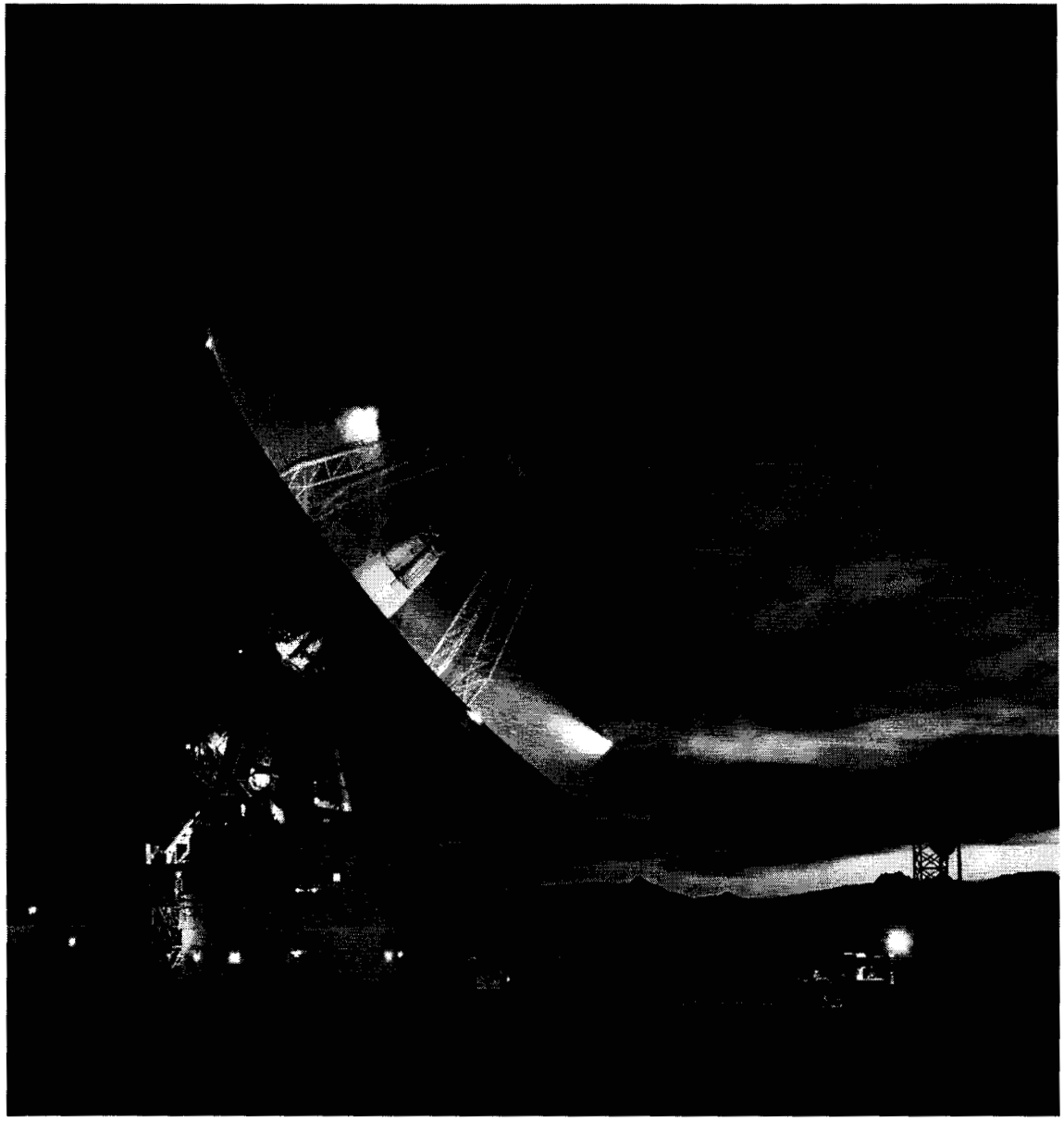
Interplanetary Network Directorate



Ground Segment Engineering and Architectures

Long-Haul Performance Tradeoffs

Presented by

Julian C. Breidenthal

Stephen A. Townes

Jet Propulsion Laboratory

June 3, 2002

Acknowledgements

The research described in this paper was carried out by the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration

The authors wish to thank _____ for their assistance during preparation of the paper

We also wish to thank NASA BEACON Architecture Team, particularly Charles Brown, Ken Freeman, Sina Javidi, Richard R. Kunath, Al Levine, Michael J. Manering, Peter Shames, William E. Teasdale, Bessie H. Whitaker, Keith A. Williams (lead), and Badri Younes for their assistance during the background development of this paper

Increasing Demand for Deep Space Communication

- NASA anticipates a significant increase in demand for long-haul communications services
  - Near term – increasing data production by more capable instruments, increasing number of missions
  - Far term – extreme missions, HEDS
- Range of communications challenges
  - Distances from 0.1 AU up to >200 AU
  - Bit rates at least >10 Mbps and perhaps >100 Mbps
    - for routine operating conditions for mid-range distances of a few AU
  - Emergency and critical operations
    - High reliability communication from spacecraft
    - Potentially limited resources or highly non-ideal operating environments

Architectural Styles Considered

- Radio communication
  - X-, Ka-, or W-band (60 GHz)
- Optical communication
- Single hop communication systems
  - Large Earth-based aperture
    - Monolithic apertures
    - Arrays
  - Single hop with large space-based aperture in the general vicinity of the Earth
- Multihop communication
  - A number of space-based relay terminals between the Earth and the target

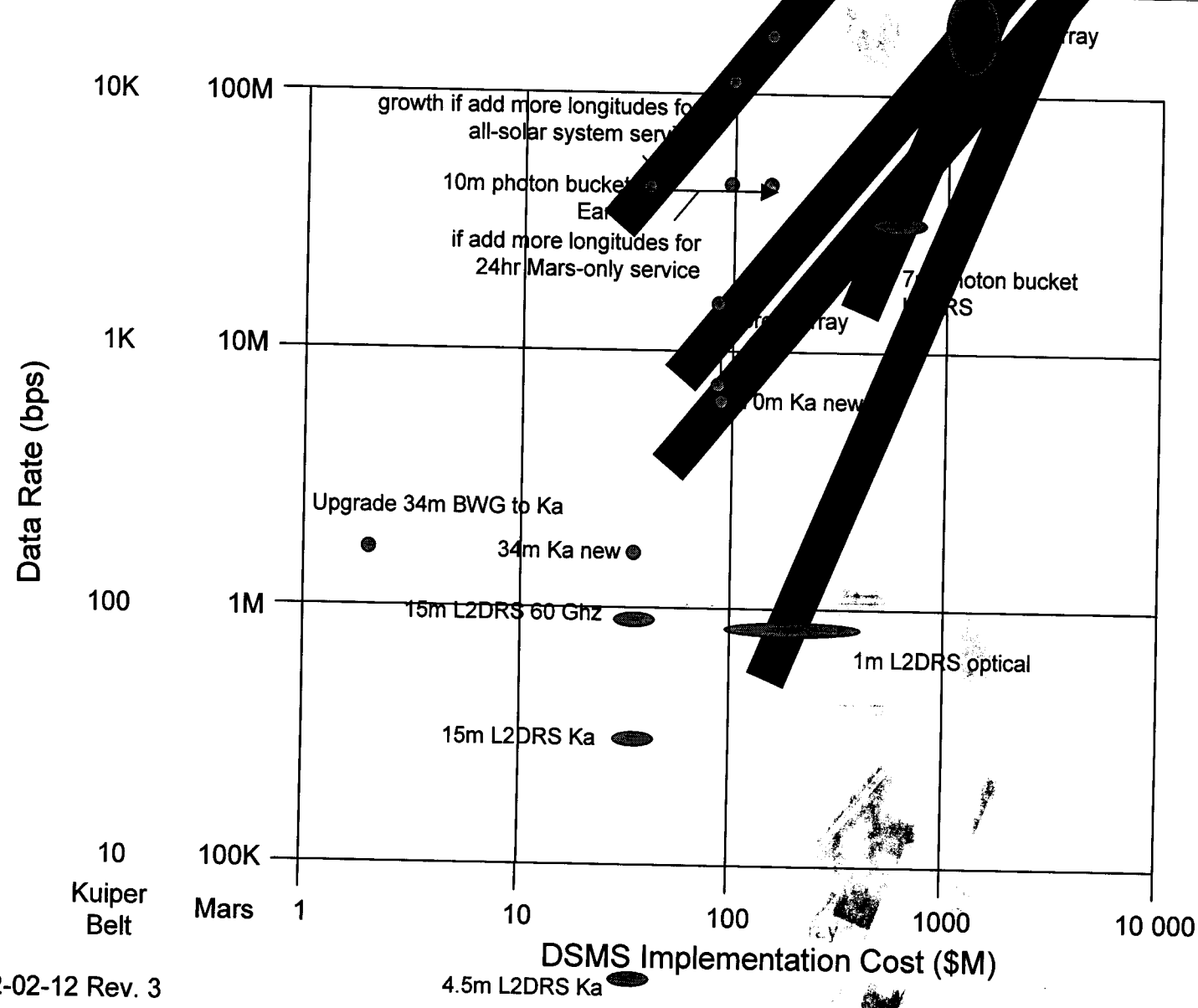
Application of Styles to Meet Demand

- Assumed that each of the architectural styles can be scaled to higher capacity by replication
- Single-hop: system capacity grows proportional to investment
- Multihop: system capacity grows with the square of investment
  - Consequence of inverse square law for space loss
- Evaluation Criteria
  - Considered only DSMS implementation cost
    - Not lifecycle cost
    - Not customer spacecraft (but did consider DSMS spacecraft cost)
  - Considered only Bit Rate based on physical limits
    - Not compared to customer data source distribution (e.g. Mars vs. outer planets)
    - Not reliability e.g. tolerance to system failures
    - Yes, included 90% weather (I think)

Sample System Characteristics

- Mars at Max range 2.3 AU
- Kuiper Belt 230 AU
- Spacecraft RF characteristics:
  - 100 W RF Pwr
  - 2.5 m Ant
  - Turbo Code
- Spacecraft optical characteristics:
  - 200 W DC Pwr
  - 40 cm Telescope
- Marginal cost for single RF L2DRS piggyback on some other spacecraft stationed at L2
- Full cost for optical L2DRS, incl. launch

Long-Haul Performance and Cost



Assumptions:

Mars at Max range 2.3 AU

Kuiper Belt 230 AU

Spacecraft RF characteristics:

100 W RF Pwr

2.5 m Ant

Turbo Code

Spacecraft optical characteristics:

200 W DC Pwr

40 cm Telescope

Marginal cost for single RF L2DRS piggyback

Full cost for optical L2DRS, incl. launch

Preliminary Conclusions

- Single hop large Earth aperture systems offer a five-to-tenfold advantage over the alternate solutions considered
  - Either optical telescopes, or arrays of medium-sized (around 10m) Ka-band antennas are very good
  - Too close to tell which will prevail when other factors are considered
- Conclusion applicable under a certain range of conditions:
  - Data rates from 100 kbps to 1 Gbps
  - Typical Mars distances (2.3 AU)
  - Typical spacecraft characteristics
  - Scaling to other distances is valid
- Space –based multihop solutions are competitive with the Earth-based approaches for ultra-high data rate demands
  - Data rates approximately greater than 1-100 Gbps at Mars distances
  - Spacecraft costs would have to fall by 5x – 10x for multihop to be competitive at the anticipated data rate needs