LANCASTER UNIVERSITY

Next Generation Networking
Multi-Service Networks workshop

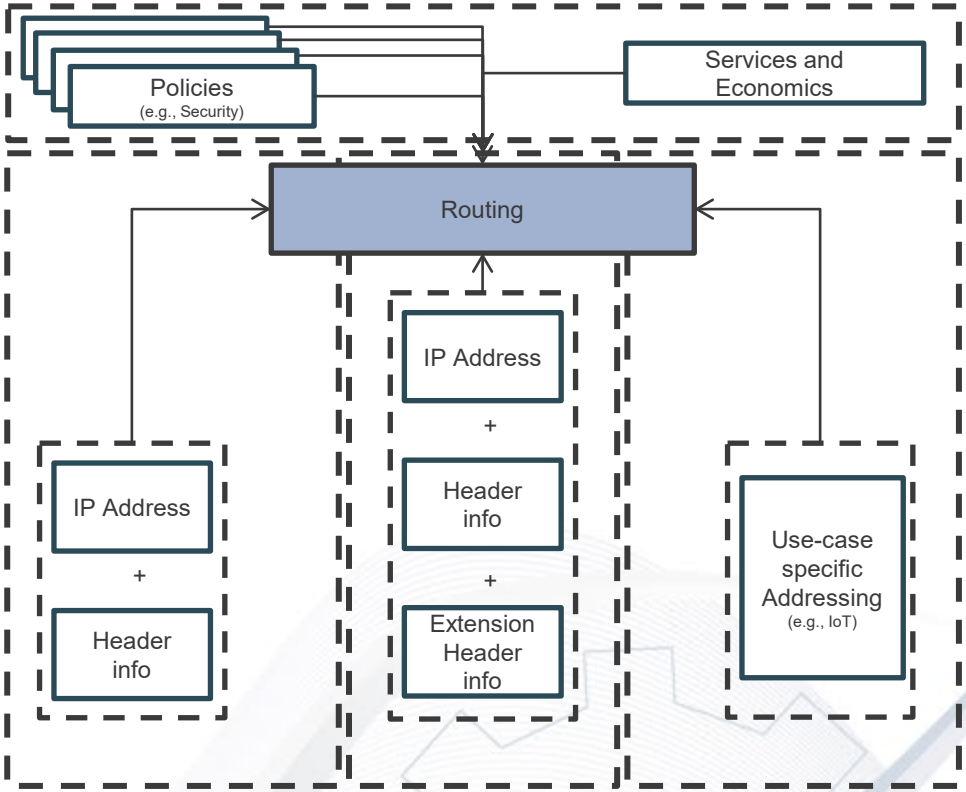
Research Challenges for the Internet Routing Infrastructure
Introduced by Changes in Address Semantics

Daniel King
d.king@lancaster.ac.uk
Researcher, Lancaster University

July 1, 2021

IP Routing
General Operation and Evolution

- Internet is being based on Internet addresses
  - Packets have a destination IP address
  - Routing finds the least cost path to the destination
- Evolution of routing applies context to IP header information
  - These fields started may be used for routing decision
- Innovation uses header extensions for additional routing decisions
- Overlay techniques have been invested to provide additional context and control of forwarding decisions
- Generally, all the above techniques are driven by user, application and operator policies and economics



IP Routing
Using Overlays to Control Traffic Behaviour

- Assorted overlay applications
  - Multi-path TCP
  - ALTO
  - SFC
  - ICN
  - Etc.
- What is the relevance to IP routing?
  - The overlay uses IP underlay to get from one overlay node to the next
  - It's just tunnelling
- However, an overlay may want to influence how the underlay routes packets
- Overlay techniques increase complexity and operational costs, and may decrease overall efficiency
  - For new types of networks, it creates additional state requirements
    - Function
    - Memory
    - CPU

IP Routing
Adding Context and Control

- Semantic Addressing and Routing
  - Better Control of Traffic
    - Traffic steering; better/different security; privacy; supporting different topologies; mobility; Limited domains (LDs): more stakeholders with greater desire to LD solutions, utilizing those new capabilities; routing on new identifiers (services, host, …), routing on different network layers like IoT
  - Network Programmability:
    - Match-action capability of programmable data planes eases deployment; advances in SW & HW that enable a more complex packet processing
  - Better QoS for traffic:
    - DSCP
    - ECMP hashing on 5-tuple
    - IPv6 Flow Label
    - IPv6 Extension Headers
    - Etc.
  - Preferred Path Awareness
    - "Preferential Routing", "Policy-based Routing", "Flow steering"

Evolution of IP Routing
Blending Semantics to Forwarding Decisions

- Encoding additional information into an IP address
  - That is, giving enhanced meaning to the bits of an IP address
- There may be a scope of applicability
  - The semantics might be used only within a domain
- To some extent we have done this already by assigning prefixes
  - Documentation addresses
  - Loopback addresses
  - Multicast address space
  - Private use addresses
  - IPv4-IPv6 encoding
  - Etc.

Evolution of IP Routing
Semantic Addressing

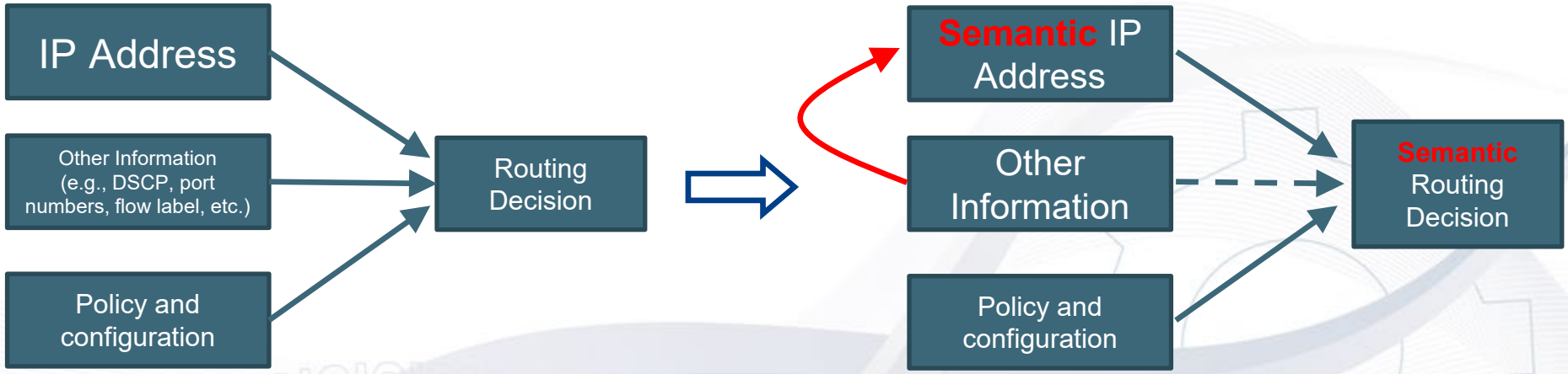
1. Address things other than interfaces
   - For example, address network functions or end-point-processing
     - Such as SRv6 Network Programming (RFC 8986)
     - Direct addressing in SFC
     - Hybrid ICN (hICN)
2. Shorter (variable/flexible) addresses
   - Useful for constrained environments?
     - IoT
     - SRv6 SID stacks
3. Hierarchically scoped addresses
   - Scaling the global address table
   - Tying geolocation to IP addresses
   - Making "simpler" multi-domain routing
4. Encode additional information in some of the bits of an address

Evolution of IP Routing
Semantic Routing

- Simply put…

  Routing on addresses that contain additional semantics

- Would provide…
  1. New capabilities: traffic steering; better/different security; privacy; supporting different topologies; mobility;
  2. Support for Limited domains (LDs): more stakeholders with greater desire to LD solutions, utilizing those new capabilities; routing on new identifiers (services, host, application) routing on different network layers like IoT;
  3. Increased programmability: match-action capability of programmable data planes eases deployment; advances in SW & HW that enable a more complex packet processing.



Prior Art

Routing using Semantic Addresses

Open Research Questions
Semantic Addressing and Routing

- Two Internet Drafts to the Internet Engineering Task Force (IRTF)
  - **A Survey of Semantic Internet Routing Techniques**
    - https://datatracker.ietf.org/doc/html/draft-king-irtf-semantic-routing-survey
  - **Challenges for the Internet Routing Infrastructure Introduced by Changes in Address Semantics**
    - https://datatracker.ietf.org/doc/html/draft-king-irtf-challenges-in-routing
  - **R1: What might be the scope of the semantic address proposal for Satellite and Beyond 5G?**
    - LEO, fronthaul, overlay, domain, domain with gateway, IoT/Industry 4.0…
  - **R2: Do we care about the impact on the existing routing system?**
    - Do protocols have to change? What happens if semantic addresses "escape"?
    - What path characteristics are mapped from the addresses?
    - What info does the network need to collect? How is it distributed?
    - Or… Should we just look to replace exiting IP entirely?
  - **R3: Will we need new software and hardware?**
    - What are the optimisation versus generalisation trade-offs?
    - Performance (convergence, on-wire), memory (routing table, other state)?
  - **R4: Would Standardisation be required?**
    - Would this technology only apply to closed, isolated or limited domains?

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

- **Semantic Addressing and Routing for Future Networks workshop (SARNET-21) 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.
- 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**"
- Yizhou Li, Zifa Han, Shuheng Gu, Guanhua Zhuang, Feng Li, "**Dyncast: Use Dynamic Anycast to Facilitate Service Semantics Embedded in IP address**"
- Gao Zheng, Ning Wang, Rahim Tafazolli, XinPeng Wei, Jinze Yang, "**Virtual Data-Plane Addressing for SDN-based Space and Terrestrial Network Integration**"
- Ryota Kawashima, "**A Vision to Software-Centric Cloud Native Network Functions: Achievements and Challenges**"
- Rene Glebke, Dirk Trossen, Ike Kunze, Zhe Lou, Jan Rueth, Mirko Stoffers and Klaus Wehrle, "**Service-based Forwarding via Programmable Dataplanes**"
- 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**"
- Mays AL-Naday, Irene Macaluso, "**Flexible Semantic-based Data Networking for IoT Domains**"
- Nikos Fotiou, Yannis Thomas, Vasilios A. Siris, George Xylomenos and George C. Polyzos, "**Securing Named Data Networking routing using Decentralized Identifiers**"
- Francesco Tusa, David Griffin, Miguel Rio, "**Private Routing in the Internet**"
- Nirmala Shenoy, Shreyas Chandraiah, Peter Willis, "**A Structured Approach to Routing in the Internet**"
- **Workshop Report tools.ietf.org/pdf/draft-galis-irtf-sarnet21-report-00.pdf**

Semantic Addressing and Routing
Continuing the Research Discussion

- Research Mailing list "Semantic Addressing Routing and Hardware (SARAH)"
  - Signup is https://www.jiscmail.ac.uk/cgi-bin/webadmin?A0=SARAH
  - sarah@jiscmail.ac.uk

Hello, welcome to Semantic Address Routing and Hardware" – SARAH – discussion list.

Historically, the meaning of an IP address has been to identify an interface on a network device. Routing protocols have been developed based on the assumption that a destination address has this semantic with routing decisions made on addresses and additional fields in the packet headers. Recent research proposals suggest adding additional semantics within IP addresses to aid routing and define how packets should be handled.

Challenges for the Internet Routing Infrastructure Introduced by Changes in Address Semantics
https://datatracker.ietf.org/doc/html/draft-king-irtf-challenges-in-routing

Several research challenges and opportunities present themselves:

R1: What is the scope of the semantic address proposal: Global, backbone, overlay, domain, domain with a gateway?
R2: What is the impact on the existing routing system; do protocols have to change?
R3: What happens if semantic addresses "escape" the semantic domain?
R4: What path characteristics are mapped from the addresses; what info does the network need to collect?
R5: How might semantic address pools be distributed?
R6: What is the impact on the control plane and forwarding plane, are there hardware implications?
R7: What are the optimisation versus generalisation tradeoffs?
R8: What is the performance (convergence, on-wire), memory (routing table, other state), and scaling impacts?
R9: Would multicast traffic be supported?
R10: What are the security and privacy implications?

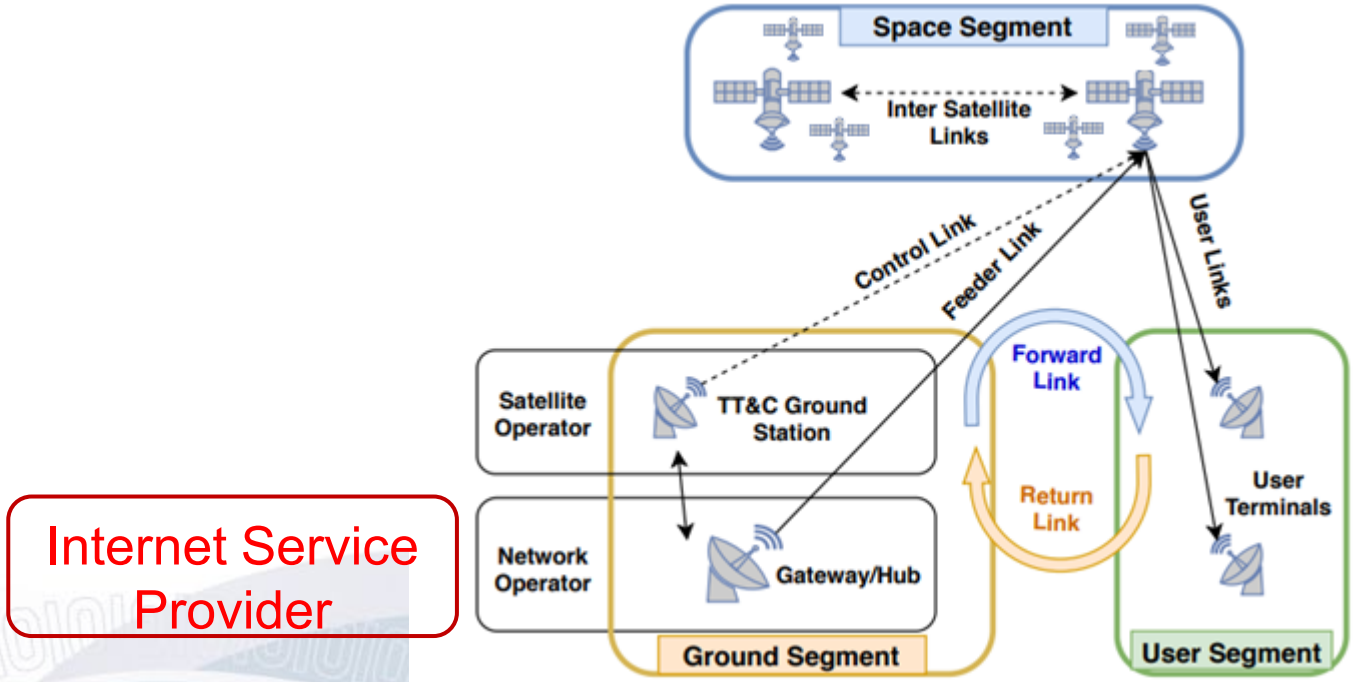
This list provides a forum for discussion of address semantics and routing system challenges, proposals, and research. It can be used to discuss software and hardware research opportunities into new or modified routing protocols and network architectures to make use of address semantics.

Semantec Addressing Use Case

Integrating Space and Terrestrial Networks

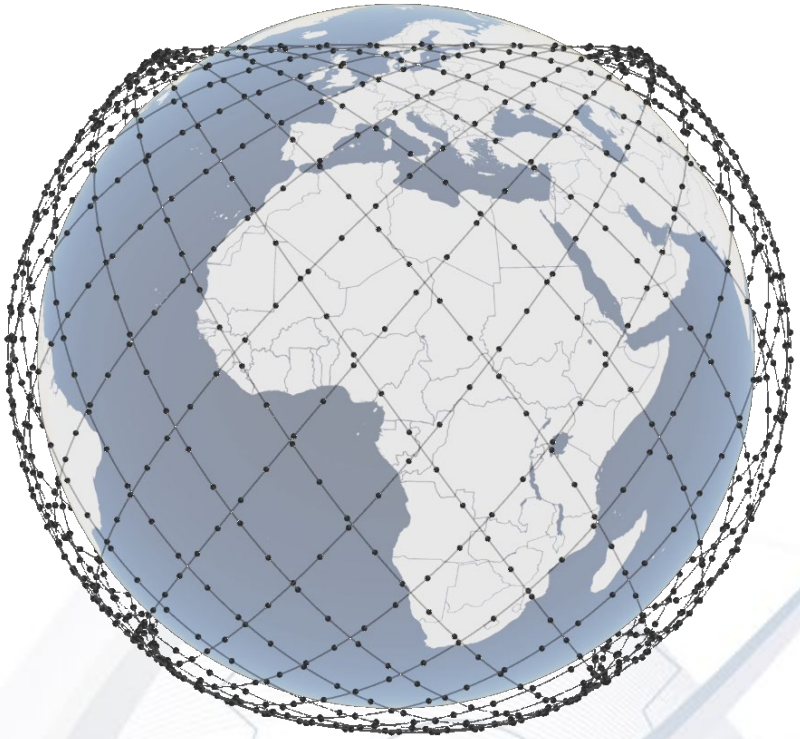
Semantic Addressing and Routing
Integrating Space and Terrestrial Networks

- Satellite communication consists of multiple segments
  - These include the satellite constellation with multiple ISL types, ground segments, GW stations and terrestrial links for backhauling.
  - Space segments currently use proprietary network technologies and addressing.
  - Translation between network types is performed by gateways and translators



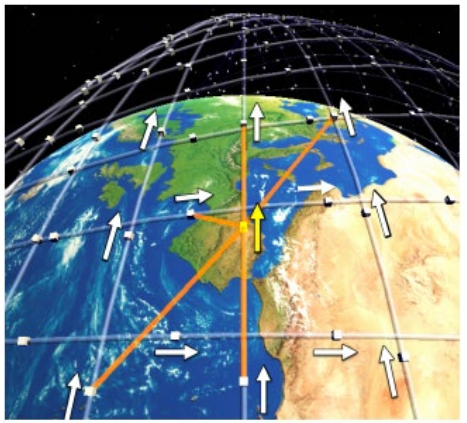
Semantic Addressing and Routing
Architecting the space-to-space segment

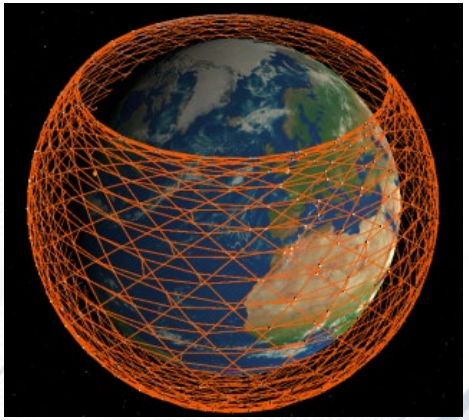
- Newer constellations have complex paths and networking topologies
- Acquisition and tracking of satellites as they move, and calculating relative velocity
- Inter-satellite or inter-orbital links must cover larger distances; therefore, the transmission scheme must be power-efficient with good sensitivity at the receiver
- Need to consider power versus transmission costs, and path viability
- Emerging technology of Steered Lasers



Space Communication Networks
Network Link Connectivity

- Using Starlink Phase 1 Example*
  - Working assumption is that each satellite will have five free-space laser links to connect to other Starlink satellites.
  - Space links operating at 100 Gbps
  - At least four links will be used for N, S, E, W, communication
  - Space-to-earth FSO and RF communication links will be for a ground station to connect to the satellite that is most directly overhead
- The network is not static; the satellite most directly overhead changes frequently, the laser links between satellites change frequently, and link latencies for links that are up change constantly.
- Choice of Free-Space-Optics (ISL) and Radio Link paths





* "Delay is Not an Option: Low Latency Routing in Space", Mark Handley, University College London

Space Communication Networks
Network Link Dynamicity

- Assuming the space and terrestrial network could use existing IP addressing and routing, would be problematic due to the differing constellation behaviours
  - Space-terrestrial link can be unstable, which will lead to potential problems such as frequent and simultaneous link broken events, space-to-space links are likely to change, in both cases we expect RF and FSO link variation as well
  - Relying on traditional routing protocol convergence, optimizing multiple constraints, across many 100s and thousands, of nodes and links, is not feasible

Space Communication Networks
Semantic Network Addressing and Routing

- Seamless routing across space segments, and using semantic-based addressing system in the space network
  - Using the existing IP system for the terrestrial network and developing an addressing and routing system for the space network, would initially seem a radical option, but given the network graph requirements, may be the favoured solution
- Routing Table Management
  - Routing table size and complexity is often cited as an obstacle for performing contextual forwarding, onboard satellite nodes
  - Overlay technologies are unlikely to be feasible given the additional processing
- Addressing Requirements
  - Variable-length and domain, or semantic-based, addressing. This would facilitate seamlessly support cross-network communication between terrestrial and space networks
- Support for Variable-sized Packets
  - FSO and RF based links between satellites will vary in speed and characteristics

Space Communication Networks
Building a Semantic-based Network Graph

- Given
  - Constellation's satellite trajectories,
  - Small to medium number of inter-satellite connection units at each satellite
  - A target traffic matrix between terrestrial endpoints
  - Choice of links and path based on traffic type and constraints
- Our goal is to decide which end-to-end connections to build, we must:
  - Minimize latency and hop-count in end-end paths
  - Consider fixed and static variants (satellite motion and Earth's rotation)
  - Utilise links efficiently and attach to gateways based on optimal delivery of traffic
  - Choose the correct ground-stations
  - Consider resilience requirements, based on the traffic type
- Solution would be to encode preferred path requirements using a semantic IP addresses in the packets.
  - Enables traffic steering without overlay protocol overhead

Questions?

- Daniel King
  d.king@lancaster.ac.uk