A Concept for a Constellation of CubeSats at the Lunar Lagrangian Point 1 (LL1) for radio aperture interferometry measurements: network analysis and simulation

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Outline

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  - Statistical analysis in case of spacecraft failures
  - Results for the statistical analysis
- Conclusion

SOLARA Mission Concept

- Space-borne radio aperture synthesis interferometer
- Observes frequencies from 30 kHz to 30 MHz
- Placed at LL1

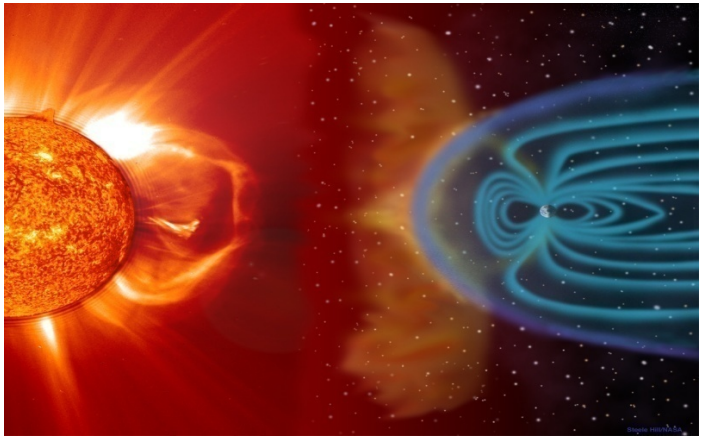


Image Credit: NASA/ESA

- Possible observations:
  - Coronal Mass Ejections: dangerous to spacecraft, astronauts, and terrestrial power grids. Can be tracked in 3D
  - Giant Planet Magnetospheres (Earth, Jupiter, Saturn, Uranus, Neptune). Has not been done since Voyager S in 1973.

Communication Network of CubeSats

- The concept is composed by 20 six-unit CubeSat spacecraft arranged in a rough 10-100 km configuration
- Collect data using dipoles and a distributed correlator for aperture synthesis imaging.

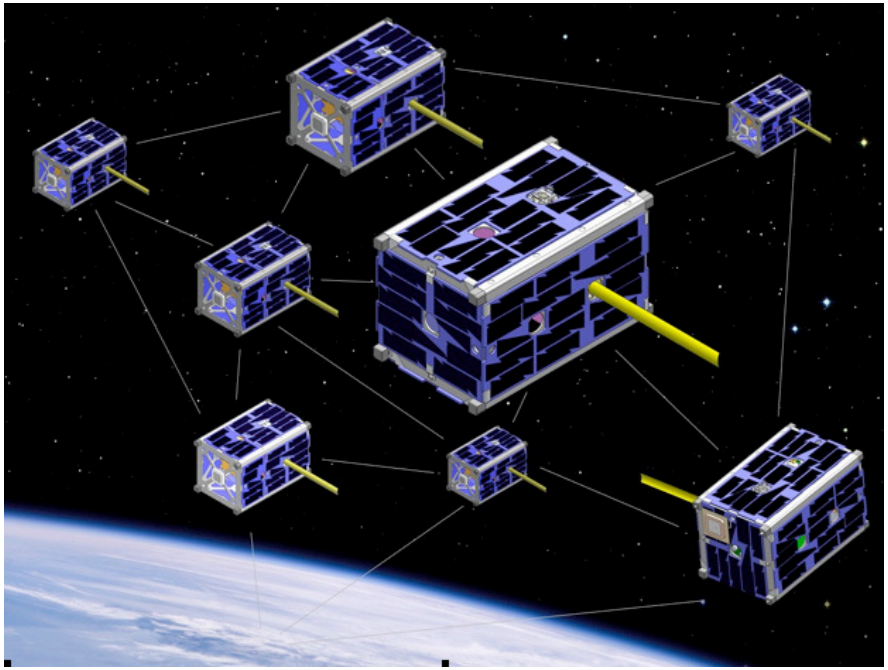
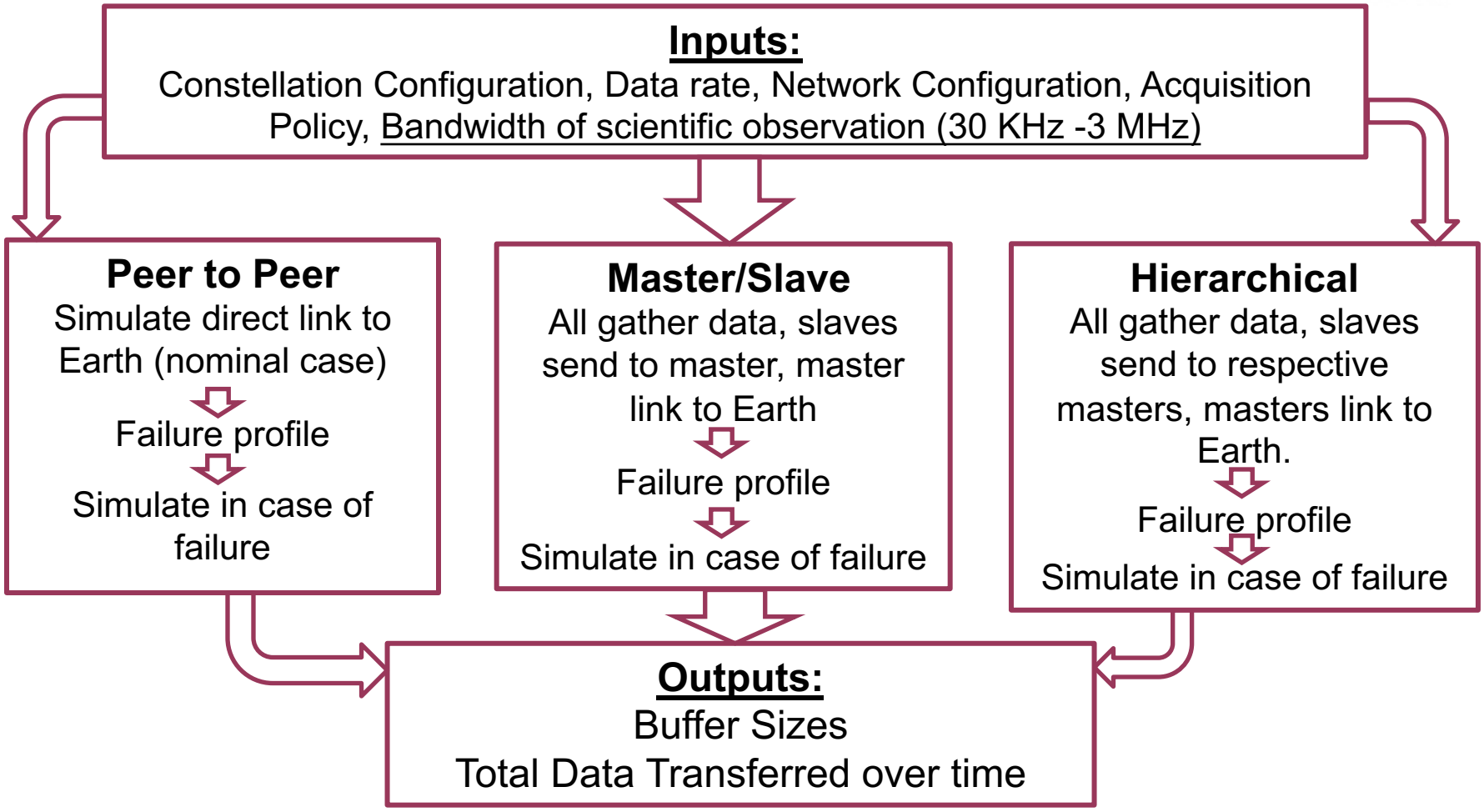


Image Credit: NASA

Objectives of Communication Network Analysis

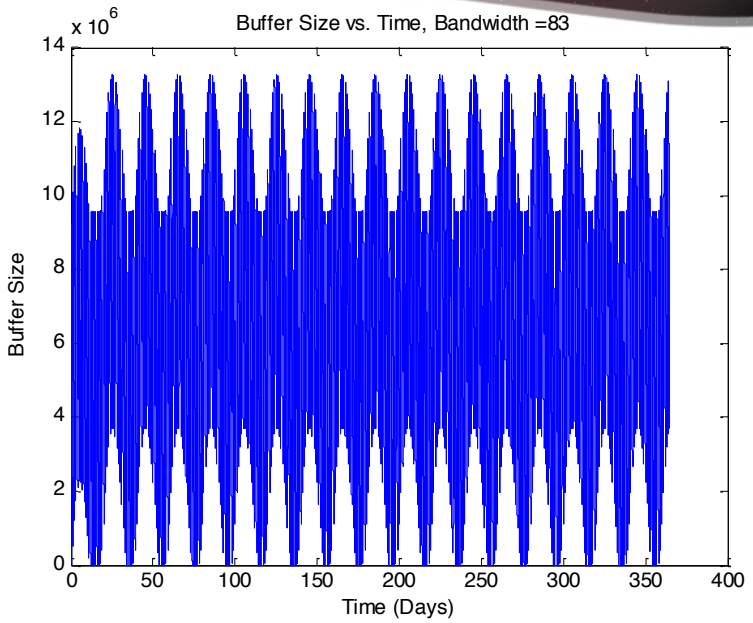
1. Compare different configurations:
   - Peer to Peer
   - Master/Slave
   - Hierarchical
2. Determine the best strategy for
   - Contention
   - Congestion
   - Power consumption
3. Account for potential failure of CubeSats:
   - Maximize data return while minimizing communication time and data losses if one or more CubeSats fail.

Outline of Simulation



Results for the nominal case Peer to Peer

- Each satellite gathering information and sending to earth.
- Simulation run for 365 days, gathering data for 1 hour per day
- Maximum data rate: 125 kbps
- Maximum bandwidth possible: 83 KHz



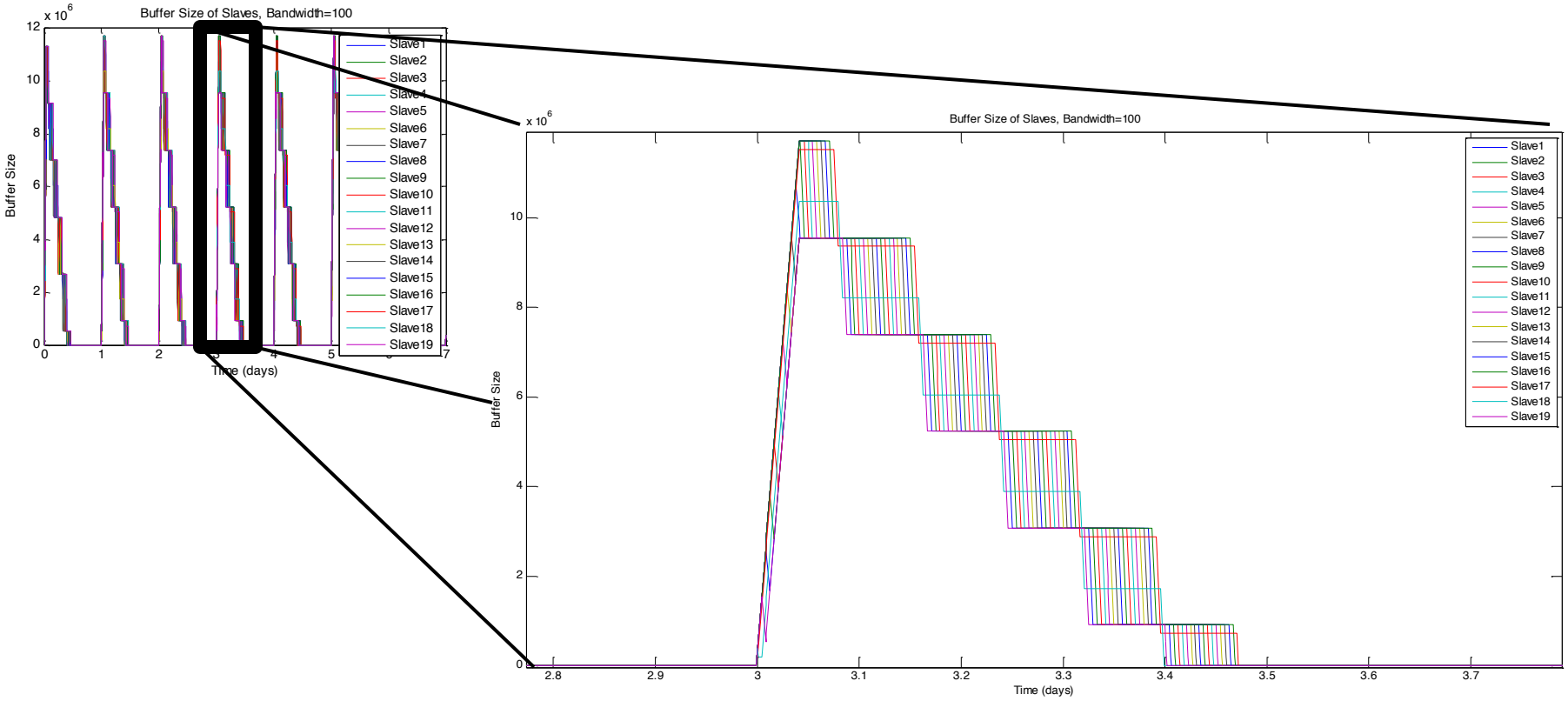
Bandwidth (KHz)	30	40	50	60	70	80	83
Total Data Transferred by 20 peers for a year (Tera Bits)	25.22	33.64	42.05	50.46	58.87	67.28	69.8

Results for the nominal case Master/Slave

- All satellites gather data, then slaves send to one master which transmits to earth
- Data rates:
  - From slave to master: 6000 kbps
  - From master to earth: max 3125 kbps
- Simulation run for 365 days, gathering for 1 hour per day
- Acquisition policy: TDMA
  - Each slave has a fixed time (6 minutes) to communicate with the master
- Maximum bandwidth possible: 109 kHz

Bandwidth (KHz)	30	40	50	60	70	80	90	100	109
Total Data Transferred (Tera Bits)	25.22	33.64	42.05	50.46	58.87	67.28	75.68	84.09	91.55

Results for the nominal case Master/Slave cont'd

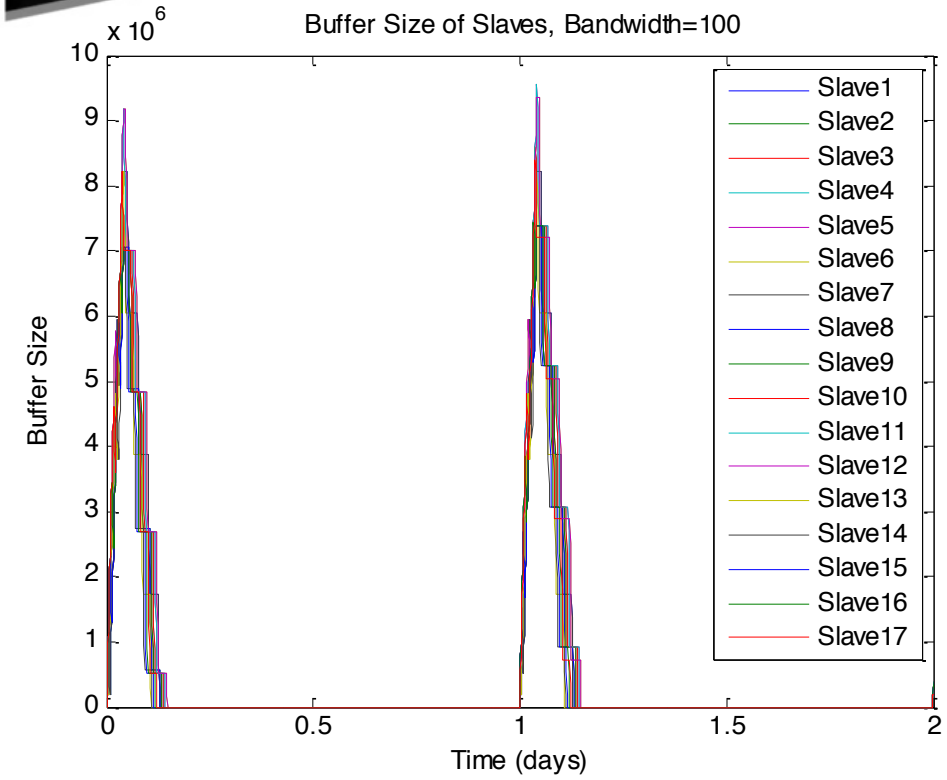


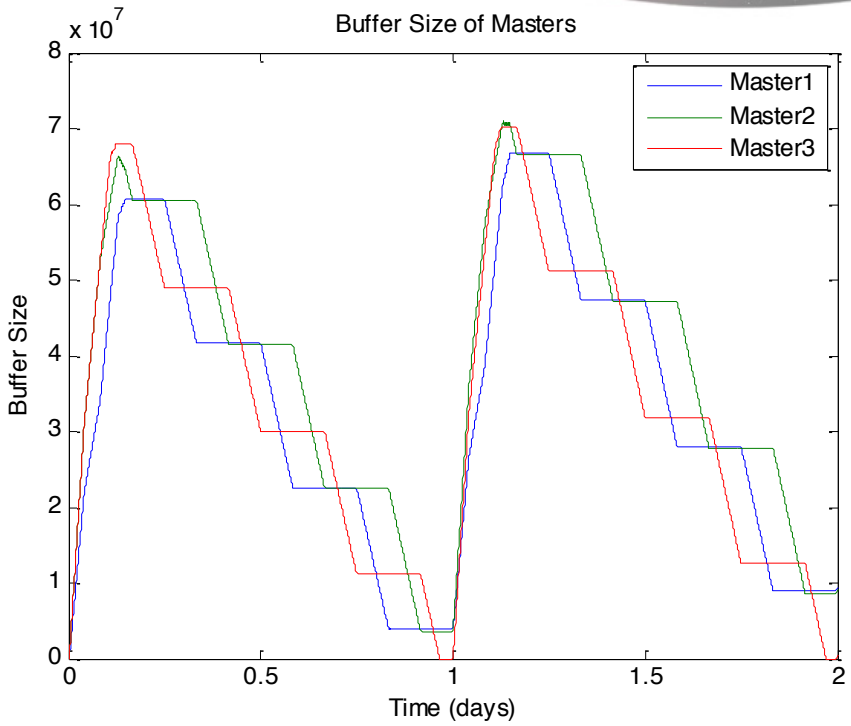
Bandwidth of 100 kHz
Slave Buffers zoomed in for one day

Results for the nominal case: Hierarchical

- All satellites gather data and send to respective masters, then masters transmit to earth
- Data rates:
  - From slaves to masters: 6000 kbps
  - From master to earth: max 3125 kbps
- Simulation run for 365 days, gathering for 1 hour per day
- Acquisition policy: TDMA both for slaves and masters
- Table of Total Data Transferred approximately the same as with one master.

Results for the nominal case: Hierarchical

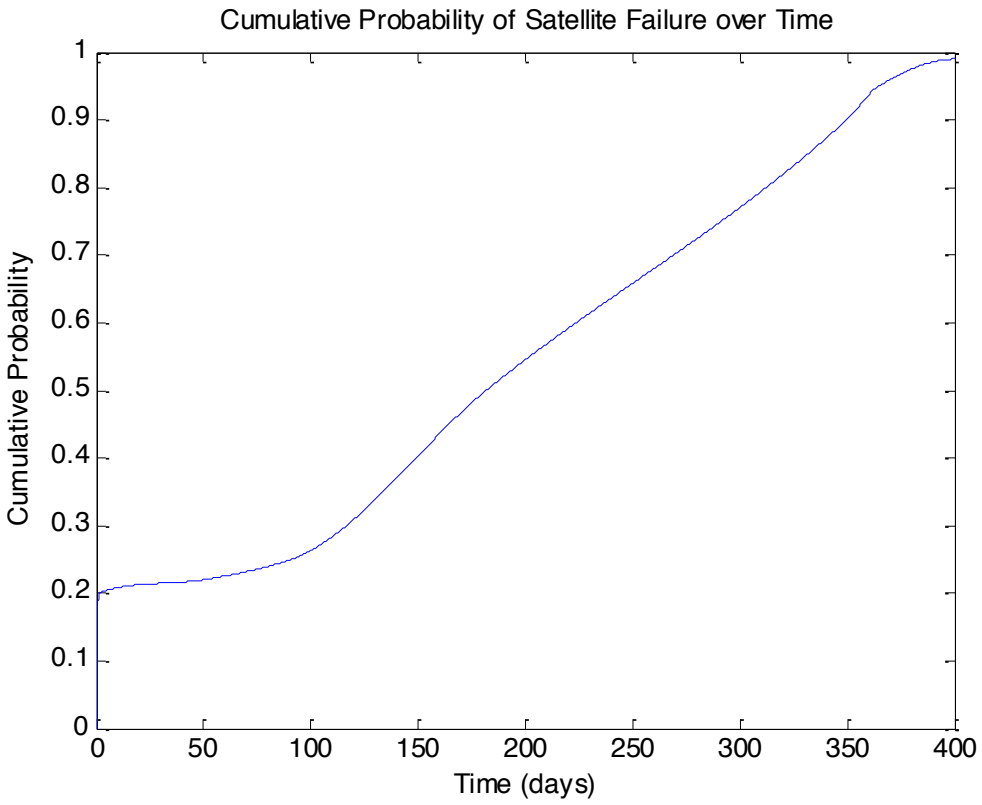




Example: 3 Masters, Bandwidth 100 KHz over a 2 day period

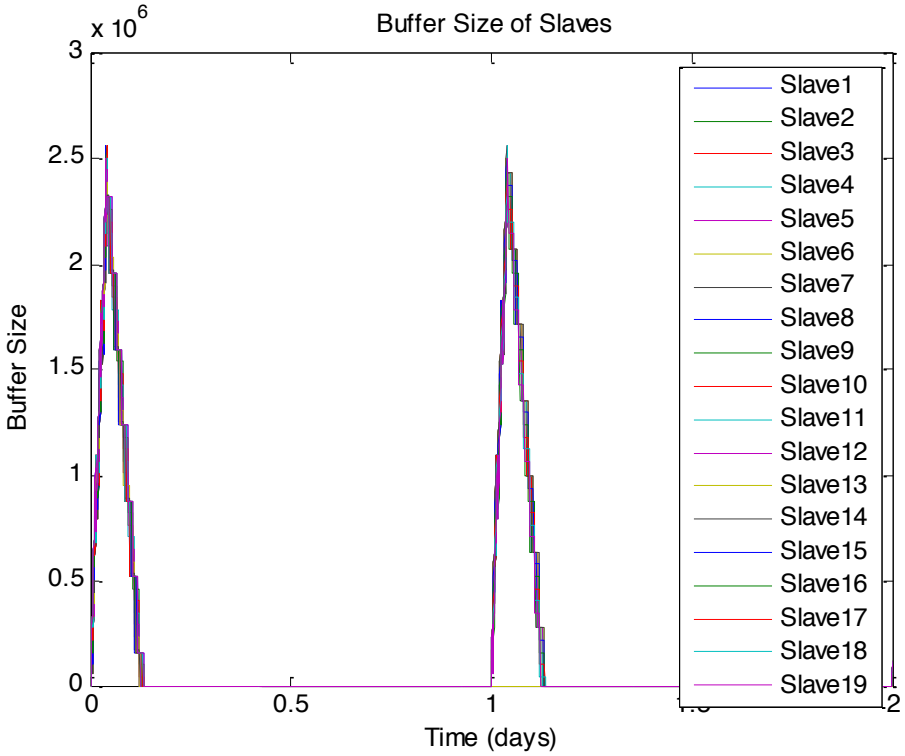
Failure Profile

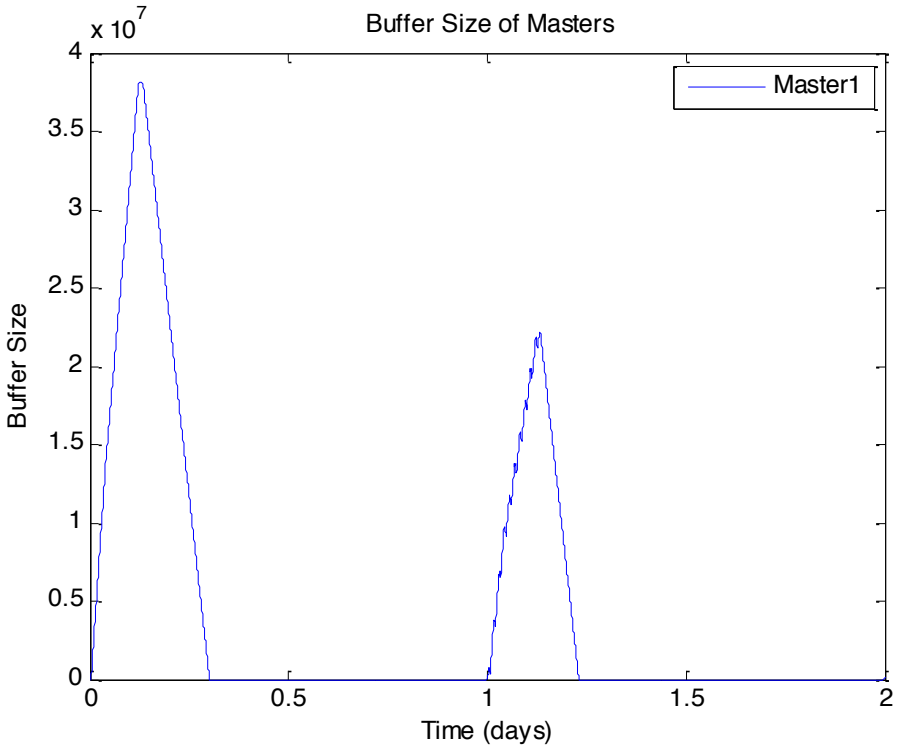
- Assumptions:
  - Initial failure in launch or setup of approximately 20%
  - Fairly stable until 3 months, then failure rate increases up to 6 months
  - Steady failure rate until most have failed by the end of a year



Results with Failure: Master/Slave

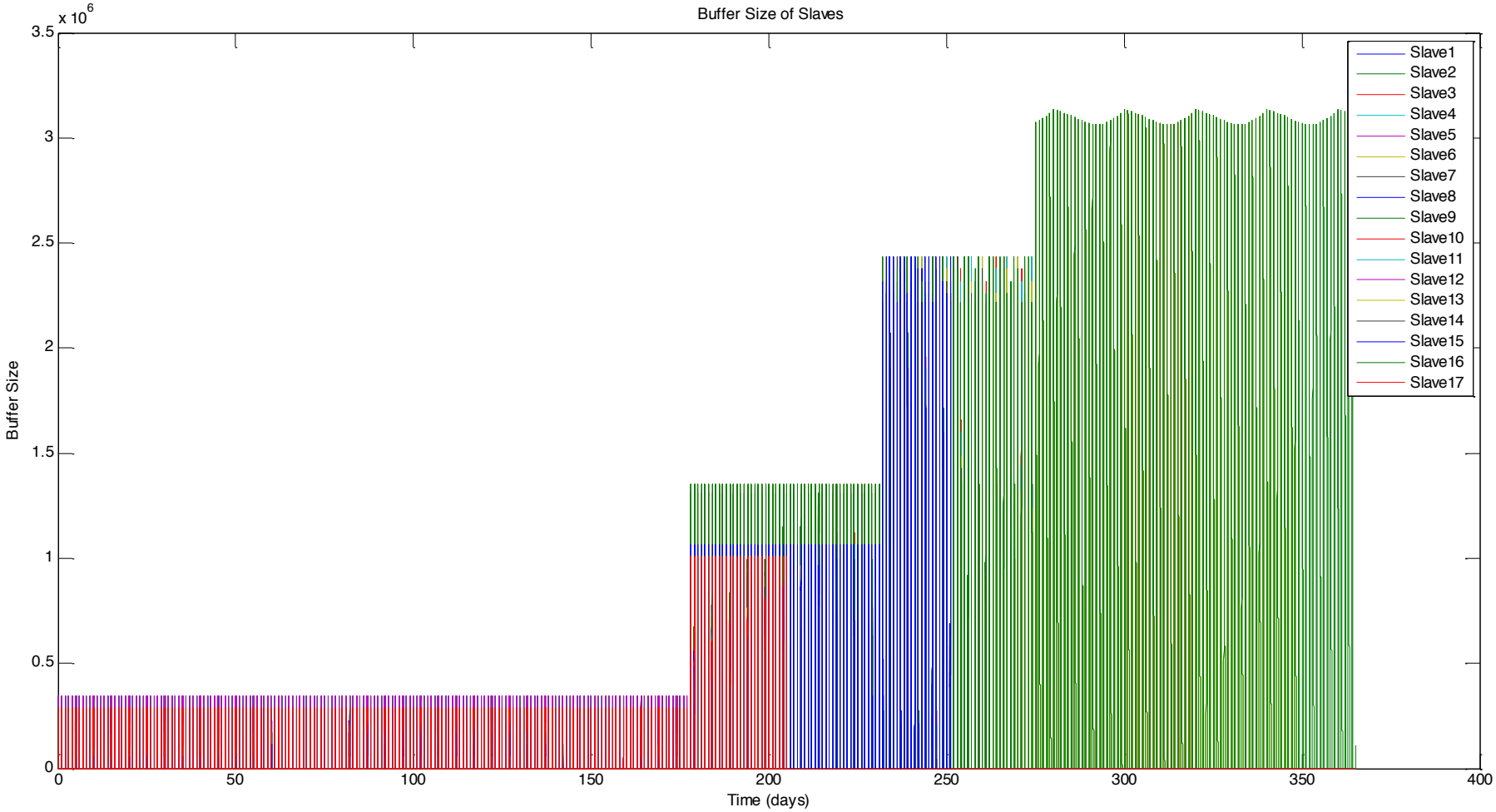
Example: 2 days, Bandwidth 30 KHz





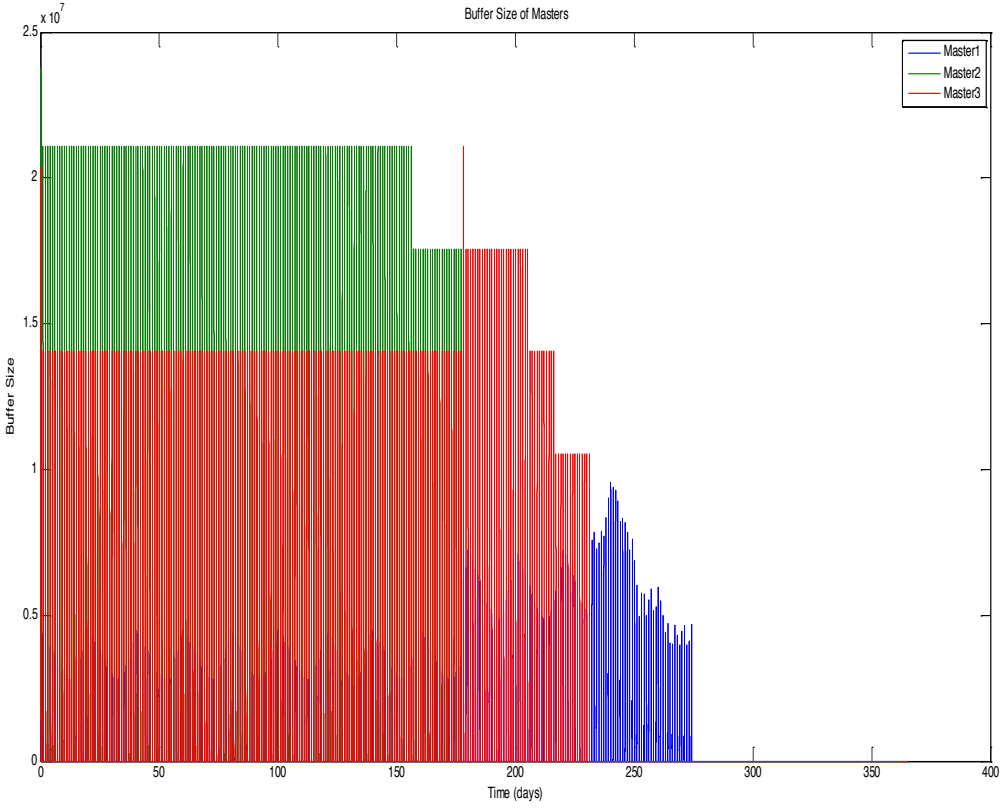
Results with Failure: Hierarchical

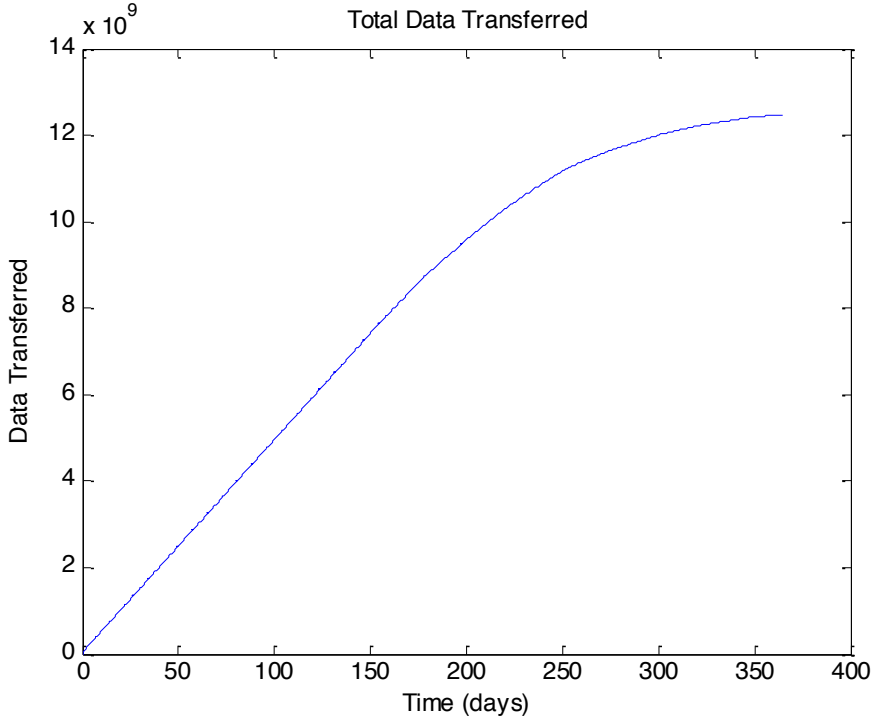
Example: 1 year, 3 Masters, Bandwidth 30 KHz



Results with Failure: Hierarchical

Example: 1 year, 3 Masters, Bandwidth 30 KHz





Analysis of Results: Maximum Bandwidth Sizes

Fixed: 8 samples

Without Failure

Number of Masters	Sampling for 60 min and transmitting continuously	Sampling for 60 min and transmitting for 12 hours	Sampling for 30 min and transmitting continuously	Sampling for 30 min and transmitting for 12 hours	Sampling for 15 min and transmitting continuously	Sampling for 15 min and transmitting for 12 hours
1, 2, 4, 5	109	54	218	108	436	217
3	104	51	208	103	416	207

With Failure
(Mean, Standard Deviation) Based on 10 trials

1	(85.2, 3.79)	(49.4, 16.4)	(177.4, 0.02)	(115, 0.8)	(382.4, 0.95)	(227.8, 1.49)
2	(85.2, 3.79)	(44.8, 1.03)	(194.8, 0.52)	(117.6, 0.8)	(412.2, 1.26)	(274.6, 1.98)
3	(85.2, 3.79)	(46.6, 4.12)	(179.2, 0.04)	(126, 0.78)	(383.4, 0.94)	(229, 1.48)
4	(88.2, 5.69)	(61.8, 24.6)	(211.6, 0.71)	(144, 0.86)	(423.2, 1.28)	(292.4, 1.97)
5	**(89.6, 7.23)**	**(57.2, 21.6)**	**(269.6, 0.89)**	**(152, 1.09)**	**(459.6, 1.48)**	**(344.8, 2.29)**

Analysis of Results: Maximum Number of Samples

Fixed Bandwidth 30 kHz

Without Failure

Number of Masters	Sampling for 60 min and transmitting continuously	Sampling for 60 min and transmitting for 12 hours	Sampling for 30 min and transmitting continuously	Sampling for 30 min and transmitting for 12 hours	Sampling for 15 min and transmitting continuously	Sampling for 15 min and transmitting for 12 hours
1, 2, 4, 5	29	14	58	28	116	57
3	27	13	55	27	110	55

With Failure
(Mean, Standard Deviation) Based on 10 Trials

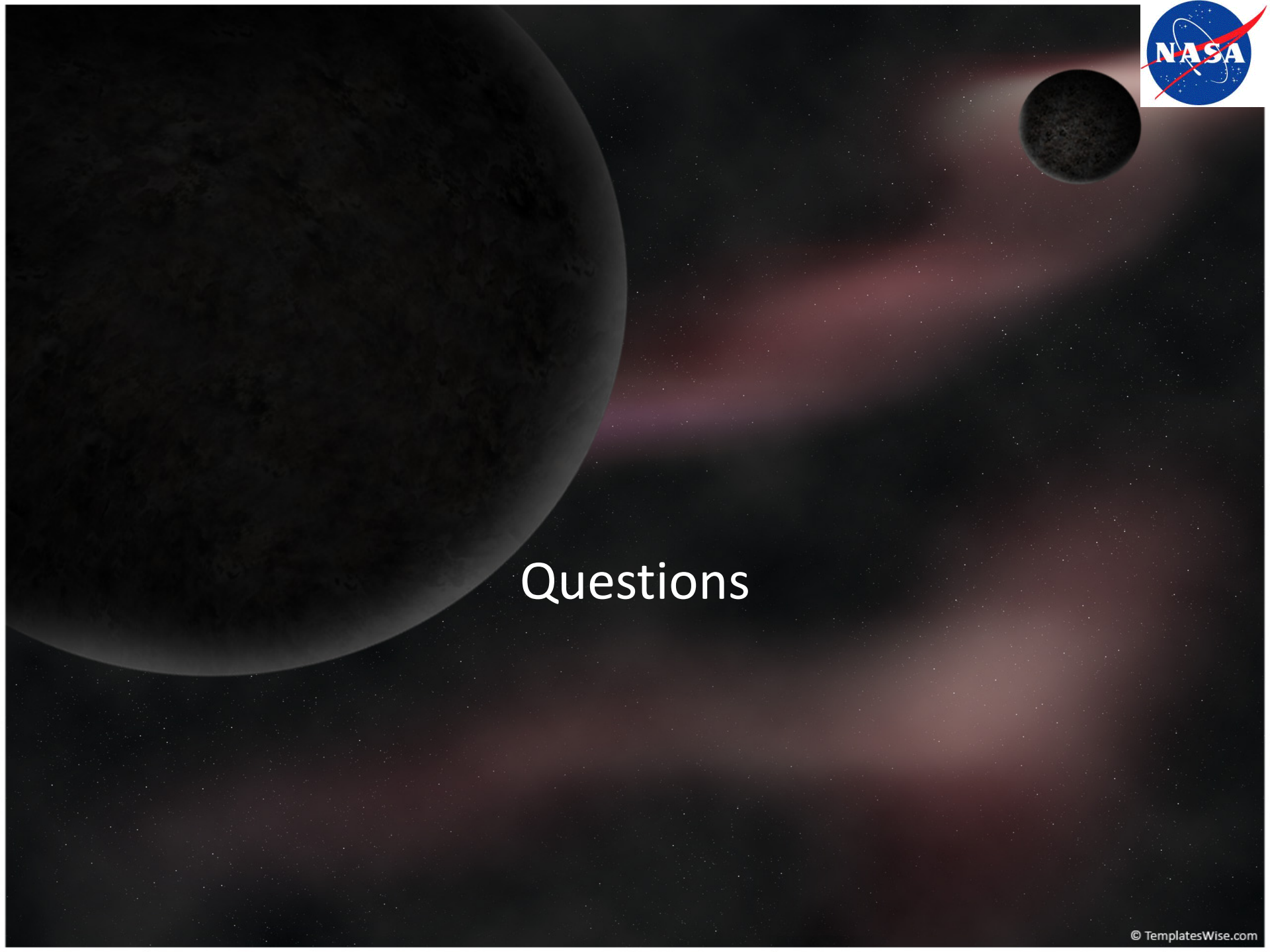
1	(26.4, 7.59)	(12, 0)	(47.2, 0.42)	(25.2, 1.55)	(102.3, 0.25)	(48.3, 1.63)
2	(26.4, 7.59)	(21.6, 15.8)	(47.5, 0.70)	(31.9, 21.16)	(95.5, 2.27)	(61.1, 40.7)
3	(26.5, 7.56)	(13.2, 1.61)	(61.6, 21.0)	(34.5, 23.13)	(111.8, 0.33)	(74.6, 52.46)
4	(26.8, 7.86)	(19.7, 14.9)	(68.9, 22.3)	(38, 24.5)	(112.9, 0.34)	(77.9, 52.4)
5	**(35.7, 13.5)**	**(20.2, 15.2)**	**(58.1, 18.4)**	**(38.9, 28.54)**	**(118.8, 0.34)**	**(89.2, 50.77)**

Conclusion

- Even if the satellites do not fail, the data collected is seriously restricted by the maximum bandwidth or number of samples.
- Hierarchical model is ideal, especially with failure, since other masters can still transmit data quickly to earth.
- Since the buffers overflow significantly more once all masters have failed, the best configuration to use is one with the most initial number of masters.

Acknowledgements

Part of this work was performed at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration



References

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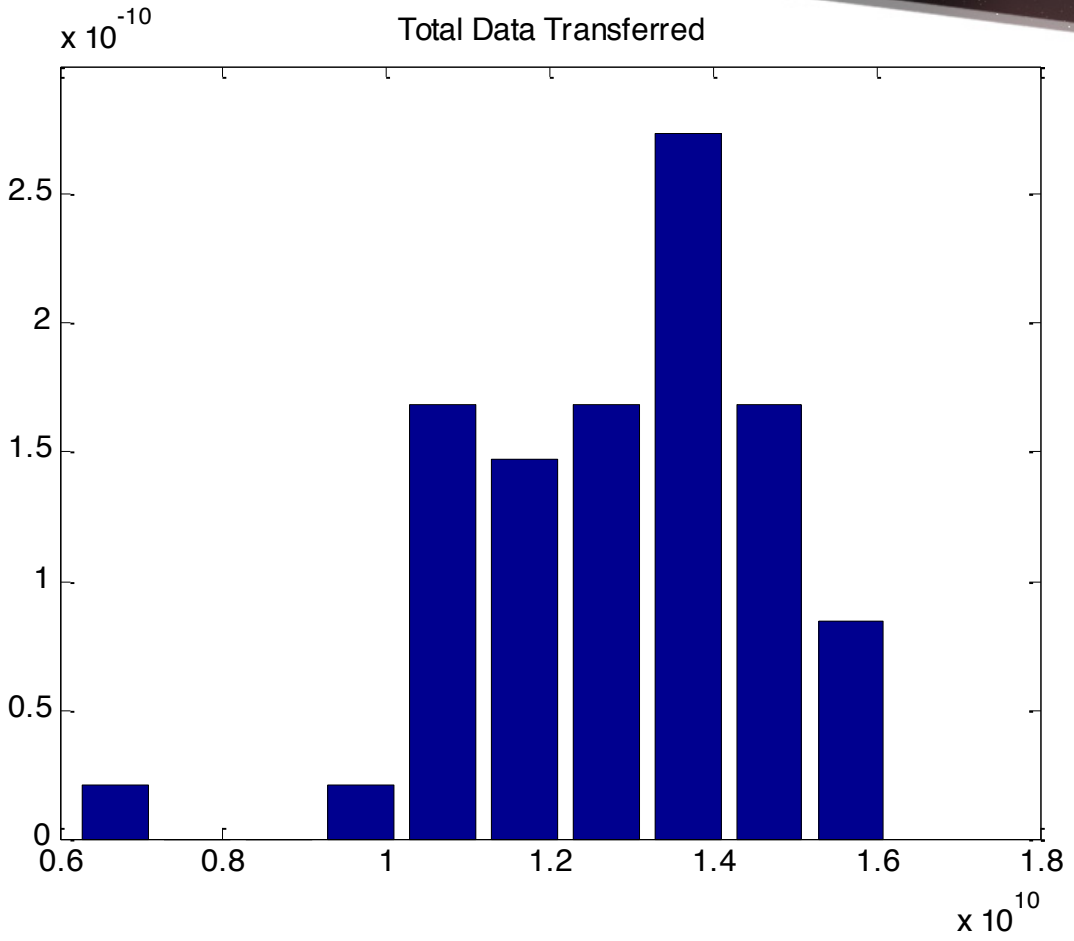
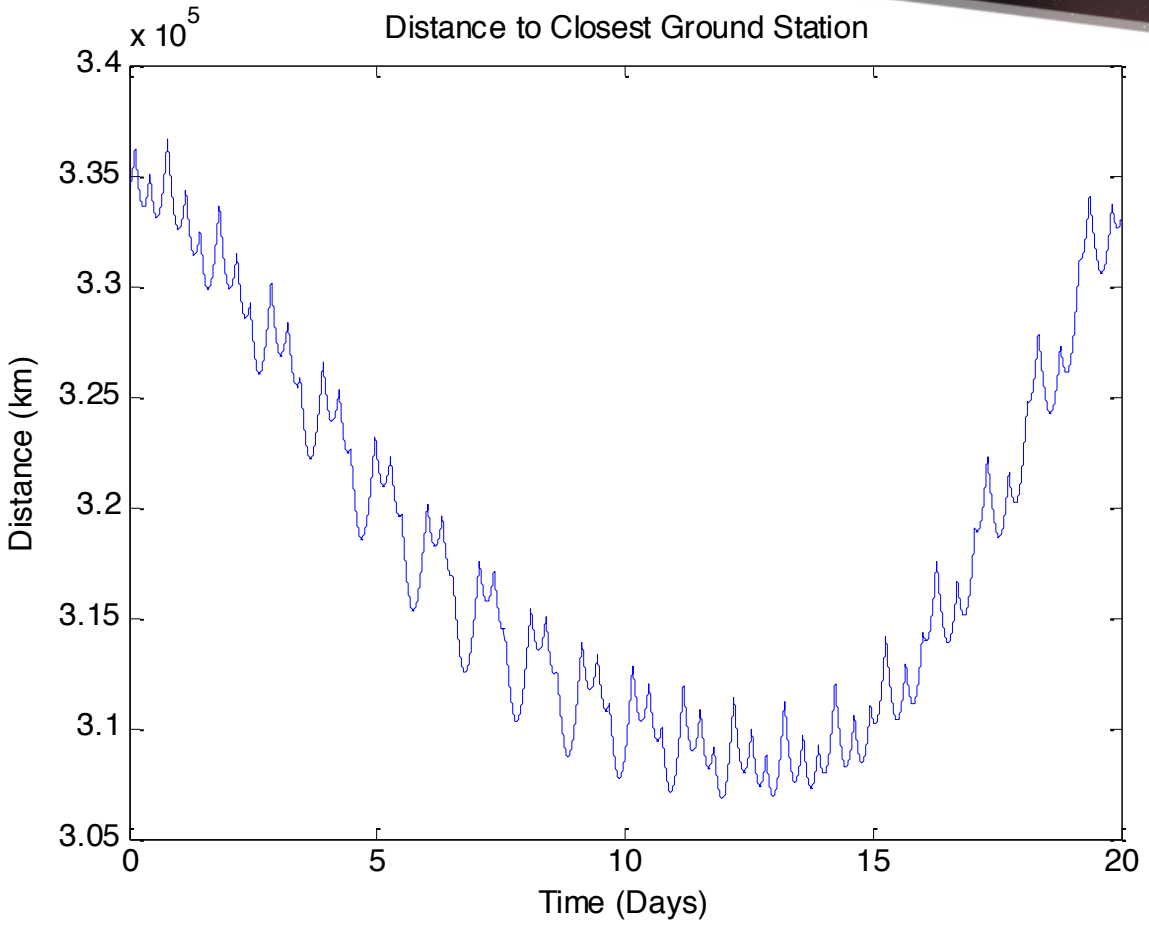
Back up

Statistics



3 masters, Bandwidth 30 KHz, with failure

Distance from Earth



Data Rates over Time