10TH INTERNATIONAL WORKSHOP ON PLANNING AND SCHEDULING FOR SPACE, 15-16 JUNE 2017

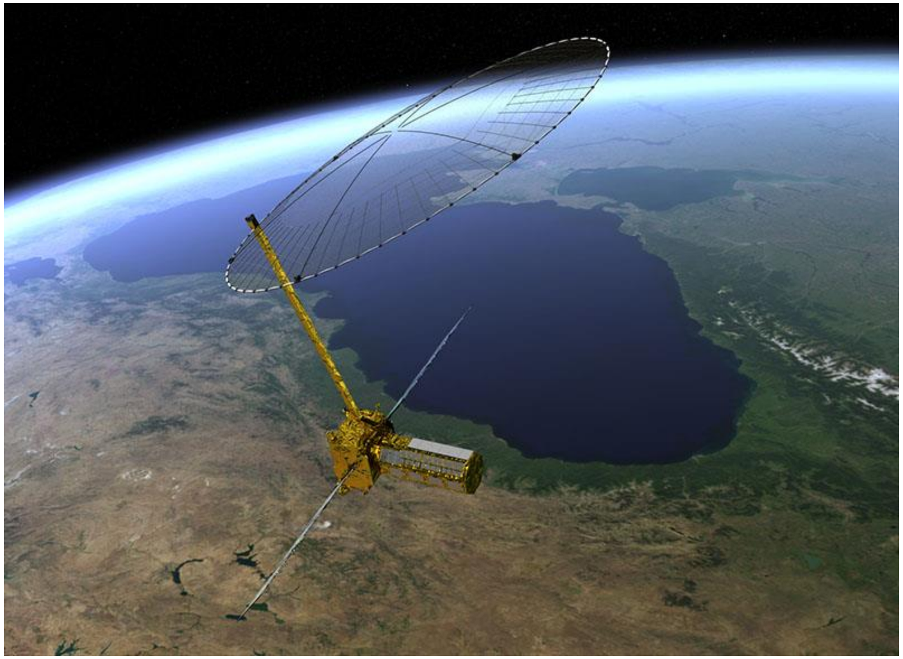
Intermediate Fidelity Solid State Recorder Modeling for NISAR

Michael Trowbridge and Joshua Doubleday
Jet Propulsion Laboratory, California Institute of Technology

© 2017 California Institute of Technology. ALL RIGHTS RESERVED. United States Government Sponsorship acknowledged.

Background

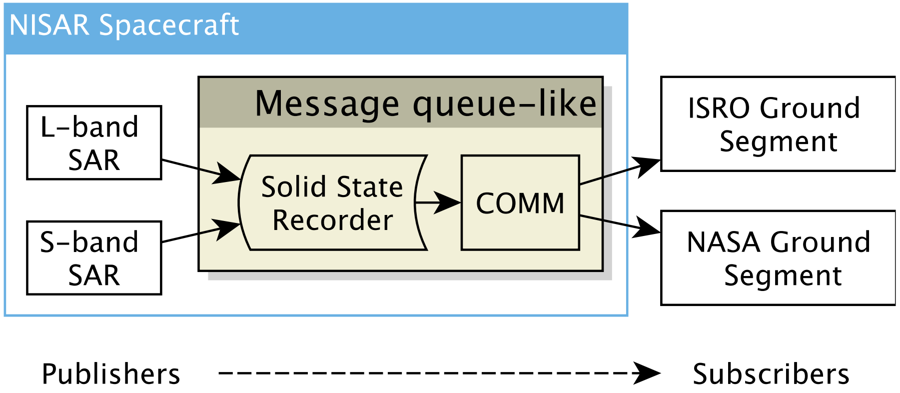
- NISAR: NASA-ISRO Synthetic Aperture Radar (SAR) mission
- Science Focus: solid Earth land mass, ice masses and ecosystems
- 747 km Low Earth Orbit
- Three year mission
- Two independent SAR payloads on spacecraft
  - L-band: NASA
  - S-band: ISRO
  - Active jointly or separately
- ISRO bus, operated by ISRO



© 2017 California Institute of Technology. ALL RIGHTS RESERVED. United States Government Sponsorship acknowledged.

Onboard Storage as a Store-and-Forward Message Queue

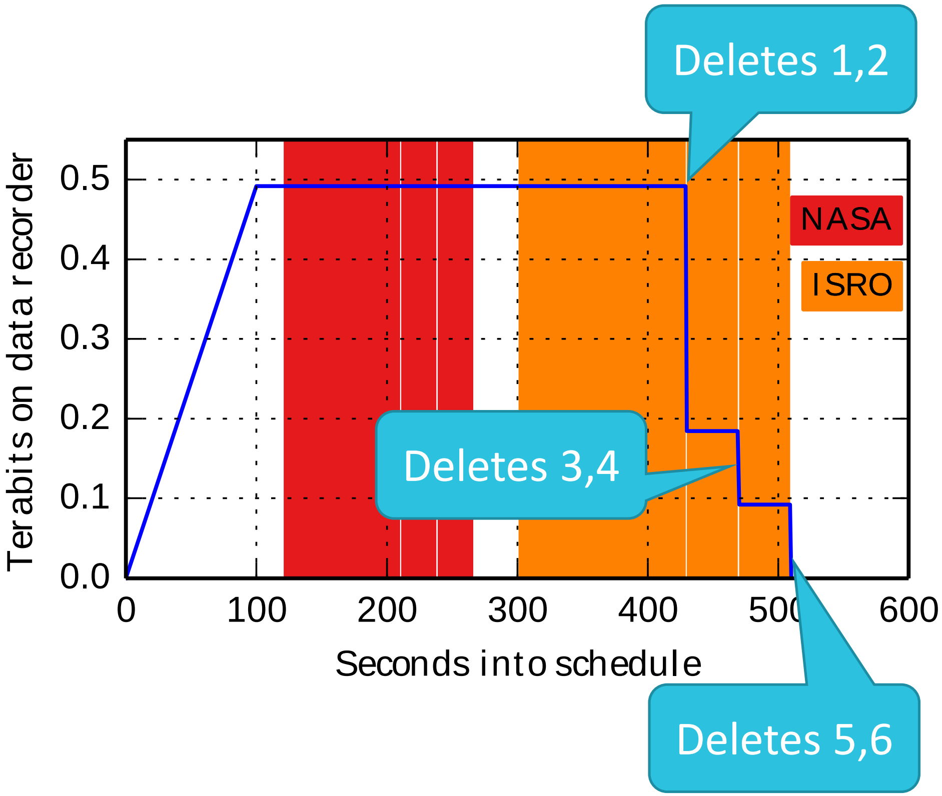
- Data buffered to an on-board recorder before transmission to ground
- ISRO and NASA ground segments are not federated
  - Variable routing polices for data – NASA, ISRO or both
  - Deletes deferred until after playback to the all destinations
- Cannot play back S-band and L-band files at the same time
  - Difficult to predict when a file will be played back
- Two playback priorities (urgent, non-urgent) with preemption



© 2017 California Institute of Technology. ALL RIGHTS RESERVED. United States Government Sponsorship acknowledged.

Discrete File Deletion Example

- 0-100 seconds: 6 files recorded concurrently
- 120-270 seconds: Concurrent playbacks to NASA
  - Cannot delete yet – must also play back to ISRO
- Concurrent playbacks to ISRO
  - 425 seconds: First file deleted
  - 460 seconds: Second file deleted
  - 510 seconds: Third file deleted



© 2017 California Institute of Technology. ALL RIGHTS RESERVED. United States Government Sponsorship acknowledged.

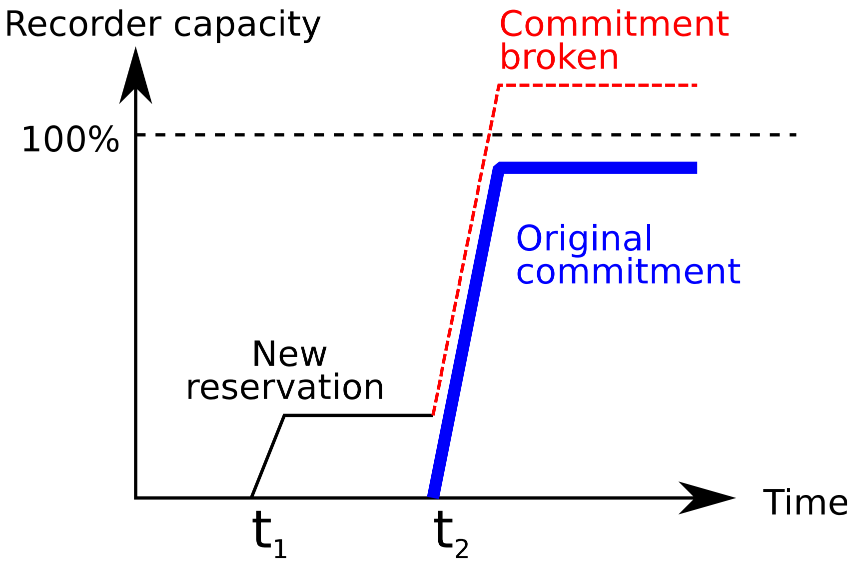
State of the Art

Prior work	How NISAR's needs are different
Piecewise linear integrals in ASPEN Eagle Eye (Knight, Donnellan and Green, 2013) and CLASP (Knight and Hu, 2009).	A free is long and slow – each bit freed as it is played back. NISAR has deferred, instantaneous free events.
Forward dispatch greedy playback scheduling for Mars Express (Cesta et al. 2002) Linear programming solution for playback schedule generation on Mars Express (Righini and Tresoldi 2010)	Mars Express planners choose which buffer to drain when, but cannot change the observation schedule. NISAR planners can change the observation schedule, but not the playback rules.
Discrete fill/drain reservations in Rosetta's max flow model (Rabideau et al. 2016)	Same as Mars Express: NISAR's observation schedule is flexible, but playback policies are fixed behavior.
Soil Moisture Active/Passive (Choi, 2012; Deems, Swan and Weiss, 2012)	SMAP files deleted by ground operators; NISAR autonomously deletes. SMAP has simpler, greedy observation scheduling.

© 2017 California Institute of Technology. ALL RIGHTS RESERVED. United States Government Sponsorship acknowledged.

Propagating Reservations: Piecewise Linear Integral Model

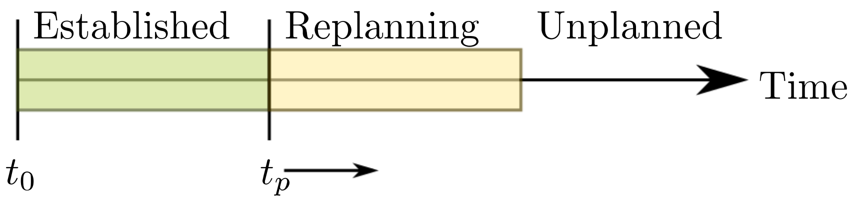
- Insufficient to only consider recorder state at t_1
- Must propagate changes forward (or capacity backward) to check feasibility of a reservation
- Similarly, propagate drain activities (playbacks) for future capacity



© 2017 California Institute of Technology. ALL RIGHTS RESERVED. United States Government Sponsorship acknowledged.

Intermediate Fidelity Recorder Model: Advancing Frontier Forward Dispatch Scheduler

- Use the observation schedule from the piecewise linear model as a starting point
- Simulate execution of the NISAR solid state recorder as a forward dispatch scheduler
- Incremental: place a reservation, retract future playbacks to t_p, re-simulate future playbacks, evaluate feasibility

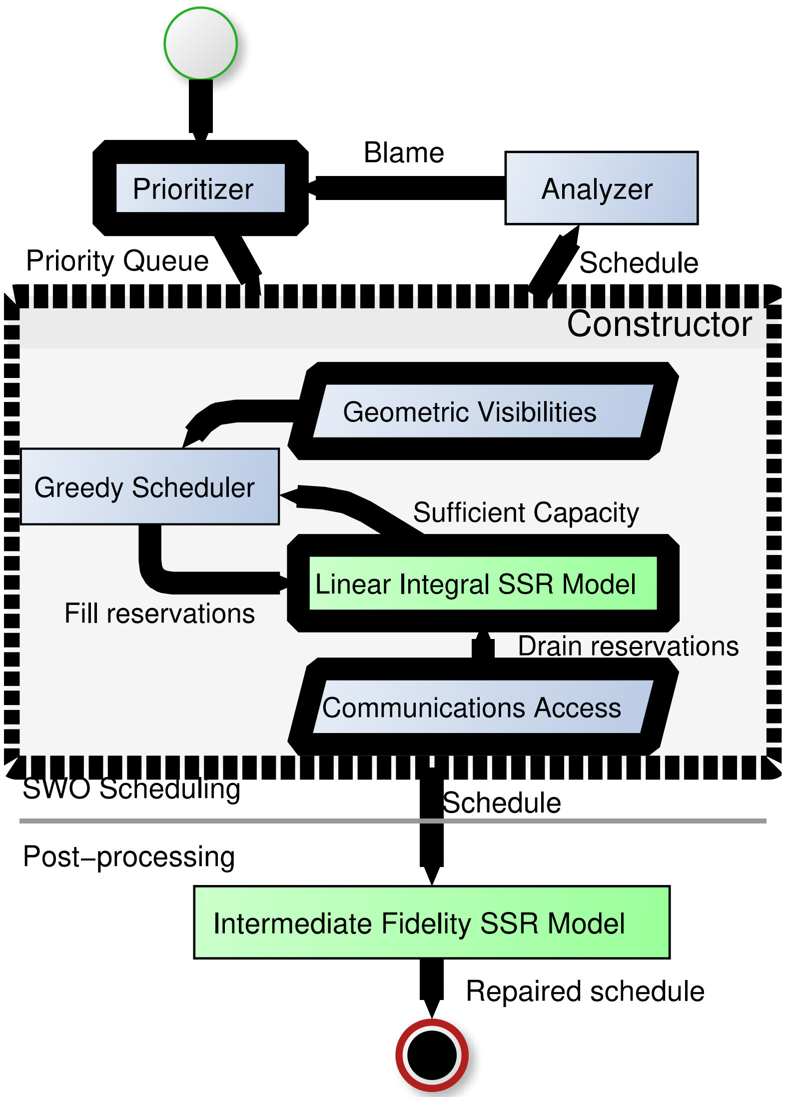


Algorithm 1 Forward dispatch playback scheduling

```
O ← SORT(Observations, by time, ascending)
t_r ← t_0                                   ▷ Failure rollback limit
failed, success ← ∅
for all o ∈ O do
    t_p ← t_f                               ▷ Propagation start
    r ← AGGREGATESIZE(o)
    if RESERVE(r) then                      ▷ Recorder reservation
        journal ← ∅
        for all c ∈ o.channels do
            f ← GETFILEOROPENNEW(o, c)
            if t_p > f.start then t_p ← f.start
            end if
            f.append (o, c)
            journal.append (f, o, c)
        end for
        ROLLBACKTO(t_p)
        if PROPAGATEDOWNLINKS(t_p) then
            success.append ()
            t_r ← t_p                       ▷ Update failure rollback limit
        else
            failed.append (o)
            ROLLBACK(journal)
            ROLLBACKTO(t_r)
            PROPAGATEDOWNLINKS(t_r)
        end if
    else
        failed.append (o)
    end if
end for
```

© 2017 California Institute of Technology. ALL RIGHTS RESERVED. United States Government Sponsorship acknowledged.

Experiment: How significant are deferred delete effects?

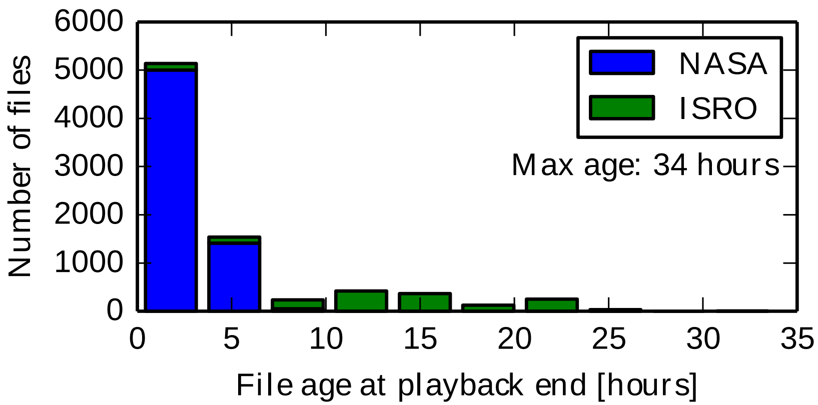


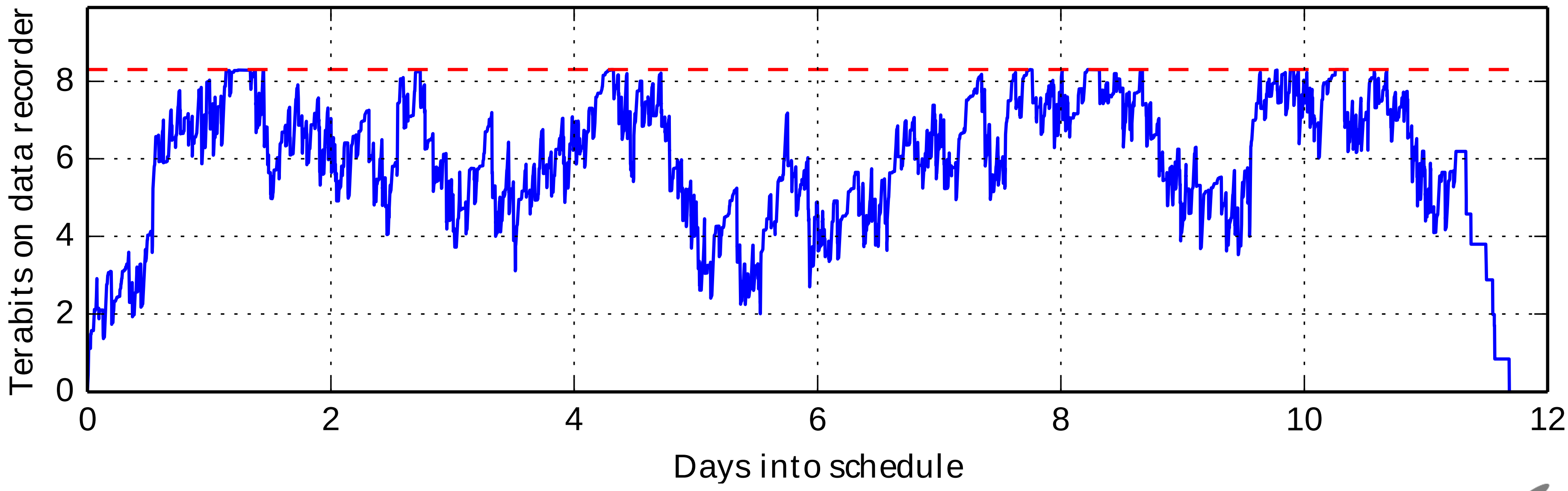
- Produce a schedule using Squeaky Wheel Optimization (Joslin and Clements 1999)
- Schedule in priority order, within geometric visibilities, when sufficient recorder capacity exists (linear integral model)
- Insufficient recorder capacity is a form of schedule saturation; observations that fail to schedule get a priority increase (blame)
- Repair final schedule by removing observations that exceed capacity in the intermediate model
- If repairs are needed, deferred deletes are significant

© 2017 California Institute of Technology. ALL RIGHTS RESERVED. United States Government Sponsorship acknowledged.

Results

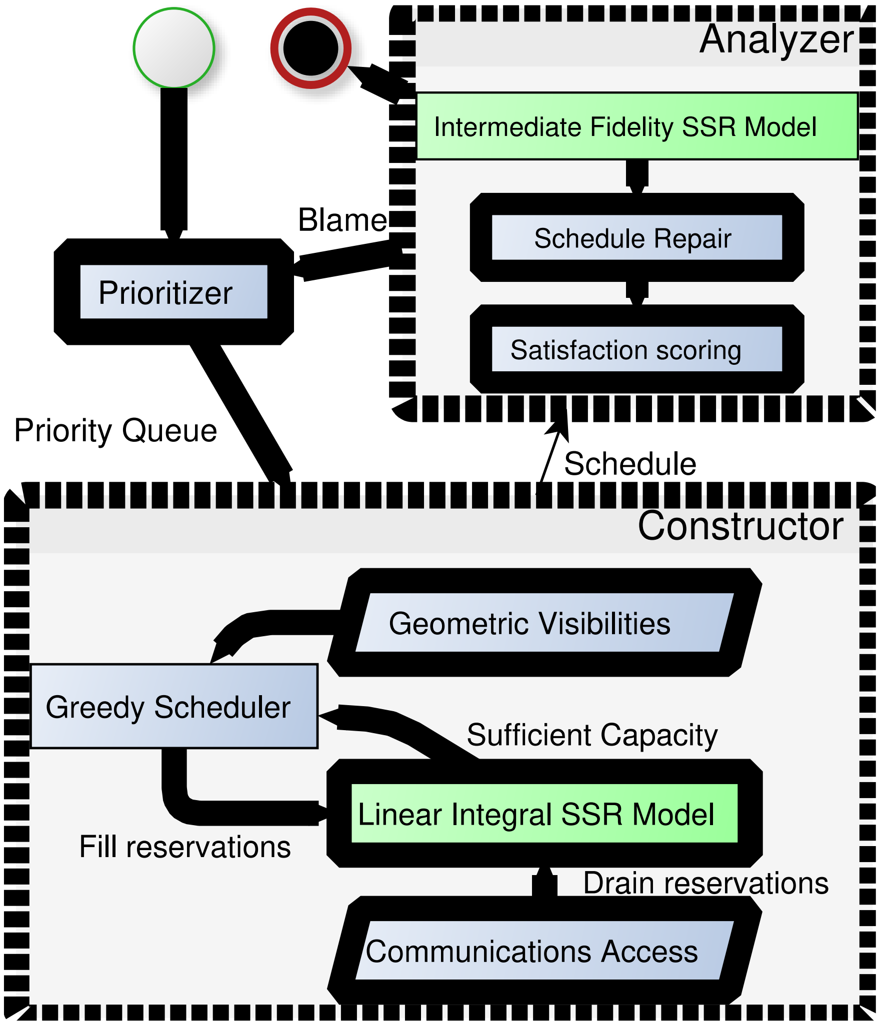
- Schedule repairs were needed (repaired version below)
- 3.87% (151 of 3902) observations in a 12 day simulation would have exceeded capacity
- Longest file lifespan: 34 hours





© 2017 California Institute of Technology. ALL RIGHTS RESERVED. United States Government Sponsorship acknowledged.

When to use the Intermediate Fidelity Model



- Replanning near the frontier makes the intermediate fidelity model slow
- We chose forward dispatch because it has O(n) complexity
- Anytime scheduling would have been O(n2)
- Wrapping anytime scheduling in a loop over multiple opportunities could be O(n4)
- Recommendation: Use the intermediate fidelity model no more than once per squeaky wheel iteration (in analyzer), in a forward-dispatch manner.

© 2017 California Institute of Technology. ALL RIGHTS RESERVED. United States Government Sponsorship acknowledged.

Recommendations for Future Work

- Consider alternative repair actions
  - Split a file if the fragment could be played/deleted sooner
  - Consider a lower-data rate mode when the recorder is near capacity
- Implement the Rosetta max-flow file model (Rabideau et al. 2016) as a compromise between the linear integral model and the intermediate fidelity model
  - Files reserve their entire space instantaneously
  - File reservations are automatically freed at the last possible final playback end time, assuming no preemption
  - Has the speed of the piecewise linear model with the deferred deletion effects of the intermediate fidelity model
  - Source: one of our paper's anonymous reviewers
- Consider applying a configuration space to the linear integral model's capacity so that its schedules do not require a repair by the intermediate fidelity model

© 2017 California Institute of Technology. ALL RIGHTS RESERVED. United States Government Sponsorship acknowledged.

Conclusions

- Discrete deletion effects are non-negligible: treating the recorder as a continuous drain device can produce infeasible schedules
- Intermediate fidelity model is too slow for use in every observation scheduling decision, but fast enough to evaluate a schedule once per squeaky wheel iteration
- Applying a configuration space the linear integral model or replacing it with a worst case file lifespan reservation may be sufficient to keep the output schedules feasible

© 2017 California Institute of Technology. ALL RIGHTS RESERVED. United States Government Sponsorship acknowledged.

Acknowledgements

- The research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.
- The authors would like to thank the reviewers for their constructive feedback.

© 2017 California Institute of Technology. ALL RIGHTS RESERVED. United States Government Sponsorship acknowledged.

Questions?

© 2017 California Institute of Technology. ALL RIGHTS RESERVED. United States Government Sponsorship acknowledged.

Backup

- Downlink propagation algorithm
- References

© 2017 California Institute of Technology. ALL RIGHTS RESERVED. United States Government Sponsorship acknowledged.

Downlink Propagation Algorithm

Algorithm 2 Propagating downlinks

```
function PROPAGATEDOWNLINKS(t_p)
    for all g ∈ ground segments do
        t ← t_p
        W ← GATHERDOWNLINKS(g, t_p)
        repeat
            W ← W.intersectWith(t, W.end)
            f ← g.queue.front()                    ▷ Next file
            t ← FINDNEXTSTART(g, t, f, W)
            finished, t_end ← PLAY(g, t, f, W)
            if finished then
                g.queue.pop()
                if PLAYEDTOALLRECIPIENTS(f) then
                    recorder.unreserve(f.size, t_end)
                end if
            end if
        until g.queue empty or W empty or t ≥ t_f
    end for
    return recorder.hasNoViolations()
end function
```

- Returning false means that there is still a data recorder oversubscription that was not corrected by propagating all downlinks at or after t_p

NISAR
NASA - ISRO SAR Mission

© 2017 California Institute of Technology. ALL RIGHTS RESERVED. United States Government Sponsorship acknowledged.

References

Cesta, A.; Cortellessa, G.; Oddi, A.; and Policella, N. 2002. Mexar: An intelligent support for space mission planning. In *Proceedings of the Workshop on AI Planning and Scheduling for Autonomy in Space Applications, Manchester.*

Chien, S. 2009. Practical planning & scheduling. In *International Conference on Automated Planning and Scheduling (ICAPS).*

Choi, J. 2012. Cost-effective telemetry and command ground systems automation strategy for the soil moisture active passive (smap) mission. In *SpaceOps 2012*. 1275978.

Deems, E.; Swan, C.; and Weiss, B. 2012. End-to-end data flow on the soil moisture active passive (smap) mission. In *2012 IEEE Aerospace Conference*, 1–16.

Doubleday, J., and Knight, R. 2014. Science mission planning for NISAR (formerly DESDynI) with CLASP. In *SpaceOps 2014 Conference*, 1757.

Doubleday, J. R. 2016. Three petabytes or bust: planning science observations for nisar. In *SPIE Asia-Pacific Remote Sensing*, 988105–988105. International Society for Optics and Photonics.

Entekhabi, D.; Njoku, E. G.; O'Neill, P. E.; Kellogg, K. H.; Crow, W. T.; Edelstein, W. N.; Entin, J. K.; Goodman, S. D.; Jackson, T. J.; Johnson, J.; et al. 2010. The soil moisture active passive (smap) mission. *Proceedings of the IEEE* 98(5):704–716.

Fox, M. S.; Allen, B. P.; Smith, S. F.; and Strohm, G. A. 1983. Isis: A constraint-directed reasoning approach to job shop scheduling. Technical report, DTIC Document.

Fukunaga, A.; Rabideau, G.; Chien, S.; and Yan, D. 1997. Aspen: A framework for automated planning and scheduling of spacecraft control and operations. In *Proc. International Symposium on AI, Robotics and Automation in Space.*

Joslin, D. E., and Clements, D. P. 1999. Squeaky wheel optimization. *Journal of Artificial Intelligence Research* 10:353–373.

Knight, R., and Hu, S. 2009. Compressed large-scale activity scheduling and planning (CLASP) applied to DESDynI. In *Proceedings of the Sixth International Workshop in Planning and Scheduling for Space, Pasadena, CA.*

Knight, R.; Donnellan, A.; and Green, J. J. 2013. Mission design evaluation using automated planning for high resolution imaging of dynamic surface processes from the ISS. In *International Workshop on Planning and Scheduling for Space (IWPSS 2013).*

Knight, R.; McLaren, D.; and Hu, S. 2012. Planning coverage campaigns for mission design and analysis: CLASP for the proposed DESDynI mission.

Rabideau, G.; Chien, S.; Nespoli, F.; and Costa, M. 2016. Managing spacecraft memory buffers with overlapping store and dump operations. In Bernardini, S.; Chien, S.; Sohrabi, S.; and Parkinson, S., eds., *Proceedings of the 10th Scheduling And Planning Appications woRKshop (SPARK)*, 69–75. London, UK: Association for the Advancement of Artificial Intelligence.

Righini, G., and Tresoldi, E. 2010. A mathematical programming solution to the mars express memory dumping problem. *IEEE Transactions on Systems, Man, and Cybernetics, Part C (Applications and Reviews)* 40(3):268–277.

Ward, J. 1990. Store-and-forward message relay using microsatellites: The uosat-3 pacsat communications payload.

© 2017 California Institute of Technology. ALL RIGHTS RESERVED. United States Government Sponsorship acknowledged.