Scalability and Development of Space Networks

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Executive Summary

Future space networks could leverage on high-readiness terrestrial technology. Terrestrial networks have been designed and built with a primary concern for *scalability*. The white paper

- Conducts an assessment of the scalability paradigm in terrestrial network design,
- Conducts an assessment of future scalability needs for space networks, and
- Identifies gaps between space needs and terrestrial approaches.

In conclusion, the paper derives implications for potential lifecycle steps during a spiral development process.

Scalability in Terrestrial Networks

Scalability refers to the ability of a system to sustain seamless operations when certain system parameters increase [1]. Scalability can be considered in four dimensions (compare with [7]):

- *Numerical*. A distributed system seamlessly continues operations with an increased number of user, resources, and services. For example, a Web server would continue to be responsive during unanticipated flash crowds [4].
- *Geographical*. A distributed system would enable communication among users and resources that lie far apart.
- *Administrative*. A distributed system would be easy to manage even if it encompasses multiple administrative domains.
- *Functional*. A distributed system would accommodate more complex functionality (e.g., a larger number of function points). In particular, system complexity could be effectively harnessed through convergence layers or reusable middleware components.

Scalability is traditionally considered as the primary design objective for terrestrial networks. The reason is that terrestrial network systems have increased rapidly in terms of, for example, the number of users, the volume of data, geographic reach, the number of administrative domains, and application complexity. Furthermore, scalability is commonly considered as a quality assurance ("if it scales, it must be working") [9].

The emphasis on scalability has led to the design and implementation of expandable and reusable solutions. For example, the Internet Protocol (IP) can be viewed as a convergence layer to support the interoperability among disparate physical communication technologies. As another example, advanced middleware simplifies the design, development, and deployment of applications while simultaneously reducing costs and improving system quality. In general, scalability is a pervasive paradigm that must be taken into account if one wishes to exploit existing capabilities of terrestrial networks.

Scalability in Space Networks

Scalability seldom appears as a specific objective in the design of space communication networks. The omission is perhaps best explained by the fact that scalability to large numbers is a fundamental facet of terrestrial scalability but significantly less relevant in space networks. Space networks are rather concerned with "geographic" scalability, i.e., the potential for a distributed system to cross long communication distances. Development scalability is also important and has recently led to an emphasis on flexible, sustainable, affordable, and autonomous operations. However, development scalability traditionally ruled out certain reusable solutions, such as middleware, due to severe computational and energy limitations and long communication delays.

Gap Analysis

The concern on scalability is ingrained in all activities of terrestrial networks. However, certain facets of scalability are irrelevant or detrimental for space applications. As such, *scalability is the primary gap* between terrestrial capabilities and space requirements. This white paper points out the existence of a gap and suggests a possible avenue for its resolution.

The gap is perhaps at its widest in the case of numerical scalability, since terrestrial networks can host vast numbers of communication systems, whereas space assets tend to be fewer and sparser. Moreover, different approaches have emerged in the case of networks for challenged environments, especially in regard to functional scalability. An example of challenged terrestrial networks is a sensor network. Sensor networks are severely constrained in terms of energy, computational power, and communication range, yet an on-going fundamental research thrust is to devise common architectures, interfaces, substrates, and reusable systems [8]. On the contrary, space networks have typically followed the approach of “intelligent” or optimized communication systems.

Gaps are not necessarily detrimental because the combination of different approaches could contribute more than the sum of the parts. However, fundamental gaps should be identified and resolved early during each spiral cycle. Additionally, certain spiral models contemplate anchor milestones, such as the development of lifecycles objectives and architectures, which should then resolve key differences in detail. The resolution involves the identifications of the system's stakeholders and their success conditions, and negotiation to determine a mutually satisfactory set of objectives, constraints, and alternatives [6]. The following observations could be useful at this stage:

- Most approaches are likely to devote attention to geographic scalability (e.g., Disruption Tolerant Networks [2]), development cost, quality, and process (e.g., [5]), and power conservation (e.g., [3]).
- Terrestrial capabilities are likely to place greater emphasis on scalability with respect to numbers (e.g., vast numbers of communication end-points), functionality (e.g., generality, reusability, convergence layers, and middleware), and administration. They might also place more emphasis on Quality-of-Service.
- Space requirement are likely to place more emphasis on extreme geographical scalability. Although they are interested in functional scalability, they are more likely to sacrifice generality for performance. For example, “intelligent” solutions are often preferred to reusable state-of-the-art distributed system approaches. Finally, space requirements consider numerical scalability primarily in relation to volumes of data traffic.

We reiterate that the integration of disparate capabilities and paradigms could be useful for a successful space network, but would have to be reconciled during the first steps of each spiral cycle. For example, a possible resolution could view generic solutions as a reference model and would create principles and tools to instantiate the model into optimized artifacts. Another possible resolution would be to assess the effectiveness of terrestrial sensor network middleware for space communication.

Conclusions

Scalability is the central principle in Networks and Distributed Systems. Although scalability paradigms differ, each view can be valuable and contribute to space networks. However, differences would have to be explicitly identified and resolved during specific steps of the spiral lifecycle process.

References

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