

Impact of Switch Plane Redundancy on Network Availability

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February 25, 2022

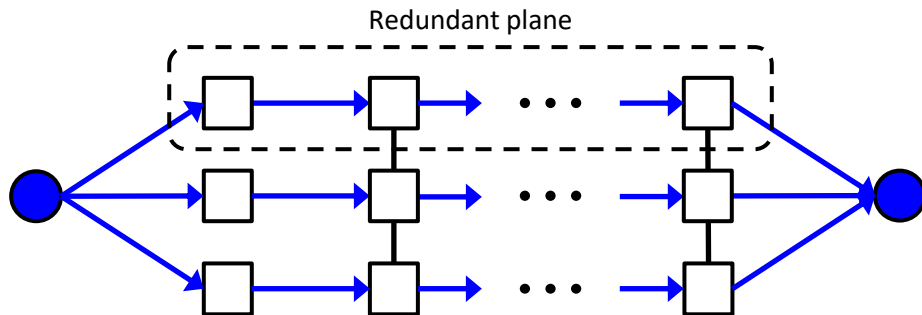


Introduction

- Critical spaceflight systems commonly use redundant planes of switched Ethernet
 - E.g., Orion, Gateway, Ariane 6, ESA micro launchers
- Typically, a 1FT requirement implies 2 planes, 2FT implies 3 planes
- However, using switches can have significant reliability impacts, since the failure of any switch in one plane prevents cross-system communication on that plane.
 - Very different from a bus (e.g., MIL-STD-1553)!
- Intent is to show the reliability trade-off when connecting to two planes vs. three
- Considers three different representative spacecraft topologies and mission durations
 - Space Station, Small (1 and 10 year missions)
 - Space Station, Large (1 and 10 year missions)
 - Capsule/Lander (1 month mission)
 - Heavy-lift launcher (6 month mission)
- Modelled using custom tools; verified with LaRC's Semi-Markov Unreliability Range Evaluator (SURE)

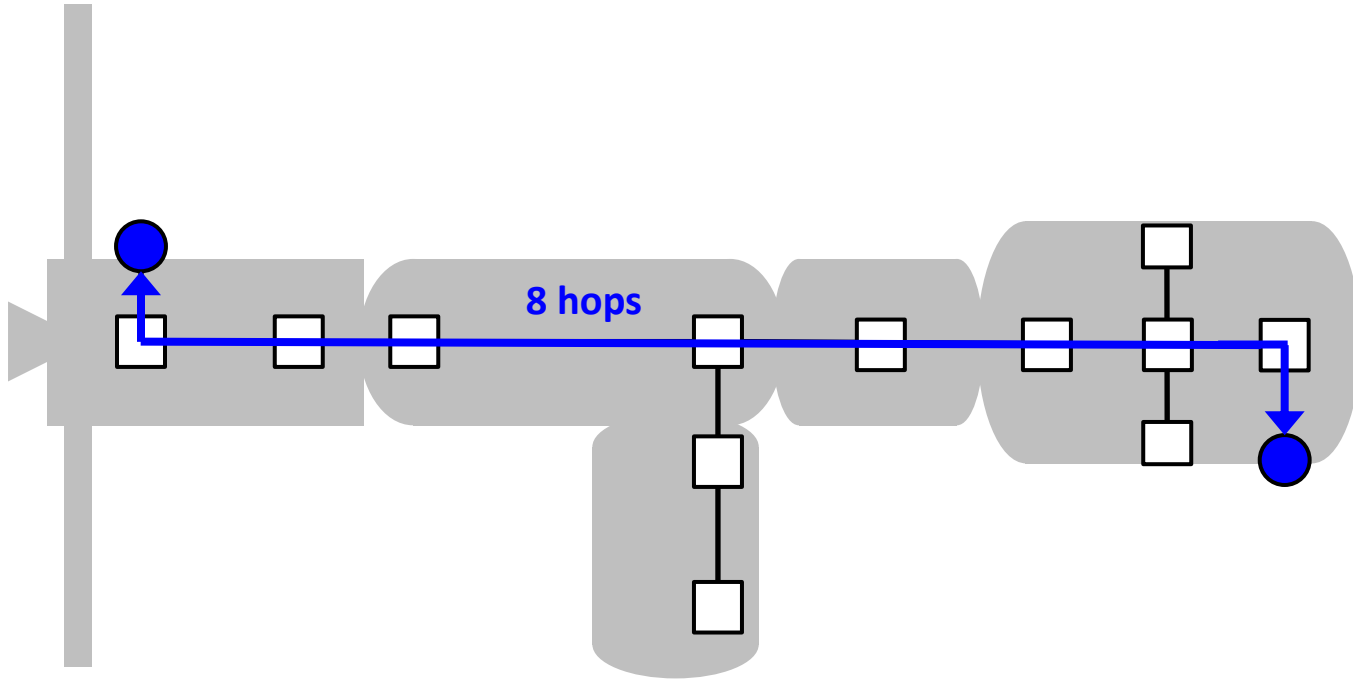
Model Assumptions

- Nodes can communicate as long as at least one plane has only non-faulty switches
- Assumes permanent switch failures only
- Assumes industry-standard switch failure rate of 10^{-6} failures/hour
 - Modern devices tend to have better permanent failure rates than this, but worse transient failure rates, so this is a safe estimate
- Assumes plane cross-connects are not used (simplifies analysis)
- Assumes all switches fail independently
 - Real life may not be so nice! E.g., Switch cards may share power



Only two nodes shown; in reality each switch card may connect to 6-12 nodes.

Example 1: Space Station, Small (1 and 10 Years)

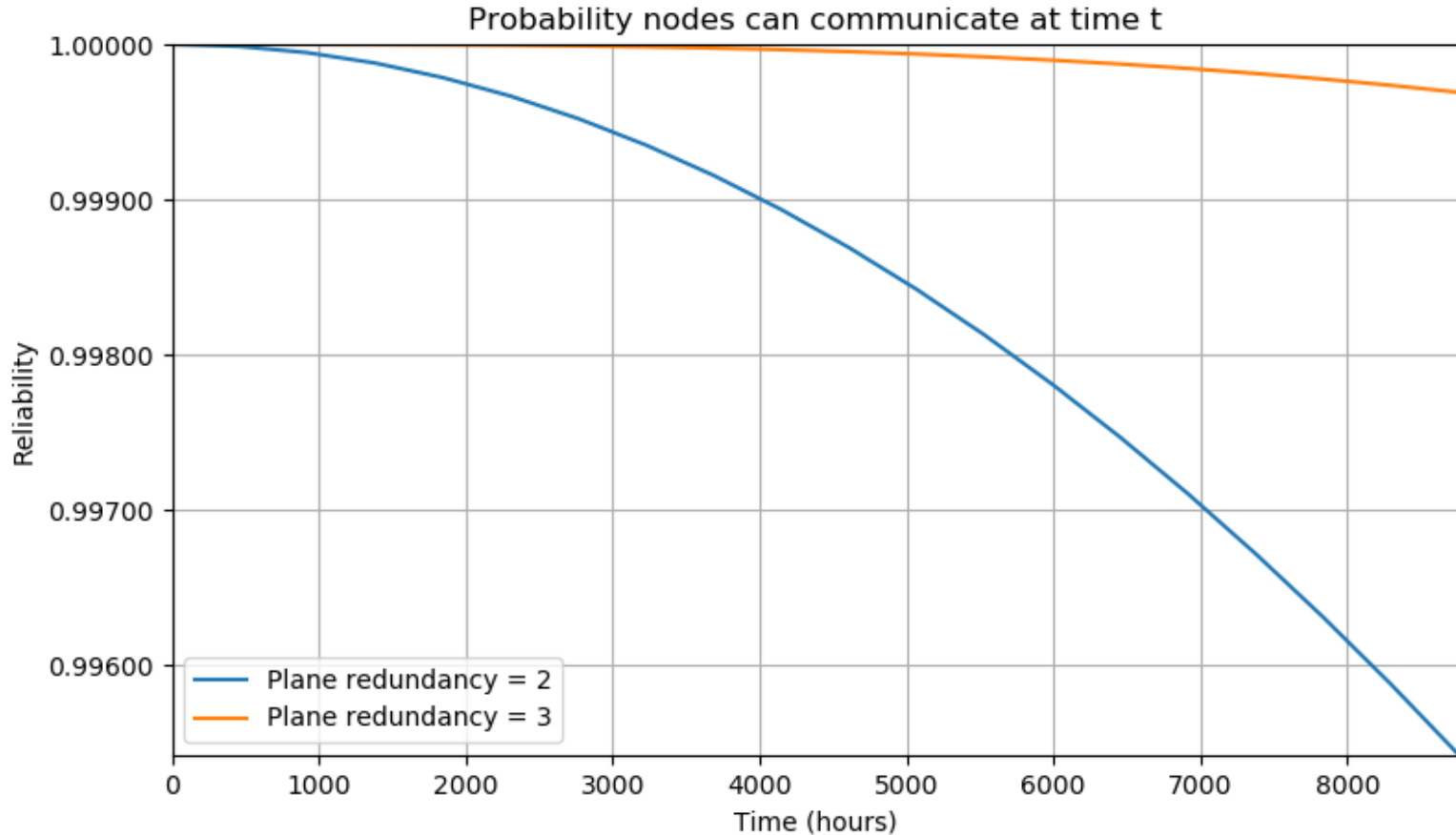


□ Switch

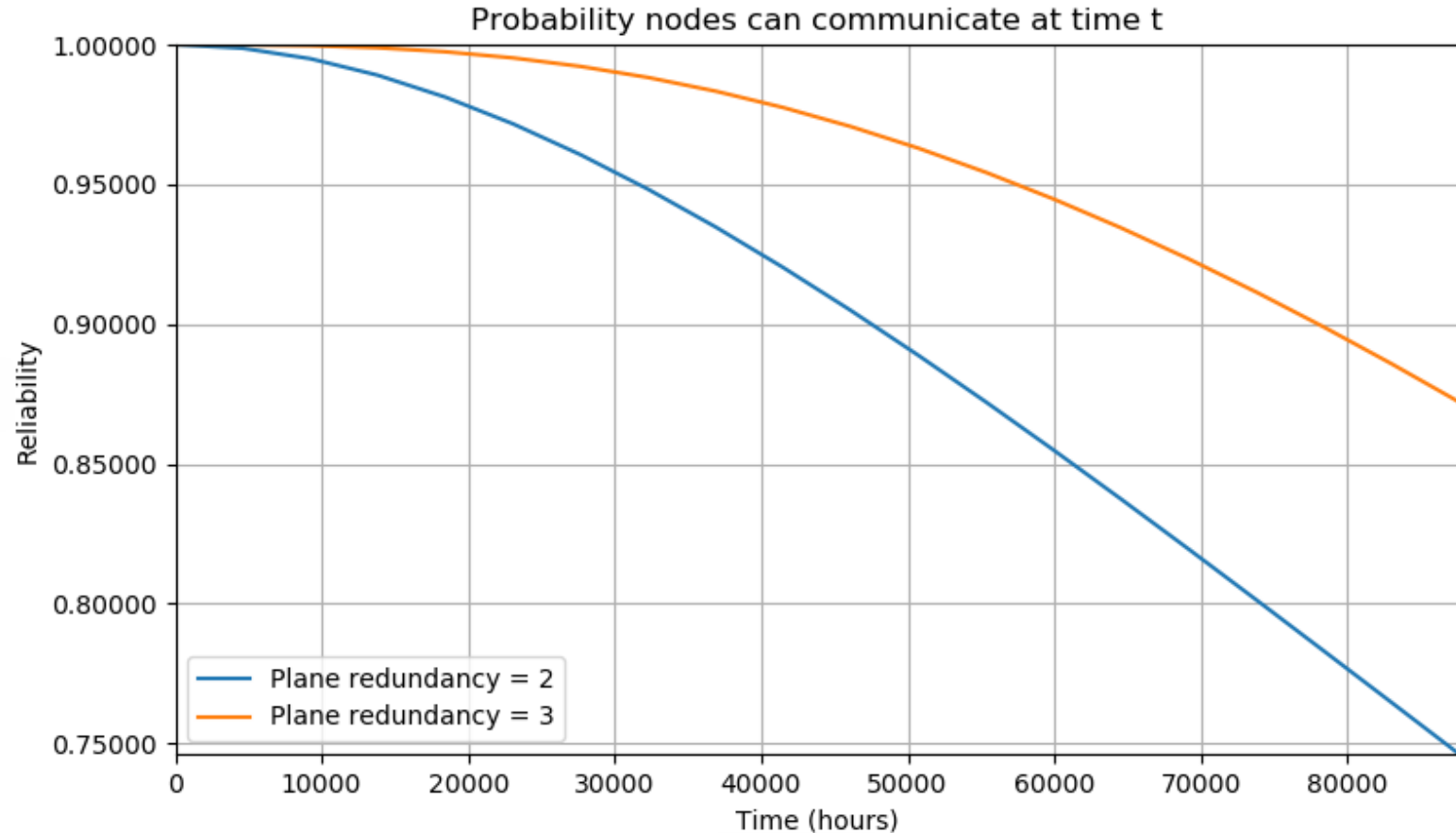
● Furthest two nodes

Size comparable to future Lunar outpost (e.g., Gateway)

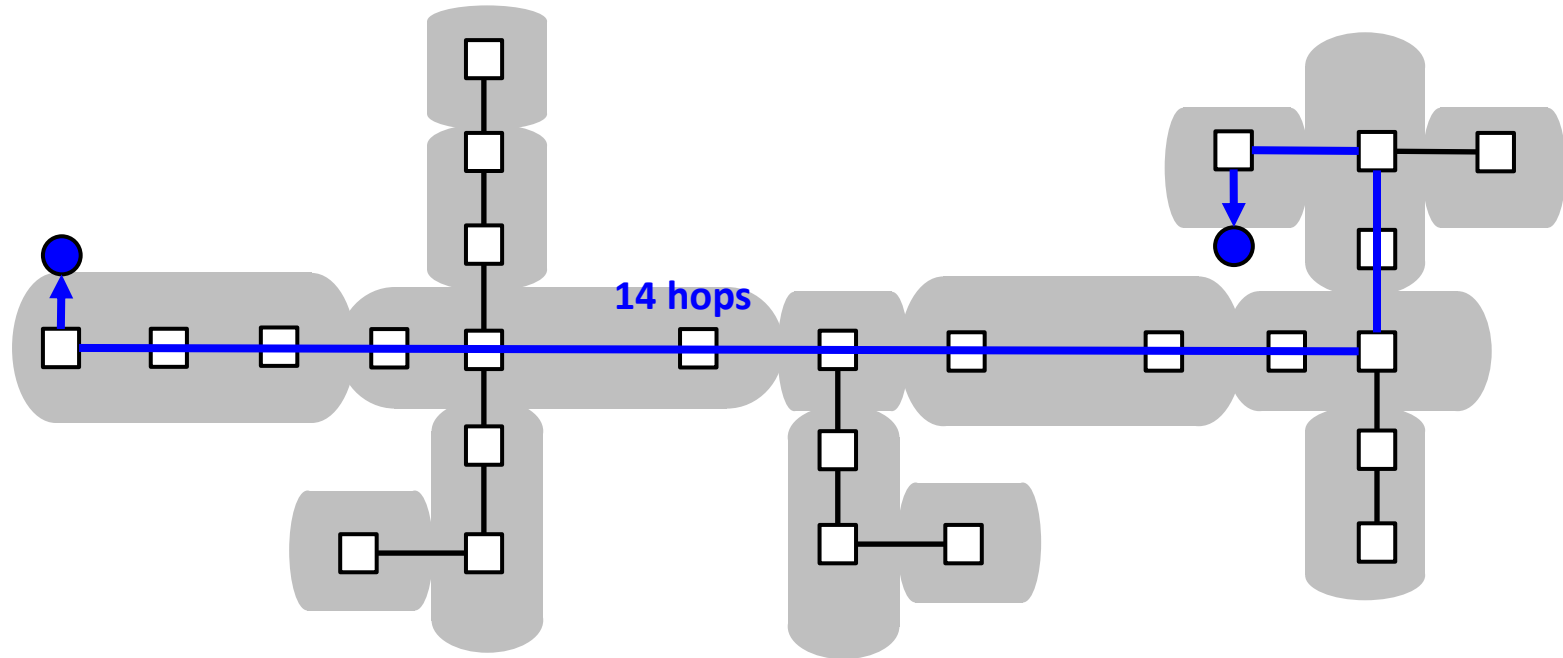
Example 1: Space Station, Small (1 Year)



Example 1: Space Station, Small (10 Years)



Example 2: Space Station, Large (1 and 10 Years)



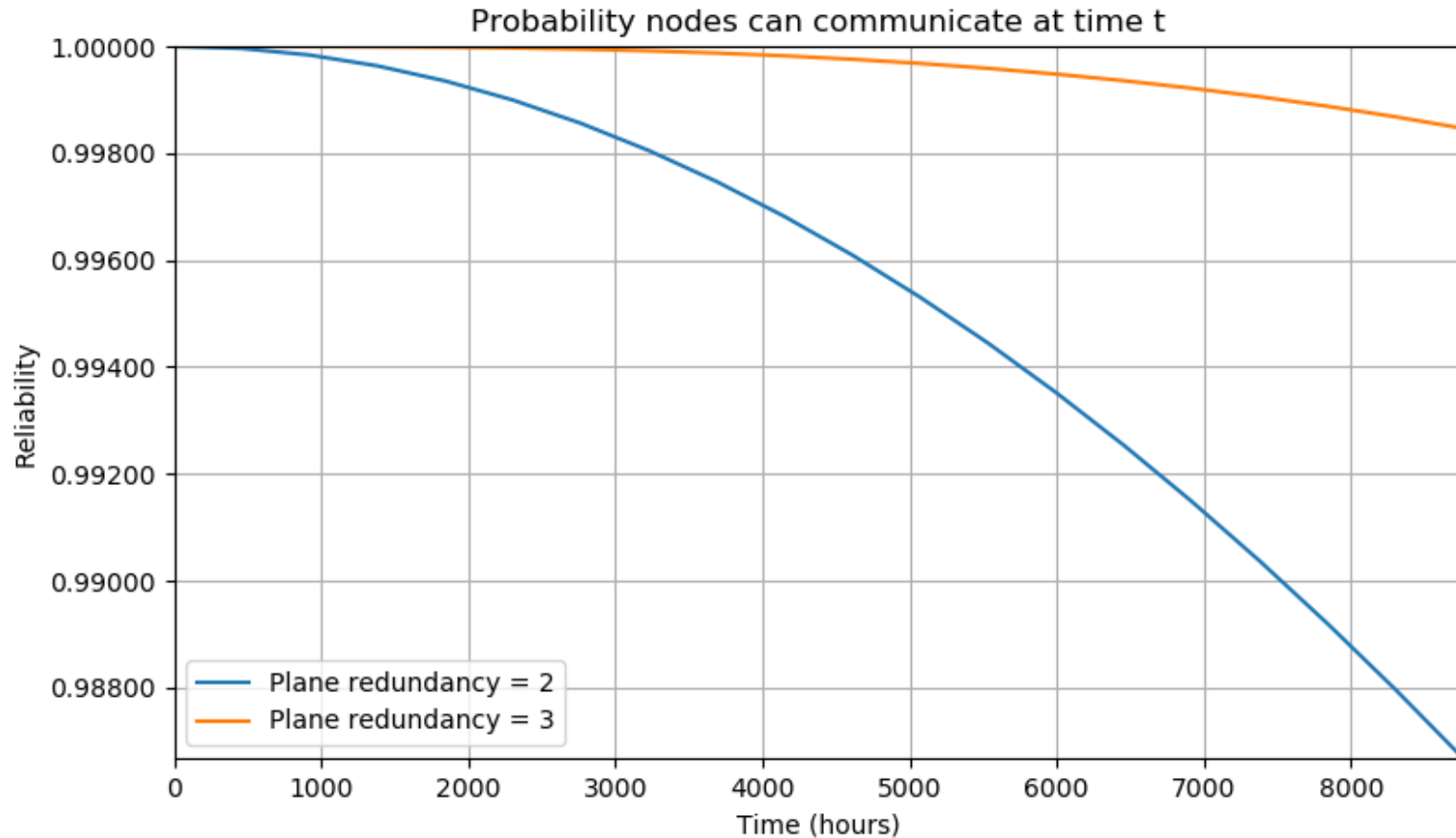
Switch



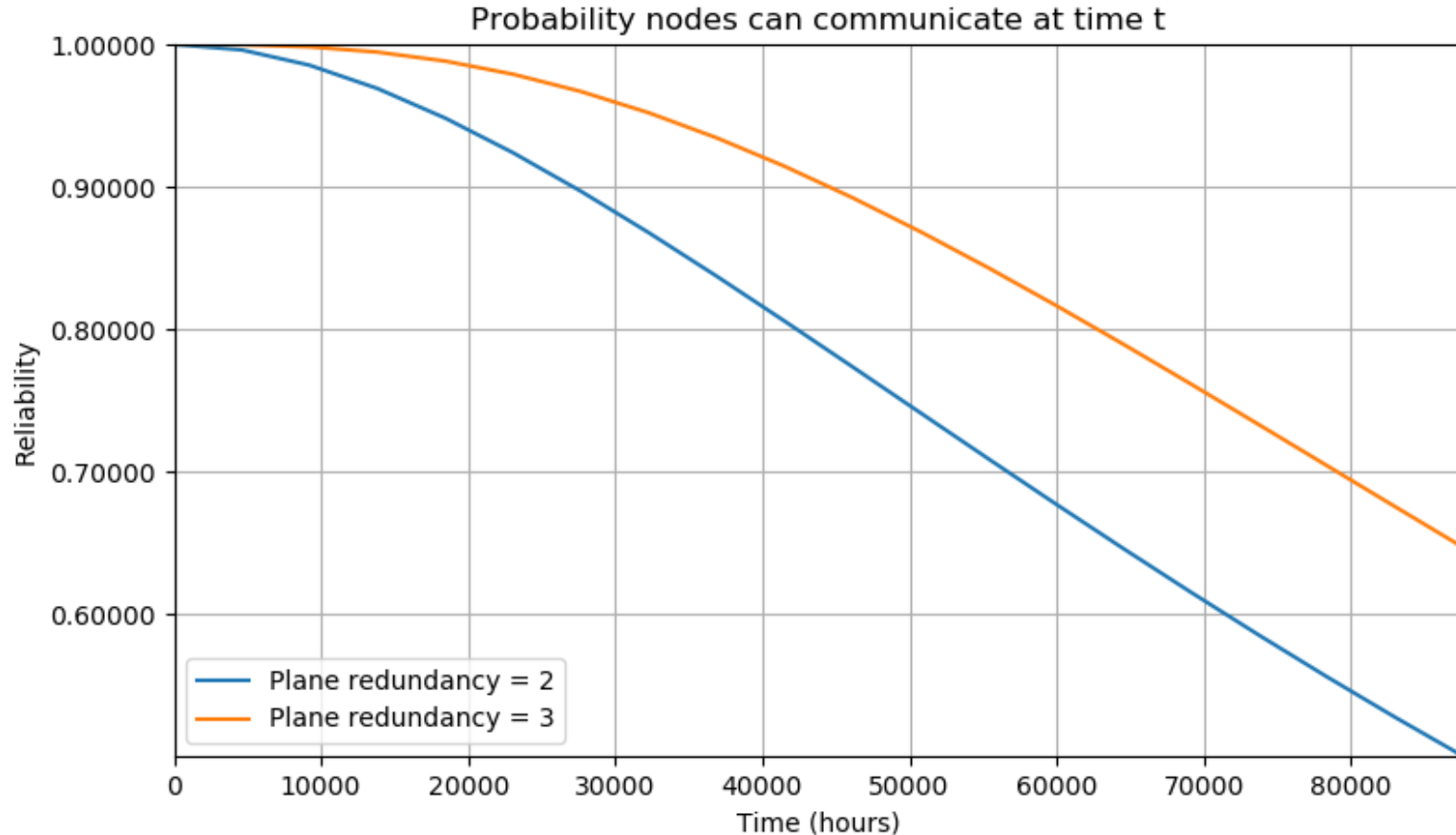
Furthest two nodes

Size comparable to International Space Station

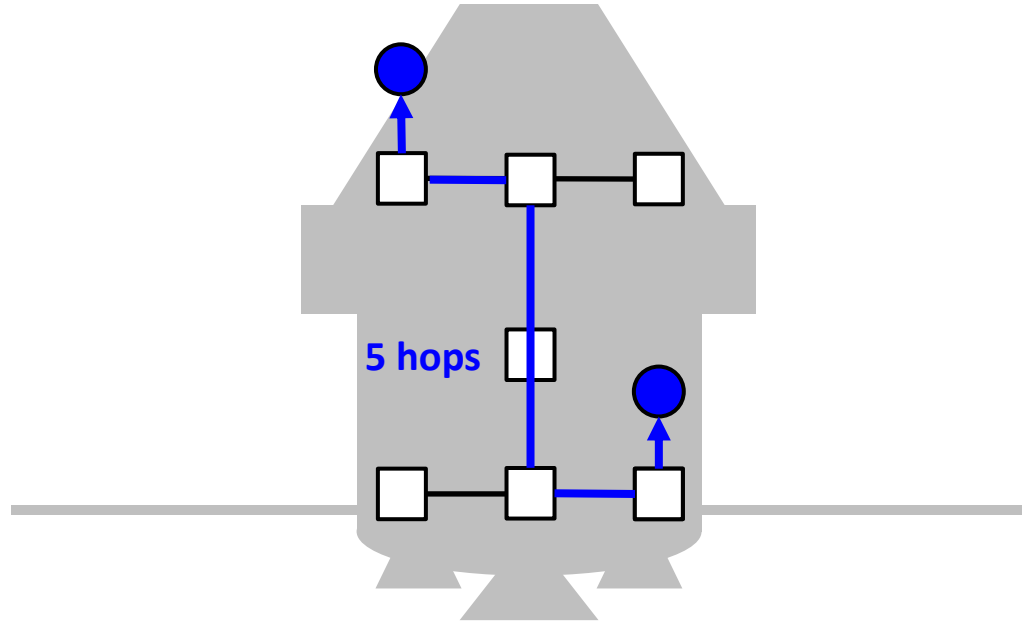
Example 2: Space Station, Large (1 Year)



Example 2: Space Station, Large (10 Years)



Example 3: Capsule/Lander (1 month)

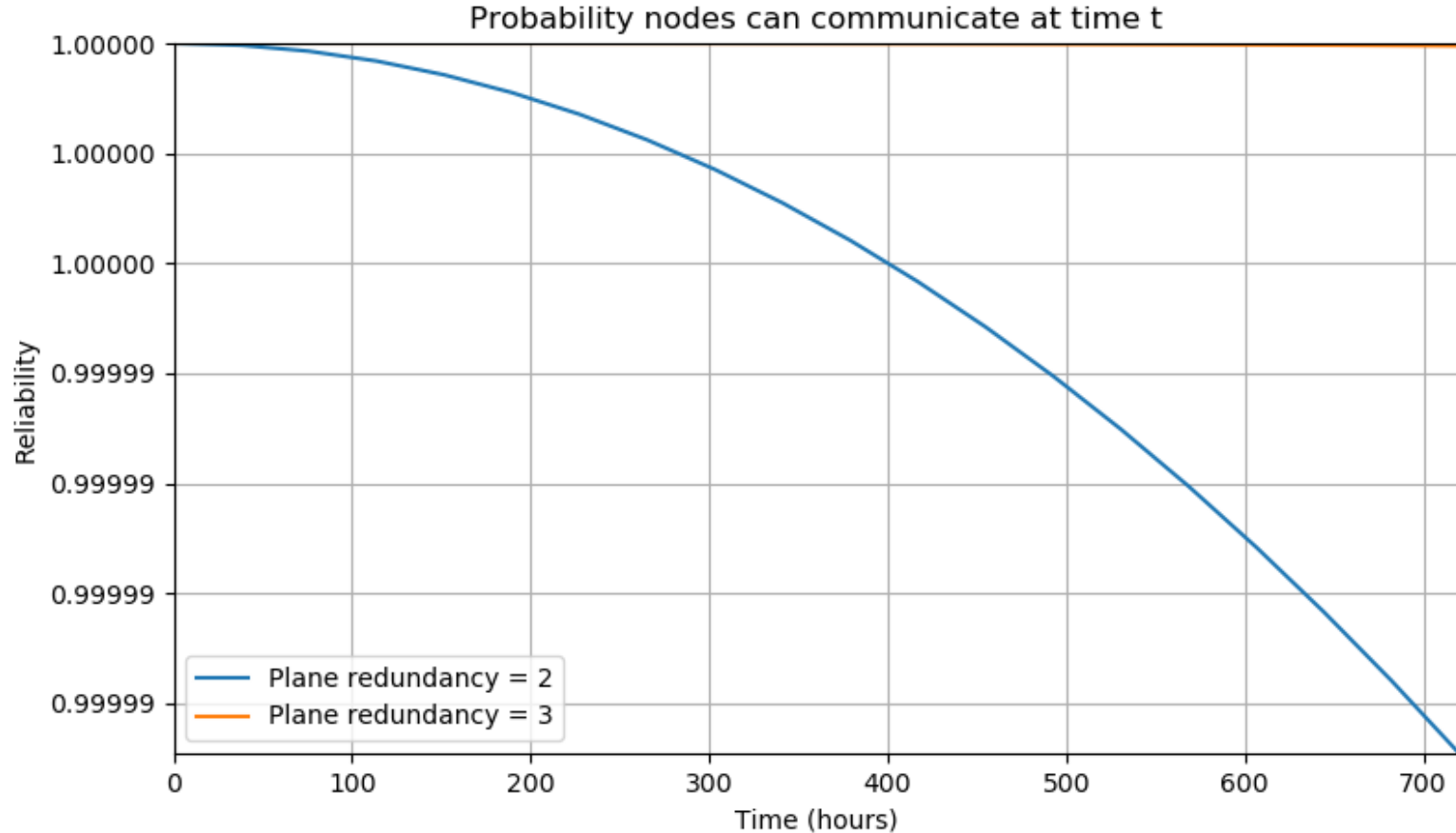


□ Switch

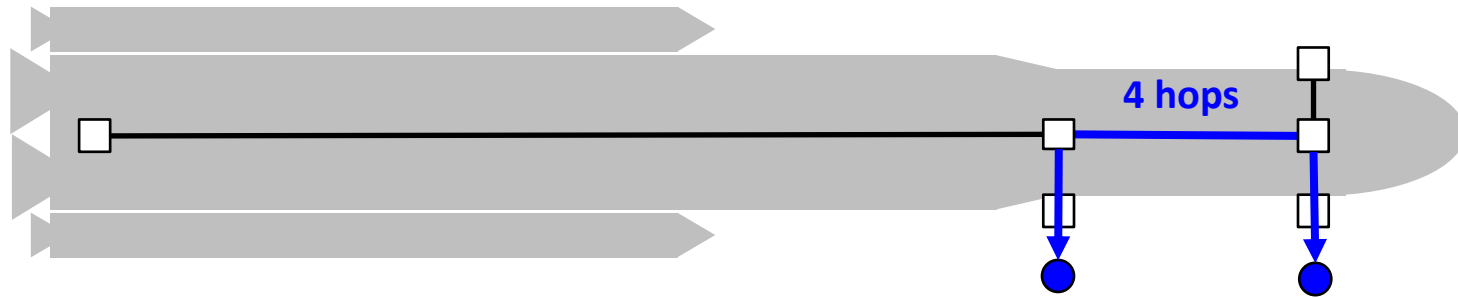
● Furthest two nodes

Size comparable to large lander or capsule + service module 10

Example 3: Capsule/Lander (1 month)



Example 4: Heavy-Lift Launcher (6 months)

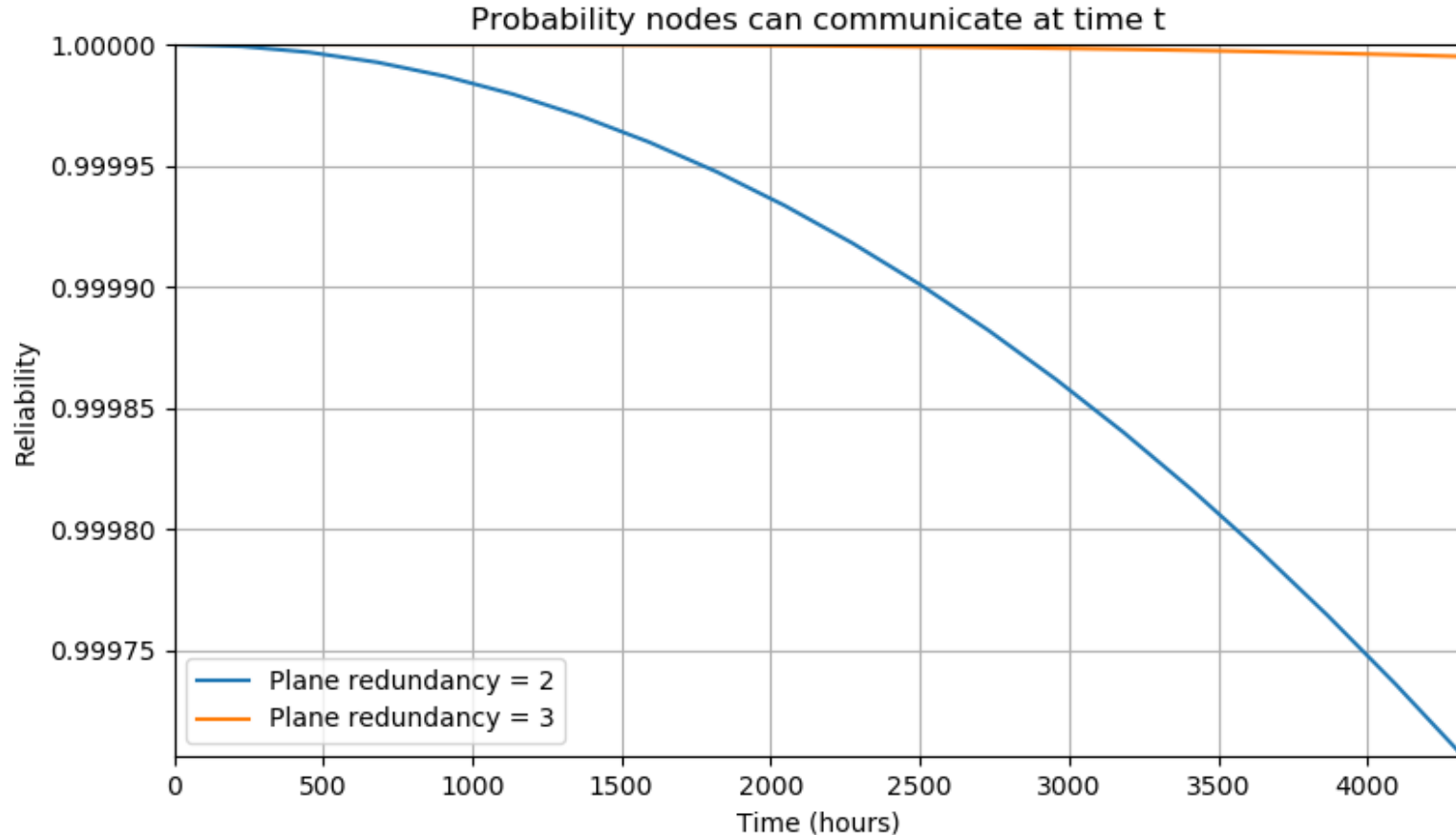


□ Switch

● Furthest two nodes (in upper stage)

Size comparable to large unmanned launcher (e.g., Ares V) 12

Example 4: Heavy-Lift Launcher (6 months)



Conclusion

- Two planes offer good reliability over short duration missions (e.g., <1 month)
- However, three planes have significant benefits when:
 - Mission duration is long (e.g. 1 year)
 - The network is large (e.g., 5+ hops)
 - The network may need to reconfigure in flight (since planes become inoperable)
- Very long missions require failed switches to be identified and replaced
 - Otherwise reliability is poor, even with 3 planes