# Evaluation of Traffic Prioritization for Multi-Hop DTN-based Lunar Communications

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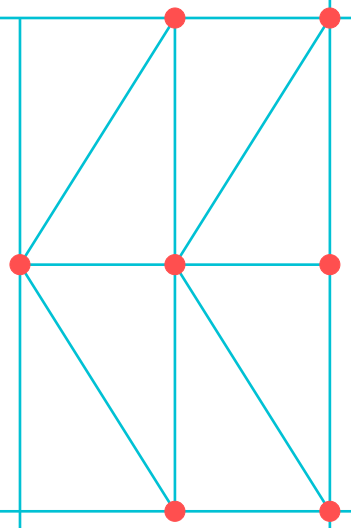

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10.05.2025

# Klara Schaper

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- Received master's degree in Computer Science from TUHH in 2025
- Works in QA at DIGITEC Financial Technologies and Services GmbH

# Teresa Algarra Ulierte

- MSc in Information and Communications Systems from TUHH in 2022
- Research Fellow and PhD candidate in Space Communications at TUHH and ESA
- Currently located at the European Space Operations Center (ESOC)

# Motivation

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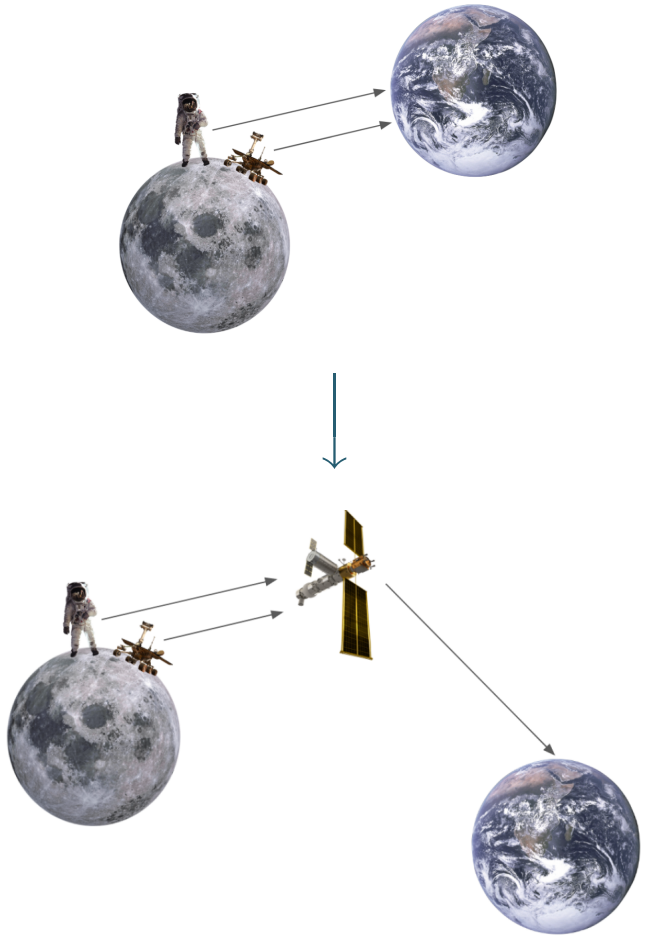
Properties of Earth-to-Moon link[1]:

- Intermittent connectivity
- Long or variable delays
- Asymmetric data rates
- High error rates

Delay- and Disruption-Tolerant Network (DTN) with Bundle Protocol (BP)

→ Lacks prioritization!





[1]F. Warthman, *Delay- and Disruption-Tolerant Networks (DTNs), A Tutorial*. Sep. 14, 2015. [Online]. Available: https://www.nasa.gov/wp-content/uploads/2023/09/dtn-tutorial-v3.2-0.pdf

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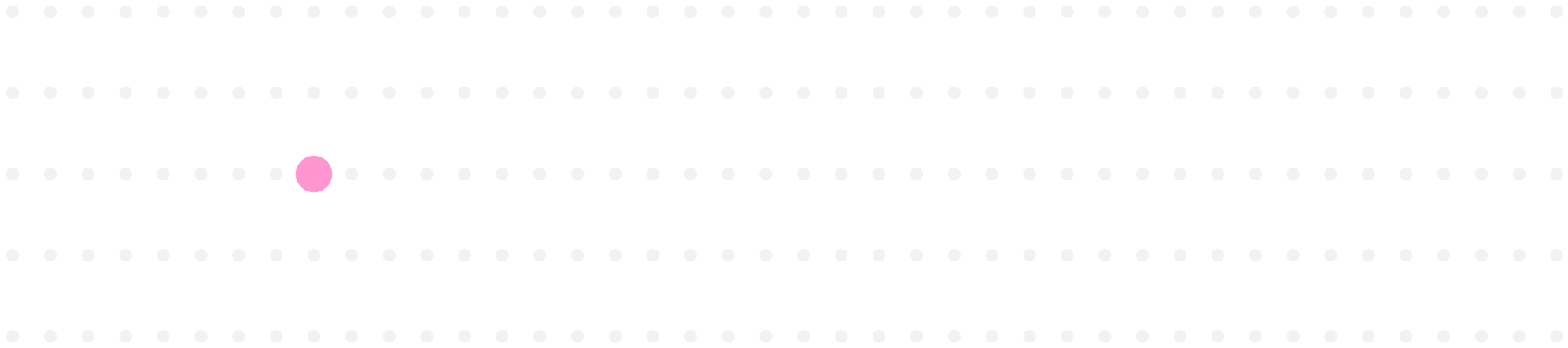
# 1. Background



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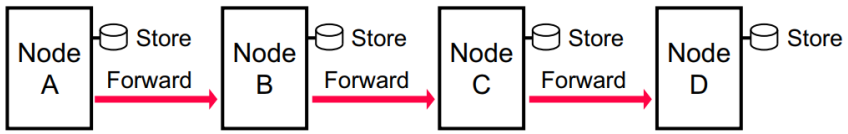
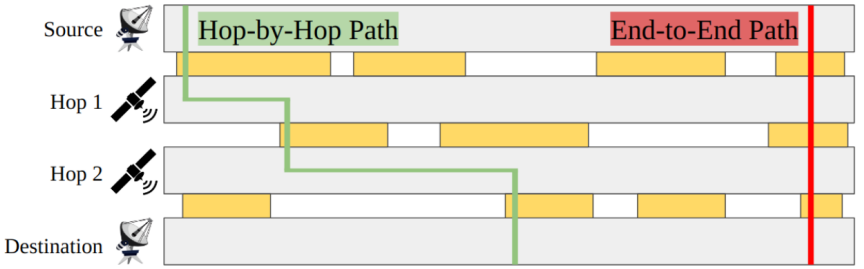
# Delay- and Disruption-Tolerant Network




Store-And-Forward[1]



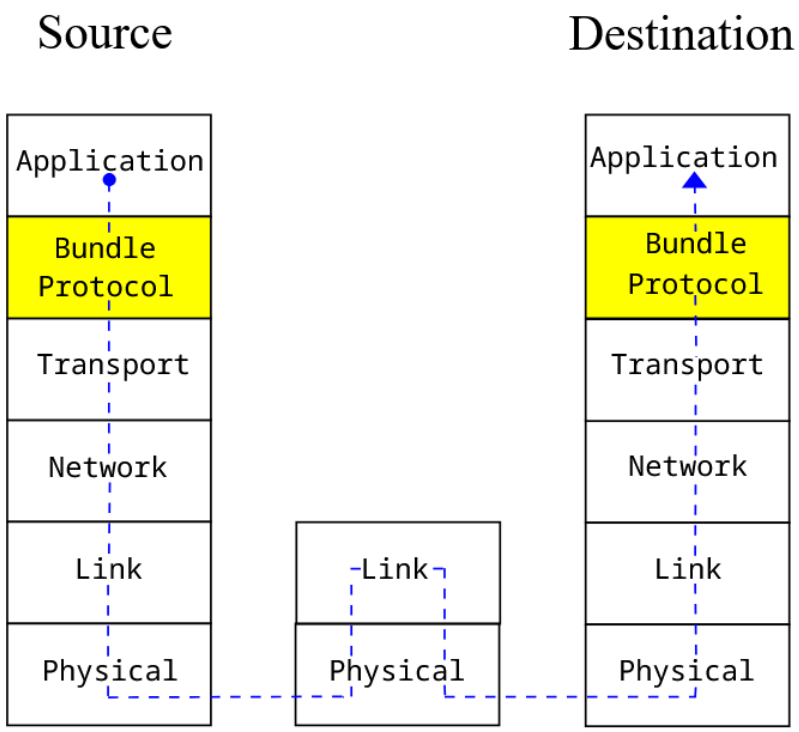

DTN compared to end-to-end[2]



[1]F. Warthman, *Delay- and Disruption-Tolerant Networks (DTNs), A Tutorial*. Sep. 14, 2015. [Online]. Available: https://www.nasa.gov/wp-content/uploads/2023/09/dtn-tutorial-v3.2-0.pdf

[2]T. A. Ulierte, K. Kuladinithi, A. Timm-Giel, *et al.*, "Adding quality of service support to bundleprotocol through an extension block [unpublished manuscript]," *IEEE International Conference on Space Mission Challengesfor Information Technology and Space Computing Conference*, 2024

# Bundle Protocol




Bundle Protocol overlay

## Bundle Protocol Agent

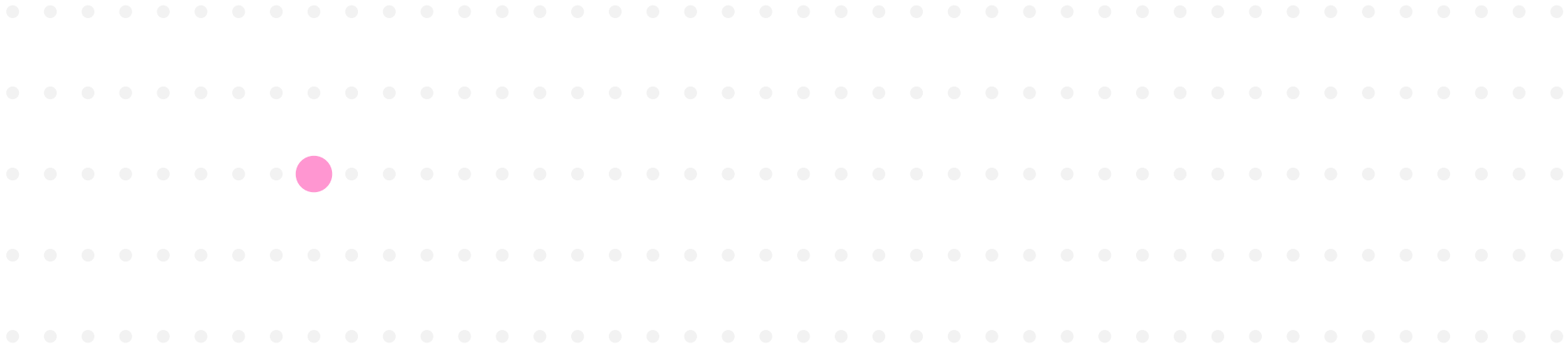
- Stores and forwards bundles or fragments between nodes


Bundle structure[2]



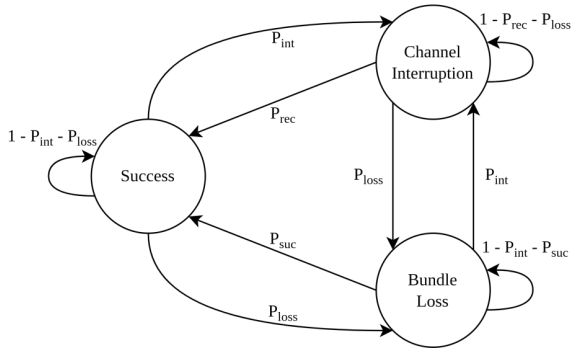
[2]T. A. Ulierte, K. Kuladinithi, A. Timm-Giel, *et al.*, "Adding quality of service support to bundleprotocol through an extension block [unpublished manuscript]," *IEEE International Conference on Space Mission Challengesfor Information Technology and Space Computing Conference*, 2024

# 2. Current State of Research and Limitations

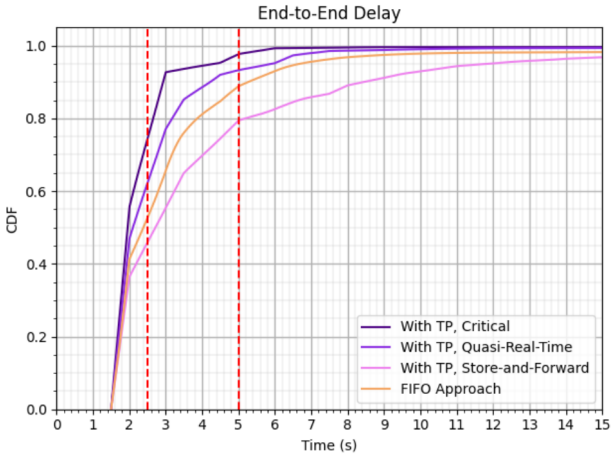


# Current State of Research

- Add prioritization to DTN with BP
  → implement Quality of Service through extension block




Three-state Markov Chain[3]



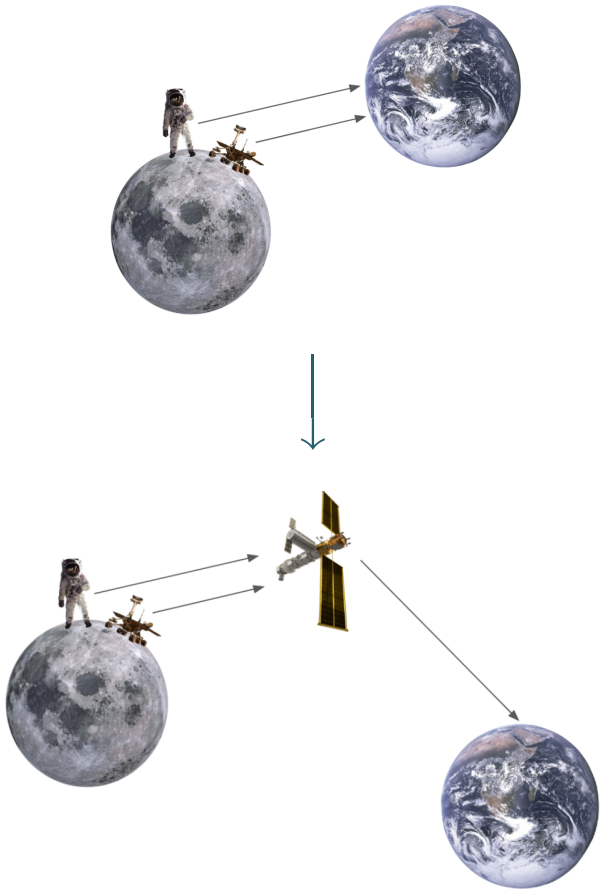

Comparison of the End-to-End delay[2]

Performance of high priority improved at the expense of low priority bundles

[2]T. A. Ulierte, K. Kuladinithi, A. Timm-Giel, *et al.*, "Adding quality of service support to bundleprotocol through an extension block [unpublished manuscript]," *IEEE International Conference on Space Mission Challengesfor Information Technology and Space Computing Conference*, 2024

[3]T. A. Ulierte, K. Kuladinithi, A. Timm-Giel, *et al.*, "Enabling traffic prioritization for spacecommunications over dtns [unpublished manuscript]," *IEEE Journal of Radio Frequency Identification*, 2024

# Limitations

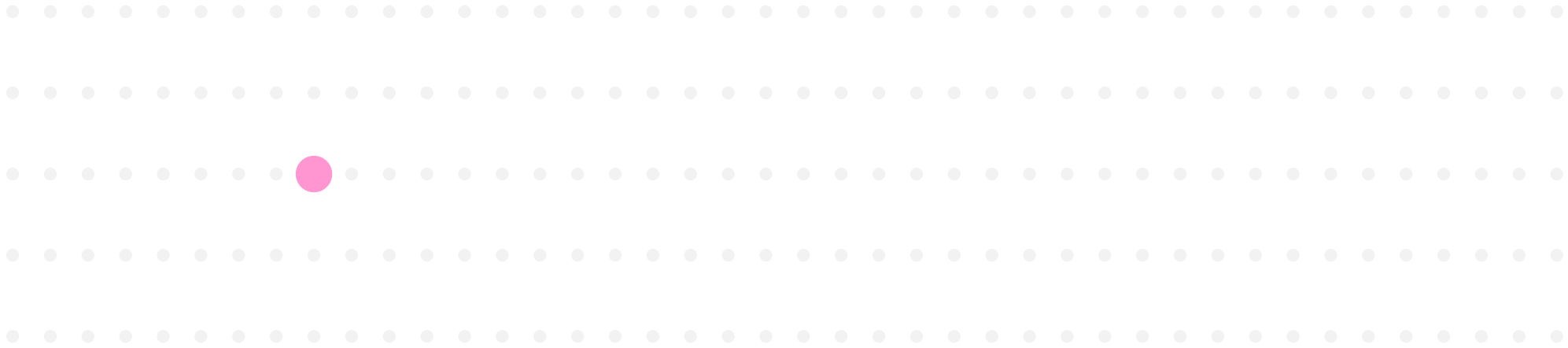


- How can the single hop mathematical model presented be adapted to a multi-hop one?
- What is the impact of traffic prioritization on inter-spacecraft scenarios?



T. A. Ulierte, K. Kuladinithi, A. Timm-Giel, *et al.*, "Enabling traffic prioritization for spacecommunications over dtns [unpublished manuscript]," *IEEE Journal of Radio Frequency Identification*, 2024

# 3. Expansion of Markov Chain



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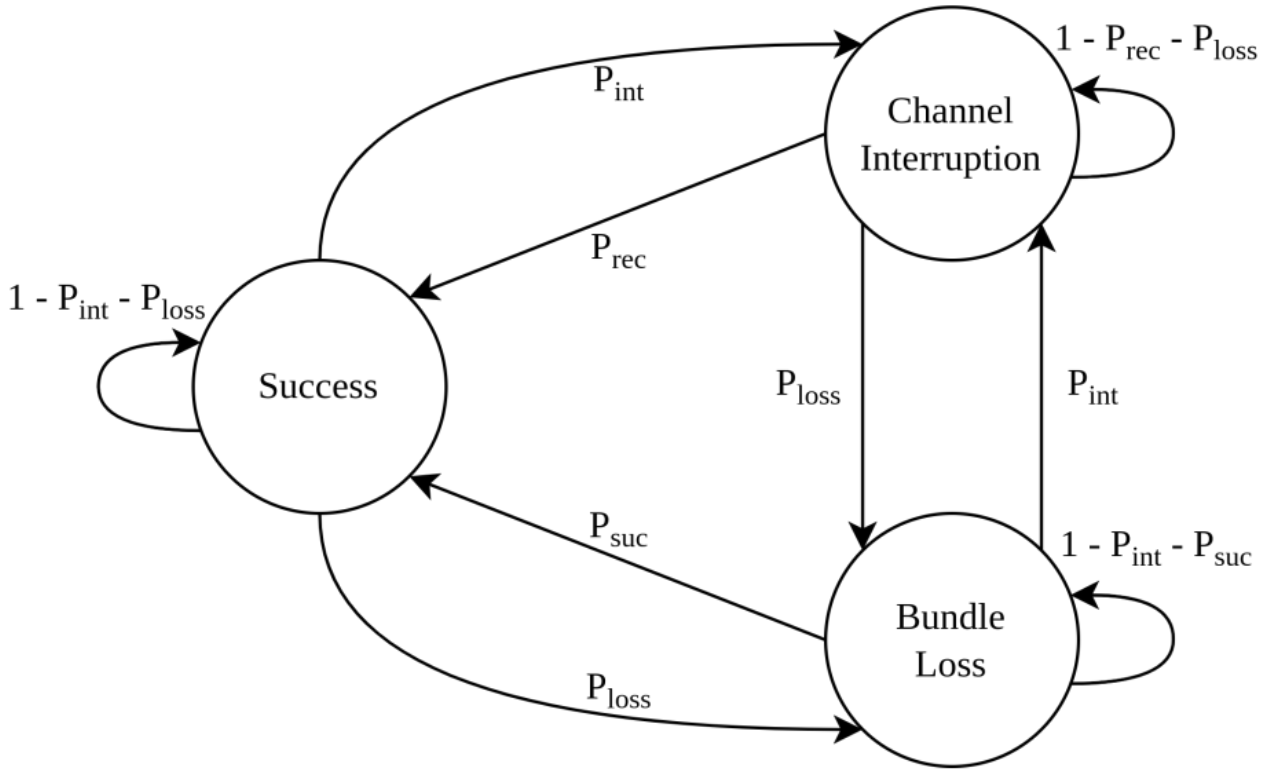
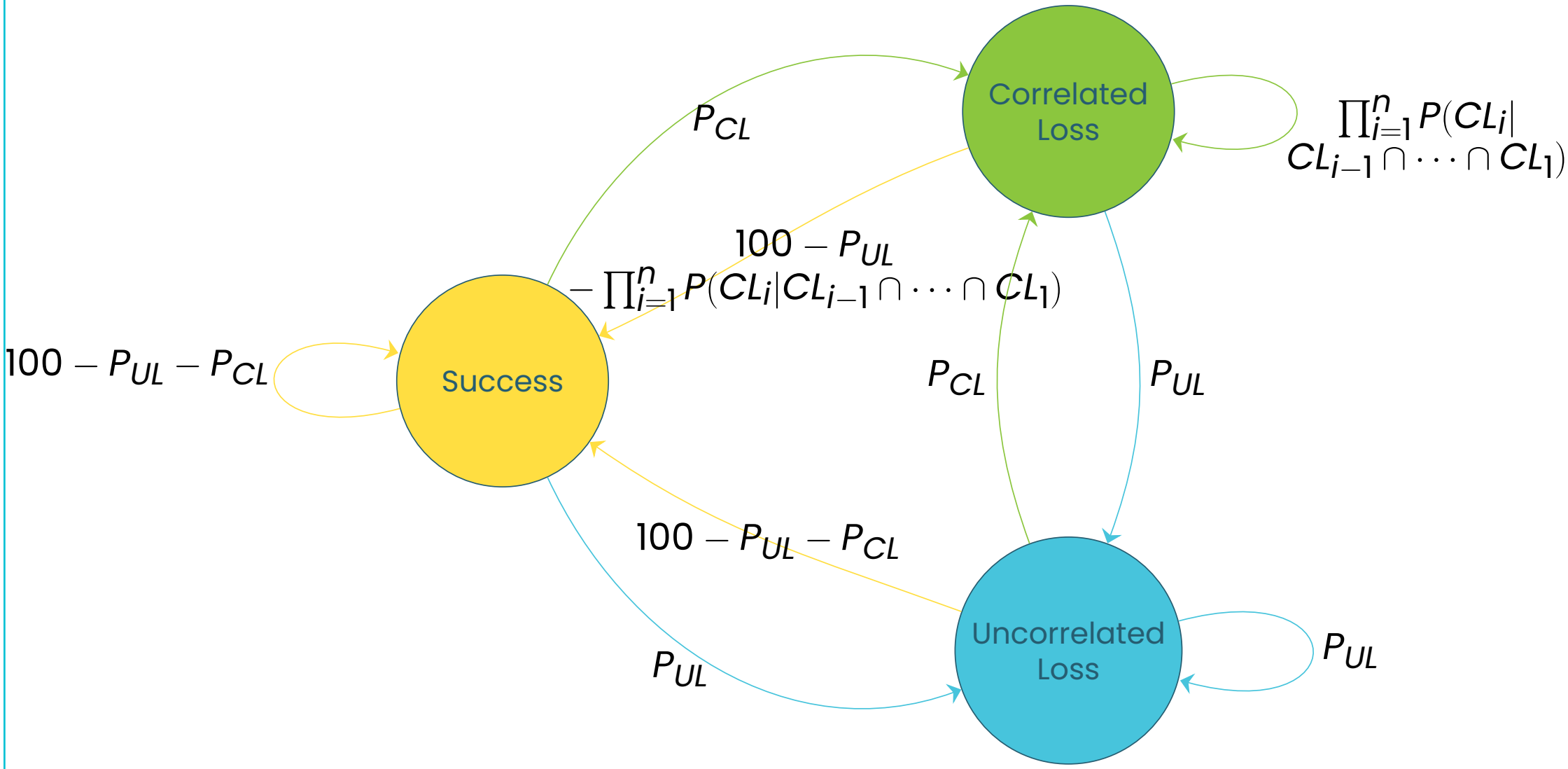
# Direct Link Markov Chain




Three-state Markov Chain[3]

[3]T. A. Ulierte, K. Kuladinithi, A. Timm-Giel, *et al.*, "Enabling traffic prioritization for spacecommunications over dtns [unpublished manuscript]," *IEEE Journal of Radio Frequency Identification*, 2024

# Multi-Hop Markov Chain



# Atmospheric Setting

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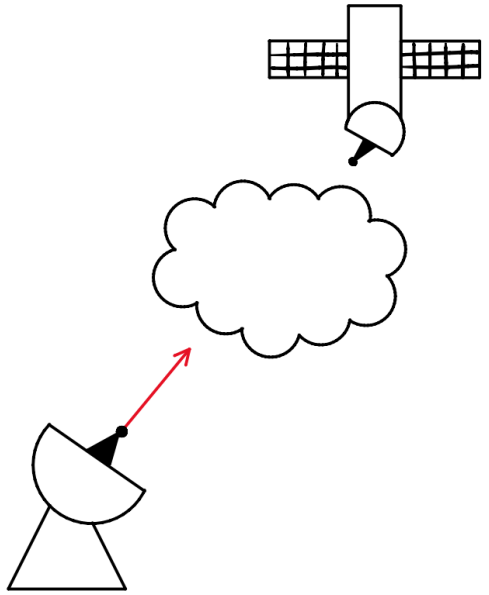
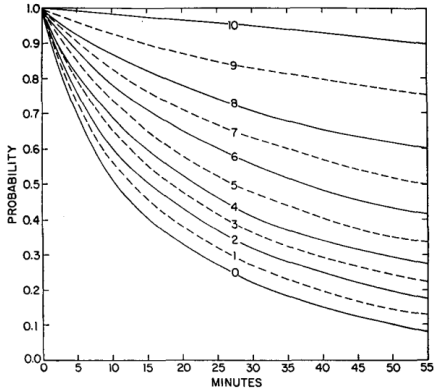
## Correlated Loss

- Clouds[4]

## Uncorrelated Loss

- Aerosol[5]
- Pointing errors[2]
- Interferences[2]
- Light atmospheric weather[2]






Cloud Persistence Function[4]



[4]I. A. Lund, "Persistence and recurrence probabilities of cloud-free and cloudy lines-of-sight through the atmosphere," *Journal of Applied Meteorology and Climatology*, vol. 12, no. 7, pp. 1222–1228, 1973. DOI: 10.1175/1520-0450(1973)012<1222:PARPOC>2.0.CO;2. [Online]. Available: https://journals.ametsoc.org/view/journals/apme/12/7/1520-0450_1973_012_1222_parpoc_2_0_co_2.xml

[5]C. Secretariat, "Real-time weather and atmosphericcharacterization data," *Informational Report, Issue 2*, Mar. 2024

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# Space Setting

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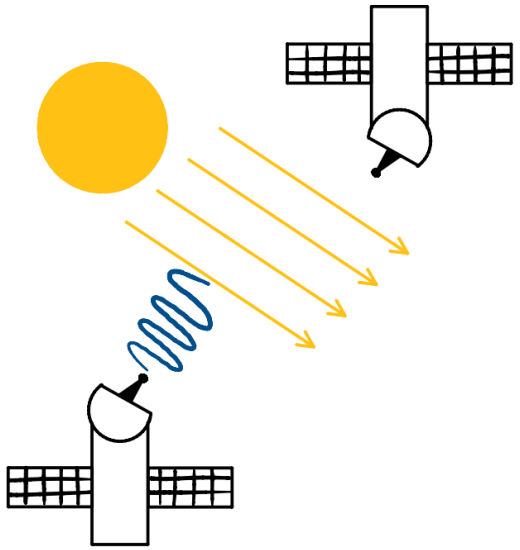
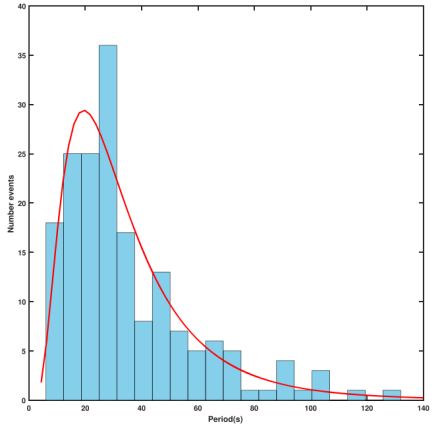
Correlated Loss
- Solar flares[6]

Uncorrelated Loss
- Pointing errors[2]
- Interferences[2]





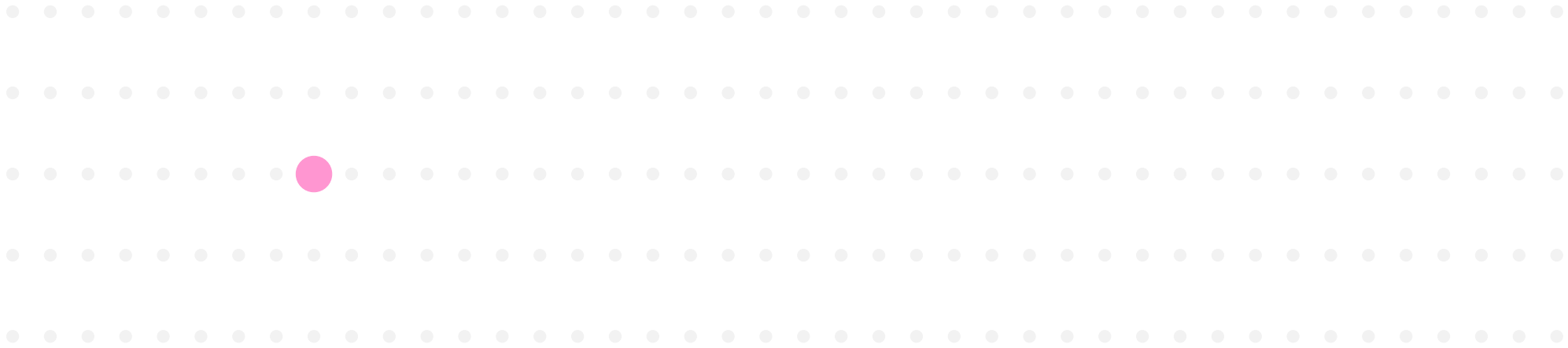

Solar Flares Function[6]



[2]T. A. Ulierte, K. Kuladinithi, A. Timm-Giel, *et al.*, "Adding quality of service support to bundleprotocol through an extension block [unpublished manuscript]," *IEEE International Conference on Space Mission Challengesfor Information Technology and Space Computing Conference*, 2024

[6]N. Nishizuka, Y. Kubo, K. Sugiura, *et al.*, "Reliable Probability Forecast of Solar Flares: Deep Flare Net-Reliable (DeFN-R)," *The Astrophysical Journal*, vol. 899, no. 2, 150, p. 150, Aug. 2020. DOI: 10.3847/1538-4357/aba2f2. eprint: 2007.02564

# 4. Experiments



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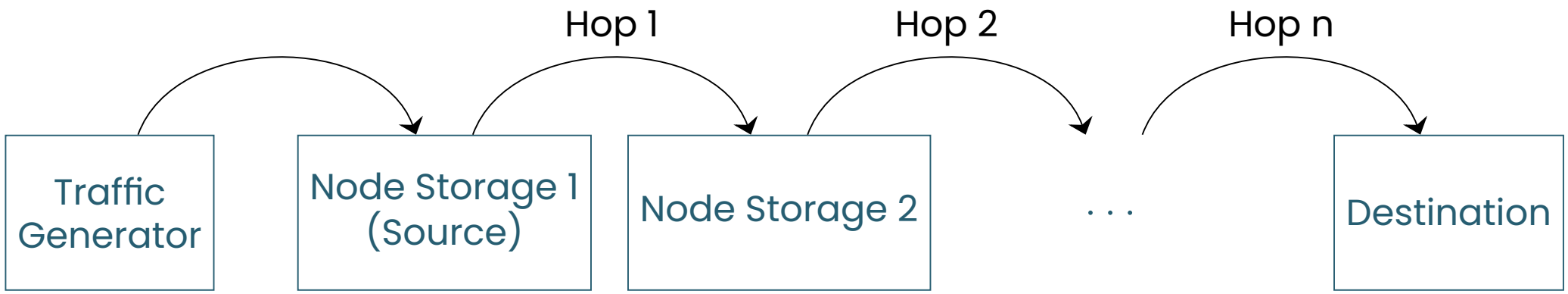
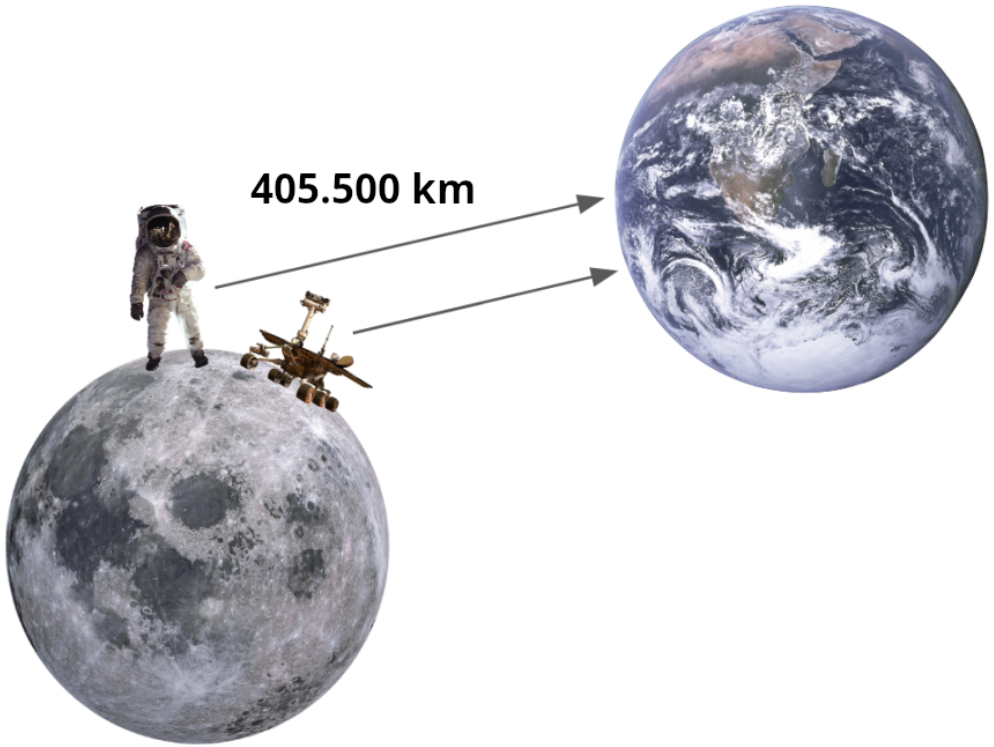
# Setup



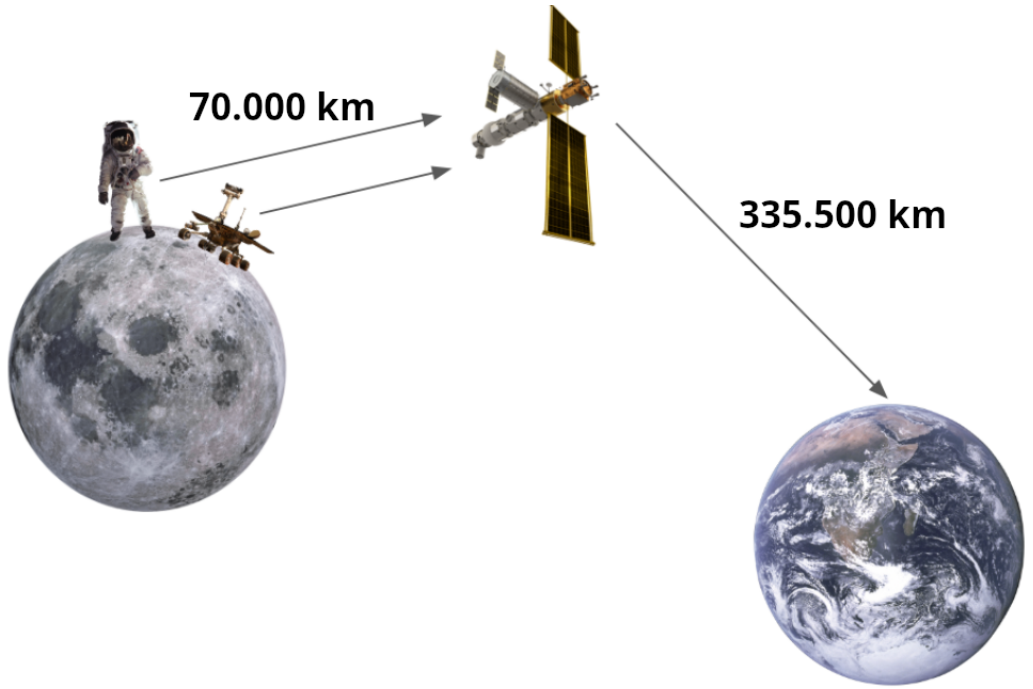

- 3 priority classes vs FIFO
- 500 simulated days
- Success or fail of sending attempt depends on corresponding Markov chain

# One-Hop Scenario



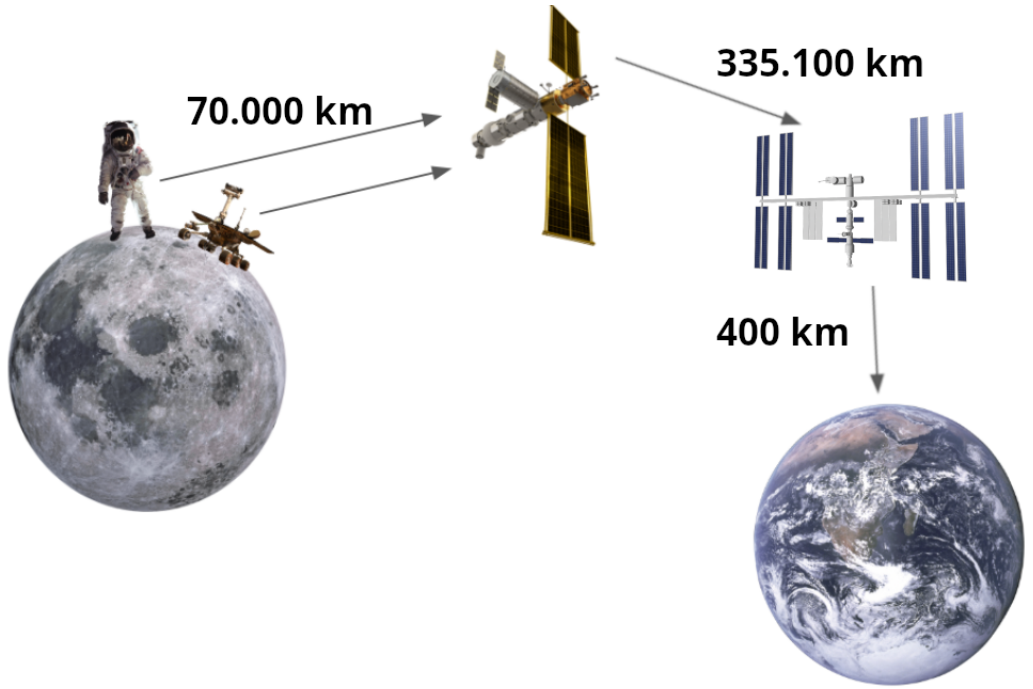

Moon → Earth

# Two-Hop Scenario



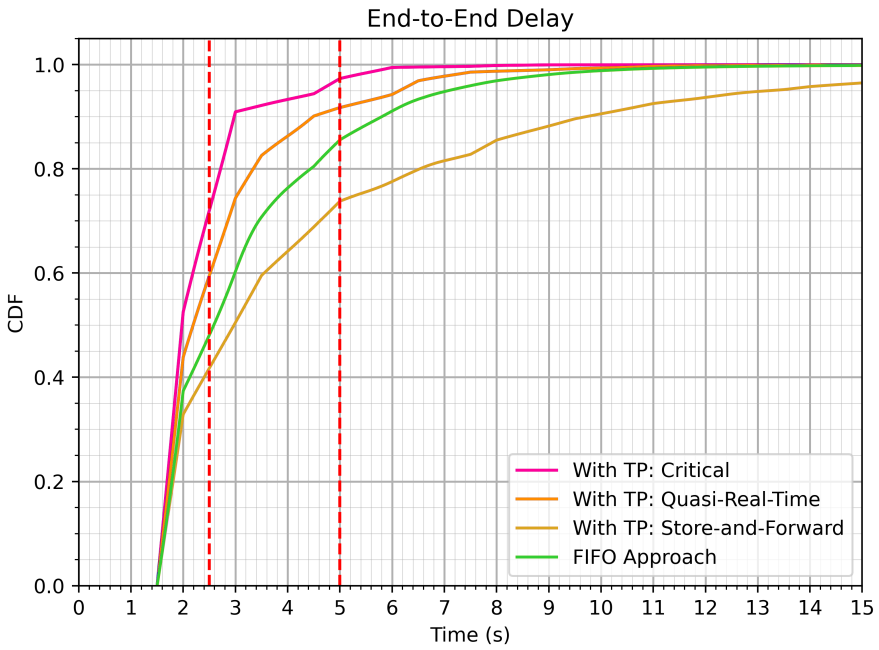

Moon → Lunar Gateway → Earth

# Three-Hop Scenario

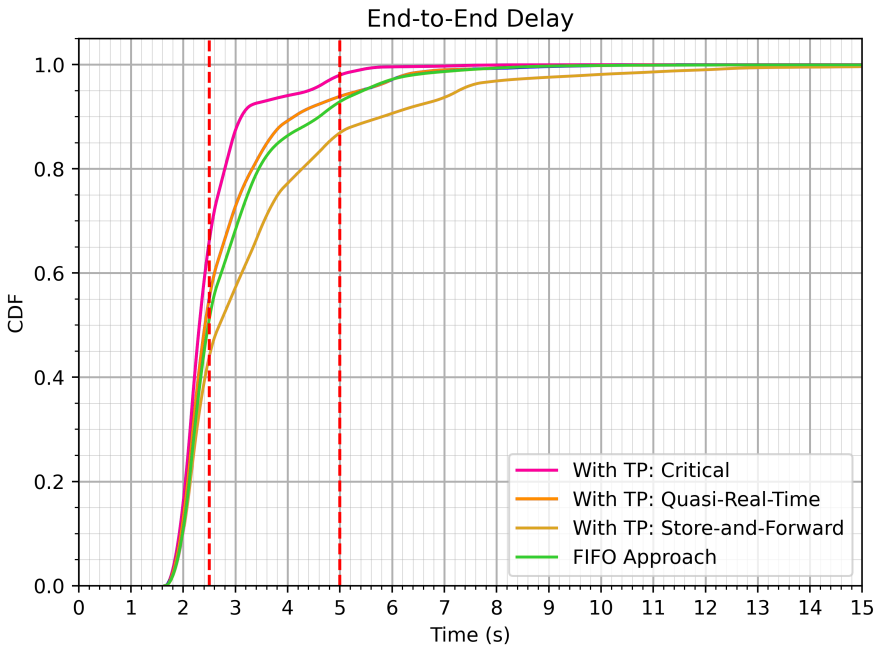



Moon → Lunar Gateway → ISS → Earth

# Results

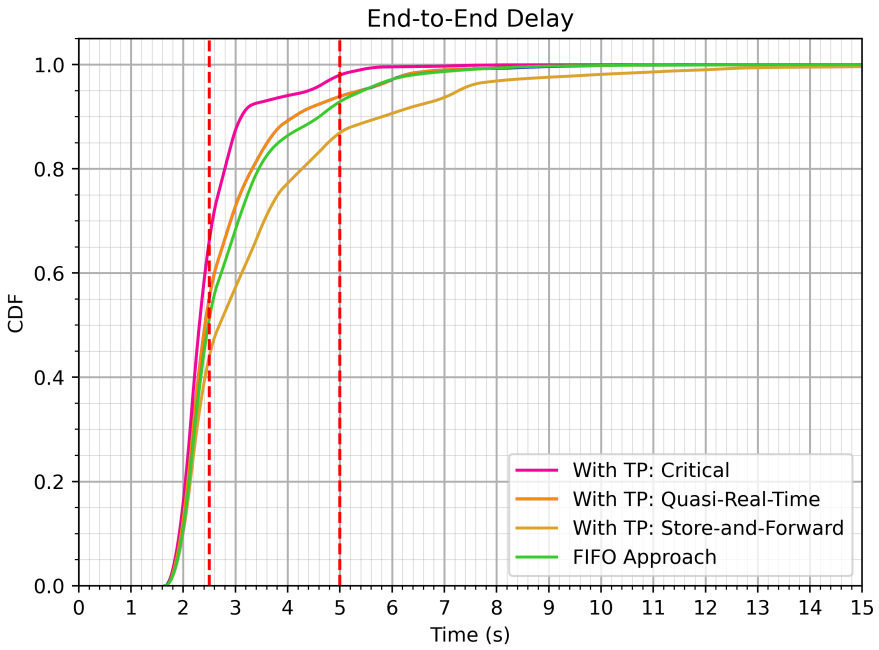



One-Hop

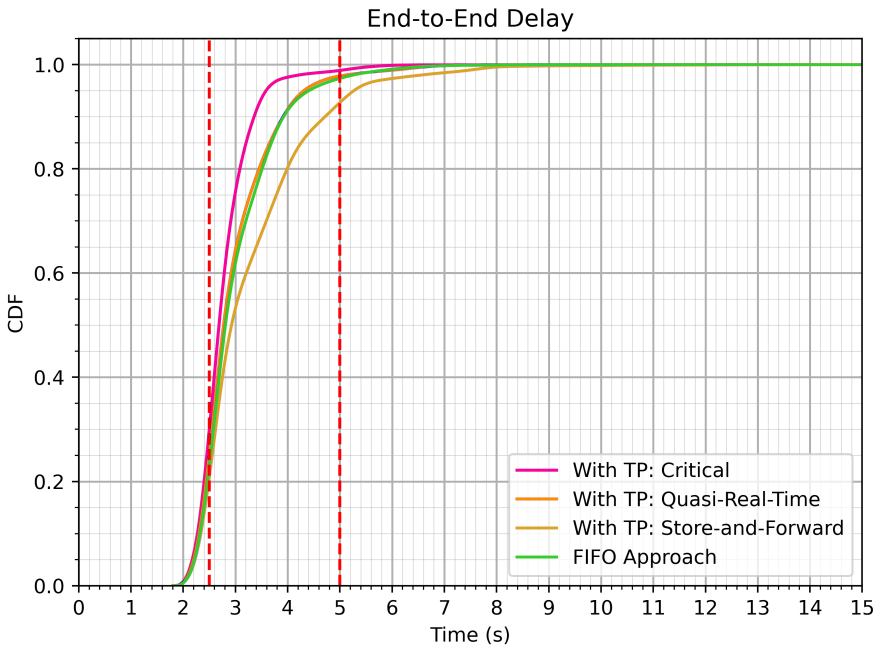



Two-Hop

# Results




Two-Hop




Three-Hop

# 5. Conclusion

# Conclusion

- Great similarities to the work of Algarra et al. [2]
- Performance improvements of critical bundles in all scenarios and conditions
- Higher performance gain respectively, if
  - Critical bundles sent over lower number of hops
  - S&F bundles sent over higher number of hops
- Space setting higher influence in overall communication path
- Run time of experiments depends on number of hops



[2]T. A. Ulierte, K. Kuladinithi, A. Timm-Giel, *et al.*, "Adding quality of service support to bundleprotocol through an extension block [unpublished manuscript]," *IEEE International Conference on Space Mission Challengesfor Information Technology and Space Computing Conference*, 2024

# Future Work

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Markov chain model

- Fine-tuning the model by conducting purpose-oriented data gathering
- Rework model to flexible transmission links
- Use model for the testing of error correction algorithms
- Use model to estimate efficiency if contact windows are present

Simulation

- Researches on the effect of routing according to the bundles priority
- Analyse weighted queuing instead of strict prioritization
- Investigate additional QoS assessments
- Deploy traffic prioritization to evaluate actual gains and missed problems

# Thank You very much

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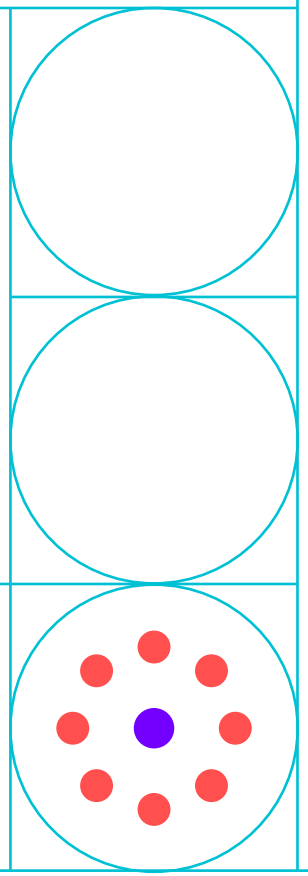

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# References


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