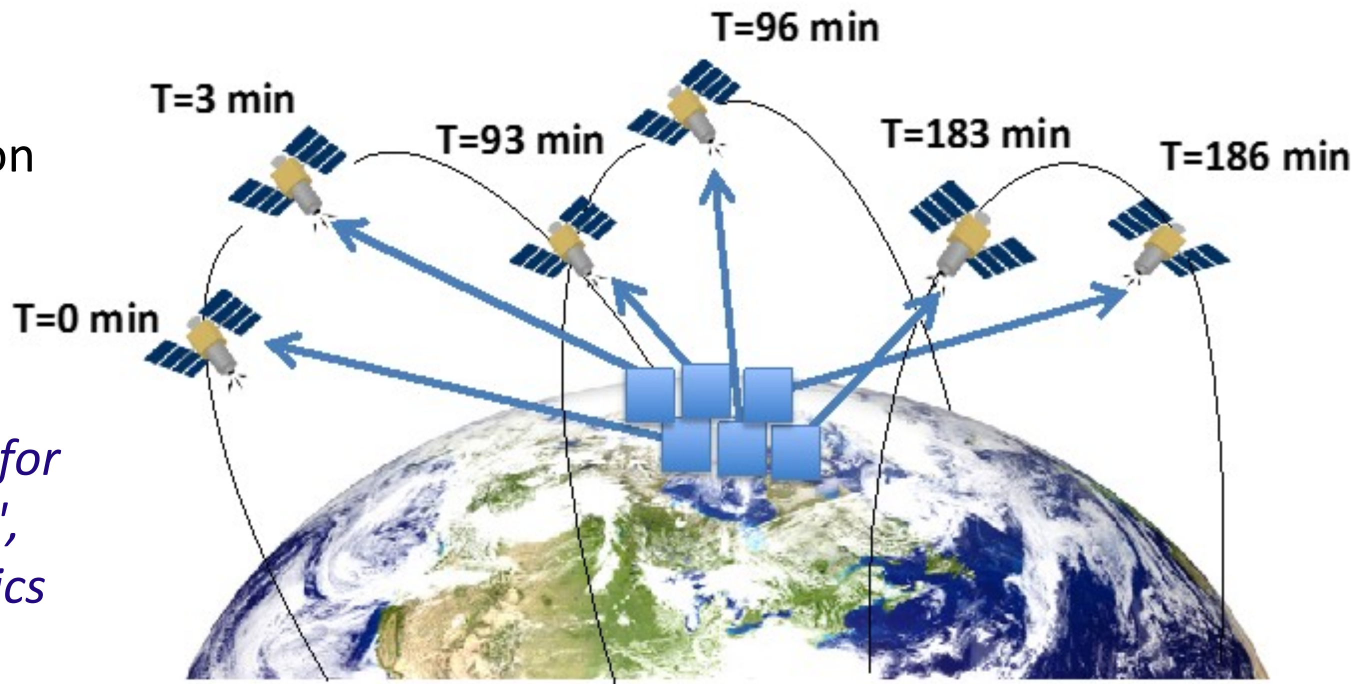


Planet Labs constellation

Dynamic Programming based Ground Scheduler

Given a global set of images, a fixed constellation of satellites with agile ADCS, MOI/ ADCS specs and coverage constraints, what is the fastest route to cover those images?

- Need a linear-time algorithm, generalizable for any constellation and targets
- Using Landsat as first case study (710 km, SSO, 15 deg FOV) w/ a 14 day revisit. Daily revisit needs ~15 satellites or 4 satellites with triple the FOV.
- Instead assuming a 20 kg satellite platform to try the option of agile pointing
- The images, constellation/satellite number, specs and constraints (e.g. clouds, ground station outage) are assumed modular for generality



S. Nag, A.S. Li, J.H. Merrick, "Scheduling Algorithms for Rapid Imaging using Agile Cubesat Constellations", COSPAR Advances in Space Research - Astrodynamics 61, Issue 3 (2018), 891-913

Results with a Two-Sat Constellation

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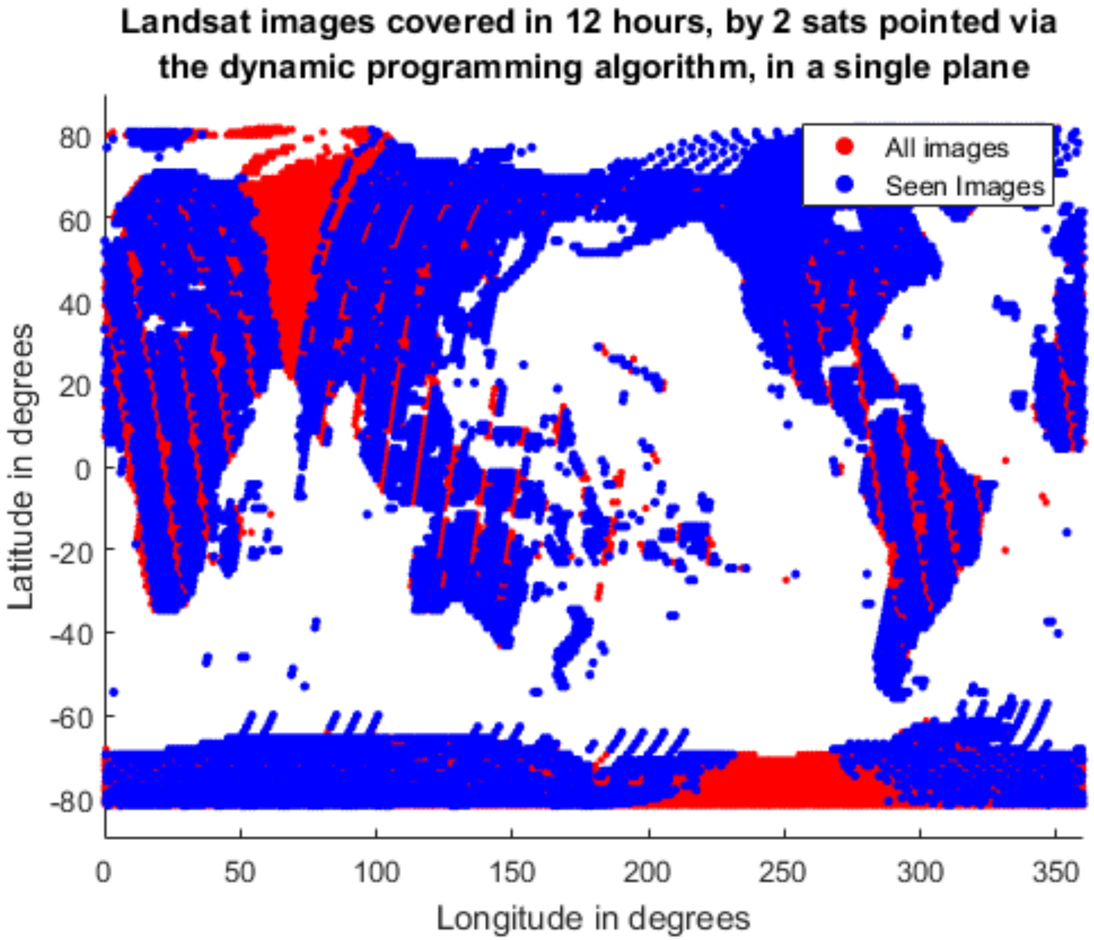
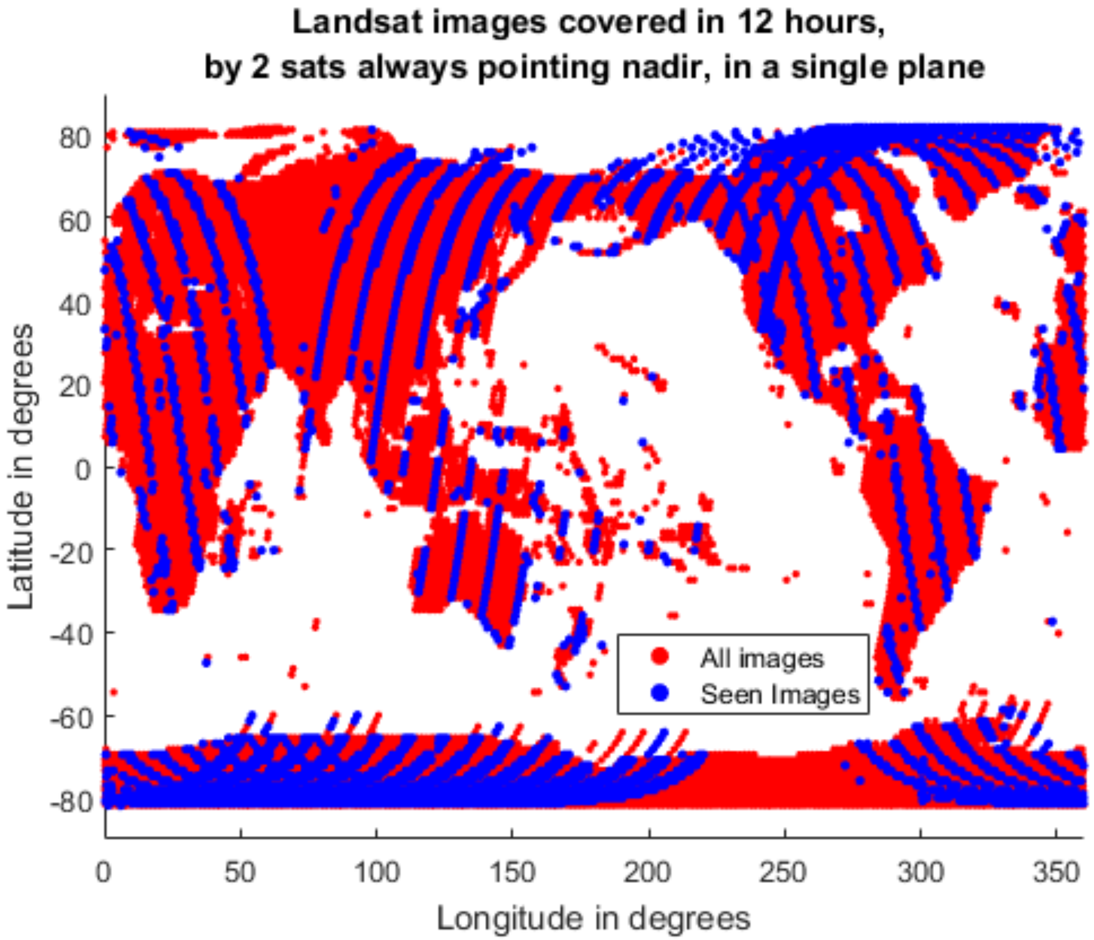
Over 6 hours of simulation/43200 seconds using 2 satellites, 180 deg apart in the same plane :

- Using our **proposed DP algorithm**



- Using a **fixed Landsat sensor**, as is



Of 14164 possible images, 10848 were seen. Algorithm covered 76.6% from possible images and 65% from total … 2.5x the number using the fixed pointing approach. 1.5x possible with a 4-sat, single plane constellation.

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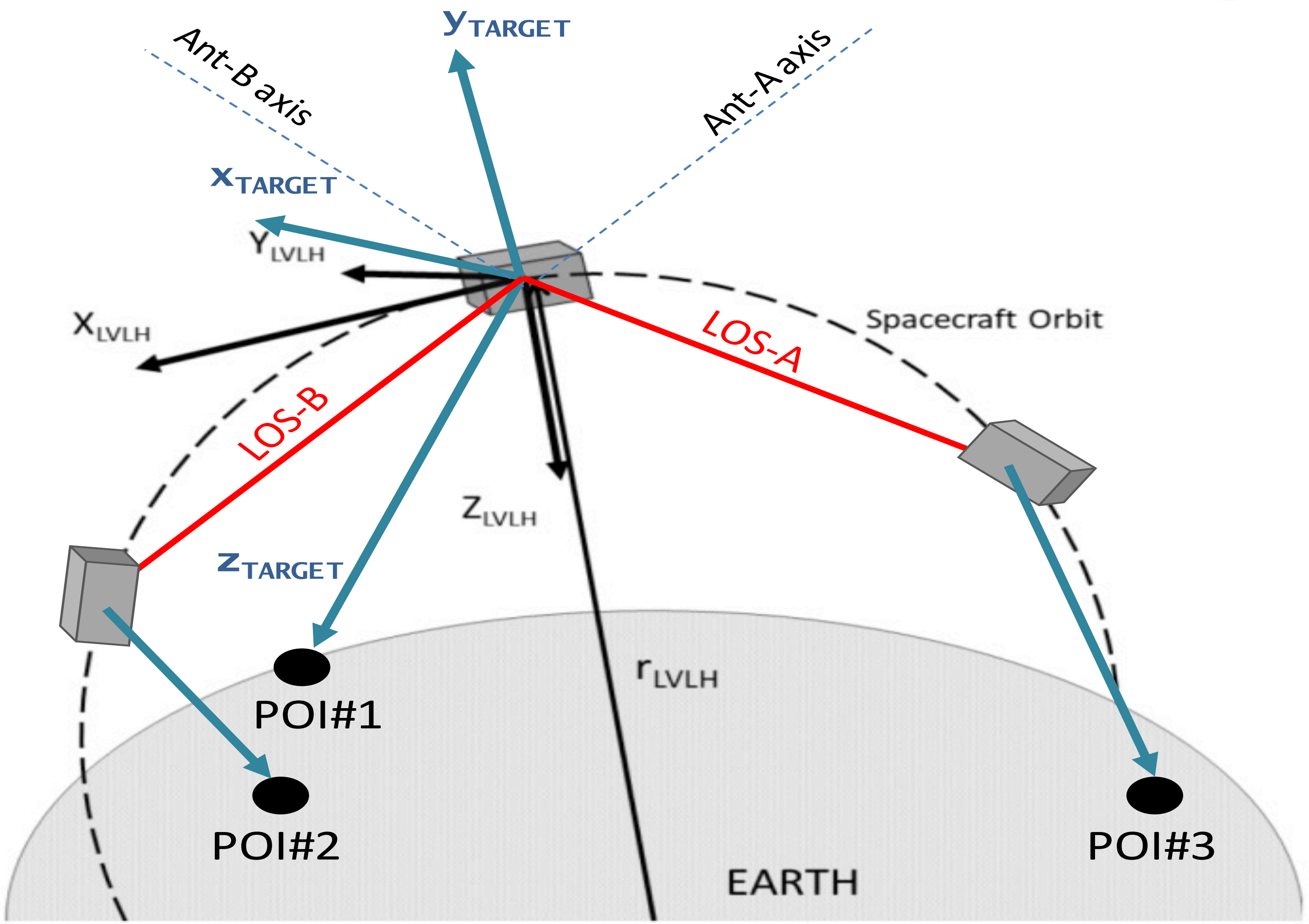
Can the Scheduler also run Onboard?

- Will need inter-sat communication, and onboard processing
- Algo expected to run on the satellites ~ can make observation decisions in a distributed fashion and react to the changing ground conditions quickly
- Ground-based centralized w/data downlinked & schedules uplinked vs. Onboard decentralized w/ data communicated & implicit consensus of schedules
- Factors: Onboard capacity, GS network, need for schedule consensus inv. prop to time transiency of phenomena.



S. Nag, A. S. Li, V. Ravindra, M. Sanchez Net, K.M. Cheung, R. Lammers, B. Bledsoe, "Autonomous Scheduling of Agile Spacecraft Constellations with Delay Tolerant Networking for Reactive Imaging", International Workshop on Planning and Scheduling for Space

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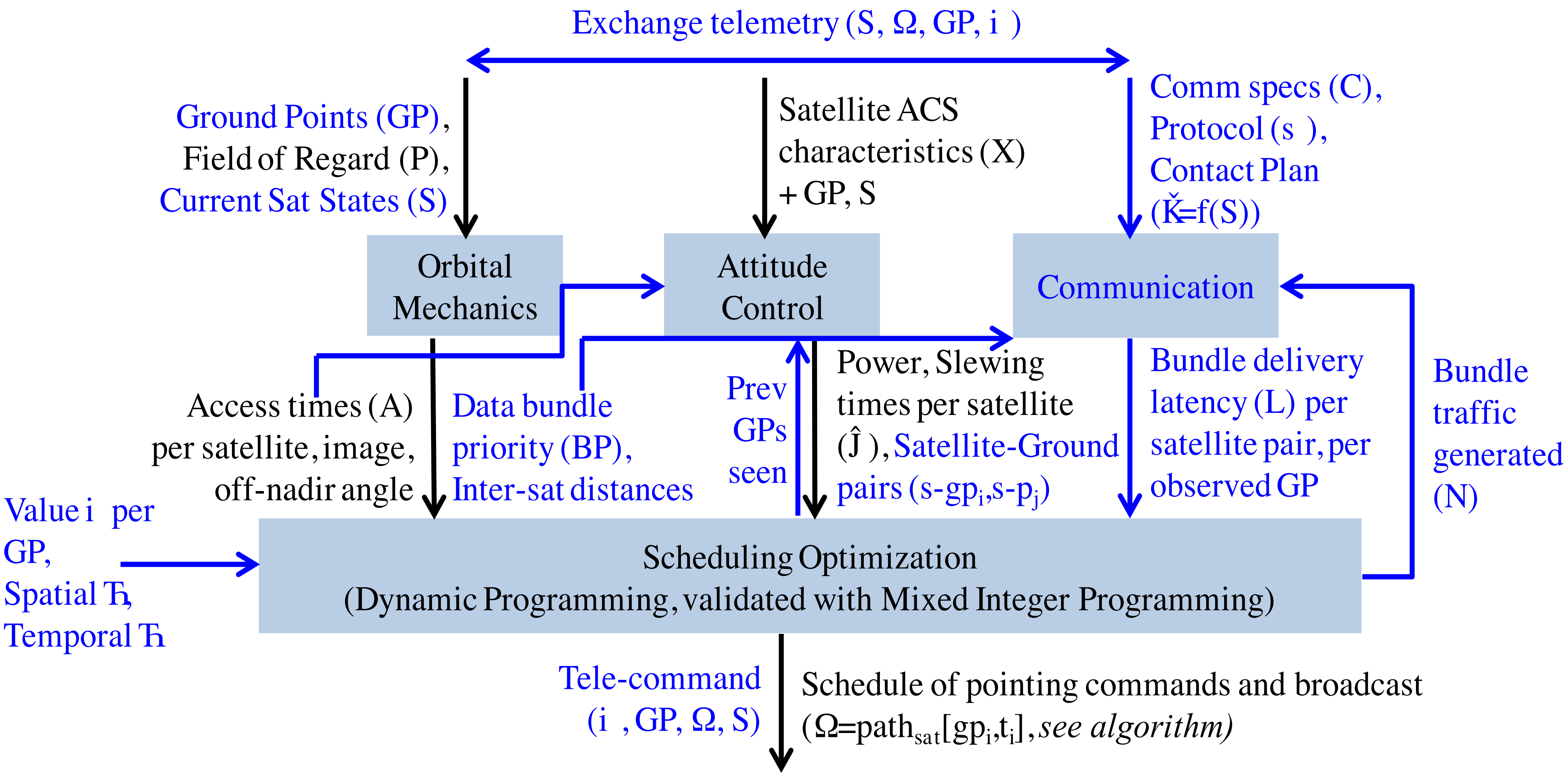
DP-based Onboard/Ground Scheduler

Information Flow between Scheduler Modules:



Algorithm Advantages

- Runtime $\propto$ n(T). If access is soon & a schedule is needed fast, n(T) ~ only the FOR access over the region. Needs to be rerun only if value changes
- Scheduler steps through planning horizon, can be stopped at any point in the runtime & is complete until then. Executed as future schedules are being computed
- Complex value function with non-linear dependencies (e.g. on view geom or solar time) or multi-system interactions (e.g. proprietary software) easy to incorporate
- Algorithmic complexity per sat ~ $O(n(S)\times n(T)\times n(GP)^2)$, where n(GP) is the points in the region and n(S) is the sats *that can access the same GPs at the same time*. GPs Nyquist sample the footprint, thus runtimes are instrument dependent
- If satellite FORs are non-overlapping, complexity does not depend on constellation size. Unless the constellation has tightly clustered satellites n(S) is likely only a few
- Integer programming (IP) was able to verify that optimality for non-overlapping regions was within 10%, and find up to 5% more optimal solutions, however the DP schedules were found at nearly four orders of magnitude faster than IP

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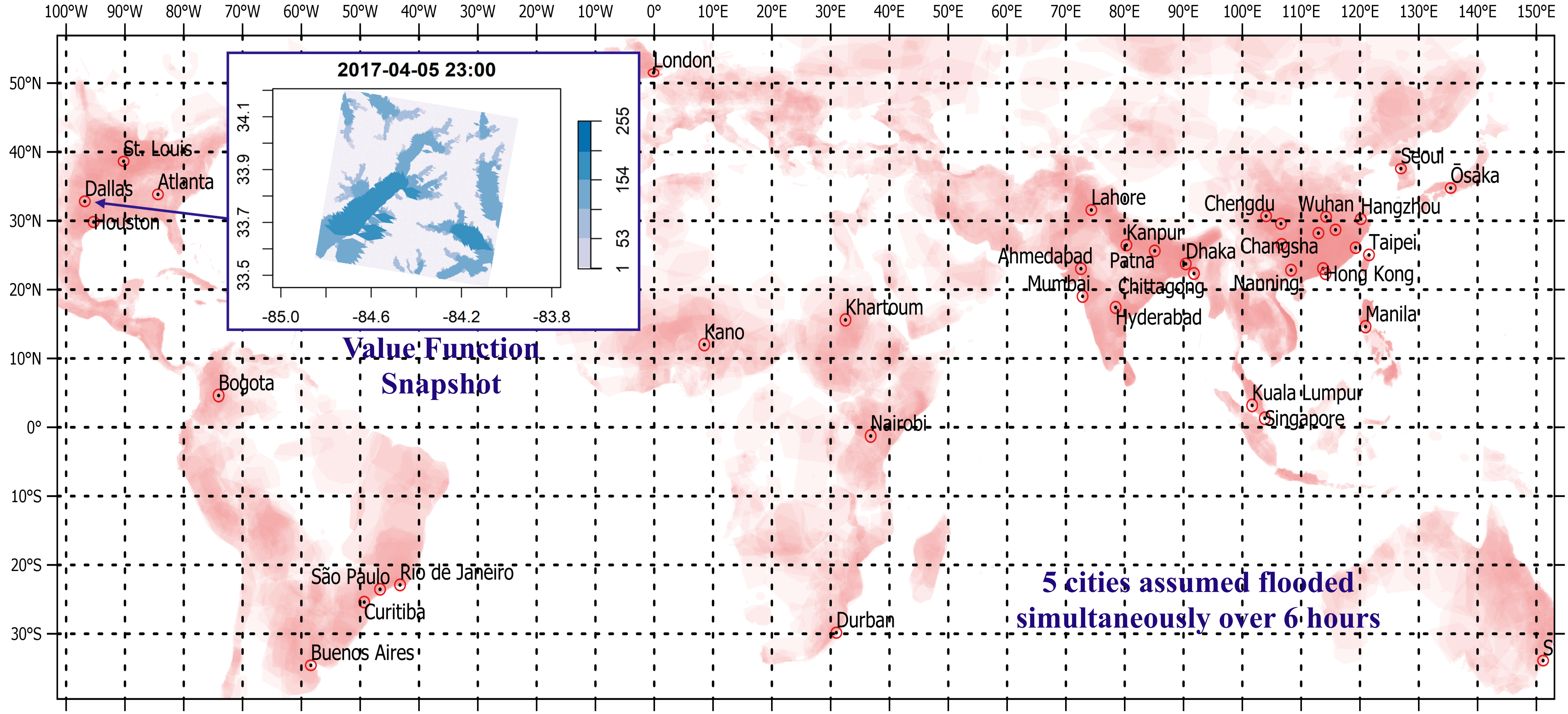
Use Case: Episodic Precipitation and Transient Floods



Data: Dartmouth Flood Observatory (Brakenridge 2012)

Value Function Modeling

- Scheduler must “understand” the relative value of measuring any point in space and time, to assign observations accordingly, i.e., Value = function (space, time)
- However, value changes with observations:
  - Observing a certain GP reduces the value of observing it and its immediate neighbors in the future, since computational models prefer a spread in space and time
  - Onboard processing of collected measurements allows sats to update their knowledge and the value function of the region
- A high fidelity scheduler in a rapidly changing environment should account for the implemented observing schedule, process data, update future value, re-compute its schedule accordingly and pass along insights and intent to the other satellites.

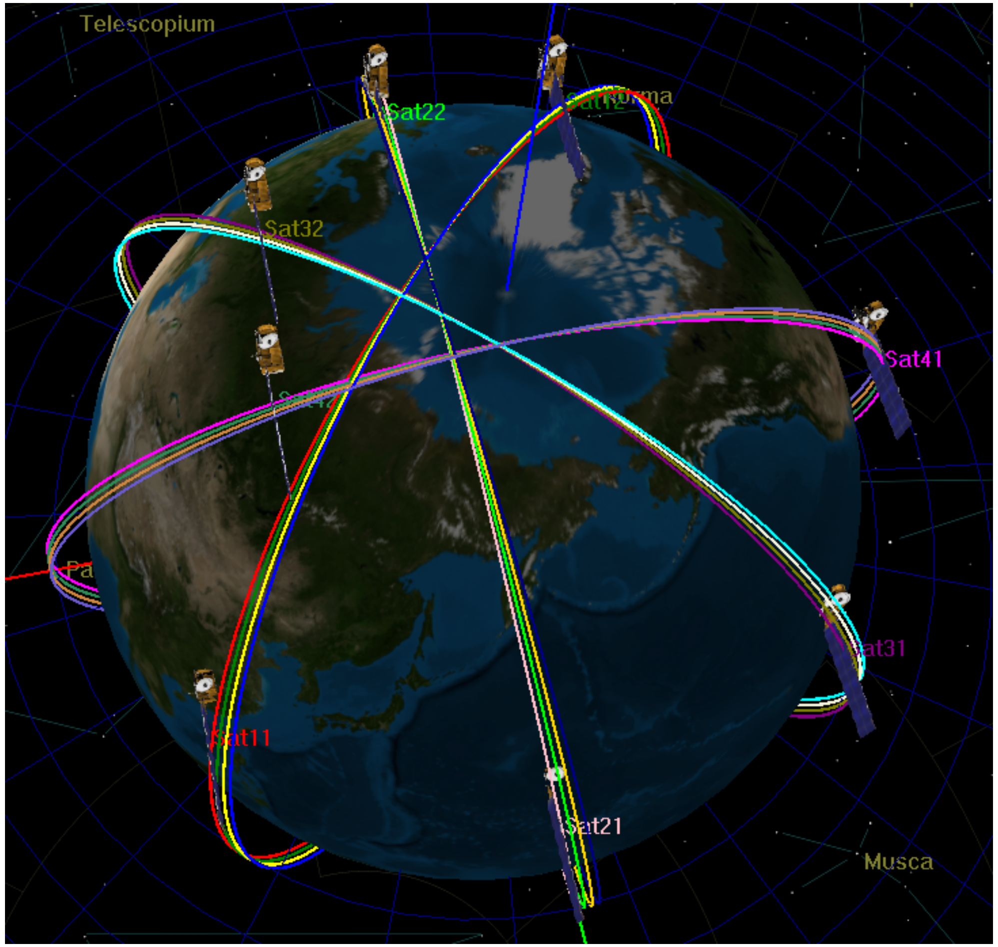
Value Functions for the Use Case

- OSSE time resolution ~ 15min, i.e. cumulative value of observing a GP in 15m is constant. Seen once? Subsequent observations in 15m ~ value=0
- Value re-computation based on collected data is approximated from flood model value (*absval*): Value of observing GP after 15min is a fraction (= number of times it has been seen) of *absval* with added random noise. Ensures that a diversity of GPs observed over time
- Value of observing GP can be inv. Prop. to its distance to already observed GPs, to max. the spatial spread of information collected
- Applied a standard normal distribution with a 2%-8% (uniformly random) standard deviation to *absval*, to generate slightly different values to be used by each satellite's optimizer. Accounts for differences in onboard processing of their respective collections.

Instead, we are trying to build a low-computation model that can re-compute value of any region (e.g. predicted movement of fire), as trained by higher fidelity simulators. Level-2 products need to be correlated to Level-0 products to identify triggers or rules, that can be executed quickly.

Simulated 24-sat Constellation

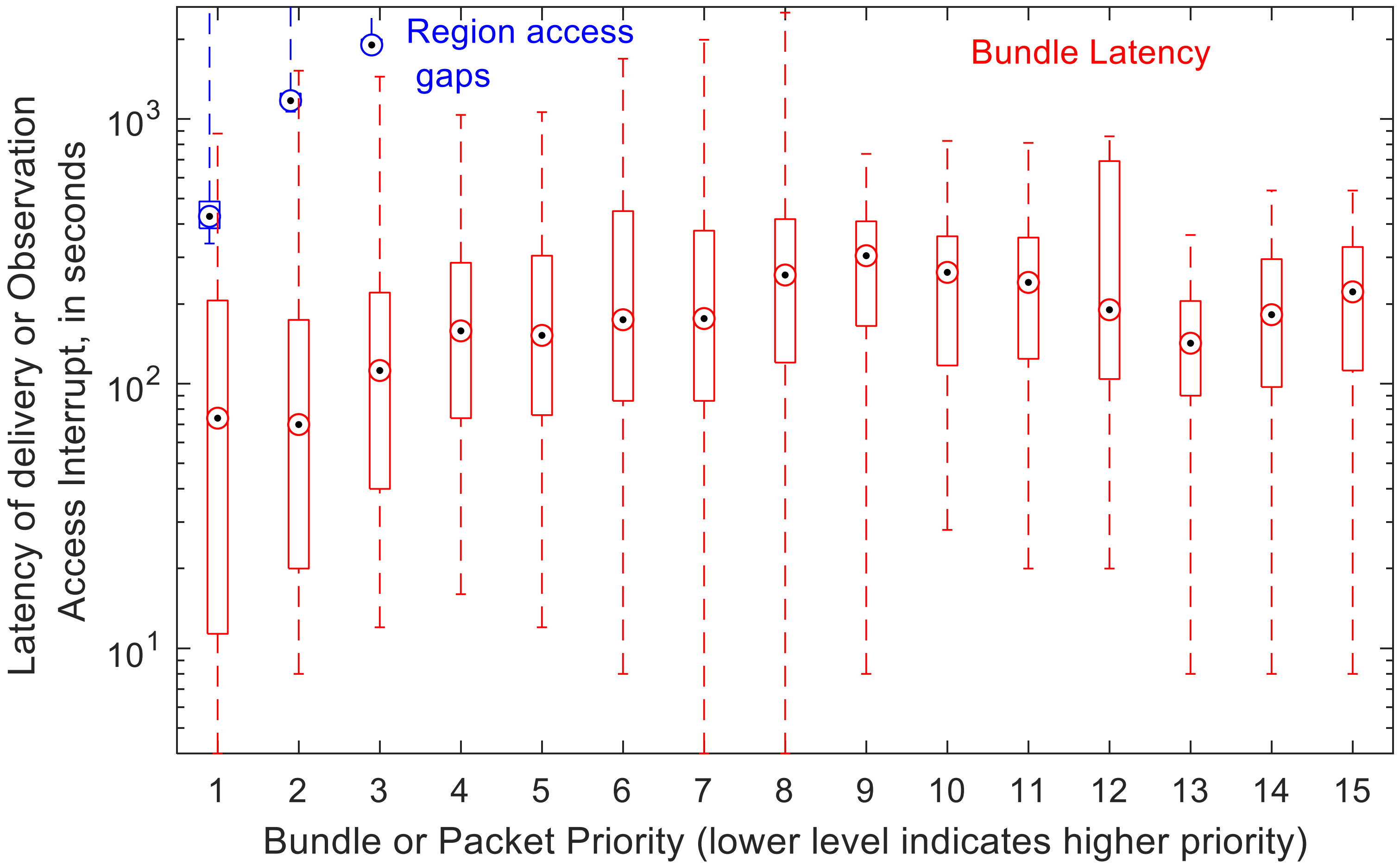
- 24 (20 kg cubic) satellites in a 3-plane Walker constellation observing floods in 5 global regions of interest (ROI)
- 710 km, sun sync orbits (Landsat, A-Train)
- Median 5.2 mins & max 6.2 mins of access time (within FOR) to ROIs
- 3 planes: Median gap ~ 56 mins & max gap ~4.5 hrs
- 8 sats per plane: At chosen altitude, this ensures consistent in-plane LOS, cross-plane LOS is restricted to polar regions only
- 5W RF power => 1kbps data rate. 2 kbits of payload data assumed per GP observed, but easily changeable



GMAT example of 4 orbital planes

Comm Latency vs. Imaging Gaps

Latency of data bundle delivery over all satellite pairs compared to the gaps between satellite Field of Regard access to any region:



If longest latency < shortest gap, for pairs with the same priority => each satellite can be considered fully updated with information from all others, i.e. perfect consensus is possible, in spite of distributed decisions made on a disjoint graph.

S. Nag, A. S. Li, V. Ravindra, M. Sanchez Net, K.M. Cheung, R. Lammers, B. Bledsoe, "Autonomous Scheduling of Agile Spacecraft Constellations with Delay Tolerant Networking for Reactive Imaging", International Conference on Automated Planning and Scheduling SPARK Workshop, Berkeley CA, July 2019

Discussion of Results

- Scenario 1: Scheduler runs on onboard & uses collected information from other sats as they come through the DTN
- Scenario 2: Scheduler runs on the ground and uses collected information from other sats as they downlink. Ground stations are placed at both poles to emulate the best possible scenario of collection-based re-computation twice an orbit
- Scenario 1 predicts GP value at an average of 4% different from actual value, due to bundles about some GPs arriving later than the satellite has observed them
- But scenario 2 predicts GP value at an average of 70% different from actual value, because value functions are based on data collected approximately an orbit earlier, i.e. up/downlink latency between any sat pair
- The DTN-enabled decentralized solution provides 16% more value. Eitherway, a constellation with no agility sees 8.4% GPs
- Runtime per sat ~ 1% of the planning horizon

	Scenario#1 (Distributed)	Scenario#2 (Centralized)
Cumulative Value (6h)	26120	21820
% of all GP observed	95.2%	99.2%

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Earth Science Case Studies

OSSE simulation to inform heuristics in DP algorithm, as a function of time-critical EO cases:

- **Observation of Episodic Precipitation Events and Consequent Floods**
  - NU-WRF nature run in continental U.S. at ~3km spatial resolution 2006-08
  - Space-time coordinates that a constellation of radars and imagers are required to observe
  - OSSE outputs will include WRF-EDA for precip. observations and LIS for soil moisture states
  - Sensitivity analysis and opportunity cost functions of making/not making req. measurements
  - Add new observations, with and without agile pointing, to evaluate goodness of schedule
- **Tracking Specific Angular Geometries for Multi-Angular Cloud Observation**
  - Cloudbow tracking around a scattering angle of 130-160 deg
  - Sensitivity analysis of observations in temporal-angular space to evaluate schedule goodness
  - Demonstrate that algorithm can also enable Arctic profiles by avoiding Cloud Cover
- **Observation of Wildfire Spread**
  - WRF-SFIRE model (fire data from MODIS/VIIRS, NDWI, NDVI) to provide nature run of fire spatio-temporal coordinates. Detection algorithm = Δsurface characteristic temperature > proj. threshold
  - Goodness of schedule evaluated by percentage of known fires observed

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Acknowledgments:

NASA New Investigator Program and JPL Interplanetary Networking Directorate for project funding.

Questions?

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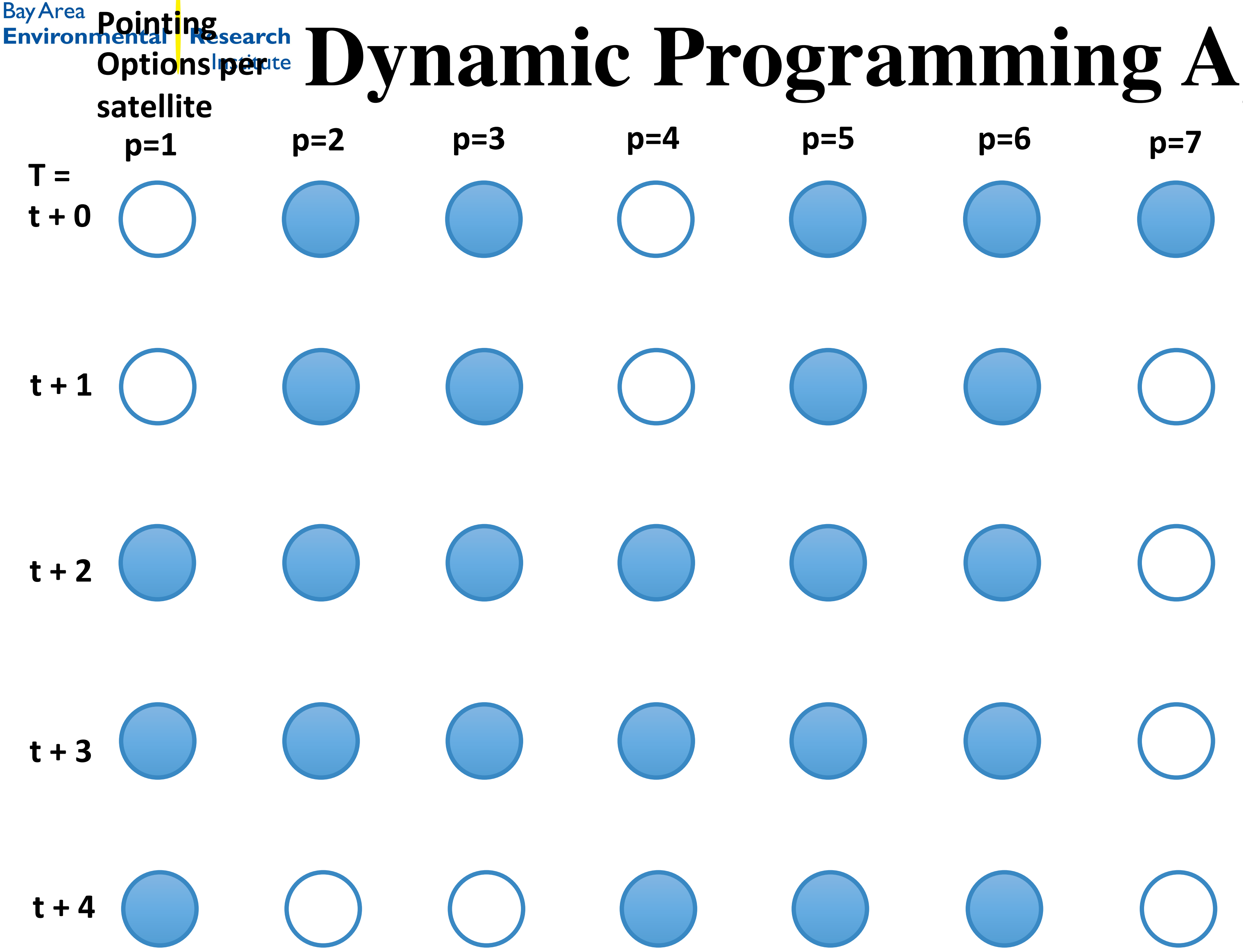
Dynamic Programming Approach



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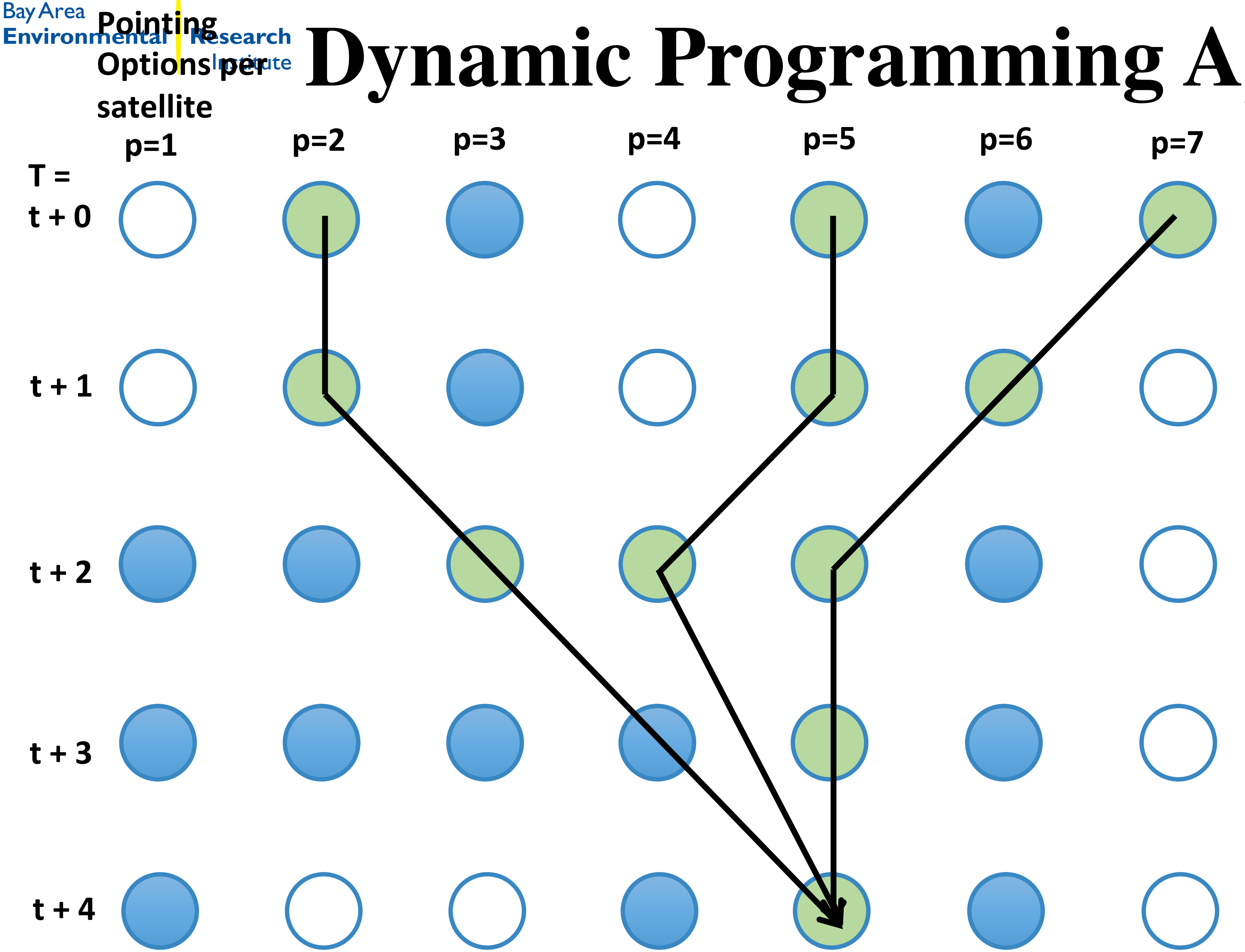
Dynamic Programming Approach



Proposed Algorithm:

- For every time step and every node:
- Find all paths leading to it (from 19 pointing options) and select+store the 'best' path/s only
- 'Best' is evaluated in 2 levels:

1) Path/s with the maximum unique number of seen images
2) Paths/s for which there are the least number of remaining opportunities for the seen images in the path

- No recalculation is needed because the unique images, paths and opportunities are stored up to the previous node and can be appended to.

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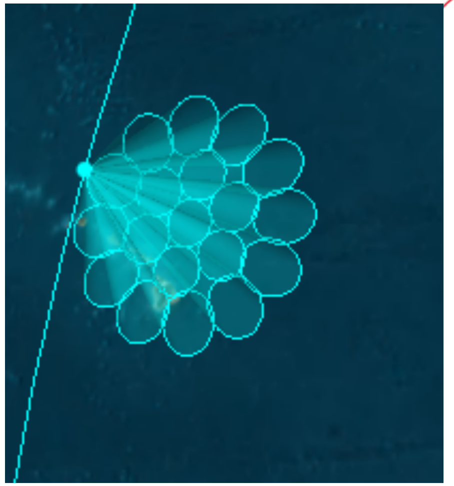
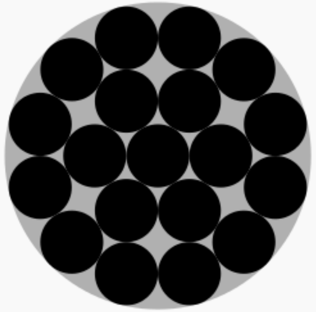
Breaking Down the Problem



- 16986 Landsat images imported as lat, lon, alt
- Limit simulation to one day at time resolution of 1 sec
- FOV = 15 deg, 710 km 98.2 deg orbit, max slew < 30 deg
- All possible pointing options discretized to 19 options based on the 2D circle-packing-in-circle solution

19	$1+\sqrt{2}+\sqrt{6} \approx 4.863...$	0.8034...	Proved optimal by Fodor in 1999.[8]	

https://en.wikipedia.org/wiki/Circle_packing_in_a_circle

```
PointNumber:        0
Lat:                -1.42862442392132e+000
Lon:                2.53334889992827e-002
Alt:                0.00000000000000e+000
NumberOfAccesses:   24
17    2.16472247288690e+004   2.16682342027050e+004
16    2.16803324637031e+004   2.17019188513764e+004
19    2.75134863884224e+004   2.75352535285753e+004
18    2.75312718745623e+004   2.75551035673686e+004
7    2.75540277660315e+004   2.75832837351813e+004
6    2.75839494706595e+004   2.76132749995163e+004
15    2.76124735607921e+004   2.76351519882569e+004
14    2.76310365887511e+004   2.76549902722753e+004
19    3.34074109272497e+004   3.34350444375388e+004
2    3.34335923377278e+004   3.34633601183685e+004
1    3.34644770731449e+004   3.34917946612874e+004
5    3.34928682064443e+004   3.3522[illegible]03785727e+004
14    3.35214143114703e+004   3.35484367052491e+004
19    3.92990388572563e+004   3.93214955190352e+004
```

- Use MATLAB, STK, MS Connect to simulate ***orbital mechanics*** and compute access reports: For every satellite, every pointing option and every image, when to when is it visible
- Use MATLAB Simulink to compute pointing switch time

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Attitude Control

Assumptions:

- No external moments
- Satellite inertial properties evenly distributed as a cube
- Sensor error: 0.1° in pointing, 0.01° error in rate gyro
- Reaches goal when pointing error < 0.2°

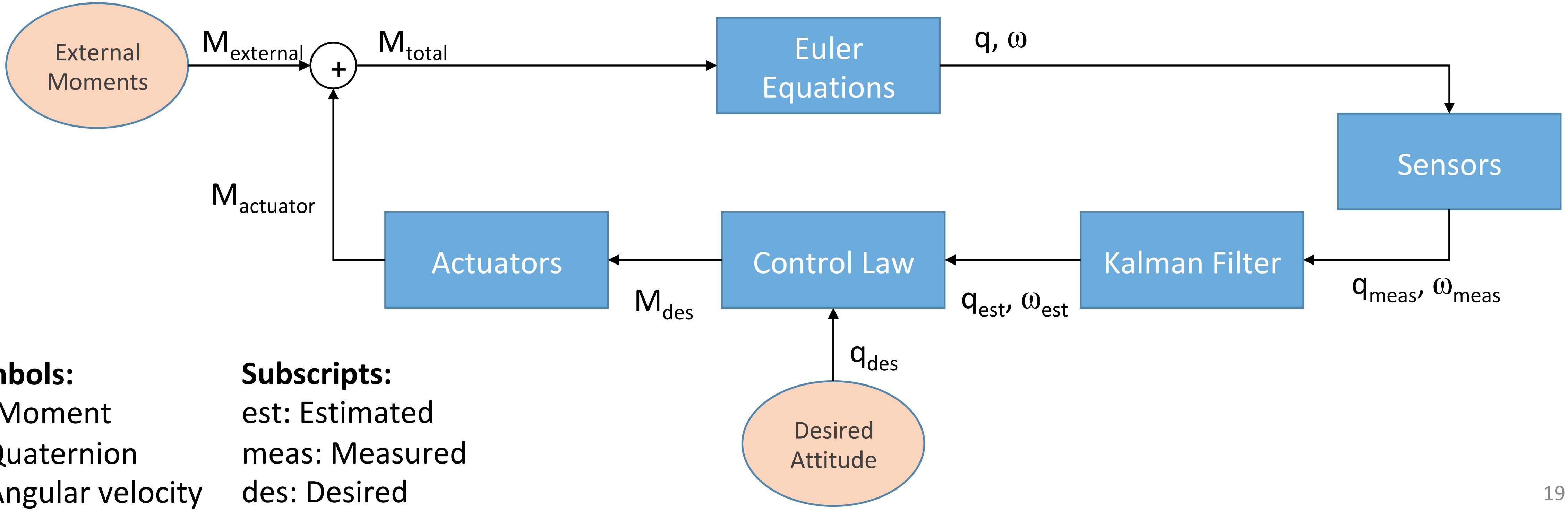
Specifications:

Mass = 20 kg
Max. moment = 0.025 Nm
Max. momentum storage = 0.5 Nms

Implementation:

- Actuators: 4 Reaction wheels
- Sensors: Sun sensor, magnetometer, rate gyro (with bias)
- Bang-bang control, with PD control when approaching desired attitude

Simplified Block Diagram



Symbols:
M: Moment
q: Quaternion
ω: Angular velocity

Subscripts:
est: Estimated
meas: Measured
des: Desired

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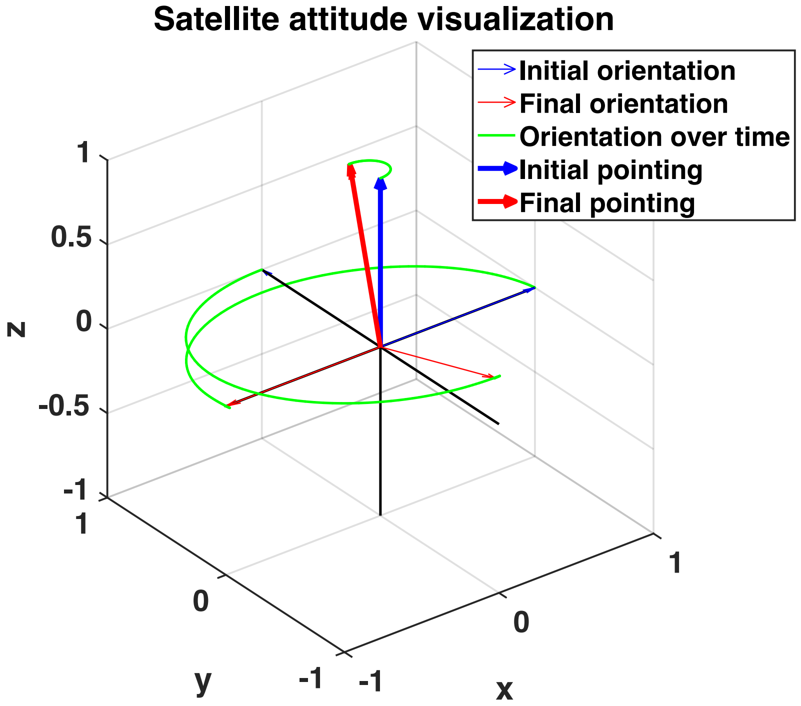
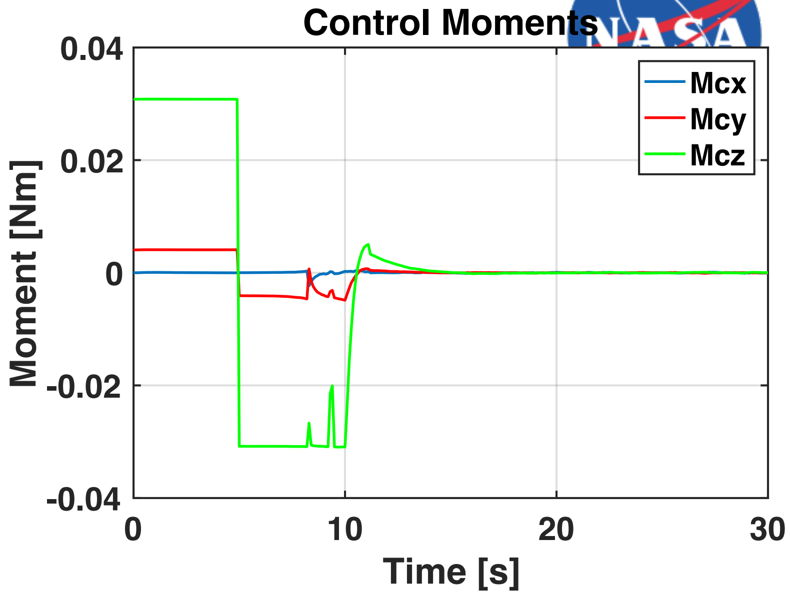
Attitude Control

Full pointing mode:

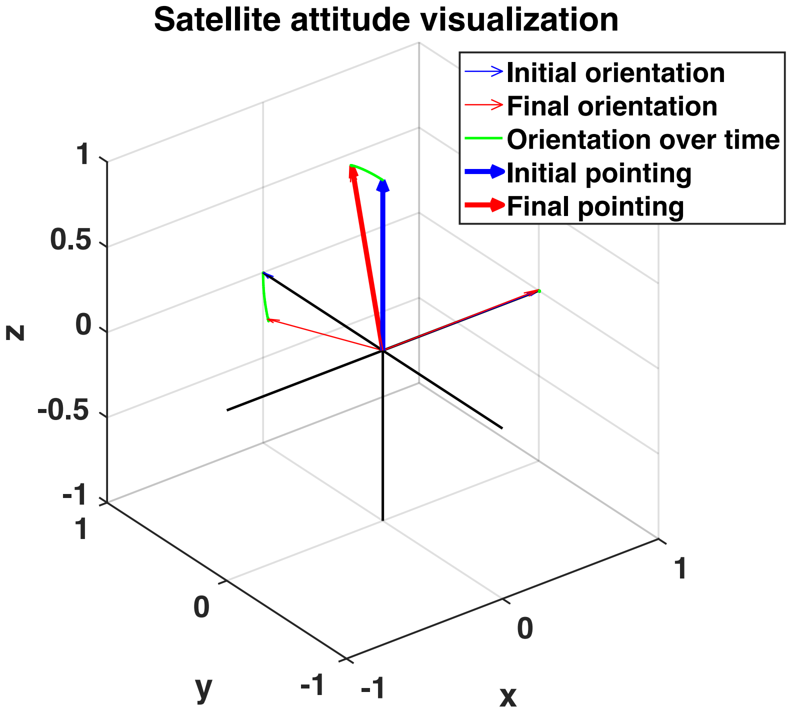
- Align all axes to desired
- Useful for aligning solar panels
- Requires more energy (E = 38.2 J)
- Slower in general

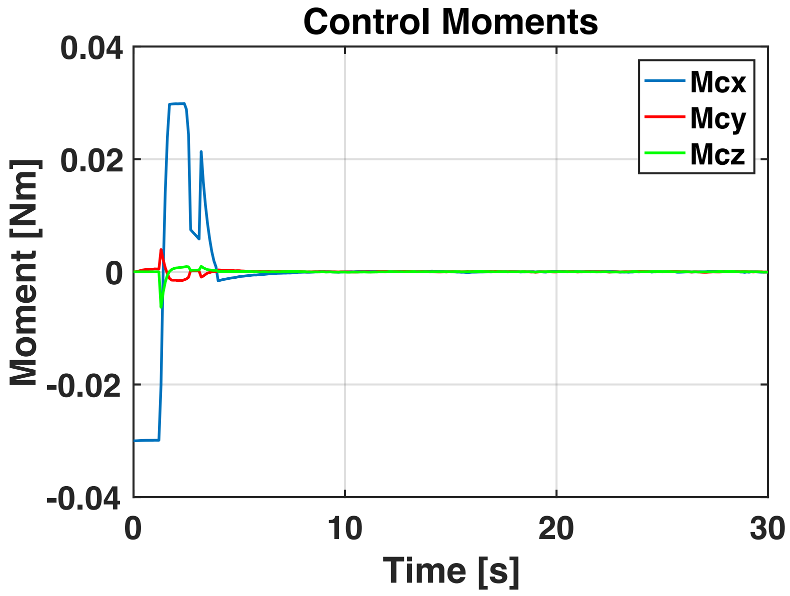




Fast pointing mode:

- Align ONLY pointing axes
- Useful for only aligning pointing direction
- Requires less energy (E = 2.8 J)
- Faster in general





Crosslink Budget Analysis

- Assumptions:
  - The link has a total 6MHz of usable due to NTIA regulations at S-band for class A missions.
  - The spacecraft in the constellation utilize the same patch antenna to transmit and receive with 7dBi of peak gain. However, data rate is computed at -3dB pointing.
  - The RF power of the small sat is pessimistically estimated at 10W and (very) optimistically estimated at 100W.
  - Assume NRZ encoding and BPSK with SRRC pulse shaping (standard practice).
  - Coding is assumed to be LDPC or Turbo (performance is ~1dB from capacity).
  - No atmospheric effects considered.
  - Link range varies between 1000km and 6000km.

- Link Considerations:
  - For distances >1000km, the link is always in the power constrained zone.
  - Therefore, changes in distance and/or coding will have a perfect linear effect in the link performance (e.g. if power is cut in half, so is the data rate).
  - For power constrained link, the optimal solution is to use very low rate codes (e.g. LDPC 1/6). However, these are not typically used in near-Earth communications and therefore are not typically implemented in radios. Therefore, we assume a minimum code rate of 1/2.
  - For distances <1000km, the link starts to also be bandwidth constraint. Therefore, optimal selection of code rate can lead to significant link rate improvements.

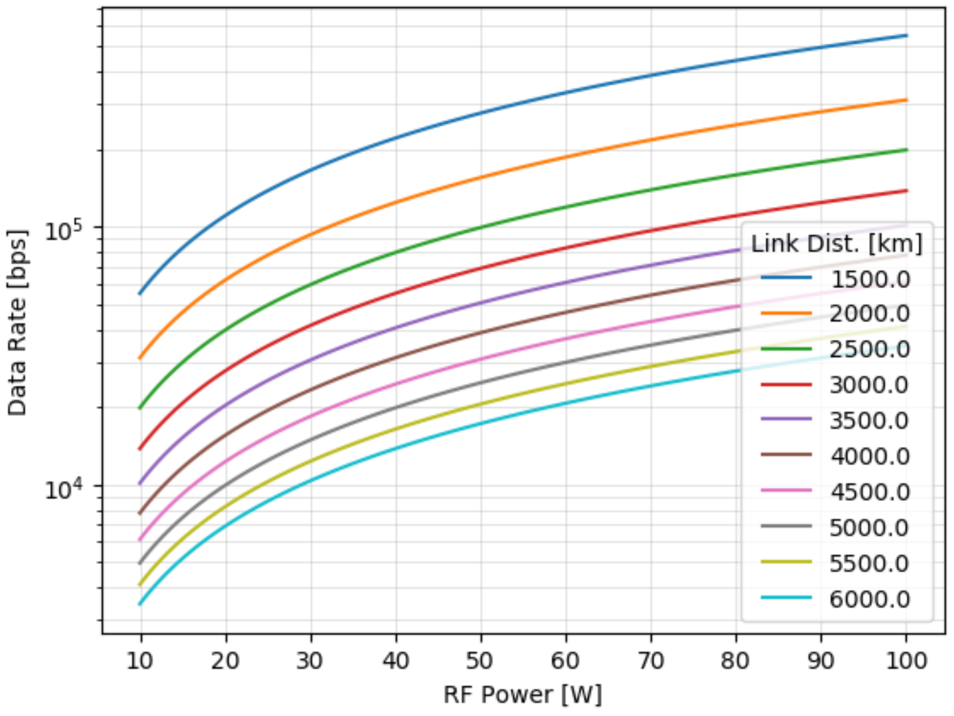
DTN Routing Analysis

- Assumptions:
  - Satellites can exchange information whenever there is visibility between them (irrespective of range). All links have a normalized propagation delay of 1second.
  - Link data rate is fixed and constant during a simulation depending on the link budget.
  - Link data rate is effective rate after losses and protocol overhead (not accounted for).
  - Each satellite generates one 2.3MB or 1.3MB packet every 1h or 1.5h destined to all other satellites in the constellation (i.e. broadcast).
  - Each satellites carries a simplified version of the DTN routing algorithm where:
    - Packets are routed doing a shortest path search over the time-varying network topology. The objective is to minimize the best case packet delivery time.
    - In the real DTN routing protocol specification, an ad-hoc heuristic algorithm to predict congestion in links based on local information is specified.
    - This heuristic is the reason why routing in DTN is limited to ~15 nodes since it renders the routing procedures computationally complex.
    - In the simulation, a simplified version of the heuristic is utilized to minimize computational burden.
    - The route followed to destination will have no loops, but no effort to minimize number of hops is made.

- Performance Metrics:
  - Number/Percentage of packets lost because they are unroutable and cannot be delivered before the end of the simulation.
  - Average latency experience per packet in time units.

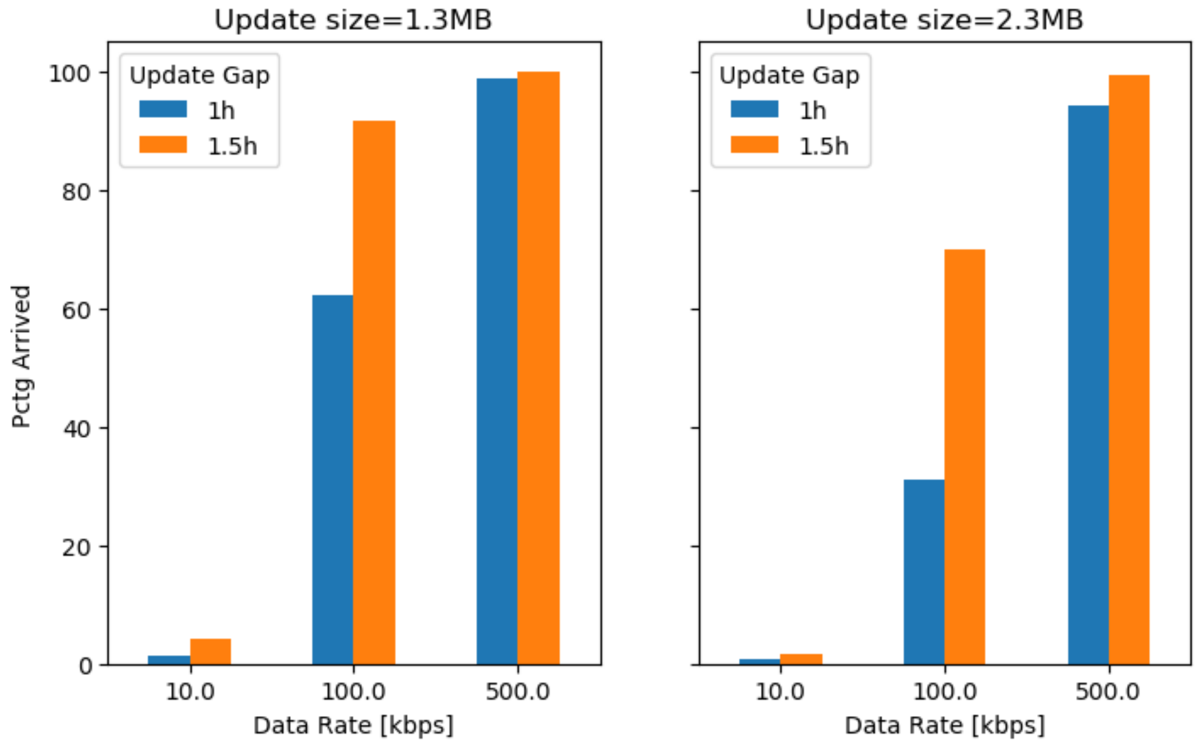
Crosslink Analysis – 15 sat. constellation

Instantaneous Link Data Rate



% of packets received

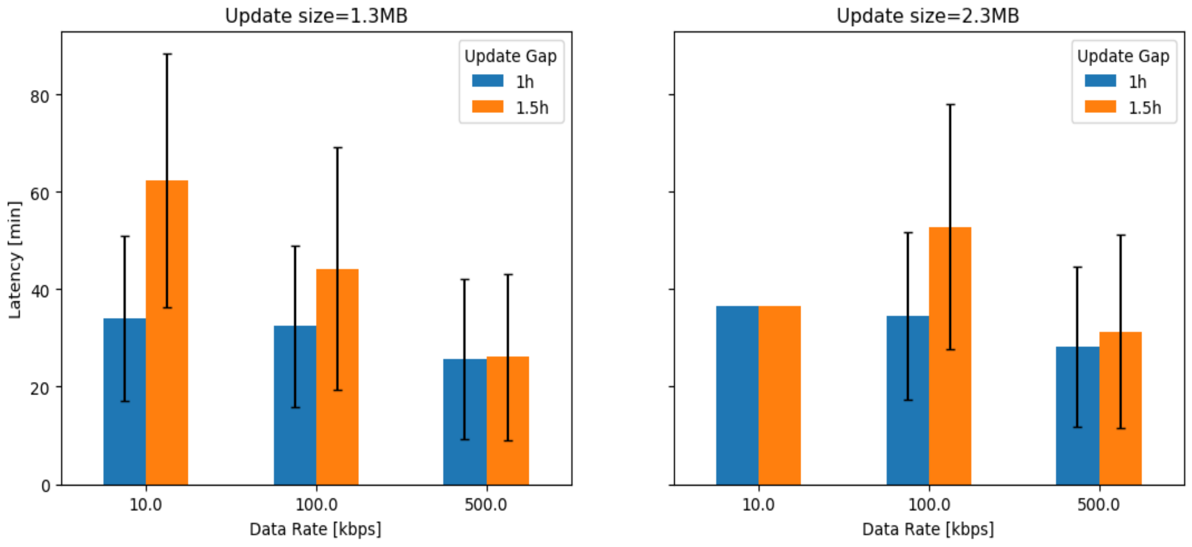
- Results are obtained assuming that the link closes at any distance (up to 6000km).
- With 100kbps, you only get about 90% of packets to destination if the file size is 1.3MB and they are issues every 1h:30min.
- For very high delivery probability we would need to close the link at 500kbps ideally.



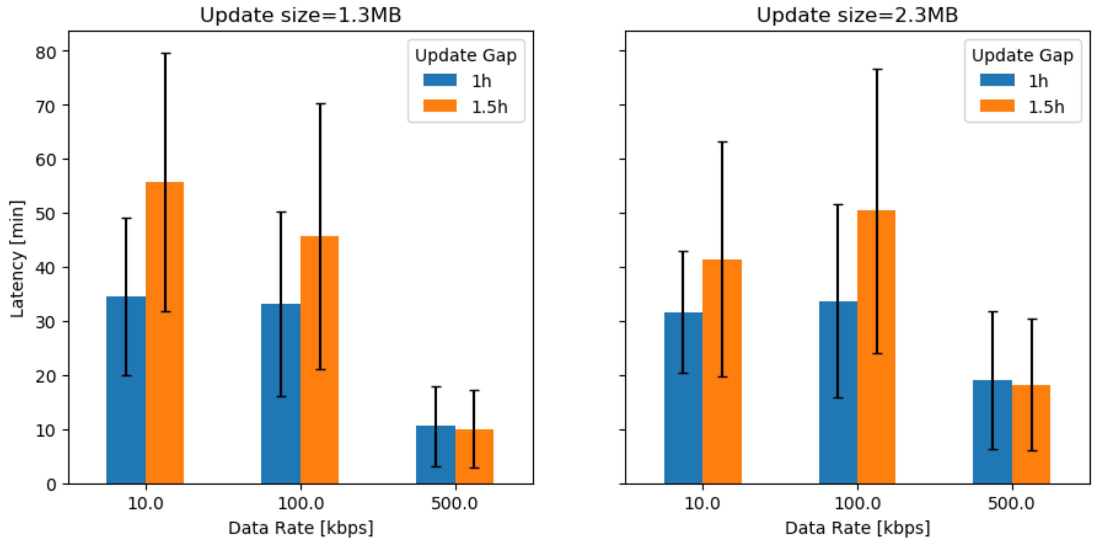
Latency Analysis – 15 vs 24 sat. constellation

- If system is too congested (e.g. 10kbps links), then latency is low because it is only measured from packets that arrive to destination.
- In the 15 satellite constellation, file updates will at best take between 10 and 30 minutes.
- In the 24 satellite constellation, file updates can be delivered in 10 to 20 minutes thanks to the intra-plane links.
- The latency variability is very high regardless of the constellation.

<u>15 satellite constellation</u>



<u>24 satellite constellation</u>



Latency Matrix

- Each latency matrix shows a latency statistic for a given origin-destination pair (origin is row, destination is column).
- The results shown here are just an example obtained with the following configuration: 24 satellites, 2.3MB file sent every 1.5h over 500kbps links.
- Statistics are collected over a very limited sample (4 files only). However, standard deviation is not expected to decrease significantly.
- As expected variability in the files sent within the same plane is significantly lower (2-4min). For delivery across planes, variability is very high.

Average Latency [min]

	s11	s12	s13	s14	s15	s16	s17	s18	s21	s22	s23	s24	s25	s26	s27	s28	s31	s32	s33	s34	s35	s36	s37	s38
s11		0.63	7.53	14.5	16.22	9.44	6	1.86	17.87	17.46	12.04	21.52	21.6	20.66	12.37	9.67	16.34	17.11	20.23	31.43	29.97	26.65	25.76	31.08
s12	0.63		0.63	6.92	11.57	14.66	8.82	6.16	11.08	15.45	13.09	13.72	16.58	19.47	17.25	15.44	31.48	24.56	21.94	19.64	27.76	36.84	23.33	30.81
s13	6.27	1.24		0.63	5.54	10.74	13.21	11.31	21.47	17.63	11.7	24.11	16.15	17.31	26.88	27.23	24.32	17.34	19.73	21.57	20	31.89	28.2	22.5
s14	13.21	8.14	1.86		0.63	5.38	10.44	15.37	25.7	19.9	16.65	8.86	5.53	8.97	20.5	25.88	23.3	17.44	24.36	14.29	21.28	20.37	34.59	26.96
s15	16.86	13.96	9.64	2.47		0.63	6.95	14.77	24.48	21.49	22.98	13.61	22.1	18.87	15.94	23.51	24.58	29.65	30.19	23.51	21.11	18.19	18.99	19.72
s16	15.77	15.74	14.83	10.44	2.47		1.24	9.51	21.92	28.33	31.01	28.32	12.34	6.85	14.03	23.98	29.56	26.6	35.35	26.87	19.86	32.15	18.8	22.89
s17	9.21	16.95	18.62	13.93	7.99	1.86		2.47	18.55	27.62	30.88	23.77	25.53	18.4	12.56	14.74	27.81	36.7	34.46	32.72	28.59	25.74	19.94	20.23
s18	0.63	8.45	13.27	17.27	11.72	6.49	1.86		14.96	23.16	20.64	31.73	24.69	20.12	7.04	15.97	19.25	28.75	34.87	39.73	31.46	20.49	15.2	12.58
s21	11.66	14.01	15.89	27.2	28.2	25.25	11.4	17.94		3.41	9.46	16.75	20.66	10.12	7.34	3.22	7.91	12.07	17.74	29.94	28.88	23.96	12.62	13.12
s22	7.81	11.52	19.5	16.41	21.35	20.95	20.04	15.03	1.86		2.32	8.16	14.25	16.93	10.14	7.26	17.3	21.49	18.4	26.83	28.19	23.99	24.66	22.16
s23	13.93	14.68	19.64	16.3	16.74	26.5	22.88	19.68	8.04	3.24		2.32	6.76	11.8	15.91	12.9	25.2	17.4	22.76	30.71	19.77	23.73	25.62	25.54
s24	18.83	13.58	21.87	9.82	6.17	10.96	21.48	26.56	13.38	10	4.31		1.84	6.73	11.1	16.32	25.14	17.61	16.15	11.65	12.8	13.71	26.34	23.97
s25	27.92	21.61	20.89	14.34	8.59	17.1	21.63	26.25	20.95	17.24	12.81	5.38		2.16	7.93	15.85	27.12	26.26	25.59	17.76	10.2	9.23	18.04	24.66
s26	25.74	28.86	27.27	25.03	6.83	6.82	18.61	29.47	19.83	21.43	17.92	11.24	3.7		3.24	11.37	23.89	27.8	29	27.44	25.22	13.33	10.46	22.27
s27	16.28	30.06	32.24	28.11	19.81	21.22	13.59	19.25	10.72	17.97	24.24	15.18	9.11	3.54		4.31	22.99	26.33	28.15	29.04	23.36	16.78	29.52	31.24
s28	8.36	17.52	23.69	25.39	23.21	17.8	16.02	14.59	3.08	11.62	15.2	23.17	12.97	7.52	3.38		16.07	24.44	28.1	27.27	24.12	20.39	10.71	9.5
s31	11.02	13.91	14.84	28.99	26.67	33.26	14.69	19.78	19.27	21.73	18.06	24.3	24.42	26.47	14.43	18.98		5.69	11.68	16.31	19.08	12.64	8.65	3.54
s32	25.19	23.51	23.55	17.7	17.64	19.73	15.05	23.55	18.91	24.08	16.62	15.66	23.44	29.74	21.95	27.33	4.77		4	10.56	13.6	16	12.66	8.92
s33	20.92	22.35	23.46	21.11	25.33	19.56	35.27	31.94	25.19	22.89	24.4	15.55	25.02	22.07	23.27	30.16	9.86	5.23		4	9.18	12.19	15.99	13.01
s34	22.37	17.13	11.55	21.28	20.14	20.94	33.28	30.21	27.54	24.36	18.35	15.54	16.45	17.72	24.6	33.18	14.12	11.83	7.68		3.08	8.35	12.91	15.81
s35	29.61	29.16	23.36	23.11	13.78	13.1	22.05	28.63	28.11	31.28	32.27	17.55	13.77	19.2	19.29	23.31	19.13	18.96	15.58	7.84		3.24	8.96	14.56
s36	22.66	37.94	33.96	32.79	27.32	22.61	15.09	18.28	27.03	29.76	29.57	23.58	27.14	21.38	14.65	20.55	17.15	21.85	20.35	14.63	6		5.23	12.36
s37	21.06	32.07	35.2	31.57	32.32	16.91	12.31	21.28	27.56	31.47	33.94	25.12	19.25	21.19	16.87	26.64	11.69	18.13	20.65	17.69	12.51	5.23		6.46
s38	18.95	26.58	23.2	31.79	32.73	32.54	12.67	16.44	19.17	28.2	29.48	30.31	27.37	25.81	12.71	9.91	5.88	13.96	16.42	20.83	15.32	10.27	5.5	

Standard Deviation Latency [min]

	s11	s12	s13	s14	s15	s16	s17	s18	s21	s22	s23	s24	s25	s26	s27	s28	s31	s32	s33	s34	s35	s36	s37	s38
s11		0	2.08	0.96	2.21	1.91	1.53	0	19.03	14.16	7.19	11.14	9.63	11.86	7.07	6.75	18.4	9.53	13.27	19.45	14.98	4.64	9.38	12.01
s12	0		0	1.16	2.34	4.46	2.44	2.11	12.94	17.19	14.66	7.46	8.58	7.44	4.88	10.67	20.43	17.62	18.87	12.77	14.08	15.2	5.52	20.95
s13	2.42	0		0	2.12	4.06	0.79	2.35	11.7	13.33	10.68	15.83	11.34	1.3	12.4	14.34	16.94	13.94	12.77	11.49	12.93	14.53	13.59	12.17
s14	2.57	2.09	0		0	1.96	2.39	2.66	13.99	17.21	19.13	9.56	2.17	2.68	8.9	7.76	11.77	9.9	15.53	6.78	14.51	12.89	2.39	7.38
s15	2.13	3.28	0.97	0		0	2.12	2.27	5.78	9.07	7.77	6.22	16.07	20.03	9.49	10.32	6.31	6.96	9.29	11.24	24.06	17.61	11.01	7.01
s16	1.98	3.12	2.17	0.5	0		0	1.53	12.24	13.51	12.33	16.27	13.78	7.3	11.66	11.23	16.82	12.99	9.68	13.16	11.08	19.04	18.36	11.8
s17	0.5	1.43	0.76	2.55	2.79	0		0	7.08	5.5	8.84	10.15	15.31	13.11	11.09	6	12.82	10.99	12.07	16.7	16.51	20.57	12.54	9.05
s18	0	0.92	3.4	1.84	3.48	2.47	0		11.37	9.63	8.54	0.17	10.53	14.3	9.55	20.24	9.07	19.13	14.86	13.21	16.15	10.93	8.17	7.59
s21	8.12	10.36	10.29	13.59	13.42	15.53	8.58	17.06		0.63	3.82	5.71	5.9	1.1	2.37	0.91	5.55	4.11	1.13	7.62	10.21	7.46	5.68	5.29
s22	6.04	13.44	17.75	10.68	8.09	3.44	10.93	6.11	1.5		1.26	2.73	3.66	3.43	1.95	0.98	10.9	17.8	15	17.03	15.54	7.95	11.01	12.95
s23	6.86	9.27	18.79	19.63	15.76	9.67	10.04	4.02	2.56	1.45		1.26	1.73	3.11	1.12	2.31	19.55	11.4	17.01	18.82	8.48	4.41	11.54	15.14
s24	3.68	9.3	17.99	10.46	2.36	4.25	10.69	10.04	2.65	4.65	0.71		0.87	2.66	1.86	0.8	20.16	12.44	13.51	8.44	6.98	6.81	11.27	7.91
s25	6.41	15.86	16.69	7.62	8.31	15.83	17.6	9.51	5.15	5.48	2.25	0.31		1.06	3.19	2.55	8.38	6.83	5.31	8.49	9.64	5.99	10.57	12.53
s26	9.1	10.12	12.84	14.42	4.25	6.95	16.34	13.48	7.52	6.7	2.67	2.02	1.5		1.45	3.24	12.33	9.63	9.11	16.23	18.83	9.68	8.71	11.26
s27	7.25	9.46	14.08	11.55	14.62	16.65	14.7	18.58	2.9	6.38	4.14	4.49	3.18	1.26		1.73	12.29	8.33	6.6	13.41	11.75	14.15	21.78	18.29
s28	2.6	2.34	11.72	8.57	7.97	9.69	13.81	9.75	1.23	2.68	4.36	8.59	3.1	2.59	1.05		7.66	11.19	10.55	6.78	9.28	14.43	9.86	6.16
s31	7.19	4.93	6.38	11.82	12.92	8.71	4.85	14.68	10.94	13.34	10.57	10.67	6.93	7.86	2.87	6.16		1.61	3	3.98	5.81	1.96	3.26	1.96
s32	14.64	18.61	19.94	4.16	1.83	2.4	7.87	5.58	12.94	16.67	17.37	10.95	10.86	11.77	6.68	16.41	2.62		2.53	4.23	3.34	2.12	3.5	1.58
s33	9.42	19.58	20.08	16.39	11.62	1.47	19.47	12.38	15.99	14.44	16.79	12.68	12.47	8.13	4.77	13.94	3.41	2.9		2.53	2.86	0.9	5.15	2.27
s34	6.98	10.02	8.33	19.44	16.24	10.26	6.02	10.02	9.33	17.08	16.59	8.32	11.81	14.23	4.52	4.02	1.58	2.51	1.54		1.73	2.37	2.61	1.93
s35	8.08	10.23	9.22	13.05	9.66	9.92	12.34	11.64	13.32	9.46	9.56	9.67	11.15	10.64	13.91	7.99	3.11	3.4	1.36	1.53		3.26	0.81	2.48
s36	3.75	11.43	15.19	13.5	11.28	15.86	8.4	3.83	14.02	10.53	10.17	9.06	13.58	20.93	10.7	7.74	5.44	4.59	3.37	5.05	2.26		2.9	2.53
s37	8.32	14.05	19.41	11.37	14.04	16.78	7.89	10.07	13.7	13.16	11.87	10.56	8.72	17.48	10.26	12.57	4.11	4.59	4.84	5.41	3.3	2.53		2.9
s38	5.18	9.57	11.52	11.79	12.46	19.28	10.37	8.95	11.8	16.05	12.42	9.19	9.38	14.51	12.54	5.92	1.77	1.26	2.81	4.93	2.55	1.66	2.95	