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Providing More Than 'Just' Reachability Through Semantic Networking
(+ some personal views)

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Context

- The Internet was designed for ensuring reachability between endpoints
  - The original IP routing system was conceived for finding connectivity paths through the network for forwarding packets to their destinations
- The Internet has evolved to support other needs rather than simply connectivity
  - Identifier/locator separation, network segmentation, differentiated QoS, …
- The need for supporting advanced services (with specific requirements) on top of the Internet has led to deploy extended capabilities enabled by distinct systems
  - Firewalls, Deep Packet Inspection (DPI), Content Delivery Networks (CDNs), Distributed Denial of Service (DDoS), …
- Development of such kind of solutions is realized in isolation, adding complexity to the Internet design and operation

What is Semantic Routing?

- Semantic Routing advocates for explicitly encoding characteristics and requirements of a given communication as part of the transferred information
- This is not totally new, since most existing routing extensions, in fact, can be seen as an application of semantic routing
  - D. Jang D. King, A. Farrel, "A Survey of Semantic Internet Routing Techniques", draft-king-irtf-semantic-routing-survey (work in progress), 2022.
- Such extensions utilize 'semantic enhancements' to packet addresses and other header fields, implying different behaviors
- However, the increasing use of specific addressing and packet header semantics, leads to issues such as fragility, complexity, efficiency, etc.

Risks of existing approach

- Deployment of novel methods in limited domains, while still relying on the public Internet for their interconnection to provide global reachability
- Risks
  - Development of extensions within a limited set of packet fields and semantics
    - Extra complexity in managing the deployment of solutions
    - Limited scope of their applicability and the risk of jeopardizing the stability of the Internet
  - Lack of an explicit and prescriptive usage model of semantic enhancements across design options
    - May increase applications' complexity (and likely their usage by end-users).
  - Increasing complexity of operating networks
    - May stifle innovation for developing new communication semantics by narrowing the economic forces to those who can afford to handle that complexity, while risking the economically viable operation of the Internet as a stable and assured system.

Communication Semantics

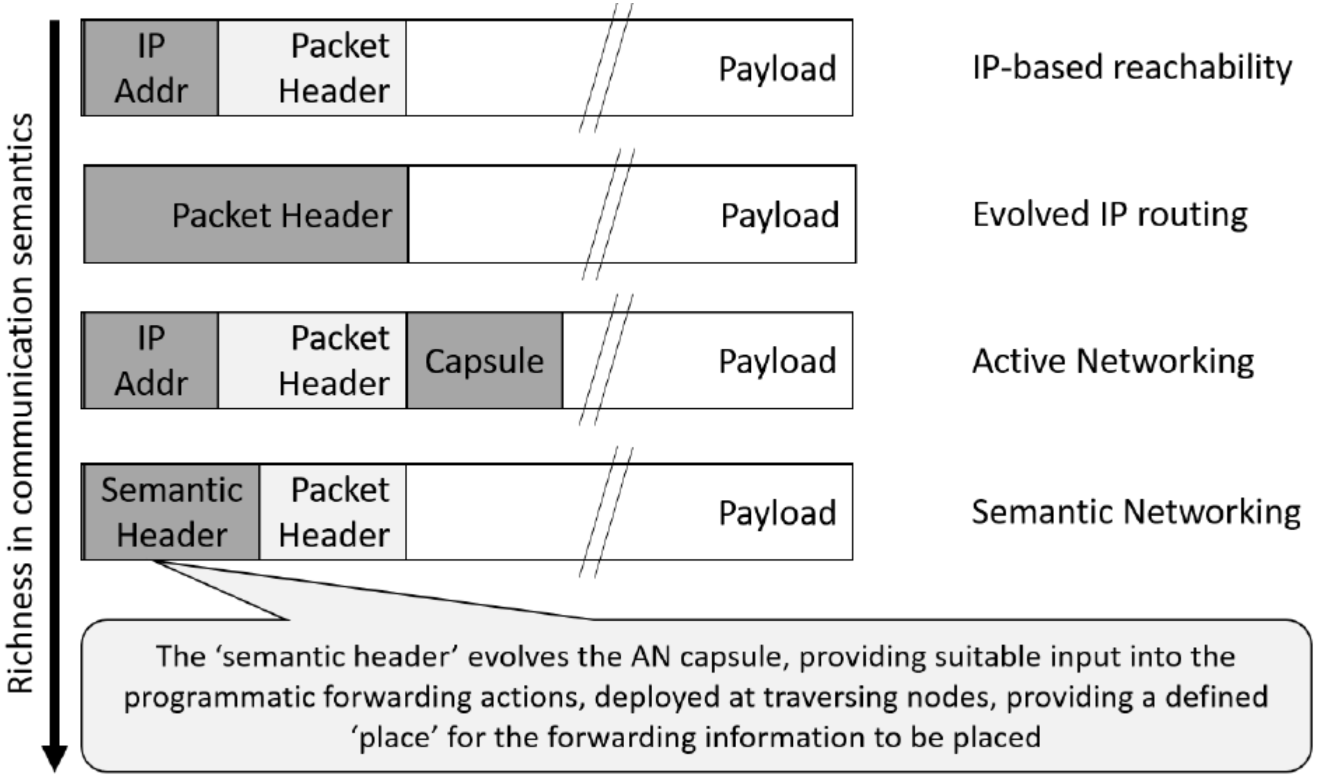
- Communications can be categorized based on
  - **Relationship** between senders and receivers
  - **Selection** of the path(s) and endpoint(s) for the delivery of packets
- Basic semantics
  - Unicast, Anycast, Multicast
- Furthermore, the relationship semantics can be further constrained through path and endpoint selection semantics
  - Examples: bestcast, chaincast

What is then needed?

- It is perceived as beneficial to follow a **generic Semantic Networking approach** going beyond the development of individual Semantic Networking solutions, each of them with their associated issues, implications and complexities
- Such a design can be enabled by
  - A **new common abstraction** to carry information of interest for the semantic communication
  - An **architectural framework** to support Semantic Networking on top of the existing Internet
- With that, Semantic Networking will allow applications to explicitly request specific semantics for data they generate and receive
  - That should be done without negatively impacting other semantically defined forwarding and routing policies, including basic IP delivery

New common abstraction

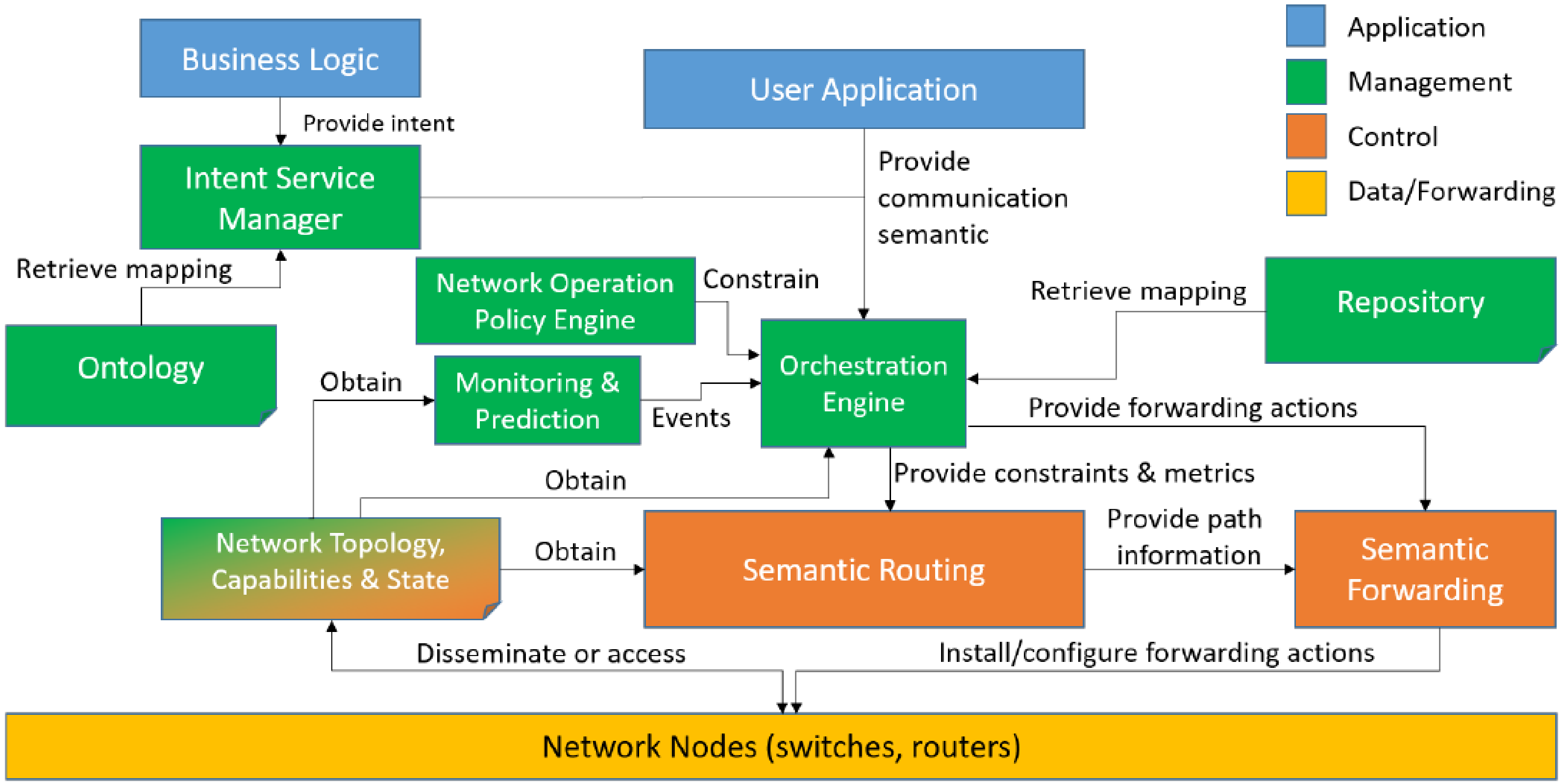
- Extensions to IP for semantic routing and forwarding have been mostly developed following an ad-hoc, solution-driven approach
  - Extensions at the network level typically use one of the addresses plus additional information encoded in various packet header fields



- Semantic Networking decouples data and programmatic actions
  - Relying on frameworks like SDN and P4 with a-priori agreed (rather than arbitrary) programmatic actions in the intermediary network elements
  - More emphasis is placed on the management and control planes.

Functional architecture for Semantic Networking

Components considered across Application layer, Management Plane, Control Plane, or Forwarding Plane.



- Ontology & Repository: mapping of semantics onto concrete sets of actions, constraints, and metrics for the required forwarding behavior, that derives from the communication semantics
- Semantic Routing, generating the needed distributed state in dependence of routing & topology constraints
- Network Topology, Capabilities & State: to ensure that information is available in a timely manner, while scaling from small to possibly very large networks.
- Semantic Forwarding: defines information to use from each packet, and operation to perform over that information to determine next hop along forwarding path
- Programmable Infrastructure: leveraging on SDN concepts and deep programmability (such as P4)

Deployment considerations

- Semantic Networking architecture targets to better accommodate new services and operational constraints, enabling the evolution of the Internet
  - To achieve that goal, the solution should not be restricted by design to a set of specific fields, but should instead support the definition of future parameters and selection criteria
- The architecture should not require that all domains involved in packet delivery must implement the same techniques
  - The selection of those techniques should be a local (i.e., per-domain) decision, while it is the responsibility of each domain to ensure the appropriate mapping onto inter-domain links.
- Additional information can be carried in data packets to explicitly signal the nature of communication for any Semantic Networking service
  - However, the usage of that information may be misused to track the end user or device activity, raising privacy concerns
  - Furthermore, such additional information could be shared only with trusted networks

What else? (just a personal –operator's – view)

- Semantic Networking should cover the complete service lifecycle
  - Service request → more manageable and controlled realization of intents by encoding of service semantics instead of inference of them
  - Service fulfillment → semantic-aware network orchestration and control capabilities able to process and understand different levels of knowledge
  - Service assurance → proper semantical translation of network events and observed telemetry data
  - Control loop → proactive and reactive control actions based on analytical processing of the assurance data
- Focusing on fulfillment as an example, new components/applications on top of SDN controllers could be required to handle semantic behaviors and to arbitrate control actions across them
  - E.g., definition/creation of a semantic-aware module on top of Teraflow SDN Controller (https://www.teraflow-h2020.eu/, https://tfs.etsi.org/)

What else? (just a personal –operator's – view)

- Multi-domain becomes also a critical point since most of the services today involve multiple providers
  - A common understanding of the involved semantics is needed to ensure accurate accomplishment of the service end-to-end
  - This implies the utilization of common intents among providers, including information and data models
- Finally, different levels of semantics can co-exist: Service semantics vs Connectivity semantics
  - Co-existence should be graceful, thus avoiding interference among them
  - A starting point for exploring it could be RFC8597

Conclusions

- Existing Internet is evolving for supporting new services and capabilities by introducing partial, ad-hoc semantic routing aspects
- Those efforts are isolated from each other, thus increasing complexity
- A generic Semantic Networking approach can simplify the evolution, offering a common framework for new semantic definitions
  - An architecture and an accompanying abstraction for encoding information on the packet flows are here proposed for that purpose
- Personal view: additional aspects (semantic-aware service lifecycle, multi-domain, service vs connectivity semantics, etc) are relevant from an operator perspective, and are seen as future lines of work

Thank You

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