Network Management Challenges for IP-based Cyber-Physical Networks

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Abstract

This short positioning papers analyzes the status quo of network management in Cyber-Physical Networks that use the Internet Protocol (IP) but differ to the general Internet. Examples include IP-based industrial networks and modern automotive networks. The use of IP in these networks currently evolves significantly, and this inherently affects network management solutions. Yet, in these industry sectors the IETF network management solutions are only used partly, or not at all. This paper discusses potential reasons and raises questions regarding the future evolution of network management operations in the IETF.

Cyber-Physical Networks

The IETF network management solutions including YANG, NETCONF, and RESTCONF are widely supported in network devices used by Internet Service Providers (ISPs), including e.g. routers, switches, optical transport equipment, etc. The IETF standards are also the basis for work in many other standardization bodies in this space, such as IEEE.

This paper explicitly does not focus on ISP networks and the general Internet. The Internet protocol stack is also used in other networks that have different characteristics, such as cyber-physical networks. One typical example for such cyber-physical networks are industrial networks, i.e., Operational technology (OT) networks. Another typical example are automotive networks, including both the In-Vehicle Networks (IVN) inside vehicles and their connection to the rest of the world, i.e., Vehicle-to-Everything (V2X). This paper focuses on these environments. The more general term Internet-of-Things (IoT) would include many other use cases.

The presented networks have very different technical needs, and they represent very different industry sectors. But they have in common that IP communication and connectivity to the Internet becomes more and more relevant, often in combination with Ethernet or other communication technologies designed for Internet traffic. Some common characteristics are:

- The network is only one component in an overall engineered physical system.
- The used embedded devices may have much less compute and memory resources than, say, a modern router.
- Publish-subscribe and cyclic communication patterns are common.
- There may be hard real-time and safety requirements.
- IETF network management solutions are not necessarily widely used.

In the following, the management of cyber-physical networks is briefly reviewed. This short paper is not meant to be comprehensive; more details could be provided as follow-up.

Modern Network Management in Industrial Networks

Industrial Networks use Ethernet and IP for decades already, typically using some Industrial Ethernet solution (PROFINET, EtherNet/IP, EtherCAT, etc.). A promising solution to overcome interoperability issues between different Industrial Ethernet networks is OPC UA by the OPC Foundation [1].

OPC UA is a solution to operate complete cyber-physical systems. OPC UA includes, amongst others, comprehensive techniques for data modeling, protocols to access data models, as well as a large set of standardizes data models for many industrial application areas. Conceptually, OPC UA has a very similar set of features like NETCONF/YANG, but the technical solution is completely different. For instance, data models are basically developed in UML, and the default communication is binary. A more comprehensive comparison between NETCONF/YANG and OPC UA could be provided in follow-up work.

OPC UA is still evolving, and new standards such as OPC UA FX for field communication emerge. In OPC UA FX, an integration between OPC UA and NETCONF/YANG may be required, as the overall industrial system is managed by OPC UA, but the management of switches for Time Sensitive Networking (TSN) is foreseen by NETCONF/YANG. However, it is still to be seen whether NETCONF/YANG will become widespread in that use case, how the several different management solutions will get implemented, and how they will interact in real deployments.

From a technical point of view, NETCONF/YANG and OPC UA could also be considered as two overlapping solutions, with OPC UA being the one that manages most parts of the cyber-physical system. This raises the question what role NETCONF/YANG may really have in future industrial systems.

Modern Network Management in Automotive Networks

While Ethernet and IP has been used in industrial networks for decades, the use of In-Vehicle Networks (IVN) with IP is a rather recent trend. More and more Original Equipment Manufacturers (OEMs) of vehicles use Ethernet as backbone network technology in vehicles. There are many ongoing engineering efforts towards a Software-Defined Vehicle (SDV). The use of Automotive Ethernet (e.g., 100BASE-T1/1000BASE-T1) and IP-based protocols such as SOME/IP [2] will most likely significantly increase in the next generation of vehicles. This also implies that an increasing number of network devices such as switches, routers, firewalls, etc. will need to be managed inside vehicles, or also from the outside.

The automotive industry differs to other industry sectors in many ways, and this also applies to network design principles and the management and operation. Currently, IETF network management solutions may not play a relevant role even for typical network use cases (e.g., configuration of an Ethernet switch or router inside a vehicle). Instead, OEMs may realize network management tasks by automotive-specific solutions, e.g., based on SOME/IP. The automotive industry traditionally uses databases for comprehensive data modeling of all communication.

The complexity of automotive network using Ethernet and IP will probably further increase, resulting in more complex configuration and network management tasks. At the time of writing, it seems an open question whether IETF network management solutions could help in that space.

Open Issues and Challenges

Analyzing cyber-physical networks requires looking left and right, as these networks differ to the general Internet in many ways. They may have not been the key focus of IETF network management solutions in the past, and this may not change any time soon. Nonetheless, it could be useful to discuss several questions in this specific context:

Question 1: Learn from others?

A first question could be: “Can IETF network management mechanisms leverage lessons learnt from other similar solutions used in cyber-physical networks?”

Regarding technical capabilities, a comprehensive gap analysis could be a starting point to address this question, but this is outside the scope of this document. It should be noted, however, that there are some apparent technical differences between NETCONF/YANG and other solutions used for similar tasks. One example may be the ease of use of pub-sub communication patterns.

Question 2: Evolve to conquer new grounds?

A second question might be phrased as follows: “What would it take to adopt the IETF network mechanisms for new use cases in cyber-physical networks?”

This is a complex, multi-faceted question that includes many non-technical issues. From a purely technical point of view, one potentially relevant question is if the current datastore concept is flexible enough for control logic of physical systems different to network devices.

Question 3: Bridging the Gap?

A third question could be: “How could different network management solutions better interoperate and integrate?”

Under the assumption that other solutions designed for cyber-physical networks will not disappear, one of the real-world challenges will be interoperability. Any integration activity in this complex space affects not

only very heterogenous technologies, but also different industrial sectors and various standardization organizations. One of the first challenges could be to bring together experts, in particular persons with expertise across different areas. Potential low-hanging fruits in this space could be a mapping of terminology (“rosetta stone”) and mapping guidelines for data models. Early work in that space may already exist (e.g., [3])

References

[1] OPC Foundation, https://opcfoundation.org

[2] https://some-ip.com

[3] https://github.com/DevarajSambandan/yangopcua