Earth-Mars Communication Windows Usage Study

It’s all about time!

Marc Blanchet, marc.blanchet@viagenie.ca, IETF 121, Dublin, 2024-11-04

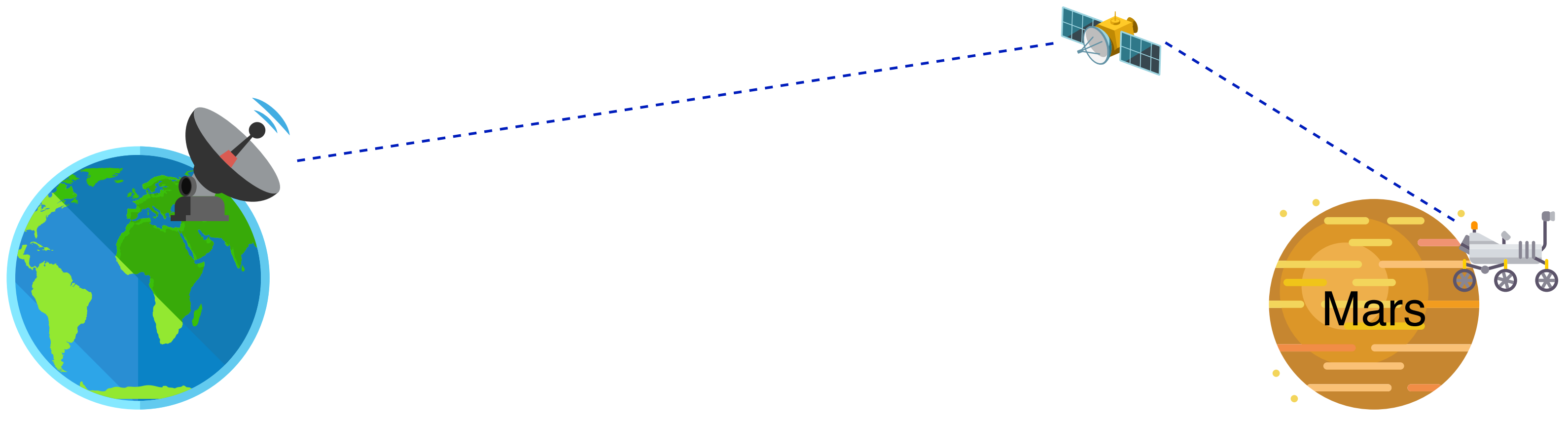
In collaboration with NASA/JPL

Terminology

- Different terms used by different areas
- For the purpose of this presentation
  - Direct-From-Earth = DFE = uplink = forward
  - Direct-To-Earth = DTE = downlink = return
  - Relay = orbiter = satellite = forwarder
  - Lander = rover

Introduction

- Study done with NASA/JPL
- Dataset of 3 months(2024Q2) of communication windows plans from the MAROS database, between:
  - Earth->Mars orbiters
  - Mars orbiters<->rovers
  - Mars orbiters->Earth



- Currently, each mission (DSN, orbiter1, orbiter2, rover1, rover2, …) inputs data in the database, and then comm windows are manually chosen and dedicated to a single mission

Goals

- Identify and understand communication windows with real data
- Use real comm windows data for larger IP network simulations
- Use as input to network/protocol engineering: on scheduling, on planning, on storage capacity and holding time, on protocol timing, …
    - N.B. we don’t have any data like that for Moon, yet.

Mars Spacecrafts Involved: Orbiters

- Orbiters:
  - MEX: ESA Mars Express
    - not used in the study, as it is used as backup and do not offer up/downlink comm windows (Mars->Earth)
  - TGO: ESA Trace Gas Orbiter
    - Typical: rover pass every 12 hours for 10 minutes; uplink every 1hour for 1 hour; downlink every 2 hours for 1 hour
  - MRO: NASA Mars Reconnaissance Orbiter.
    - Typical: rover pass every 12 hours for 10 minutes; uplink every 2 hours for 1 hour; downlink every 2 hours for 1 hour
  - ODY: NASA Odyssey
    - Typical: rover pass every 3 hours for 10 minutes; uplink every 10 hours for 1 hour; downlink every 2 hours for 1.5 hour
  - MVN: NASA Maven
    - elliptical orbit. Typical: rover pass every 6 hours for 25 min; uplink every ~ 3 days for 6 hours; downlink every 6 hours for ~2 hours
- N.B. the <u>pass timings are very very variable. Numbers above are just examples, for a general indication</u>. Don't conclude anything with those.

Mars Spacecrafts Involved: Landers

- Rovers/Landers:
  - MSL: NASA Curiosity
  - M20: NASA Perseverance
  - NSY: NASA InSight
    - not used in the study, as it is near to mission termination and no signal has been received, but we could have used it as we have all the possible comm windows
  - N.B.: Ingenuity (helicopter) is not seen in this data, as it is being proxied by M20

Raw Data

- 4500 records of Mars orbiters-landers/rovers possible communication windows
- 1300 records of Earth->Mars orbiters possible communication windows
- 3274 records of Mars orbiters->Earth possible communication windows

Time Reference

- Not all rows/files in the same time reference (some UTC, some Spacecraft local time).
  - Had to convert data to the same time reference (spacecraft time)
    - which includes taking into account the light time delay(OWLT) at that time period (~15-17 min),
      - which varies every day (not much considering the overall time, but still ~1sec/day)
  - But given the software tools for time/date are based on Earth timezones, we set the spacecraft local time artificially to UTC for easier calculations.

Considerations

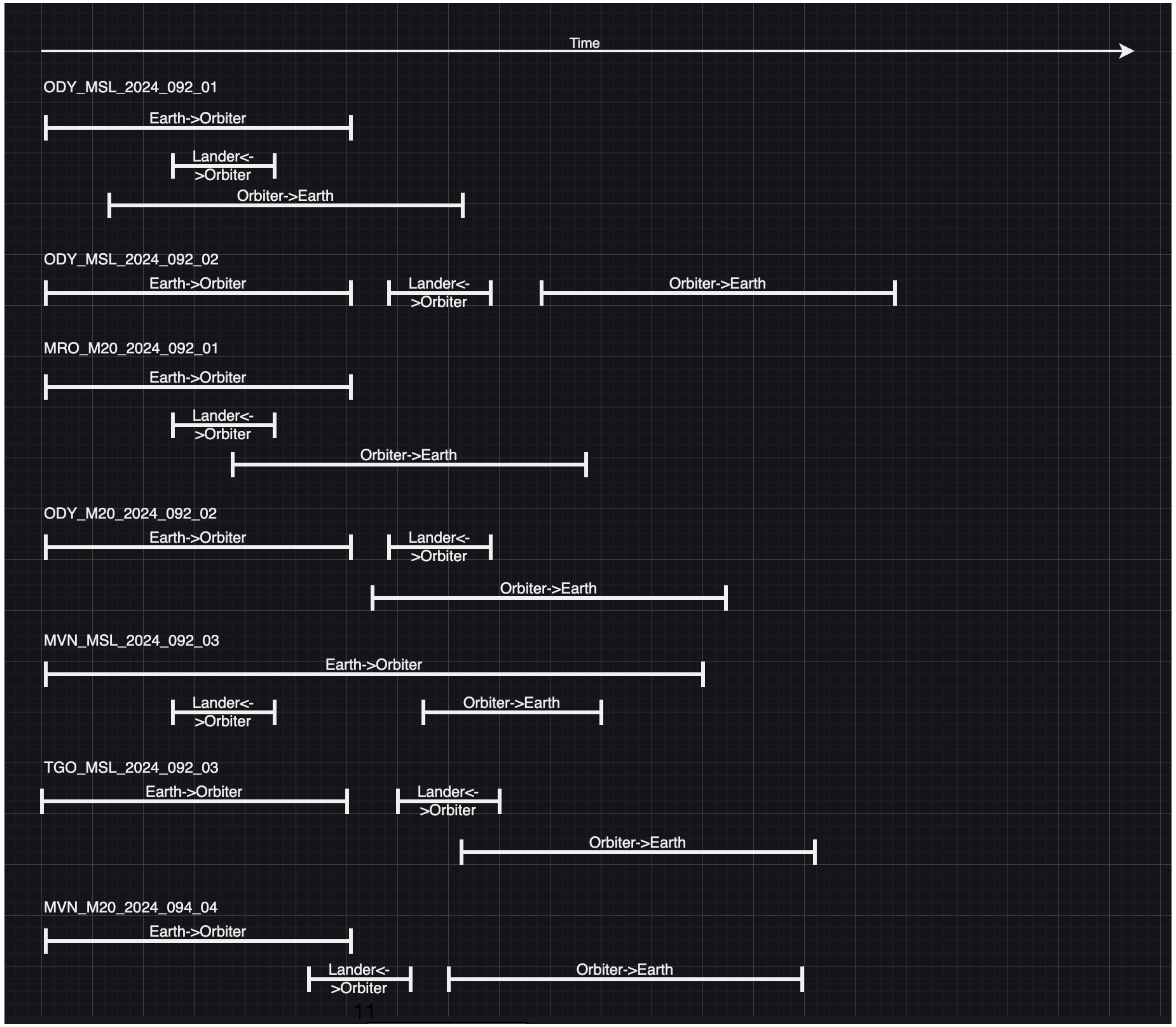
- Orbiters<->rovers: full duplex
  - Most of these comm windows are _not_ used by missions (for various reasons).
  - In this study, we used them all
- Earth-Orbiters:
  - one-way, different comm windows for each direction
    - Earth->Orbiter1, Orbiter1->Earth have different comm windows
- Data(frames) is held in the orbiter until the next comm window to the next hop happens
  - FYI, MRO has 120G of solid state memory
- The bottleneck is the rover->orbiter link bandwidth (and limited duration), not orbiter storage space, nor Earth-Orbiter links.
  - Typically, 1Mbps, 15 min window = 100MB/window (with a lot of variation)

High-Level Algorithm

- Remove entries for MEX and NSY.
  - We could have kept NSY as we had the data, while MEX we don't have the up/downlink data
- For each Orbiter-Rover comm window:
  - Find the latest before (or overlapping) Earth-(Same)Orbiter window
  - Find the soonest after (or overlapping) (Same)Orbiter-Earth window
  - Calculate:
    - "Best" RTT
    - Orbiter holding time (duration of data storage until it could be forwarded)
- Calculate various statistics: average, min, max, …
- Assume usage of all communication windows

Some Window Sequence Types

- Not all types
- Not at scale
- Some provide direct end to end (no storage or hold time)
- Some use storage in both directions
- Overlap windows are currently not used by missions because some current relay limitations
- More not shown



Results (Preliminary)

- “Knitted” 2534 round trip paths: Earth-MarsOrbiter-rover-sameMarsOrbiter-Earth.
  - of those only 532 (~20%) were actually used by the missions
- Uplink (Earth->Mars) comm window duration:
  - Average: 2.5h
  - Minimum: 10 min
  - Maximum: 10h
- Downlink (Mars->Earth) comm window duration
  - Average: 1.5h
  - Minimum: 1 min
  - Maximum: 10h
- N.B. with a lot of variations

Results (cont.)

- "Best" RTT:
  - Approximated, using some heuristics: packet sent the latest time to reach the orbiter, returned the earliest time to reach Earth. (Typically, RTT will be greater than that)
  - Average: 15h 55m
  - Minimum: 37m
    - when both uplink and downlink windows are overlapping orbiter-rover window. Therefore RTT =~ 2 way light time
  - Maximum: 171 h =~ 7 days.
    - Maven had a 7 day off between two passes

Results (cont.)

- Orbiter holding time (duration of data storage):
  - Average: 14h 56m
  - Minimum: 0
    - when both uplink and downlink windows are overlapping orbiter-rover window
  - Maximum: 170 h =~ 7 days

Important Consideration

- The “knitted” paths are based on real data
  - But they do not represent what missions currently use
  - they use a much smaller subset and have many additional considerations
    - Example: for one orbiter (MAVEN), there should be a 4 hours no comm window between each rover (MSL, M20) comm windows, so that the batteries of the orbiter can be charged in between. (for comm windows that are in the daylight)
- Instead it provides an input to properly design protocols that work in this environment.

TVR Implementation

- Time-Variant Routing(TVR) is an IETF group working on a data model (draft-ietf-tvr-schedule-yang) defining schedules to influence routing decisions.
- We generated the TVR yang communication windows of the Mars orbiters using the data.
- The current yang data model uses UTC as the time zone, which is sub-optimal for Mars orbiters, as it will need to be re-calculated locally based on the transmission light time, which varies. Therefore, it means the local device should have a table of OWLTs for the period or to calculate itself the OWLT. And are not comparable with other data, as they depend on when. SCET (Spacecraft local time) is used by NASA/space agencies/missions for on-board time.
  - Possible solutions:
    - Use the “local offset” in the date (aka: YYYY-MM-DD HH:MM:SS +HH:MM to correspond to the transmission light time at that moment. Could be computed by the orchestrator. But resolution is minutes, not seconds. Will tools work with a different offset for every record (they should!)?
    - Define a local timezone and use it in the data model. (However, then all the tools, libraries, … for time/date are not aware and will need to be augmented)
    - Don’t do anything, and just recalculate locally with variable OWLT
    - Punt this to someone else…

Next Steps

- Got additional data recently from JPL and will do another pass
- Estimate needed storage size
- Use the round trip paths data (interruptions, schedules, delays, …) into our testbed to simulate protocols, applications, ECN testing, …
- Input for discussion on scheduling, planning, comm windows hints in protocols, RTT calculations, storage capabilities, …
- Assess/augment/modify the TVR yang schedule data model
- Generate graphical timelines of the communication windows
- Create a generic model
- Train an AI model to predict next windows

Acknowledgements

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