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Semantic Addressing and Routing for Future Networks (SARNET-21) Workshop Report

Abstract

This document provides an overview of the "Semantic Addressing and Routing for Future Networks" workshop (SARNET-21), which took place on June 10, 2021, in Paris, France and online as part of the IEEE International Conference on High-Performance Switching and Routing. The main goal of the SARNET-21 workshop was to explore, together with the research community, the use cases and network requirements in the domain of semantic addressing and routing, and identify potential research challenges to be tackled in the future.

Note that this document is a report on the proceedings of the SARNET-21 workshop compiled by the authors. It captures the views and positions of the workshop participants as expressed during the workshop.

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Table of Contents

1. Introduction

Various networks, such as IoT networks, industry networks, data-center networks, content distribution networks, satellite networks, etc., have been emerging for the past decade in the light of digital transformation. These heterogeneous networks often adopt different architectures, topologies, as well as addressing and routing mechanisms. The satellite network is a typical example of a highly dynamic topology in which mobile network nodes can cause stability issues to existing routing protocols. IoT and manufacturing networks often adopt alternative addressing semantics that go beyond the network location defined in IPv4 and/or IPv6.

In simple terms, semantic addressing is about taking a regular address and assigning special meaning to some or all of the bits.

Examples include multicast addresses, segment identifiers in segment routing, and network programming abstractions. Although the specific semantics help to facilitate addressing and routing within the network, scalability challenges arise from providing the definition of those semantics, and the interconnection among such networks and the Internet.

Several techniques have been proposed that modify/improve the default IP forwarding behaviors (such as least-cost path) to better meet the application requirements, based on additional information available in the packet (both in header and payload) and configurable policies in routers. Collectively, these mechanisms are sometimes referred to as "Semantic Routing" [I-D.king-irtf-challenges-in-routing]. The alternative semantics used to make routing decisions, together with the IP addresses, could be applied to a network overlay [RFC7665], or can be directly embedded into the address field, which is the case in some limited domains [RFC8799] such as LoRaWAN deployments [LoRaWan].

However, those ad-hoc solutions have been developed in a fragmented way, which creates interoperability issues between limited domains or between individual routers, and can lead to increased fragility or even security/privacy leakage. A more holistic approach can design the architectural patterns based on semantic routing for future networks.

In June 2021, the "Semantic Addressing and Routing for Future Networks" (SARNET-21) workshop was held as part of the IEEE International Conference on High-Performance Switching and Routing. This event was held in Paris, France and online. The main goal of the SARNET-21 workshop was to explore the use cases and network requirements in the domain of semantic addressing and routing, and identify potential research challenges to be tackled in the future. The participants and audience of the workshop were drawn chiefly from the research community.

This document is a report on the proceedings of the SARNET-21 workshop compiled by the authors. It captures the views and positions of the workshop participants as expressed during the workshop.

2. Workshop Agenda

The workshop&s goal was to invite the research community to collectively explore semantic addressing and routing and identify potential requirements and networking solutions. Researchers and experts from industry and academia got the opportunity to share their experiences and achievements by addressing the challenges mentioned above.

The workshop also served as a venue to identify problems and to discover common interests that may turn into new work or into changes in the direction of ongoing work at the IETF and/or the Internet Research Task Force (IRTF).

The SARNET-21 workshop received 19 submissions and accepted 10 papers based on a minimum of three peer reviews. The accepted papers were presented in 3 technical sessions. The accepted papers are listed in Appendix B. In addition to the technical sessions, a keynote talk on "The Routing Challenges for Future Networks" was given by Prof. Olivier Bonaventure from Universite Catholique de Louvain (UCLouvain), and a panel discussion on "Semantic Addressing and Routing Impact on Future Networks" was moderated by Prof. Alex Galis from University College London (UCL).

3. Discussions

3.1. Technical Presentations

The papers that were presented in the technical sessions cover the following topics:

Semantic Addressing: Alternative addressing semantics, beyond the use of traditional network locations in IPv4/IPv6, can overcome many of the limitations exhibited by existing technologies. Papers on this topic presented approaches ranging from non-IP addresses, which are automatically derived according to the network structure, IP addresses representing a space geo-location, and anycast addresses used as service identifiers. In the case of network structure-oriented addresses, significant performance improvements have been demonstrated compared to IP with OSPF or BGP. The use of space geo-location addresses provides support for highly dynamic network topologies (e.g., in low earth orbit (LEO) satellite constellations). In contrast, anycast addresses have been shown to determine the best (instead of the closest) service instance in distributed edge compute scenarios.

Semantic Routing: Papers on this topic presented solutions in which routing decisions are based on semantic addresses and other fields in the packet, going beyond the traditional shortest path first algorithm. One such paper used an application-layer overlay to act as the routing substrate to perform traffic differentiation and fine-grained per-flow traffic management based on tags added to packets that signify, for example, the desired QoS levels. Another example concerned the use of service names (simple binary identifiers of fixed size) to route traffic within a domain, which improves service access in terms of network and service latency.

Security:

Security was one of the capabilities that have been overlooked in the original design of the Internet. Two papers in the workshop proposed solutions in this space. The first was developed in the context of named data networking where decentralized identifiers are used to build self-verifiable content advertisements. Based on these, routers can verify that a content advertisement originates from an authorized entity without requiring any trusted third party, thus preventing DoS attacks. The other paper presented an approach that overcomes privacy violations as a result of using location-oriented IP addresses. This is based on source routing with public-key cryptography to establish connections and simple private symmetric encryption in the data path that allows for fully stateless packet transmission between two endpoints in the Internet.

Programmability: Network programmability has been an instrumental topic for a while due to its benefits in terms of flexibility and adaptability. Papers on this topic focused on using SDN to configure forwarding rules according to semantic routing policies (e.g., QoS), changing the forwarding behavior of a programmable data plane through P4, and using flexible virtualization technologies for the realization of network functions.

Limited Domains: Various limited domains have been targeted by papers presented at the workshop. There took their unique characteristics and requirements into account when designing the respective solutions. Included among these were satellite and vehicular networks that have highly dynamic topologies, industrial networks with strict QoS expectations, and IoT networks that involve efficient delivery of bulk data and short addresses.

3.2. Panel on the Impact on Future Networks of Semantic Addressing and Routing

A panel of experts was convened and chaired by Prof. Alex Galis:

*Christian Jacquenet (Orange, France)

*Rui Aguiar (University of Aveiro, Portugal)

*Adrian Farrel (Old Dog Consulting, UK)

*Mohamed Faten Zhani (ETS, Canada)

The panelists and audience had a fascinating and constructive discussion for about 2 hours. The panelists, in their presentations, raised essential points including:

- Significant changes can make network operators nervous. Hence, there is a need for robust standardization effort to ensure graceful and safe co-existence with legacy equipment and a clear migration path.

- The set of questions that research should address.

- Privacy and security are critical requirements for future addressing/routing solutions.

- Semantics tend to be service-specific.

- Routing protocols should be customized to the needs of the applications.

During the session, the panelists expressed the opinion that although semantic routing also exists today to a certain degree (e.g., ECMP, IP Flex-algo, etc.), any change that will question decades of IP network operation will undoubtedly make operators nervous. Any new addressing/routing system and framework will need to coexist with legacy gear and thus requires a robust standardization effort with one of the focal points on avoiding semantic leakage between routing domains/limited domains/slices/ partitions on the Internet.

While this is a fundamental topic, the panel recognized that the potential impacts and benefits of changing the addressing and routing system have been overlooked. There is, hence, a need to revisit the origins of the Internet. Given that the Internet architecture is composed of many limited domains interconnected by a transport layer and associated protocols, the panelists said that understanding what is happening with limited domains and why they exist will help us better understand the impact of semantic addressing and routing. New protocols could be deployed and evaluated starting from such limited domains or network slices, where the effect is contained. Due to its fragility, there was general consensus that care needs to be taken over any changes in the backbone of the Internet.

As semantics is mainly service-specific standardized dynamic links between forwarding plane and services are instrumental. As such standardized, safe deterministic network programmability and frameworks enabling semantic addressing and new routing protocols with guarantees are needed, also enabling cost-efficient solutions of (In-time and On-time) service-inferred performance management.

Another conclusion of the panel was there is a need to explore new routing technologies and protocols inside limited domains to deliver new capabilities and better QoS, enabling application-level innovation and precluding pollution between domains. There was an observation that we are already re-using many protocols in limited domains that are currently used in the Internet, e.g., TCP/IP, BGP, etc. While this is not a bad practice, it is necessary to clearly state their "private" nature. For instance, BGP was used for routing in SIP, but it was given a new protocol ID. The panelists said that if we design protocol extensions or entirely new protocols, we need to make them compatible to avoid distorting the Internet routing system.

In terms of standardization, the panel concluded that researchers should be encouraged to communicate and exchange their research results. Doing research in silos doesn't help the adoption of new technologies and protocols. Fragmenting the problem and farming out the necessary engineering work to some existing silos standardization groups doesn't solve such systemic challenges either. While permissionless innovation is a way to achieve agile development of new ideas and see them deployed in limited domains, the panel's view was that mutual review is essential for stable protocols, and widescale adoption is dependent on standardization. The opinion that the IRTF is an effective and suitable place to facilitate this kind of discussion and progress was expressed.

4. Summary, Next Steps and Conclusions

Semantic addressing and routing is an exciting topic attracting a lot of attention from the research community. New semantics have been invented and deployed in limited domains for new capabilities, better QoS, higher flexibility, and efficiency. This enables incremental deployment of new technologies on "isolated islands" for innovative solutions that may or may not percolate to the whole Internet at a later stage. However, it is challenging to securely and seamlessly connect a limited domain that uses new semantic addressing and routing capabilities to the Internet. How will the new semantics will be treated in the Internet? What if different devices have different semantic routing schemes? Although non-scalable patch solutions could be used to solve this issue to some extent, this is more of a research problem rather than an engineering issue. A "holistic" approach would be to look for potential architectural patterns or common building blocks to facilitate the interconnection between the limited domain and Internet.

To conclude, the area of semantic addressing and routing deserves further research. The output of this research can be published and presented at future workshops, but equally important is the

standardization effort that should be invested to ensure stability, scalability, and interoperability of potential solutions.

Based on the open discussions among the workshop participants and our overall experience with the workshop, several observations have been made, which could lead to some actions as follows:

SARNET-22: SARNET-21 was the first time the workshop had been held, and was a successful event. It has attracted high-quality technical papers, was very well attended, and featured lively discussions. The outcomes suggest holding a follow-up workshop next year.

Research questions: Important research challenges have been identified by workshop participants, which deserve careful consideration. A coordinated effort in addressing these challenges could constitute a meaningful target. The challenges will continue to be documented in [I-D.king-irtf-challenges-in-routing], and a discussion venue is provided by the SARAH email list [Sarah].

IRTF RG: Several participants, including panelists, expressed the need for coordinated research and a concerted standardization effort. A research group could facilitate such activities umbrella of the IRTF that might lead to new work in the IETF.

5. Security Considerations

This document is a workshop report and has no direct impact on security. Many of the ideas in the papers and presentations discussed at the workshop could have different security impacts. Each workshop paper should be read for its own security considerations. The security consequences of semantic addressing and routing demand further research.

6. IANA Considerations

This document has no IANA actions.

7. Acknowledgements

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8. Contributors

TBD

9. Informative References

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[LoRaWan] The LoRa Alliance, "The Long Range WAN Link Layer Specification", Specification v1.0.4, <https://lora-alliance.org/resource_hub/lorawan-104-specification-package/>.

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Appendix A. SARNET-21 Technical Program Committee

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Appendix B. Accepted Papers

The following 10 papers were presented at the workshop (listed in presentation order):

*Paolo Bellavista, Mattia Fogli, Luca Foschini, Carlo Giannelli, Lorenzo Patera, Cesare Stefanelli, "QoS-Enabled Semantic Routing for Industry 4.0 based on SDN and MOM Integration", <https://ieeexplore.ieee.org/document/9481869>

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*Ryota Kawashima, "A Vision to Software-Centric Cloud Native Network Functions: Achievements and Challenges", <https://ieeexplore.ieee.org/document/9481848>

*Rene Glebke, Dirk Trossen, Ike Kunze, Zhe Lou, Jan Rueth, Mirko Stoffers and Klaus Wehrle, "Service-based Forwarding via Programmable Dataplanes", <https://ieeexplore.ieee.org/document/9481814>

*Paul Almasan, Jose Suarez-Varela, Bo Wu and Shihan Xiao, Pere Barlet-Ros and Albert Cabellos-Aparicio, "Towards Real-Time Routing Optimization with Deep Reinforcement Learning: Open Challenges", <https://ieeexplore.ieee.org/document/9481864>

*Mays AL-Naday, Irene Macaluso, "Flexible Semantic-based Data Networking for IoT Domains", <https://ieeexplore.ieee.org/document/9481800>

*Nikos Fotiou, Yannis Thomas, Vasilios A. Siris, George Xylomenos and George C. Polyzos, "Securing Named Data Networking routing using Decentralized Identifiers", <https://ieeexplore.ieee.org/document/9481850>

*Francesco Tusa, David Griffin, Miguel Rio, "Private Routing in the Internet", <https://ieeexplore.ieee.org/document/9481808>

*Nirmala Shenoy, Shreyas Chandraiah, Peter Willis, "A Structured Approach to Routing in the Internet", <https://ieeexplore.ieee.org/document/9481818>

Appendix C. Workshop Materials

The keynote and panel slides can be found in the following link, <https://github.com/danielkinguk/sarah/tree/main/conferences/sarnet-21>

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