

Future Directions

Networked Systems (H)

Lecture 10

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Evolving the Network (1/2)

- The course has focussed on how can the Internet change and evolve to address coming challenges:
  - How to establish connections in a fragmented network?
  - How can encryption protect against pervasive monitoring and prevent transport ossification?
  - How can we reduce latency and support real-time and interactive content?
  - How can we adapt to the vagaries of wireless networks?
  - How can we identify and distribute content? How can we manage the tussle for control of the DNS and naming?
  - How can we manage interdomain routing to efficiently delivery content?
  - How can we re-decentralise the network?

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Evolving the Network (2/2)

- To address these challenges, the Internet is in the middle of a significant change
  - IPv6 as a basis for routing and forwarding evolution
  - TLS 1.3 to simplify and improve security
  - QUIC as a basis for future transport evolution, avoiding protocol ossification
  - HTTP/3 as a basis for web evolution
  - DNS over encryption (HTTPS, TLS, QUIC) for secure name resolution
  - CDNs and overlays









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Future Directions

- What are the longer-term challenges for the development of the Internet?
- *(Nothing in this section is assessed)*

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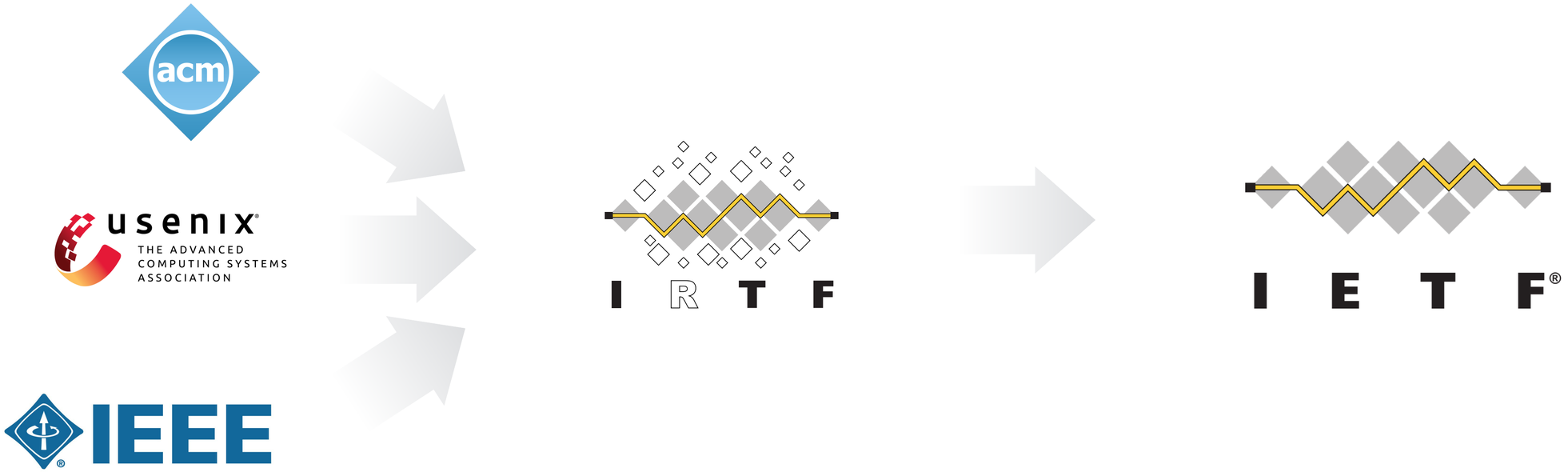
Long-term Evolution of the Network

- The Internet Research Task Force (IRTF) promotes evolution of the Internet through applied, longer-term, research on Internet protocols, applications, architectures, and technology → https://irtf.org/



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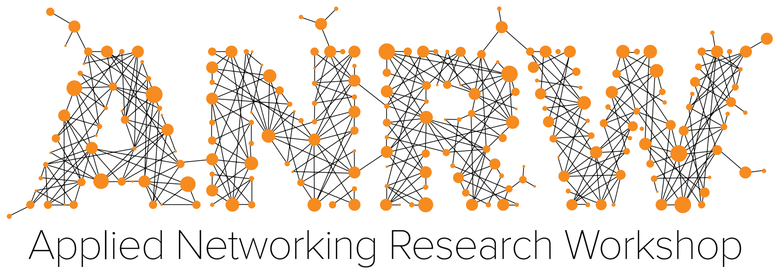
IRTF Activities

- Organised around longer-term research groups
- A forum where researchers and engineers can explore the feasibility of research ideas
- A venue where researchers can learn from the engineers who build and operate the Internet – and where the standards, implementation, and operations community can learn from research



CFRG
Crypto Forum Research Group

COIN
Computation in the Network

DINRG
Decentralised Internet Infrastructure

GAIA
Global Access to the Internet for All

HRPC
Human Rights Protocol Considerations

ICCRG
Congestion Control

ICNRG
Information-centric Networking

MAPRG
Measurement and Analysis for Protocols

NMRG
Network Management

NWCRG
Network Coding

PANRG
Path Aware Networking

PEARG
Privacy Enhancements and Assessments

QIRG
Quantum Internet

T2TRG
Thing-to-Thing

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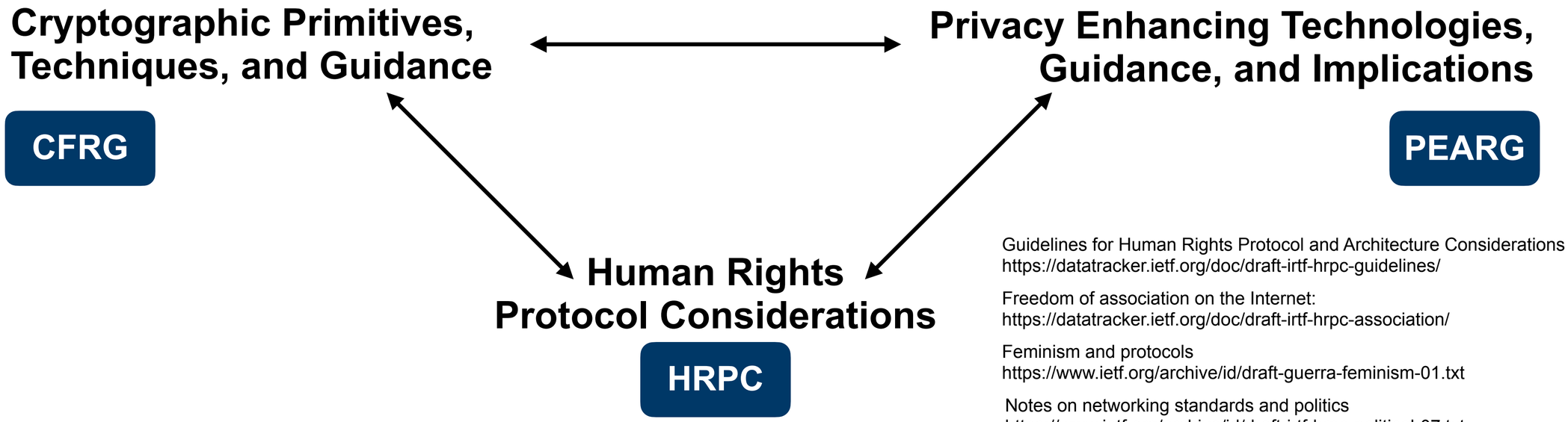
Security, Privacy, and Human Rights



Guidelines for Human Rights Protocol and Architecture Considerations
https://datatracker.ietf.org/doc/draft-irtf-hrpc-guidelines/

Freedom of association on the Internet:
https://datatracker.ietf.org/doc/draft-irtf-hrpc-association/

Feminism and protocols
https://www.ietf.org/archive/id/draft-guerra-feminism-01.txt

Notes on networking standards and politics
https://www.ietf.org/archive/id/draft-irtf-hrpc-political-07.txt

- Begin to understand how Internet protocols and standards impact human rights and privacy – at the Internet infrastructure level
- Discuss interplay between security mechanisms, privacy, and human rights; seek to raise awareness of broader societal and policy issues to the IETF community

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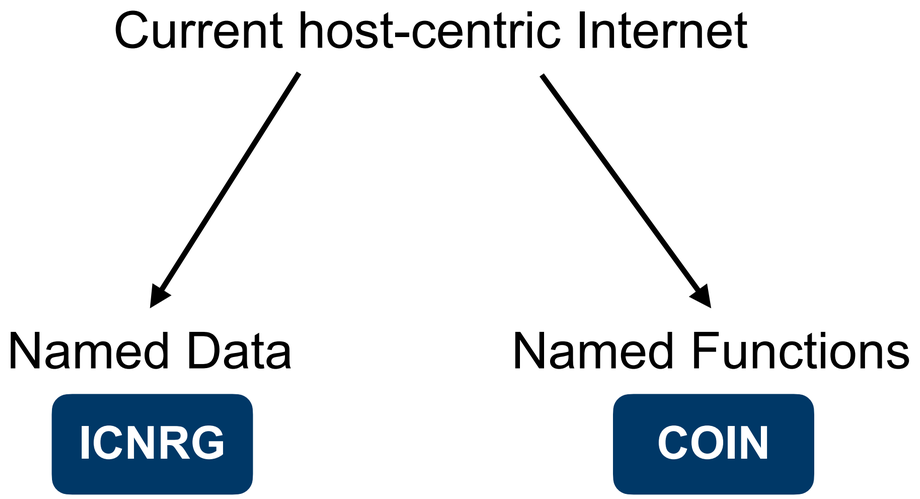
Computation in the Network

- Speculative new architectures for an internet, emphasising named data or named functions
  - Generalisation of content distribution networks and web caching infrastructure – mature work, with competing experimental implementations
  - Generalisation of lambda functions and “server-less” computation – early stage research
- Long-term replacements for the Internet?



- Does it make sense to re-architect the network around content or computation? To replace IP addresses with content names?
- What are the implications of such a change for the content provider/consumer relationship – democratisation or ossification of current roles?

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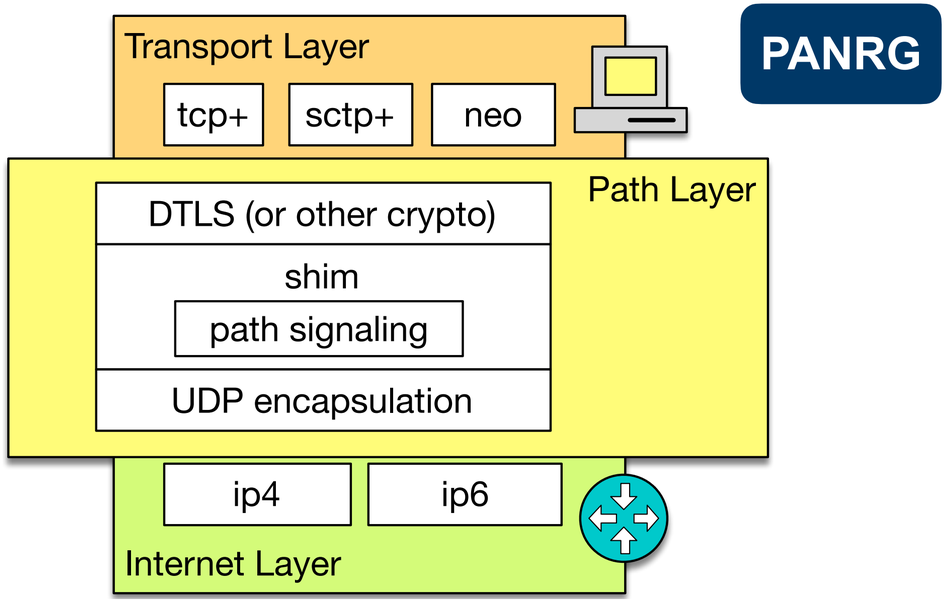
Path Aware Networking



Source: Brian Trammell, presentation at IETF 96 PLUS BoF

- Can we benefit from making applications and transport protocols aware of the network path taken – or by making the network path aware of the application or transport?
- Introduces a new control point for operators; questions around trust, privacy, and network neutrality are poorly understood
- IETF community seems determined to enter a standardisation phase: SRv6, APN, …
- IRTF considering broader questions around privacy, security, path definitions, incentives

Current Open Questions in Path Aware Networking
https://datatracker.ietf.org/doc/draft-irtf-panrg-questions/

Path Aware Networking: Obstacles to Deployment (A Bestiary of Roads Not Taken)
https://datatracker.ietf.org/doc/draft-irtf-panrg-what-not-to-do/

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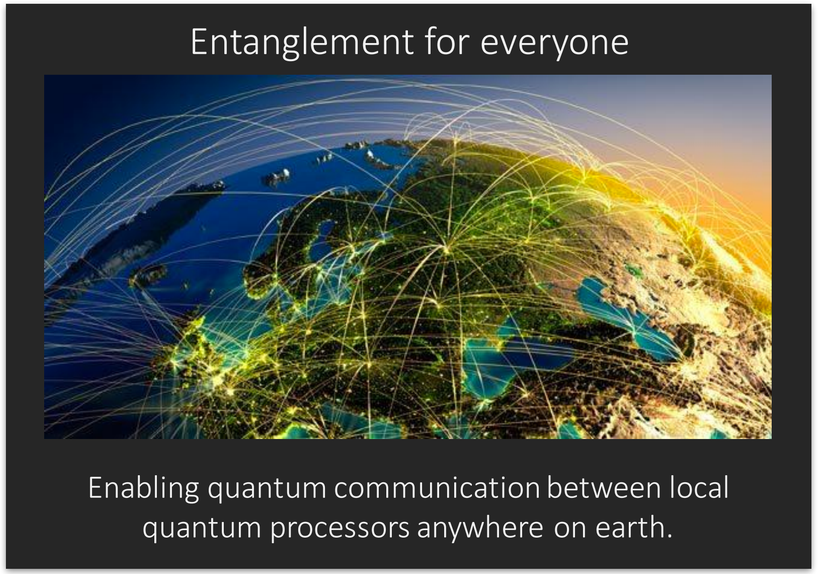
Designing the Quantum Internet

- How to establish and control inter-domain paths that can distribute entangled quantum state?
  - Quantum key distribution for security
  - Distributed quantum computation
  - **Quantum entanglement as a service**

- Architecture and approach generally well defined
  - Classical control plane
  - Managed distribution of entangled quantum state
- Entering a phase of experimentation to validate the architecture, develop prototypes



Source: Axel Dahlberg, presentation at IETF 103 QIRG meeting

QIRG

Architectural Principles for a Quantum Internet
https://datatracker.ietf.org/doc/draft-irtf-qirg-principles/

Applications and Use Cases for the Quantum Internet
https://datatracker.ietf.org/doc/draft-irtf-qirg-quantum-internet-use-cases/

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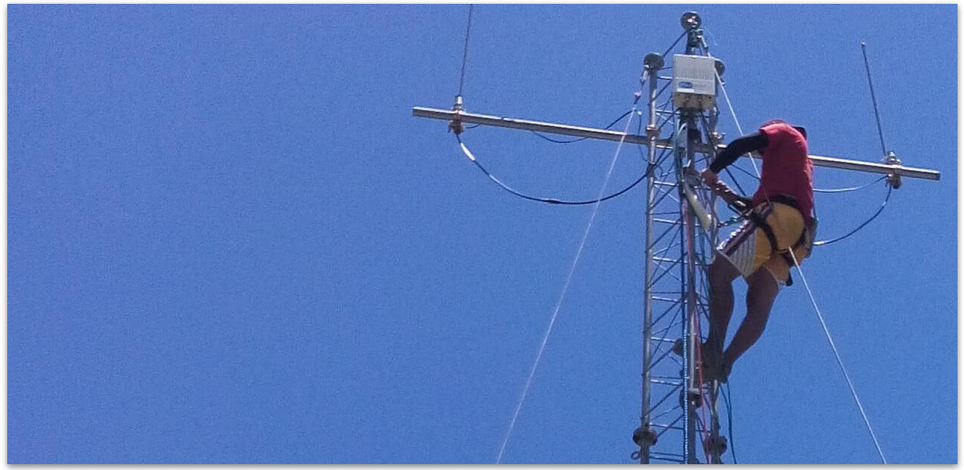
Global Access and Sustainability



Source: Maria Theresa Perez, “Community Cellular Networks in the Philippines: Experiences from the VBTS project”, Presentation to IRTF GAIA RG, November 2019, https://www.ietf.org/proceedings/106/slides/slides-106-gaia-up-vbts-philippines-00

GAIA

- How to address the global digital divide?
  - To share experiences and best practices, foster collaboration, in building, deploying and making effective use of the Internet in rural, remote, or under-developed regions
  - To create increased visibility and interest among the wider community on the challenges and opportunities in enabling global Internet access, in terms of technology as well as the social and economic drivers for its adoption
  - To create a shared vision among practitioners, researchers, corporations, non governmental and governmental organisations on the challenges and opportunities
- Sharing expertise, raising awareness of global access challenges

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Advanced Protocol Development

MAPRG

ICCRG

NMRG

NWCRG

DINRG

T2TRG

- Measuring and understanding network behaviour
- Interfacing between research and standards community to:
  - Develop and validate new congestion control and network coding algorithms in the real world
  - Develop intent-and AI-based approaches to network management
  - Understand issues of trust- and identity- management, name resolution, resource/asset ownership, and resource discovery in decentralised infrastructure
  - Understand research challenges in IoT based on initial real-world deployment experience

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Future Directions

- The Internet is **not** finished – the protocols and fundamental design are still evolving
- With the introduction of IPv6 and QUIC, we see a significant change in network design
- Coming changes are potentially even more significant



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Wrap-Up

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Assessment

- Marks for assessed coursework will be available shortly

- Final exam, worth 80% of the marks for the course, will be held in April/May
  - Three questions, focussed on testing your understanding of networked systems
  - **Tell be what you think** – online, open book, exams focus more on deeper understanding than on bookwork
  - Past papers are on Moodle – the style of questions in the 2020 exam is most representative

- No specific revision lecture – use the Teams chat, or email, for revision questions

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Level 4 and MSci Projects

- If you are interested in Level 4 or MSci projects relating to networked systems, please contact me – colin.perkins@glasgow.ac.uk
  - Keen to work with motivated students to develop projects on topics including:
    - Improving Internet protocol standards and specifications
    - Transport protocols, real-time applications, and QUIC
    - New networking APIs in high-level languages (e.g., Rust)
    - Network measurement
  - Strong focus on interactions with IETF standards and research communities:
    - Some potential projects are strongly technical
    - Others focus heavily on the standardisation process

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