Jet Propulsion Laboratory
California Institute of Technology

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Mars On-site Analytics Information and Computing

J. Vander Hook, T. Vaquero, F. Rossi, M. Troesch, M. Sanchez-Net, J. Schoolcraft, JP de la Croix, S. Chien

Joshua Vander Hook, PhD
Jet Propulsion Laboratory
California Institute of Technology
hook@jpl.caltech.edu ; 818-354-5455

Bottom Line Up Front

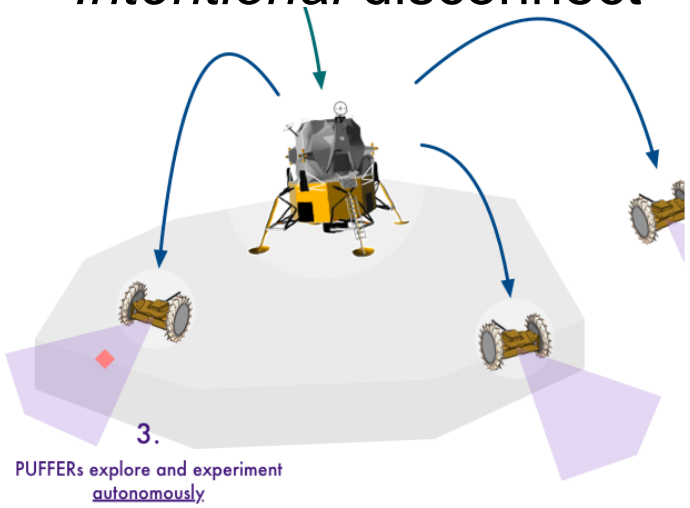
We present a **Mixed Integer Program** which solves for **processing** and **communication** schedules

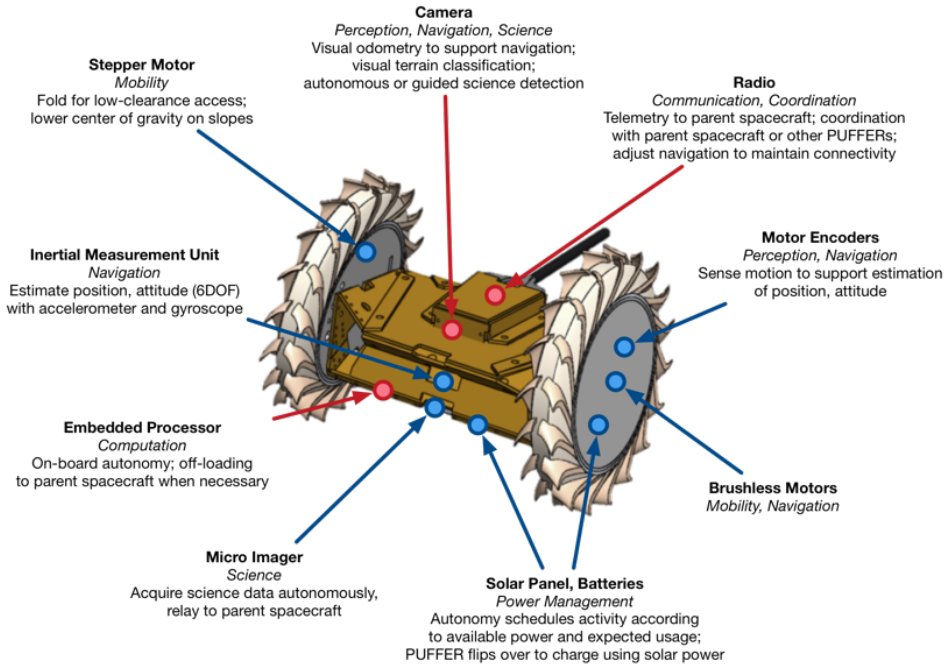
- on a **heterogeneous network**
- with **time-varying communication** links
- some tasks are **pinned** to some nodes
- some tasks are **optional**
- tasks have dependencies
- tested in a distributed system

Heterogeneous Network

Small / Multi-robot systems with intermittent connectivity

- CPU support nodes
- Network failures
- *Intentional* disconnect

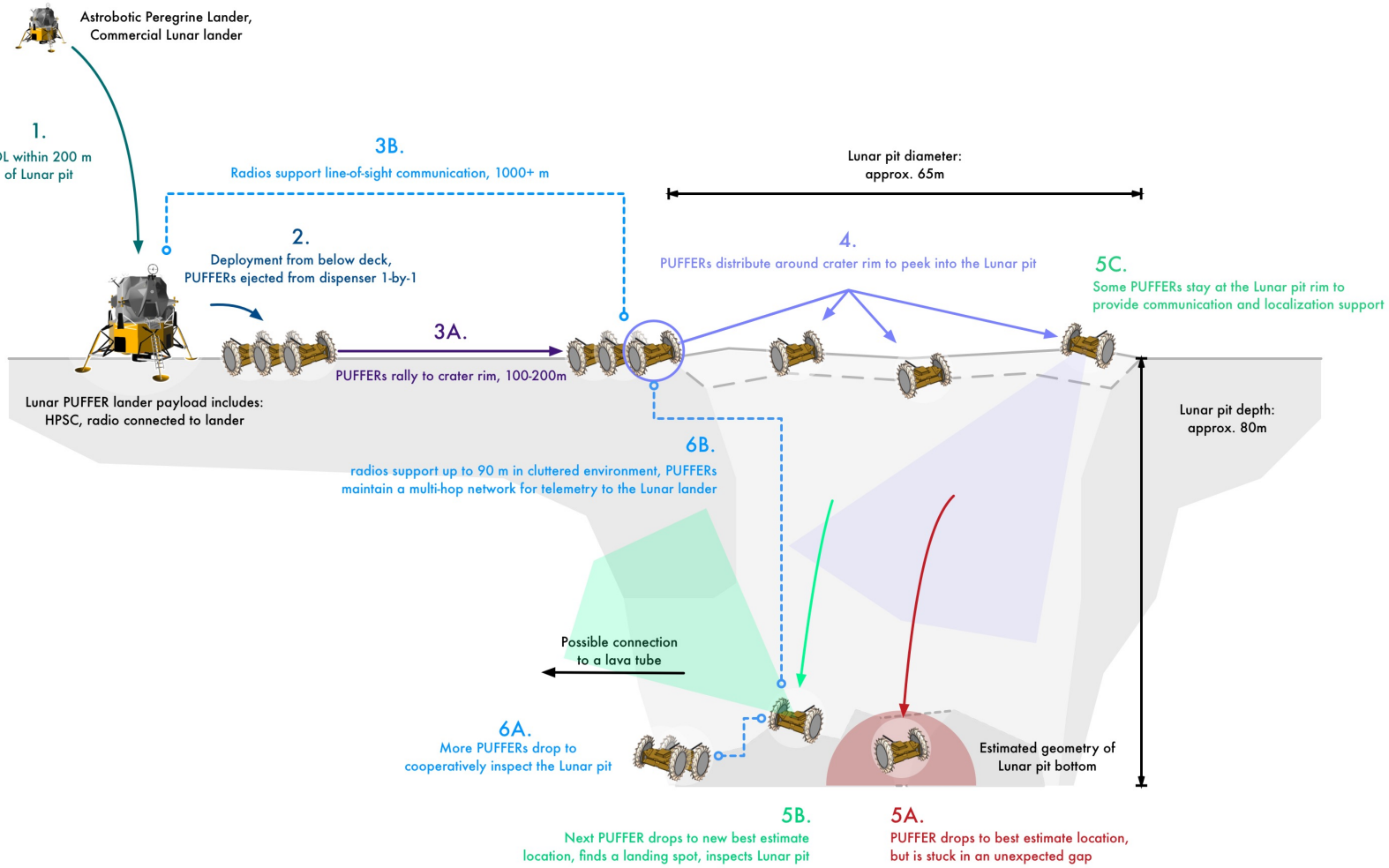




http://www.kiss.caltech.edu/lectures/2019_PUFFER.html

Heterogeneous Network

Small / Multi-robot systems with intermittent connectivity



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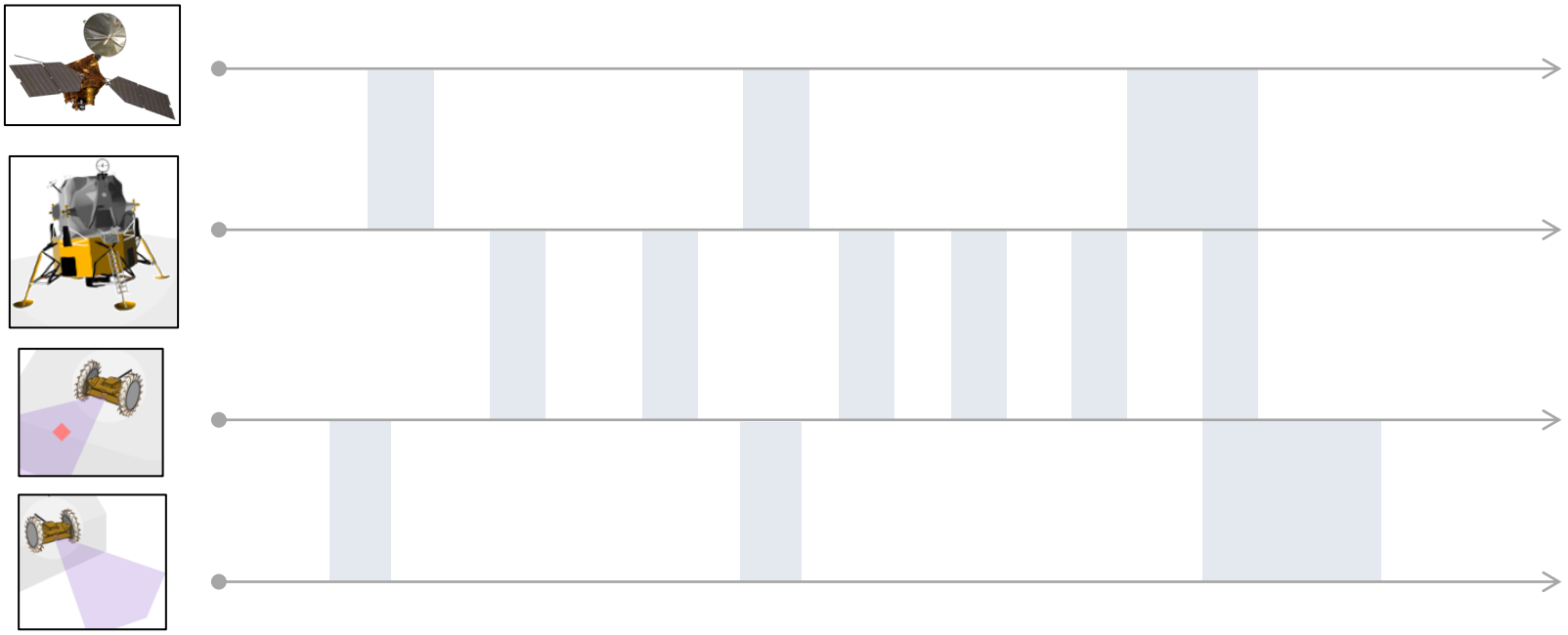
Time-varying communication links

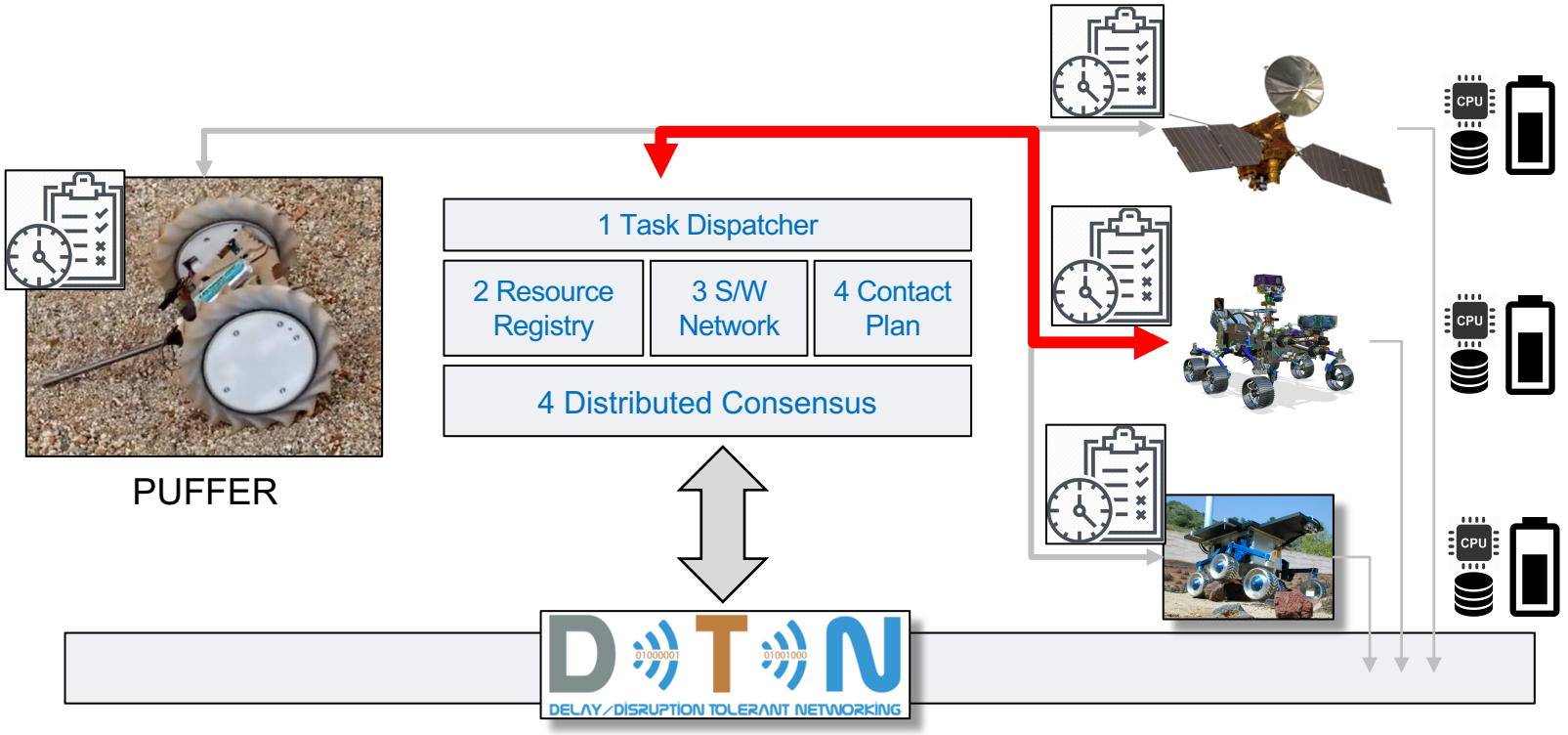
Delay / Disruption Tolerant Networking (DTN)

- Contact plan
- Mobile autonomous agents can share intended motion



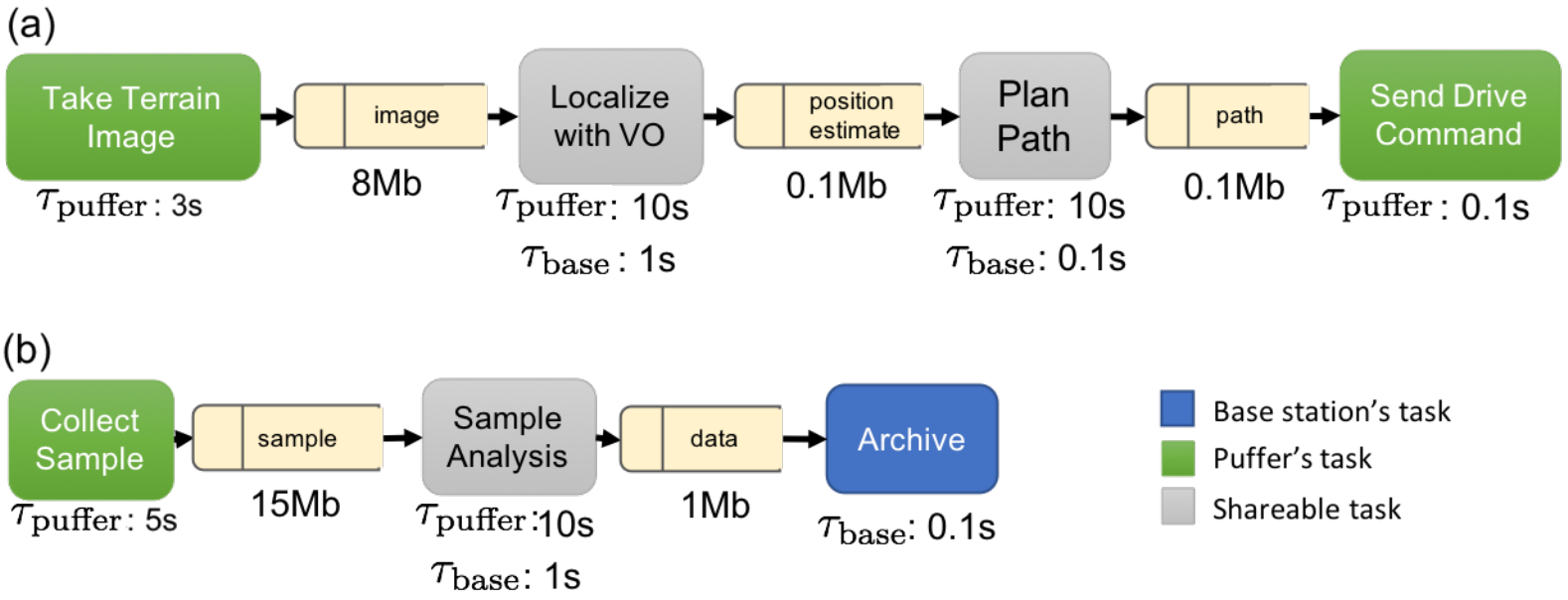
https://www.nasa.gov/content/dtn

Stack Overview



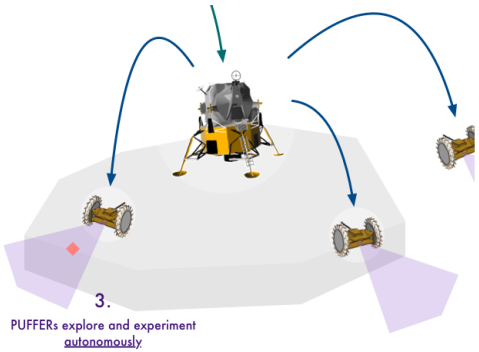
1. Pluggable Distributed Resource Allocator
2. Resource Registry: What tasks, battery, cpu, storage for each nearby node
3. (Ideally) Software Tasks for other nodes
4. All sync'd over the network

Software Network Models



(a) Housekeeping and (b) Science task chains

- "Archive" is optional, but rewarding



Reward

Agent, task, time

$$\sum_{i=1}^{N} \sum_{T \in \mathbb{R}} \sum_{c=1}^{C_d^\star - \tau_i(T)} r(T) X(i,T,c)$$

Max. number of optional tasks completed

$$\sum_{i=1}^{N} \sum_{c=1}^{C_d^\star - \tau_i(T)} X(i,T,c) \leq 1 \quad \forall T \in \mathbb{R} \tag{2a}$$

Optional tasks are performed at most once

$$\sum_{i=1}^{N} \sum_{c=1}^{C_d^\star - \tau_i(T)} X(i,T,c) = 1 \quad \forall T \in \mathbb{T} \setminus \mathbb{R} \tag{2b}$$

All required tasks completed once

$$X(i,T,c) \leq D(i,L,c)$$
$$\forall i \in [1,\ldots,N], T \in [1,\ldots,M], L \in P_T, c \in [1,\ldots,C_d^\star] \tag{2c}$$

Only start a task once you have req inputs

$$\sum_{T=1}^{M} \left[\sum_{j=1}^{N} / \left(C(i,j,T,c) + C(j,i,T,c)\right) + \sum_{\hat{c}=\max(1,c-\tau_i(T))}^{c} X(i,T,\hat{c}) \right] \leq 1$$
$$\forall i \in [1,\ldots,N], c \in [1,\ldots,C_d^\star] \tag{2d}$$

One thing at a time (cpu, coms, or idle)

$$D(i,T,c+1) - D(i,T,c) \leq \sum_{\tau=1}^{c} \sum_{j=1}^{N} \frac{r_{ji}(c)}{s(T)} C(j,i,T,c) + \sum_{\tau=1}^{c-\tau_i(T)} X(i,T,c)$$
$$\forall i \in [1,\ldots,N], T \in [1,\ldots,M], c \in [1,\ldots,C_d^\star - 1] \tag{2e}$$

Only have data by calculating or receiving

$$C(i,j,T,c) \leq D(i,T,c) \quad \forall i,j \in [1,\ldots,N], T \in [1,\ldots,M], c \in [1,\ldots,T] \tag{2f}$$

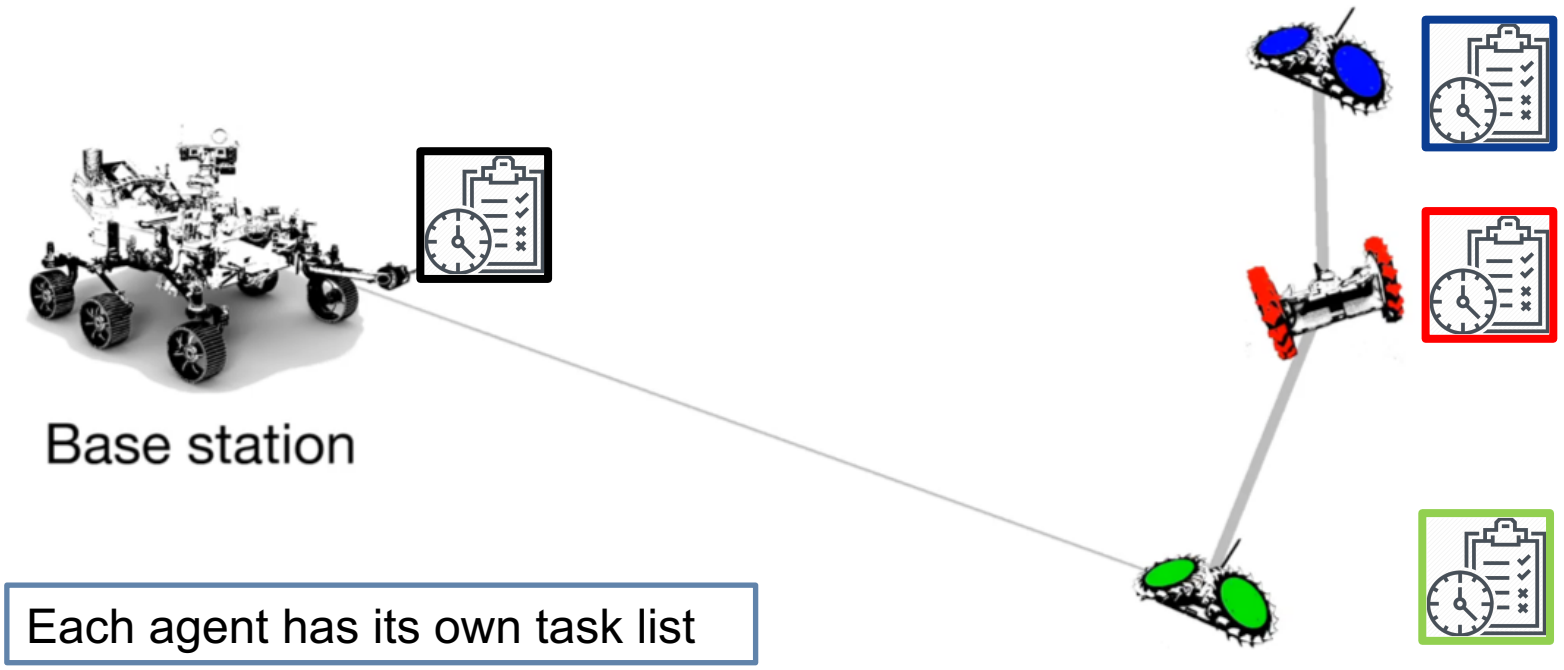
Only communicate what you have

$$D(i,T,1) = 0 \quad \forall i \in [1,\ldots,N], T \in [1,\ldots,M] \tag{2g}$$

Start with no data

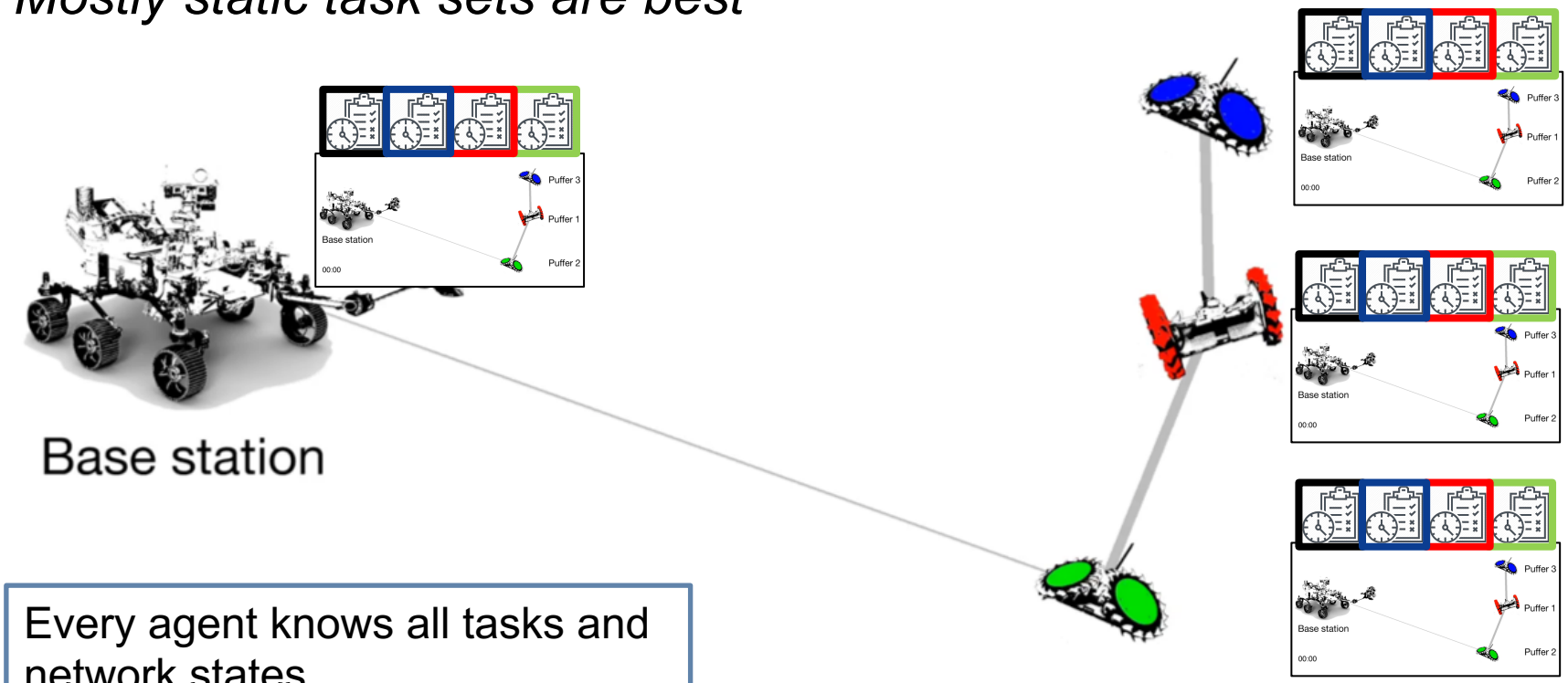
A word about distributed implementation

- Gossip, Plan, Act
- Caveat: consensus is hard, and we do require it



A word about implementation

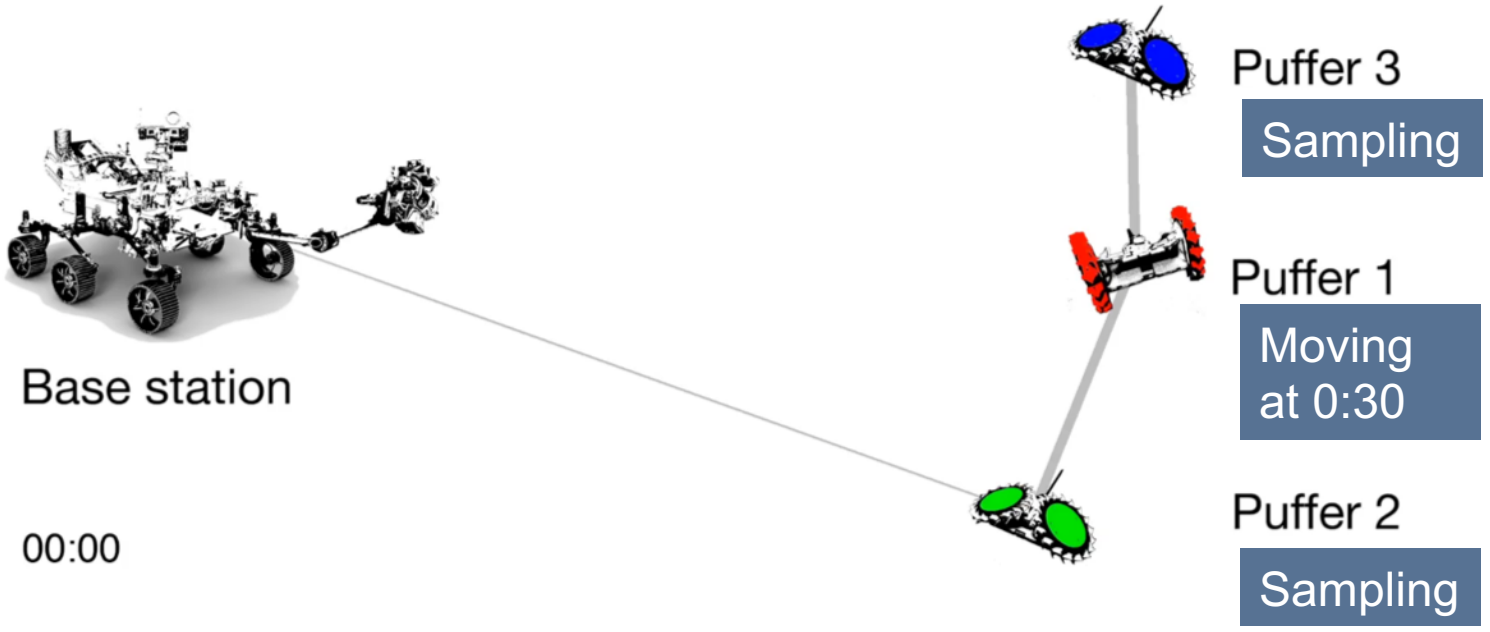
- Gossip, Plan, Act
- Caveat: consensus is hard, and we do require it
- *Mostly static task sets are best*



Every agent knows all tasks and network states

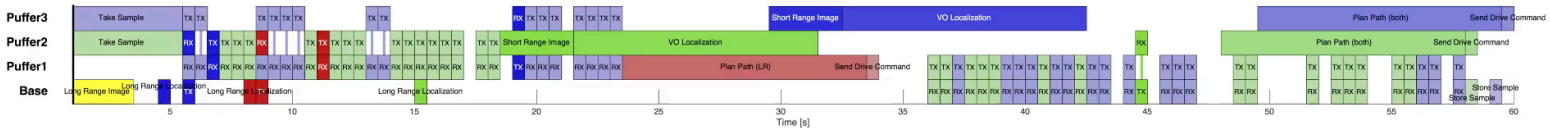
Example Solution

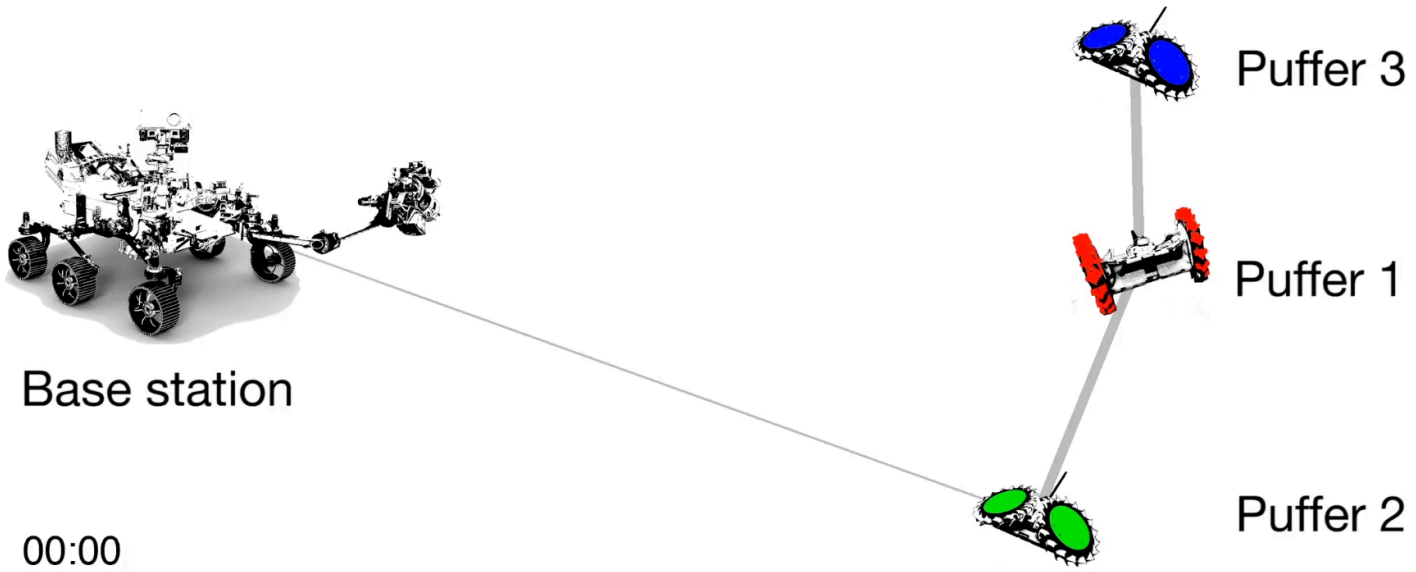
Data Mule



Example Solution

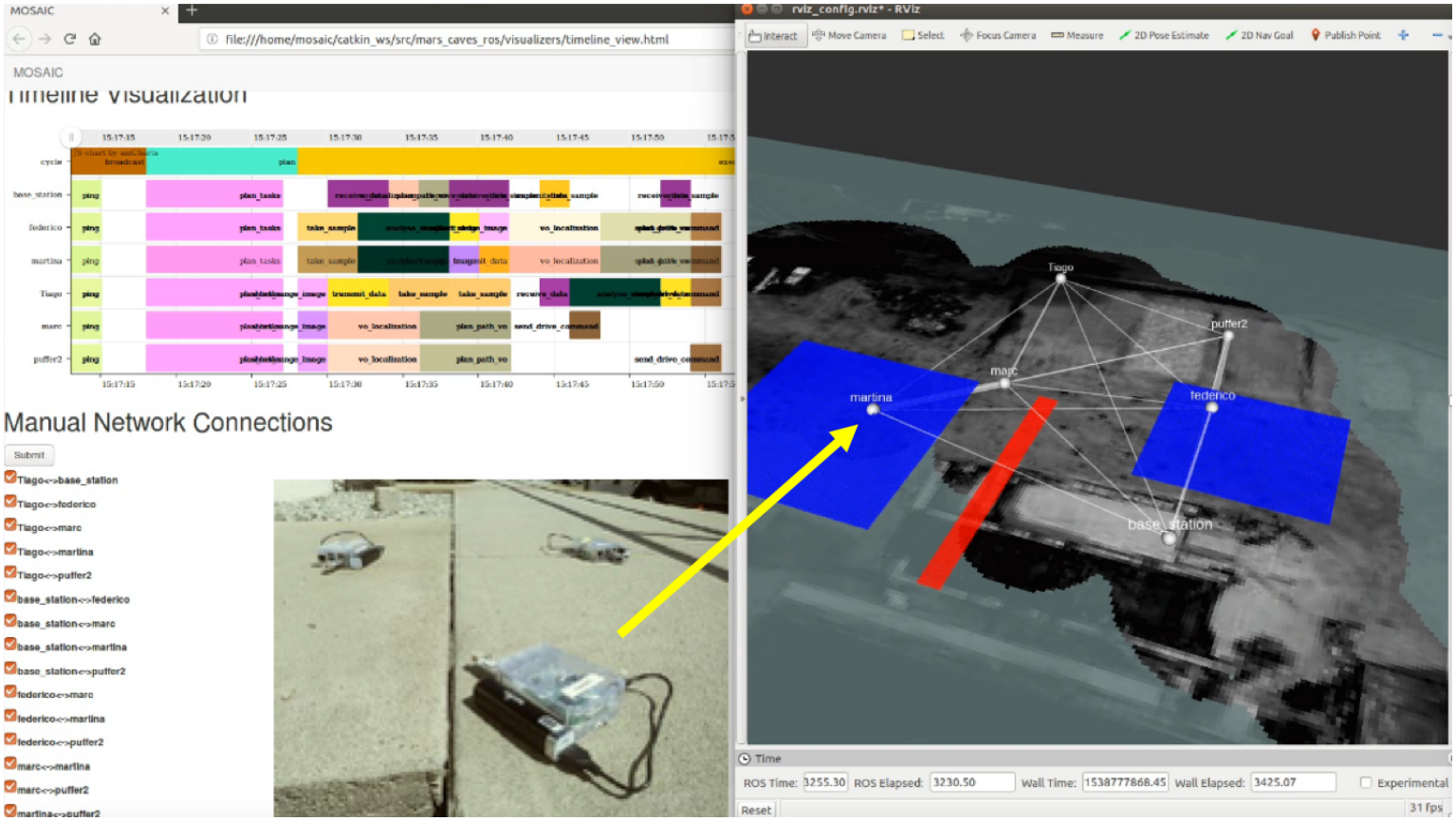
Data Mule

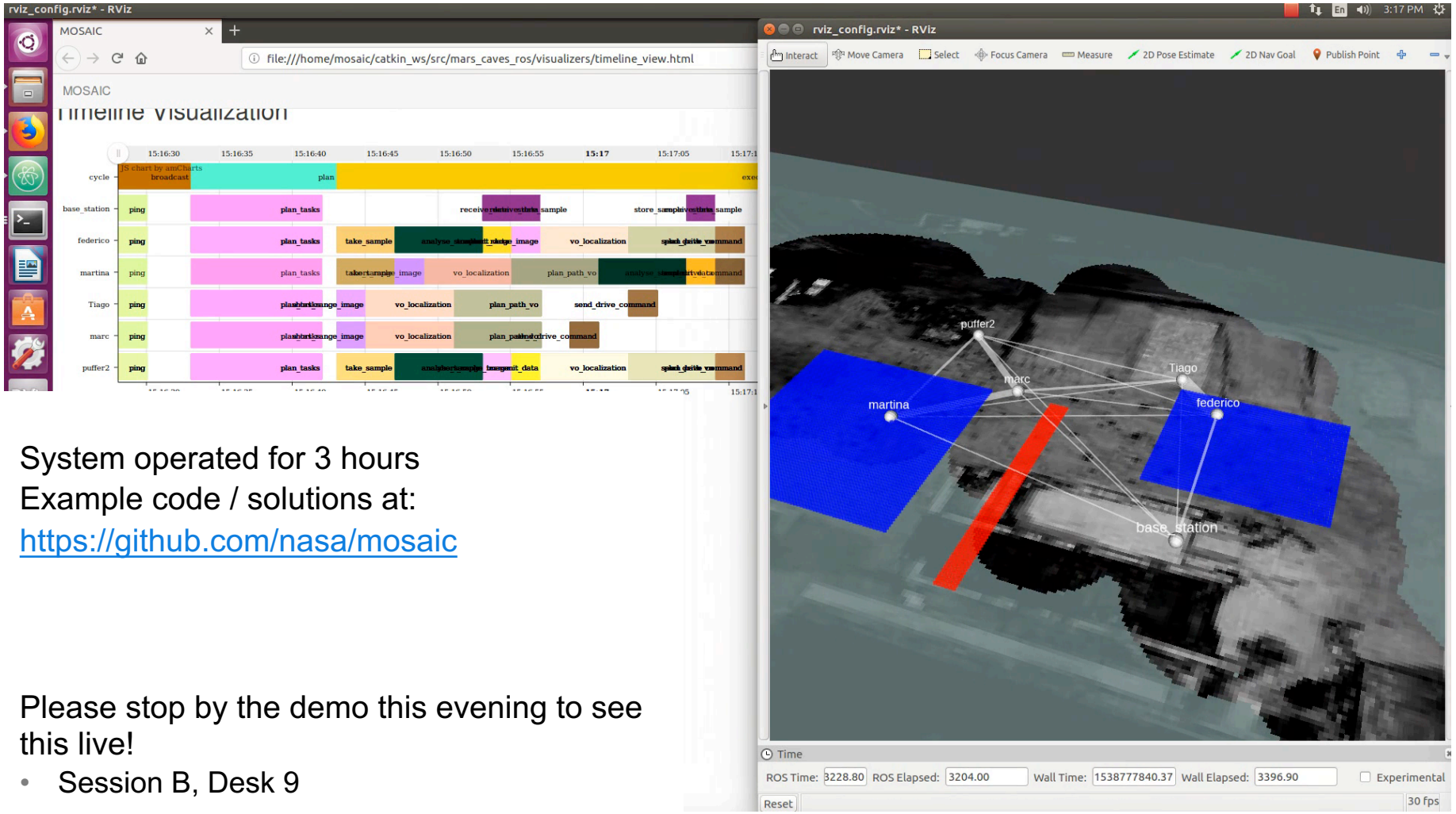




Field Tests (Video Preview)

Fully Distributed Systems



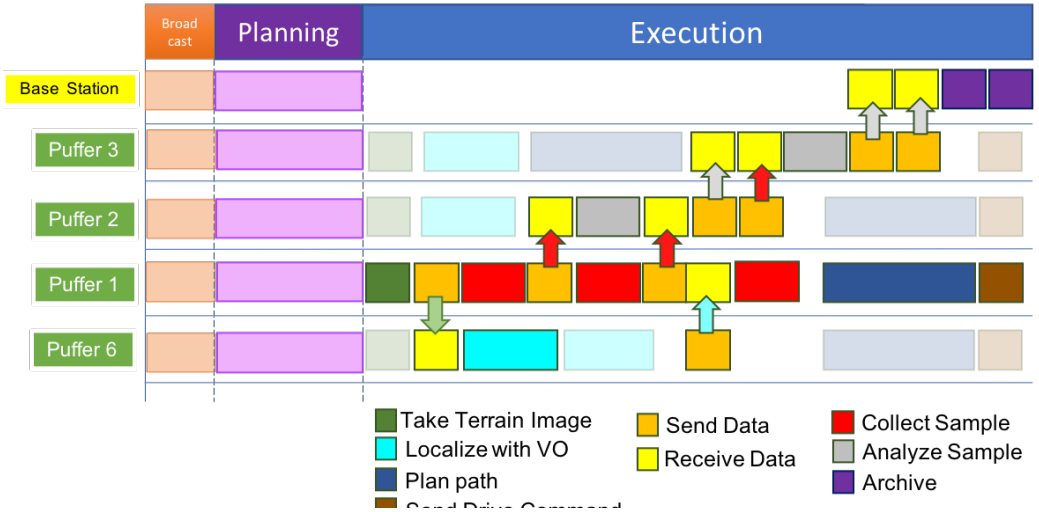


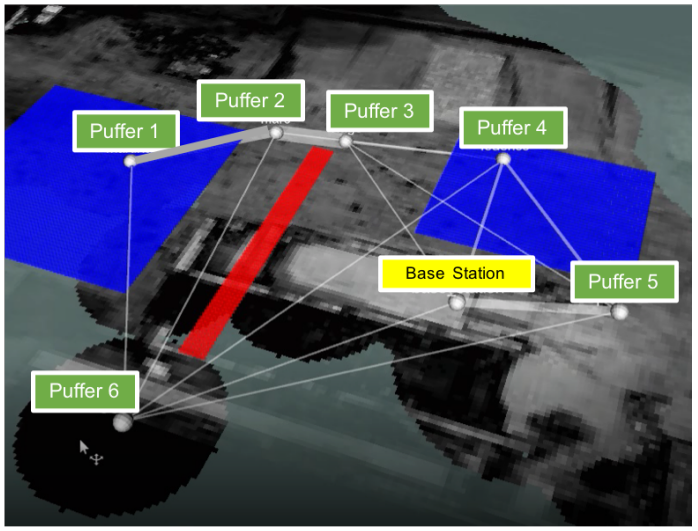
System operated for 3 hours
Example code / solutions at:
https://github.com/nasa/mosaic

Please stop by the demo this evening to see this live!

- Session B, Desk 9

Field Tests (Callout)





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Bottom Line

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Showed

- Emergent data mules, assembly lines in distributed system

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jpl.nasa.gov

Backup

High Performance Spaceflight Computing

Trim Video to about 13s

- Rad-Hard “Laptop like” performance going forward
- Other indicators: MarCO, Mars Heli
- Scalable computing / power requirements

Image from GCD slides

https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20180007636.pdf