Neighbors on the Red Planet: Mars Science Laboratory Relay Coordination Post InSight Arrival

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Abstract*— *The Mars Science Laboratory (MSL) strategic communications planning toolset selects orbiter relay opportunities that the rover will use for transmitting data back to Earth. The toolset was extensively reworked in preparation for the Interior Exploration using Seismic Investigations, Geodesy and Heat Transport's (InSight) arrival at Mars in November 2018 and the regular use of Mars Atmosphere and Volatile Evolution (MAVEN) and Trace Gas Orbiter (TGO) orbiters as relay assets in addition to Mars Reconnaissance Orbiter (MRO) and 2001 Mars Odyssey (ODY). Overflight selection criteria was automated in the new toolset to take into account overflight deconfliction and down-selection as well as tactical timeline planning impacts and total data return. This was done while remaining flexible and configurable for changing mission priorities. As the Curiosity rover ages, the MSL planning team must overcome issues such as reduced budgets, memory bank anomalies, and reduced power availability. These are some examples of factors that affect the strategic communications planning toolset.

In addition to adapting to evolving internal mission needs, the toolset must also be flexible to changes in the relay planning interface with other landers. The concept of shared relay or "split passes" was introduced when InSight began operating on Mars just 600 kilometers away and at the same longitude as MSL. This proximity meant that orbiters could now communicate with two landers during the same relay session. Over time, this new operational use-case became common practice as InSight and MSL settled into relay planning negotiations. Today, many TGO relay sessions are shared between MSL and InSight. As more orbiters pursue integrating this capability into nominal relay operations, and more landers arrive on Mars, the strategic communications process and toolsets increases in complexity. Development of a single tool that schedules relay sessions for all orbiters and landers simultaneously may become necessary as the number of Martian spacecraft increases.

Examples of how toolset selection criteria and capabilities have helped or hindered MSL planning will be presented. Ongoing improvements to MSL toolsets and processes, as well as to shared relay tools such as Mars Relay Operations Service (MaROS) and General Telecom Predictor (GTP) are also discussed in this paper.

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1. INTRODUCTION

MSL (Mars Science Laboratory, aka the Curiosity rover) landed on Mars in August 2012 and has traversed over 21 kilometers (13 miles) across valley floors, ridges, and plateaus while examining the surrounding features and drilling into interesting rocks. Sequence command loads are usually transmitted to the rover from Earth via the Deep Space Network (DSN) antennas, while science and engineering health & safety data are sent to Earth via relay from one of four Mars orbiters – MRO (Mars Reconnaissance Orbiter), ODY (Odyssey), MVN (MAVEN, Mars Atmosphere and Volatile Evolution) and TGO (Trace Gas Orbiter). While passes are occasionally scheduled with MEX (Mars Exploration Express), they are not used to return science data.

Prior to early 2018 only MRO and ODY were utilized by MSL for data relay, but in 2018 both MVN and TGO were certified for MSL critical science data return. One driver for this was the arrival of NSY (InSight, Interior Exploration using Seismic Investigations, Geodesy and Heat Transport), a nonmobile lander, in November 2018. MSL and NSY are in close enough proximity on the surface of Mars that orbiters can often see and communicate with both landers at the same time. These shared viewperiods can be split between the landers to accommodate relay time for each. [Figure 1]. Crosstalk is when an orbiter hails one lander but another lander responds, and must be avoided. The MSL strategic communications toolsets were extensively reworked in 2017

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and 2018 in preparation for TGO, MVN, and NSY to handle split passes and avoid crosstalk[1]. The new toolsets were first used in October 2018.

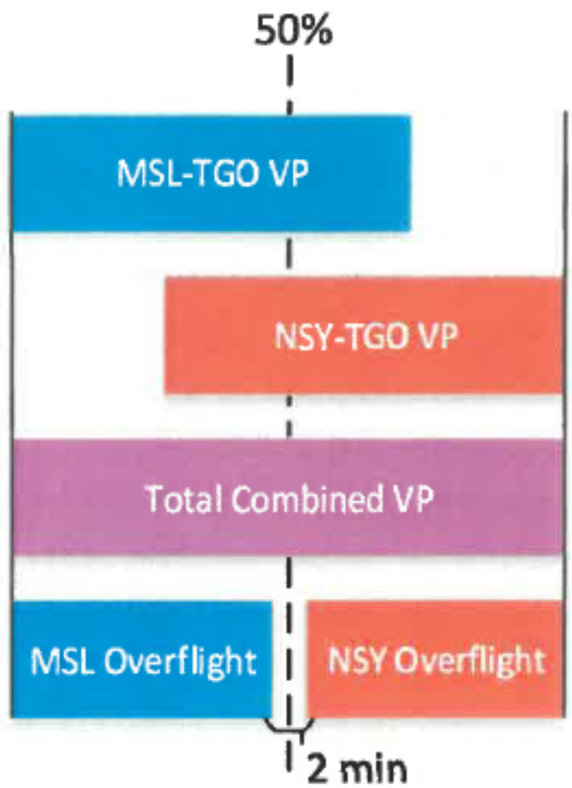

Figure 1. Overlapping viewperiods for adjacent landers are split (shared) between the landers

2. Relay and Rovers

The MSL strategic communications toolset assists in choosing which relay passes to request from amongst the 4 relay orbiters. Since the specific timing and data return of a given overflight can greatly impact a planning day for a surface mission, the new toolset was designed with several automated but flexible selection parameters. A key difference between a lander mission, particularly rovers, and an orbiter mission is the rover team performs tactical planning, in which the results of the previous day's science activities are analyzed and used to refine the science observations for the next day's plan. This contrasts to an orbiter's operations, which are planned weeks to months in advance. For a rover to operate this way, critical science and engineering data must be received on the ground in a timely fashion; "decisional pass" refers to a relay pass whose data is received before the next day's planning shift begins, and is used to make decisions about the next plan. Due to shifting Earth-Mars time (a Mars day is 40 minutes longer than an Earth day), it is not always possible to plan tactically every day[2]. It is desirable for decisional passes to downlink greater than 120 Megabits of data volume, and to be after 1600 LMST (Local Mean Solar Time) to not interfere with the CSP (Critical Science Period). CSP is the time period between uplinking a plan and its decisional pass; a 6 hour CSP is desired, but often is not supportable between late uplink windows (nominally 0930 LMST, but variable based on DSN allocations) and early decisional passes. A later decisional pass start is desired to allow more science collection time in the Mars-daylight hours when heating required to operate instruments and mechanisms is at a minimum, and when lighting conditions are optimal for most instruments. Figure 2 is a screenshot from the MSLICE (Mars Science Laboratory Interface) planning tool displaying the relationship between an uplink window (purple: DSN track), the Mars lighting geometry, and relay passes (green).

If the decisional pass is too early after the uplink track then many common types of science plans cannot happen on a given sol (Martian day). Timing, data volume return, data latency (which affects tactical shift start time), and orbiter are all considered by the toolset in selecting decisional passes. The full decisional pass selection criteria is in Table 1. The Priority 1 row indicates that if a relay pass is found that occurs on the rover after 16:00 LMST, has at least 250 Mb downlink data volume, and has a latency such that it comes down before 9: 30 a.m. Pacific time the following planning day, that is the desired decisional pass; if two passes meet these criteria, the tiebreaker is a configurable preferred orbiter list. If no passes meet all these criteria, then a pass that meets Priority 2 criteria is selected, and so forth.

Priority	>= LMST	>= DV (Mb)	Tactical Shift Start (hours from 08:00PT)	Tiebreaker
1	16:00	250	1.5	Orbiter
2	16:00	120	1.5	Data Volume
3	15:15	250	1.5	Orbiter
4	15:15	120	1.5	Data Volume
5	16:00	80	1.5	Data Volume
6	15:15	80	1.5	Data Volume
7	14:30	80	1.5	Data Volume
8	16:00	50	1.5	Data Volume
9	15:15	50	1.5	Data Volume
10	14:30	50	1.5	Data Volume
11	14:30	80	3.5	Shift Start
12	14:30	50	3.5	Shift Start
13	12:30	80	3.5	CSP
14	12:30	25	3.5	CSP

Table 1. Decisional pass selection criteria

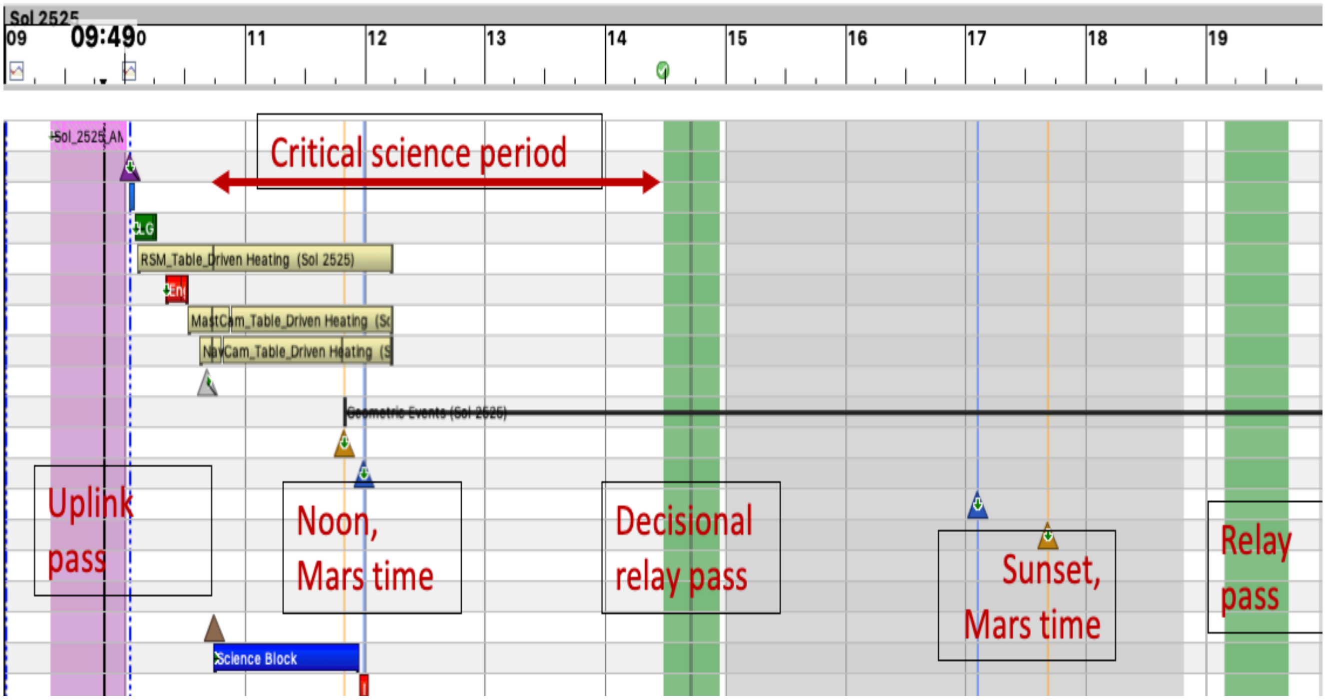

Figure 2. The MSLICE planning tool for Mars rover missions

The toolset tries to schedule both decisional passes and additional passes for data downlink (using different criteria). Much design effort went into making the new toolset robust in terms of flexible parameters, yet operational difficulties requiring tool tweaks were soon found, as described below. Sometimes orbiter teams failed to provide inputs in the required format. The MaROS (Mars Relay Operations Service) website is a tool which standardizes and integrates the relay planning and coordination data into a centralized infrastructure[3]. MaROS working group meetings are held monthly and enable discussion between developers, providers, and customers in order to drive new and updated implementations, such as input standardization agreements.

Relay Coordination

Coordinating split relay passes with the NSY mission requires numerous hand edits in MaROS, often nonintuitive between the name of the parameter and the effect in the MSL toolset. For example to make sure a single overflight is NOT selected by the toolset, the comm team member has to make up to 3 edits in MaROS. The NSY coordination process involves running the 'UHF tentatives" tool on Monday, informing NSY of the results, waiting for them to make edits in MaROS, making hand edits yourself in MaROS to mark passes as split based on the NSY requests, then on Thursday of the same week running the "UHF proposals" tool to see the results of all the edits (which often required more hand edits to fix errors/ensure the desired passes were selected). Continuous tool improvements are being made to help make this process more streamlined and less onerous on the user as well as decrease potential for human error.

Some features were added to the toolset to help with the NSY coordination process, largely involving formatting of the resultant spreadsheet of the overflight selections. Pivot tables are now created automatically to display the number of passes chosen per sol, the data volume of those passes [Table 2], and the total decisional data volume per sol. Another table is also created [Table 3] to highlight all selected TGO passes and, with some logic applied regarding minimum data volume needs, estimate which ones MSL will be able to share with NSY. To perform their own science, TGO has placed a limitation of only two relay passes per day (shared passes count as one relay pass), so if both landers (MSL and NSY) want two TGO overflights a day they have to share both of them. If MSL is unable to share one of its scheduled TGO overflights then NSY is limited to using only one TGO pass that day. This is all resolved as part of the coordination process happening between Monday's tentatives run and Thursday's proposals run.

DV per Plan Sol and orbiter					
	Selected				
Plan Sol	MRO	TGO	MVN	ODY	Total
2541	571	795			1366
2542	236	438			674
2543	261	548	837		1646
2544	544	421		30	995
2545	918	458			1377
2546	383	421	863		1667
2547	180	500	910		1691
2548	251		135		386
2549	441	757			1198
2550	813	648	782		2243
2551	440	804	994		2238
2552	424	651			1075
2553	87		660		748

Table 2. Pivot table for data volume per sol

Orbiter	Overflight ID	NSY Overflight ID	Plan Sol	Sol	LMST	Hail Duration	Max Elev	DV (Mb)	Latency	Usable	Decisional Candidate	Selected Decisional
TGO	**TGO_MSL_2019_258_01**	TGO_NSY_2019_258_01	**2526**	2527	01:47:32	0T00:16:38	34.57	***707.99***	1:22:44	TRUE	FALSE	***FALSE***
TGO	**TGO_MSL_2019_258_03**	TGO_NSY_2019_258_03	**2527**	2527	14:16:43	0T00:17:20	75.96	***825.41***	12:31:02	TRUE	TRUE	***FALSE***
TGO	**TGO_MSL_2019_259_02**	TGO_NSY_2019_259_02	**2527**	2528	02:40:26	0T00:16:34	33.44	***694.89***	1:17:16	TRUE	TRUE	***TRUE***
TGO	**TGO_MSL_2019_259_04**	TGO_NSY_2019_259_04	**2528**	2528	15:11:00	0T00:14:34	15.88	***206.26***	10:40:32	TRUE	TRUE	***FALSE***
TGO	**TGO_MSL_2019_260_01**	TGO_NSY_2019_260_01	**2528**	2529	01:36:22	0T00:17:10	54.76	***809.04***	1:18:22	TRUE	TRUE	***TRUE***
TGO	**TGO_MSL_2019_260_04**	TGO_NSY_2019_260_04	**2529**	2529	14:05:48	0T00:17:19	68.68	***812.77***	11:52:49	TRUE	TRUE	***FALSE***
TGO	**TGO_MSL_2019_261_02**	TGO_NSY_2019_261_02	**2529**	2530	02:29:57	0T00:15:35	21.66	***413.97***	1:00:28	TRUE	TRUE	***TRUE***
TGO	**TGO_MSL_2019_261_03**	TGO_NSY_2019_261_03	**2530**	2530	13:02:37	0T00:16:09	27.2	***569.27***	2:46:09	TRUE	TRUE	***FALSE***
TGO	**TGO_MSL_2019_262_01**	TGO_NSY_2019_262_01	**2530**	2531	01:25:20	0T00:17:22	86.6	***769.43***	1:03:50	TRUE	TRUE	***TRUE***
TGO	**TGO_MSL_2019_262_03**	TGO_NSY_2019_262_04	**2531**	2531	13:55:03	0T00:16:55	42.85	***759.87***	9:56:20	TRUE	TRUE	***FALSE***
TGO	**TGO_MSL_2019_263_01**	TGO_NSY_2019_263_01	**2531**	2532	00:22:28	0T00:15:21	20.12	***350.73***	0:57:36	TRUE	TRUE	***TRUE***
TGO	**TGO_MSL_2019_263_03**	TGO_NSY_2019_263_03	**2532**	2532	12:51:16	0T00:16:55	42.27	***757.85***	11:42:32	TRUE	TRUE	***FALSE***
TGO	**TGO_MSL_2019_264_02**	TGO_NSY_2019_264_01	**2532**	2533	01:14:26	0T00:17:14	59.55	***800.51***	1:04:55	TRUE	TRUE	***TRUE***

Green: OK to split
Yellow: OK to split, but prefer not to
Red: Not OK to split

(color auto-designations based on data volume and decisional pass candidacy; often we can split more passes than these rules suggest)

Table 3. Automated suggestions on splitting passes with NSY

Another table was added to the toolset output to help MSL choose ODY passes in a planning cycle. Because MSL can take advantage of adaptable data rates due to its Electra radio, MRO, MVN, and TGO passes all have much higher predicted data volumes than ODY passes (which does not have an Electra radio). As NSY also does not have an Electra radio it makes more sense for them to concentrate on ODY passes, with the occasional MRO, TGO, and MVN pass to meet data volume needs and for orbiter diversity (largely in case of a safing event on an orbiter so a lander is not completely dependent on the operational status of one orbiter). MSL's tools rarely automatically select an ODY pass due to both low data volume and the fact that NSY is planning to use most of the ODY overflights. During coordination MSL typically offers an MRO pass to NSY and requests one or two ODY passes, satisfying orbiter diversity desires for both landers. Implementing any agreements from this coordination again involves hand edits to MaROS.

Relay pass uplink and updates

Once the relay passes for a 2-week planning period have been selected by the toolset, they are reviewed by the orbiter teams, approved, and uplinked to the rover once every two weeks. Sometimes changes need to be made to relay passes after the selection process has completed. There are a variety

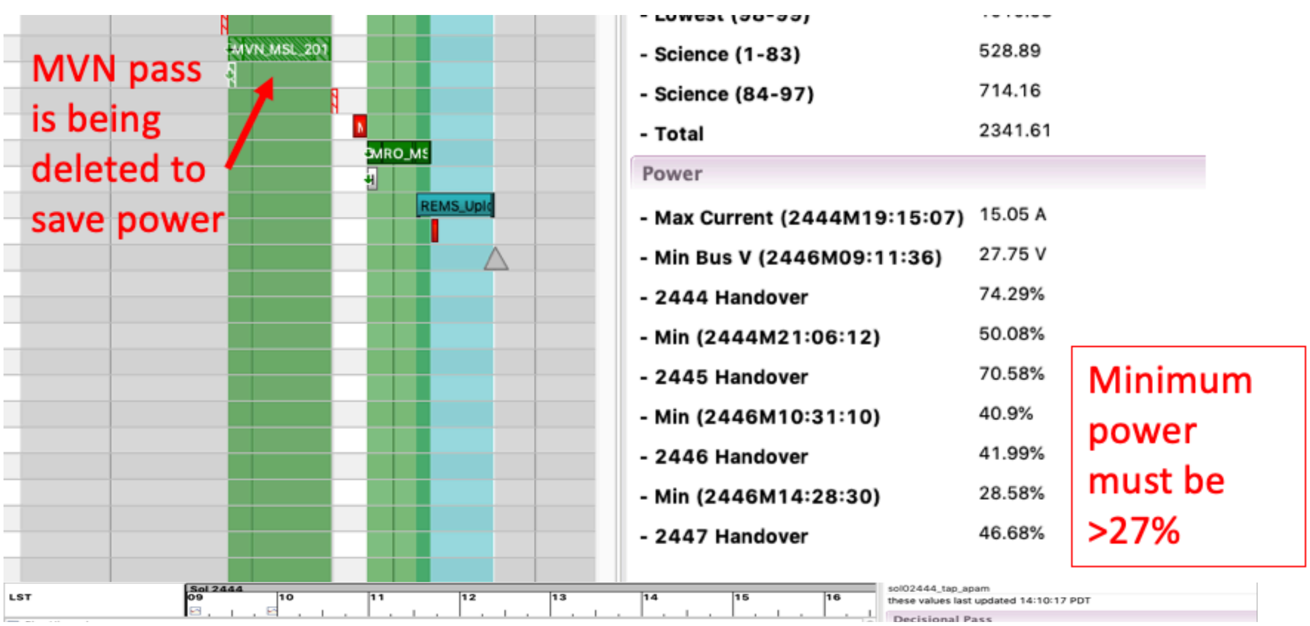

Figure 3. Power issues solved by deleting a relay pass

of reasons for this; on a power limited planning day science may choose to delete a pass to eliminate the awake period [Figure 3] or to delete a pass that interferes with the desired science due to its early timing. These deletes can be done in advance or on the actual planning day. The orbiter may still hail the rover, but MSL will not respond. These types of pass changes could be minimized by tweaking the toolset parameters. The offset in 2-week planning periods for each orbiter [Figure 4] can complicate relay pass selections and lead to more late pass deletions, if an onboard MVN, ODY, or TGO pass conflicts with a more desirable MRO pass in the following planning period.

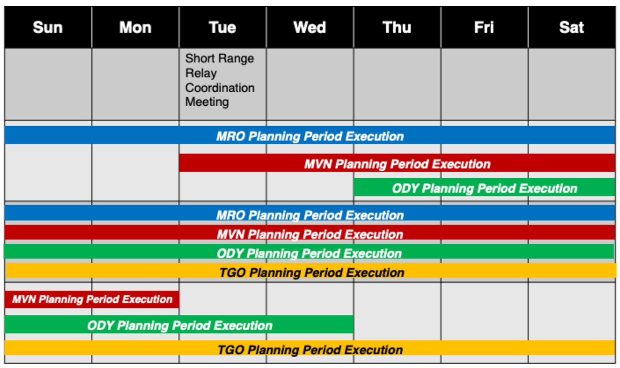

Figure 4. Relay orbiter planning cycle offsets

Another reason to delete a pass (or shift its timing) is if the orbiter's ground track has shifted, either due to the Martian atmosphere or an Orbit Trim Maneuver (OTM) performed by the orbiter. Currently the MVN orbiter occasionally performs OTMs large enough to cause planned MVN relay passes to occur when the orbiter is not in view of the rover [figure 5]. The toolset will automatically update the pass timing for future planning cycles, but any passes already onboard the rover must be manually evaluated and adjusted or deleted as necessary. Generally, the nearer a relay pass is to MVN's periapse time the more likely it is to experience a large timing shift due to OTMs.

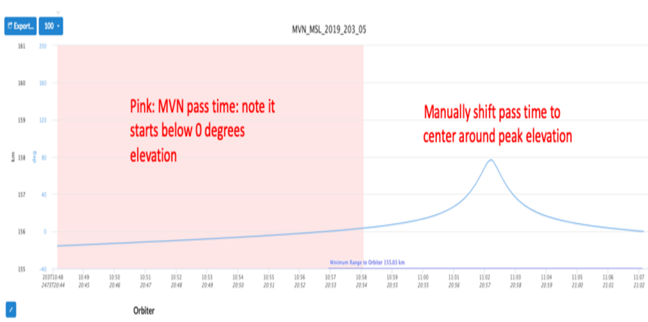

Figure 5. MVN overflight shift

Updated orbiter overflight information is delivered to MaROS once or twice a week, depending on the orbiter, in the form of an SPK (Spacecraft and Planet Kernel) file. In addition to an SPK delivery MVN provides an email to the strategic communications team summarizing geometry shifts; the format of these emails is still being tweaked to be more useful to the landers affected. In the future an automated process for evaluating and shifting/deleting passes is desired.

Finally, a relay pass may be deleted due to a change in the predicted data arrival time. Latency refers to the lag time between when the data is sent from the rover to an orbiter, and when the orbiter transmits that data to Earth. Orbiters require scheduled time on an Earth ground station, either through the DSN (all orbiters) or European Space Agency (ESA) antennas (TGO only), to downlink both relay data and their own science and engineering data. Most relay passes have latencies on the order of a few hours, but sometimes it stretches to 14 hours or more. This can cause out-of-order data, in which data recorded earlier on the rover comes down after data recorded later on the rover [figure 6].

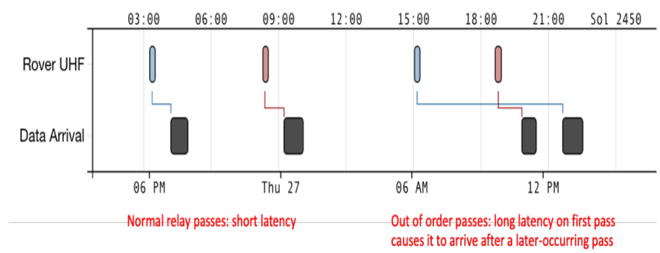

Figure 6. Out of order data downlink

If all data still comes down pre-decisional this is not an issue, but if the late-arriving data come down post-decisional then special steps must be taken to ensure no critical data is relayed on that pass (or to delete the out-of-order pass before it occurs).

Relay pass data volume

Once relay passes are requested, they are used by many other MSL teams as part of their sequence planning processes. The MSL rover activity timeline planning tool, MSLICE, ingests predicted relay pass data volumes from MaROS, which are in Megabits (Mbit = base 10 = 1,000,000 bits). Since MSL science activities book-keep their data volumes in Mebibits (Mibit = base 2 = 1,048,576 bits, which is also what MSL's data management system uses for storage), the UHF activities first convert Megabits to Mebibits. Next the activities take off an estimated amount for engineering health and safety data, 10% of the predicted pass volume to account for frame packet overhead, another 10% for orbiter uncertainty, and finally 4 Mebibits for auto-retransmits. This formula was worked and refined during the first 6 months of the mission. Thus a pass with 192 Mbit of predicted downlink data volume (183 Mibit) will only be modelled as returning about 141 Mibit of data.

The predicted data volume for an overflight is very important in determining selected passes. MSL has two methods to perform this prediction. The first is a script called dvscf_gen which utilizes historical data to create an empirical model that is then used to predict performance of future passes with similar geometries. The second is the General Telecom

Predictor (GTP) tool developed for MER (Mars Exploration Rover) at JPL using the commercial MATLAB software[4]. GTP uses a mathematical model, terrain mesh, and orbiter/lander antenna/geometry information to model pass performance and create a high fidelity data volume predict. While the GTP tool is slower to run than the empirical tool, the empirical tool cannot be used for the newer relay orbiters MVN and TGO; first, a larger data set of pass performance across all possible geometries for these newer, non-sun-synchronous orbiters must be collected.

The relay pass selection process is dependent on timely orbiter deliveries of SPKs to MaROS so that GTP can run; data volume predictions are regenerated for every new SPK. As a result, MSL developed scripts that interface with GTP and its results and work to parallelize runs of the GTP model by making use of multiple processors. Several improvements to GTP scripts were made during mid-2019 to speed up the performance; shrinking from 5 hours to process a TGO SPK to 20 minutes. Strategic communications also was assigned a dedicated new machine with more processors and its own MATLAB license.

Trending is performed to ensure actual data volume downlinked is near the predict and the models are refined in order to ensure continued accuracy of pass performance models [Figure 7].

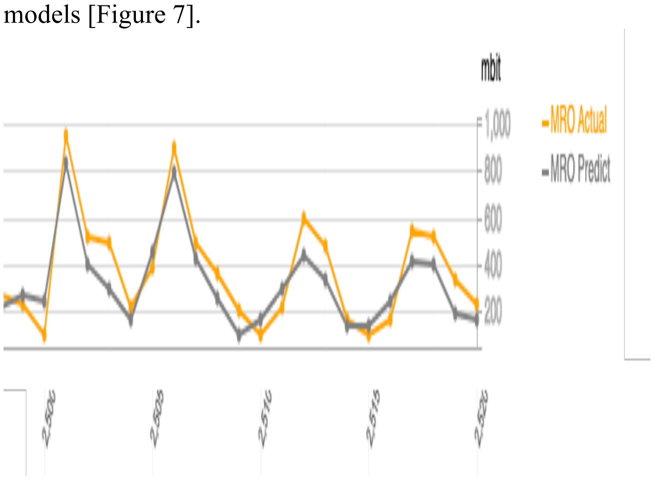

Figure 7. Relay pass performance

Data on the MSL rover is recorded to the file system with a priority designation known as a bin. Critical data are in bins 1-43; high priority data are in bins 44-66; medium priority data are in bins 67-86; and low priority data are in bins 87-99. During a tactical planning day it is desired to downlink all critical data by the decisional pass, i.e. in time to affect the next planning day. The communications planning team toolset uses latency information in MaROS to designate relay passes as decisional or non-decisional. The pass selection tables described above help the communications team member running the tools verify that there is an acceptable amount of decisional data volume for a given planning sol (at least 120 Mbit). Generally, if all critical data is returned by the decisional pass the science teams receive the data needed to tactically plan the following day, but sometimes tweaks to which bin data is placed in are made tactically based on the scheduled relay passes [Figure 8]. Reports are available to the tactical planning team indicating expected data return per relay pass and per sol [Figure 9].

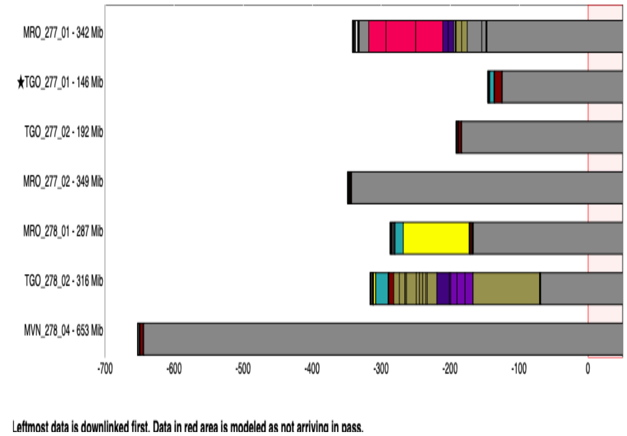

Figure 8. Decisional pass and priority data

Window ID	Pass ID	Start time (LMST)	Duration	Ret. Rate (bps)	Fwd. Rate (bps)	Downlink Volume (Mibits)	Configuration	Last Bin
35451	MRO_MSL_2019_277_01	Sol-02545M15:01:48	00:14:00	32000.0		341.93 Mibit	Two-way	99
★ 45450	TGO_MSL_2019_277_01	Sol-02545M21:09:38	00:17:00	32000.0		145.80 Mibit	Two-way	99
45451	TGO_MSL_2019_277_02	Sol-02545M23:06:10	00:17:00	32000.0		191.82 Mibit	Two-way	99
35460	MRO_MSL_2019_277_02	Sol-02546M02:54:31	00:14:00	32000.0		349.06 Mibit	Two-way	99
25461	Sol_2546_AM_HGA_DFE	Sol-02546M10:10:00	00:30:00		1000	0.00 Mibit	One-way	
35461	MRO_MSL_2019_278_01	Sol-02546M14:41:28	00:14:00	32000.0		287.38 Mibit	Two-way	99
45460	TGO_MSL_2019_278_02	Sol-02546M22:01:12	00:12:00	32000.0		316.36 Mibit	Two-way	99
55475	MVN_MSL_2019_278_04	Sol-02547M00:33:58	00:27:00	32000.0		653.44 Mibit	forward_and_return	99
25471	Sol_2547_AM_HGA_DFE	Sol-02547M09:05:00	00:30:00		1000	0.00 Mibit	One-way	

Data Acquired Summary (by plan)	Handover Sol-02547M09:37:00
Critical (Bin 1-43):	35.69 Mibit
High (Bin 44-66):	285.33 Mibit
Medium (Bin 67-86):	172.20 Mibit
Low (Bin 87-99):	105.14 Mibit
Total:	598.35 Mibit

Instrument Data Acquired Summary	Totals
Critical (Bin 1-43)	1.39 Mibit
High (Bin 44-66)	285.03 Mibit
Medium (Bin 67-86)	161.56 Mibit
Low (Bin 87-99)	97.18 Mibit
Total	545.16 Mibit

	Repri/Retran Delta (Mibit)	De De (M
Critical (Bin 1-43)	0.0	
High (Bin 44-66)	0.0	
Medium (Bin 67-86)	0.0	
Low (Bin 87-99)	0.0	-(
Sent Data	0.0	

Figure 9. Tactical plan downlink usage

Toolset parameters

Since the new toolset went active, MSL has been using parameters to select up to 4 relay passes per sol that return up to 2000 Mbit of data. This is much more data volume than was returned before TGO and MVN became part of MSL's relay orbiter set, and often more data than the rover is actually recording in a given sol. The current science office guidelines are to only record 450 MiBits of science data in a one-sol plan, 750 MiBits in a 2-sol plan, and 1100 Mibits in a 3-sol plan. This is for higher priority science data in bins 1-83; more science data can be recorded in bins 84-99, as well as the engineering health and safety data that is high priority. Once all the recorded data is downlinked the rover will send fill data to the orbiter, which is not an optimal use of resources (awake time on the rover, relay time on the orbiter, processing time on the Earth ground stations). Figure 10 shows average data volume return per sol.

critical pass selection is implemented (approximately November 2019), the toolset's pass selection parameters are likely to be updated after consultation with the science office, perhaps to 3 relay passes per sol maximum, 1000 Mbit total data return (no change to decisional pass selection logic).

This would be helpful to tactical planning as each relay pass requires the rover to be awake and usually consumes 80 Wh (Watt-hours) of power for a standard length pass; MVN passes that are 30 minutes for downlink are 46 minutes long with pass preparation/cleanup using 120 Wh of power. As the rover's power source (RTG, Radioisotope Thermoelectric Generators) decay with age (approximately 4% power loss per year), science activities are more and more limited by the available power, which is about 90 W continuous from the RTG as of August 2018, stored in two 43 amp-hour lithium-ion batteries that are managed to never go below 27% (modeled) state of charge. RTG power is shunted when the batteries are full, and used to charge the batteries when the rover total power load is less than the RTG output.

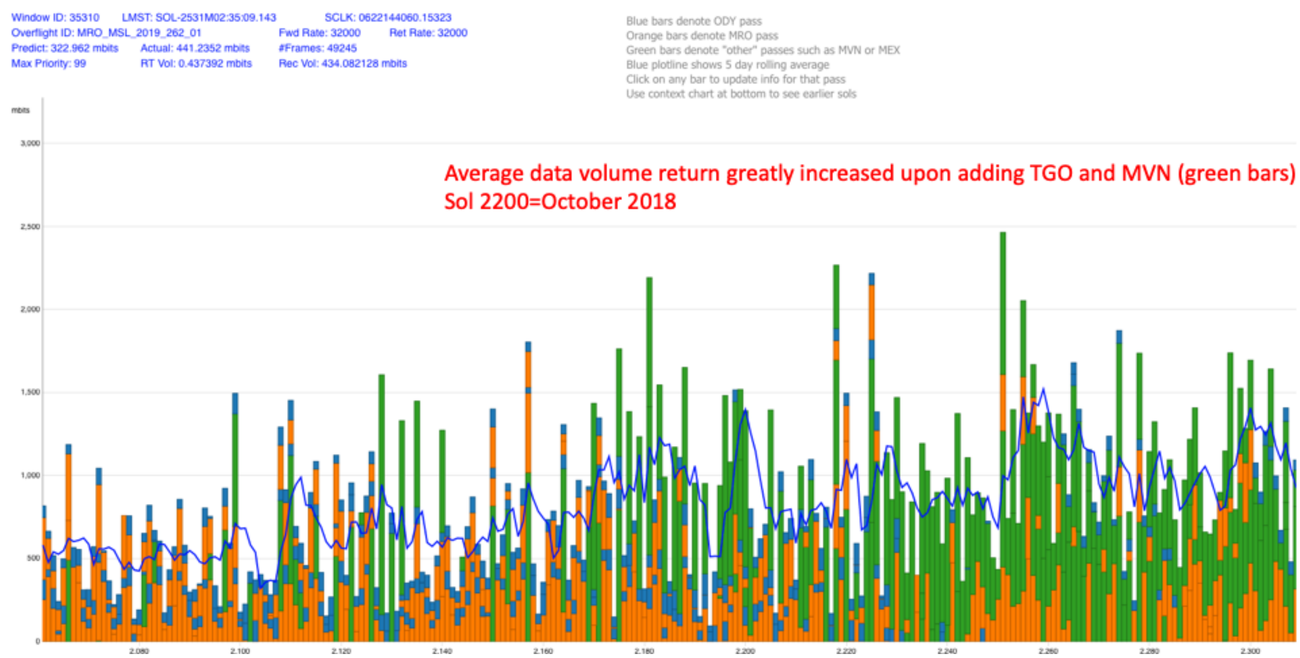

Figure 10. Data volume actuals, per sol and per pass

Prior to September 2018, it was rare to ever empty bin 99; there was a backlog of low priority science data, and just the MRO and ODY orbiters to play data back. On September 15 2018 (sol 2172) the MSL rover experienced an anomaly in the data management flight software module in which the /dp (data partition) memory failed to mount, and thus no data products could be recorded (both science data and recorded engineering health and safety data). Eventually the rover's computer memory was reformatted on March 9 2019 (sol 2342), resulting in the loss of the stored lower priority science data from before the anomaly. Starting from an empty slate, and with TGO and MVN joining the relay orbiter set in 2018, it became more likely to send fill data with the 4 relay passes/2000 Mbit pass selection criteria.

Critical pass selection

One aspect of relay pass selection was not implemented in the initial revised toolset – critical pass selection. Distinct from decisional pass selection, a critical pass is one that downlinks to Earth as early as possible in a given planning day for the purposes of vehicle health and safety assessment. A critical pass should downlink at least 50 Mbit of data and occur after 1400 LMST, downlinking soon after. Once

While science activities are seldom limited by data volume requirements (except in the case of small decisional passes), power is another story. The rover entered its third extended mission (EM3) in October 2019. EM3 power analysis showed that a standard weekend plan involving all science instruments, use of the rover arm, and a drive is not possible starting in October 2021 without additional rover nap time, and even in 2020 requires additional nap time compared to earlier years. Optimizing awake time for relay passes to the bare minimum needed for critical data return would enable more science operations time.

Another change for EM3 regards budget reductions. The money provided by NASA to JPL to operate the MSL rover covers many teams; engineering, planning & execution, science operations, and science analysis. With a reduced budget starting in October 2019 MSL decided to reduce the number of planning sols per week, which allows for reduced staffing. MSL, since a few months after launch, tactically planned five days a week when Earth-Mars geometry allowed for it. For EM3 MSL went to a maximum of four planning sols a week, taking every Thursday off. The current relay pass selection toolset does not take planning sols into account; even for weekend days the tools try to schedule optimal decisional downlinks. A future toolset improvement could be for it to treat Thursday, Saturdays, and Sundays differently than planning days by skipping some of the decisional pass logic; science is still performed on nonplanning days so the CSP should still be kept clear, and in the case of anomalies passes will still be desired for timely receipt of health and safety telemetry.

With splitting of TGO passes now routine, MVN began exploring splitting their passes in mid 2019. However solar conjunction in late August/early September (where the sun and Mars are in the same part of the sky as viewed from Earth, during which interference from the sun precludes commanding of spacecraft at Mars) and a MVN eclipse season in October 2019 interfered with testing MVN split passes; testing will occur in November 2019. It is anticipated the same MaROS fields used for TGO split relays will function similarly for MVN, and the current NSY coordination process will be extended to include MVN as well.

Future tool plans

A GUI (graphical user interface) is being developed that will display, per sol, all possible relay passes and any non-relay periods. After the tool selects candidate relay passes the communications team member could then easily change the selections using the GUI. In addition the tool would then update MaROS with the final relay pass selections and required parameters (such as for split passes), alleviating the need for hand edits.

Automated update capabilities for relay passes already onboard a lander are also in work, particularly for supporting MVN geometry shifts due to OTMs.

A change to how MVN pass durations are calculated is desired, as 30 minute passes use more power and often result in more data volume capacity than is required. Excess data volume can cause latency problems if a scheduled MVN-to-Earth downlink cannot completely play back all the MSL data onboard the relay orbiter.

3. CONCLUSIONS

The new MSL pass selection tools have been extremely helpful in managing four relay orbiters and assisting in sharing passes between two landers. The addition of more landers and/or more orbiters will certainly increase the complexity of scheduling relay passes, especially if the landers are close enough together to have pass interference (two landers can see the same orbiter at the same time). If all orbiters used the same two week planning cycle that could also reduce complexity.

The Mars 2020 rover, launching in mid 2020 and landing on Mars February 2021, will be in Jezero Crater [Figure 11] at approximately 18.4° N latitude, 77.5° E longitude. MSL, as of August 2019, is at 4.7° S, 137.38° E, while NSY is stationary at 4.5° N, 135.9° E. While Mars 2020 is appreciably farther from MSL than NSY is, crosstalk could still be an issue for the high elevation parts of MVN's elliptical orbit. In addition to crosstalk, another complication of multiple landers is that the relay orbiters are trying to perform science of their own and thus limit both the amount of time devoted to relay and the number of relay passes per day. ExoMars' Rosalind Franklin rover will utilize the TGO orbiter for its relay communications, another potential impact to the number of overflights MSL can request.

Potential multimission improvements for Mars relay planning

The number of communications planning team members on each orbiter and lander team working on scheduling relay

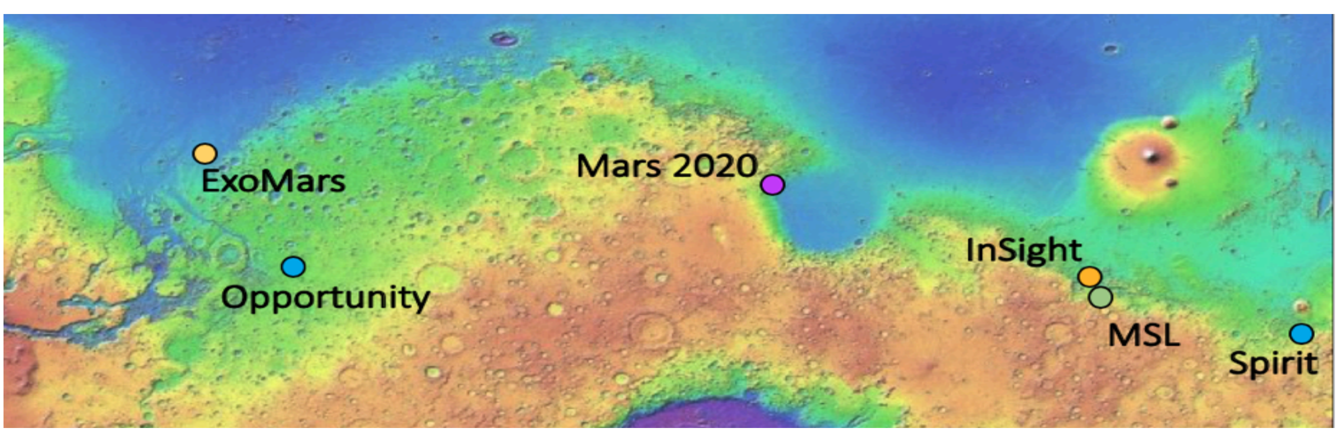

Figure 11. Rover locations on Mars

passes could be decreased if a universal scheduling tool was built based on some of the algorithms developed for MSL's new communications planning toolset. MaROS itself could be enhanced with rules for each lander's desired number of passes/total data volume return/preferred timing of passes, etc. Along with the existing relay limitations and non-relay zones for each orbiter and geometry information, a preliminary schedule for each lander could be autogenerated for each planning cycle that handles split passes as well [Figure 12]. A paper is in work for SpaceOps 2020 on this topic, including a new relay telecom predictor[5].

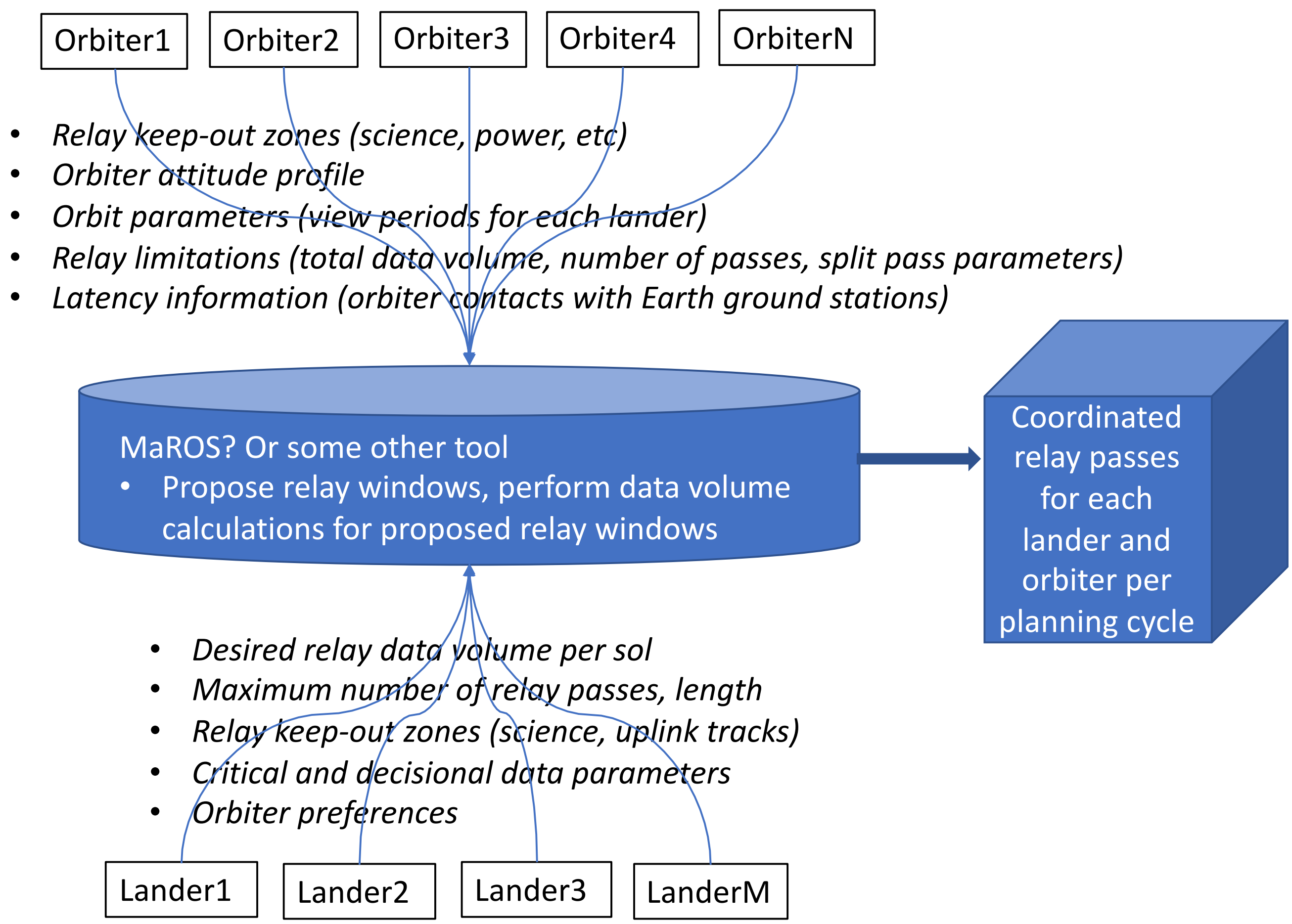

Figure 12. Universal Mars Relay scheduling tool

Lander teams would then just review the output and approve it or negotiate changes with the other landers. The effect of late orbiter overflight geometry changes could also be automated. Less work for project-specific communications planning team members would also help with the reduced budgets most extended missions face, impacting science return less.

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BIOGRAPHY

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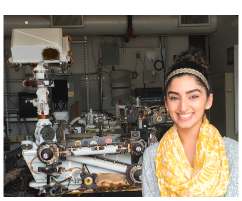

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