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A Critical Survey of Network Functions Virtualization

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Research – Team

- Lancaster University (LU)
  - Excellence in Economics and Computer Science, research-intensive British university.
  - Three year PhD program with a focus on the economic and technical aspects of Network Functions Virtualization - NFV.
- LU Team
  - PhD Supervisors:
    - Professor David Hutchinson
    - Dr Christopher Edwards
    - Dr Nicholas Race
  - Research Partner
    - Chris Ford, Lancaster University Management School
- Academic Rationale
  - Opportunity to investigate a major gap in computer science and telecommunications research.
  - Provide useful data and evidence to industry and standards development organisations.

Research – Network and Function Virtualisation

- Network operators use a variety of proprietary appliances for network function when delivering services.
- Deploying a new network function often requires new hardware components.
  - Integrating new equipment into the network requires space, power and the technical knowledge to deploy and operate the new network function.
  - This problem is compounded by function and technology lifecycles which are becoming shorter as innovation accelerates in an increasingly network-centric connected world.
- The concept of virtualization is well-known and has been used for many years, including:
  - Operating system virtualization (Virtual Machines) [1]
  - Computational and application resource virtualisation (Cloud Computing) [2]
  - Link and Node virtualisation (Virtual Network Topologies) [3]
  - Data Center Virtualisation (Virtual Data Center) [4].

[1] Barham, Paul, et al. "Xen and the art of virtualization." ACM SIGOPS Operating Systems Review. Vol. 37. No. 5. ACM, 2003.
[2] Fox, Armando, and R. Griffith. "Above the clouds: A Berkeley view of cloud computing." Dept. Electrical Eng. and Comput. Sciences, University of California, Berkeley, Tech. Rep. UCB/EECS 28 (2009).
[3] E. Oki et al., "Framework for PCE-Based Inter-Layer MPLS and GMPLS Traffic Engineering", RFC 5623, September 2009
[4] Guo, Chuanxiong, et al. "Secondnet: a data center network virtualization architecture with bandwidth guarantees." Proceedings of the 6th International Conference. ACM, 2010.

Research – Network and Function Virtualisation

Classical Network Appliance Approach


BRAS


Firewall


Carrier Grade NAT

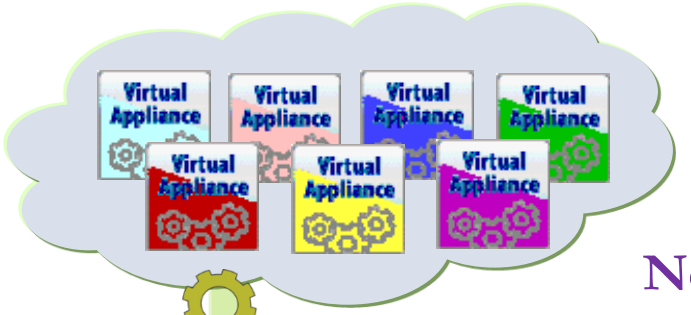

DPI


WAN Acceleration


Session Border Controller


Access Router

Network Function Virtualisation



Orchestrated Automation Remote Install

Hypervisors


Generic High Volume Servers


Generic High Volume Storage


Generic High Volume Ethernet Switches

Research – The Key Questions

- This research looks to evaluate the techno-economic drivers, enabling technologies and innovation business model required to deliver Network Functions Virtualization (NFV).
- These may be phrased as the following research questions:

R1: What are the economic and technical drivers behind NFV?

- **R1.1**: How applicable are existing technologies to enabling NFV?
- **R1.2:** Does automation have a role in the deployment and operation of NFV?

R2: What is the role of Open Innovation in the development and deployment of NFV?

- **R2.1**: Which aspects of NFV development benefit from open approaches and how are these being managed and developed ?
- **R2.2:** What opportunities exist for both well established firms and new ventures, arising from the development of open business models for NFV?

"The Future of Open Innovation" by Gassmann, Enkel & Chesbrough (2010) identifies gaps in open innovation theory which can be informed by this research. The virtualization literature presents a wide consensus that virtualization provides significant benefits in general, but insights into why and how network functions may be virtualized are not readily available.

Research – Investigating the Problem Space

- Evidence gathering
  - "A Critical Survey of Network Functions Virtualization" to help define the problem space
    - Qualitative and exploratory study (Eisenhardt 1989, Yin 2009, Thomas 2011)
    - Inductive, hypothesis-generating approach
    - Guided by tenets of Grounded Theory (Glaser and Strauss 1967, Charmaz 2006, Corbin and Strauss 2008, Suddaby 2006)
- Analysis (Miles and Huberman 1994)
  - Detailed coding of interview transcripts (nVivo).
    - Development of concepts and their dimensions.
    - Intensive review around each concept.
- Interpretation
  - Combining memos & concepts into cohesive whole.
    - Establishing cross-user connections.
    - Identifying industry comparatives to inform analysis (eg Human Genome Mapping)
- Writing up
  - Develop substantive model and frameworks.
  - Construct authentic & plausible arguments (economic and technical) based on evidence.
  - Publishing findings and conclusions documents (including IETF informational I-Ds and ETSI contributions).

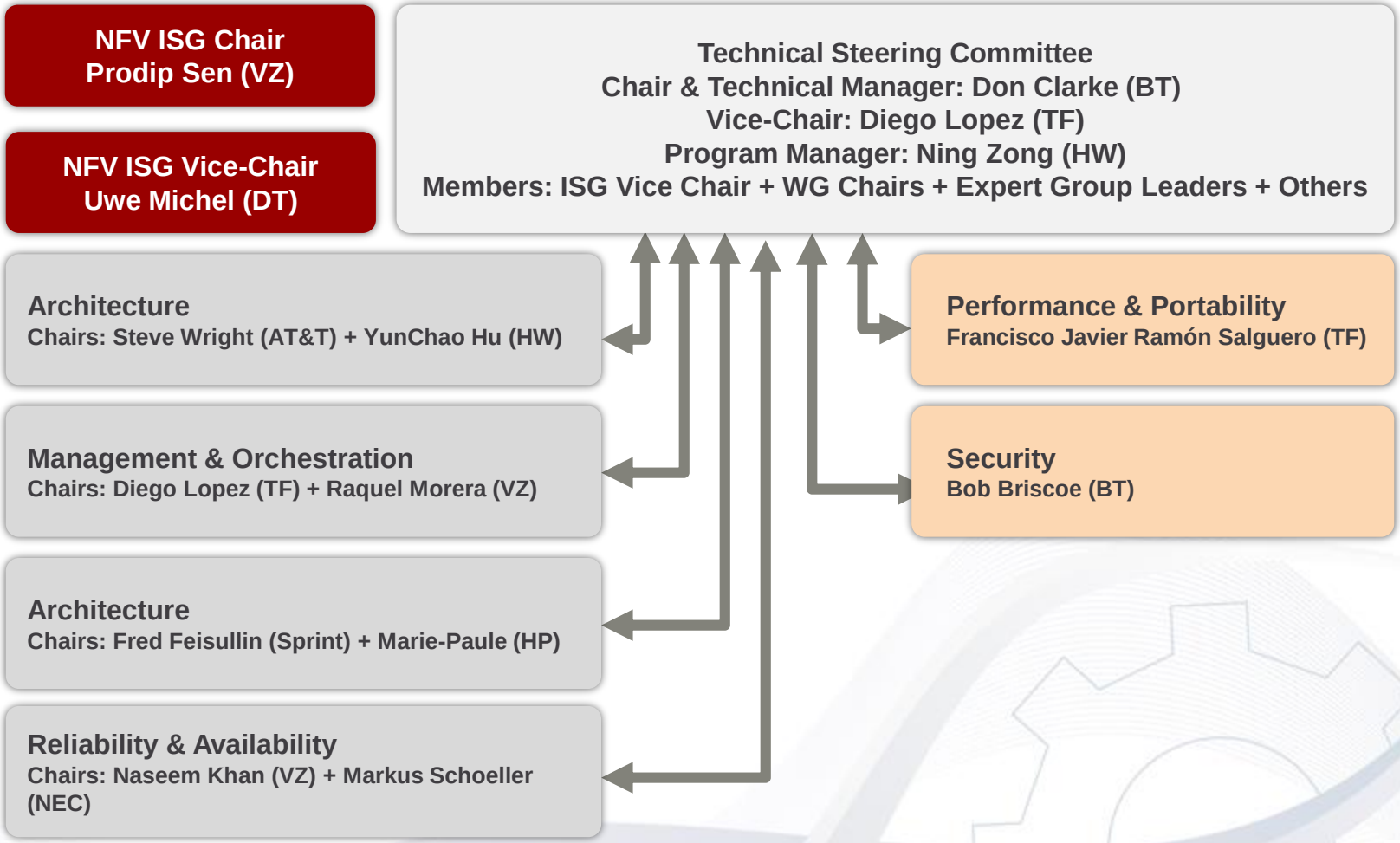
Research – Limitations and Challenges

- Theoretical Sampling & Saturation
  - Multiple interviews per organisation.
  - Suitable diversity of network operators.
  - Dealing with Industry and Standards bias.
- Validity (Construct, Internal and External)
  - Need to satisfy the tests "commonly used to establish the quality of any empirical research." (Yin 2009, p40)
  - Robust research processes with significant external engagement.
- Reliability
  - Qualitative, exploratory study.
  - Two researchers, covering technical, ethnographic, economic and open innovation areas of expertise.
  - Multi-disciplinary team of advisors.

Research – NFV Concept Development

- European Telecommunication Standards Institute (ETSI)
  - Role has been to provide an environment to develop the problem space.
  - Responsibility to publish problem statements, requirements and recommendations.
- ETSI NFV History
  - Whitepaper "Network Functions Virtualisation - An Introduction, Benefits, Enablers, Challenges & Call for Action", October 2012.
  - Initial concepts discussed at the end of 2012 in ETSI Future Networks Workshop.
  - Formal Industry Specification Group (ISG) session in January, 2013.
  - NFV ISG has met twice in 2013, with a third session planned for Bonn in July 2013.

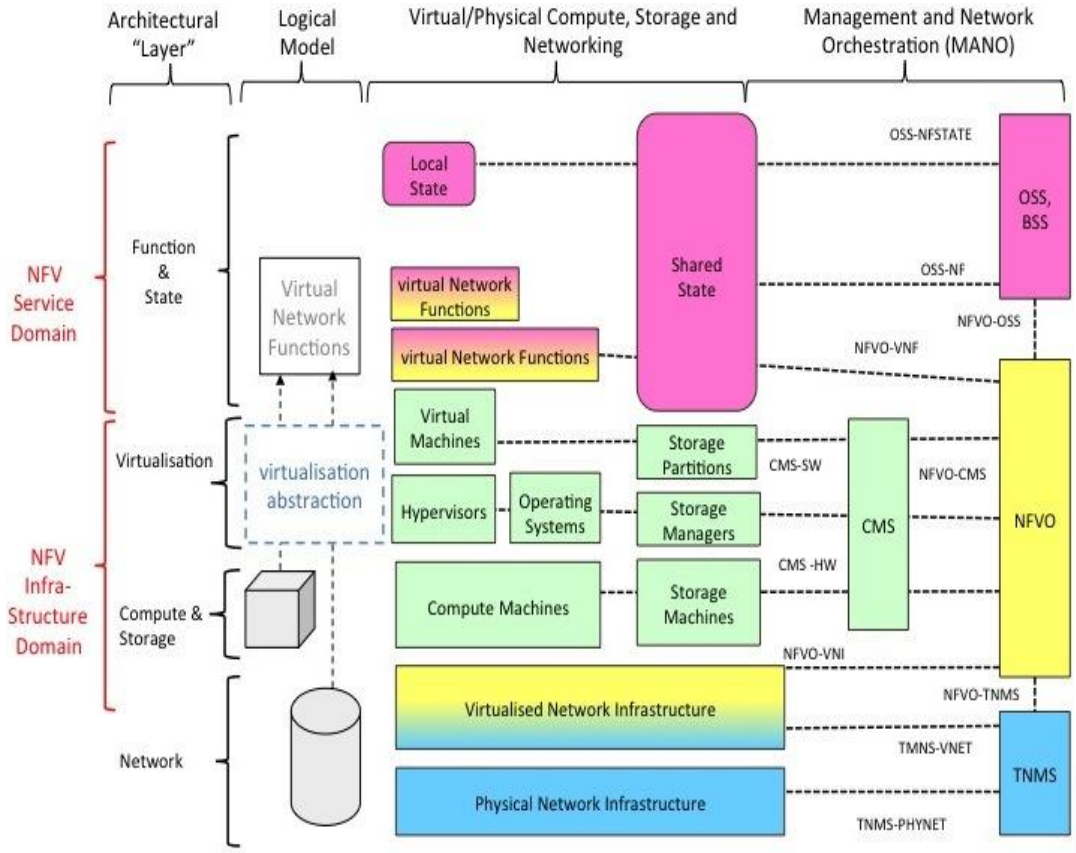
Research – ETSI NFV ISG Structure



Research –NFV ISG List Members

- The main NFV mailing list currently has 577 subscribers.
- The WG lists for AVINF, MANO, REL and SWA and the PER & SEC EG lists were created post NFV#1 (23 Jan 2013). Current subscriptions are:
  - AVINF: 244
  - MAN: 244
  - REL: 178
  - SWA: 230
  - PER: 81
  - SEC: 122 (the SEC EG did not start working until March 2012)
- NFV_E2E_ARCH: 130 subscriptions
- NFV_USE_CASES: 112 subscriptions
- There is also a Network Operator Council (NOC) closed list – 2 delegates per operator- with 46 subscribers.

Research –NFV ISG Work Contributions



- Orchestration and Management
- Network Operation and Interfaces
- Identify Applicable Standards
  - Collect and Organise them
  - Create Best-practice Guides
- Use Cases
  - Practice Incompatibilities
  - Additional Complexity
  - Security Issues.

Research – NFV Interviewees

- A total of Twenty (20) CSPs have been identified and targeted.
- Discussions and interviews to date:
  - British Telecom
  - Verizon
  - KDDI
  - AT&T
  - Telefonica
  - Telstra
  - NTT docomo
  - France Telecom
  - Deutsche Telekom
  - [Please insert your company here!]
- Initial focus on CSPs to gain rich data and develop initial concepts.
- Second round includes vendors and other stakeholders.

Findings – So Far (1)

- Operators have been independently researching network and function virtualisation with hardware and software vendors for years.
- "Enablers for NFV?"
  - Open Innovation during early stages of process and technology development
  - Commodity Hardware
  - Success of previous Hosted and Cloud Services
- Most interviews highlighted that industry cooperation would be required to:
  - Sanity check use cases.
  - Apply pressure on vendors.
  - Provide the economy of scale for commercial development, deployment and operation of NFV-enabled services.

Findings – So Far (2)

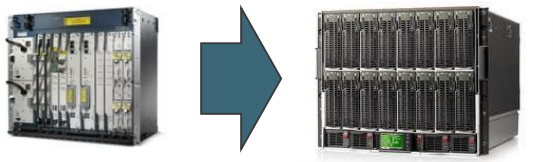
- Infrastructure Complexity
  - Increasing variety of proprietary hardware and dedicated function.
  - Current nodes are fragmented with disparate operation and management.
- Energy Consumption
  - Sites are expanding while operators and customers are being directed to reduce CO2 emissions.
- Service Deployment
  - The time to specify, procure, integrate and deploy needs to be radically reduced.
  - Increased automation of service deployment.
- Rationalisation of Operation Support Systems
  - Physical presence and consequent operations per component and site.
  - Too many disparate OSS and NMS entities in the network.

Findings – Network Functions Virtualisation

- BT Virtualisation Testing from 2012 [1]
- Combined BRAS & CDN functions on Intel® Xeon® Processor 5600 Series HP c7000 BladeSystem using Intel® 82599 10 Gigabit Ethernet Controller sidecars
  - BRAS chosen as an "acid test"
  - CDN chosen as architecturally complements BRAS
- BRAS created from scratch so minimal functionality:
  - PPPoE; only PTA, priority queuing; no RADIUS, VRFs
  - CDN COTS – fully functioning commercial product

[1] Bob Briscoe, Don Clarke, Pete Willis, Andy Reid, Paul Veitch, "Network Functions Virtualisation"
http://www.ietf.org/proceedings/86/slides/slides-86-sdnrg-1.pdf

Findings – Network Functions Virtualisation



Test Id	Description	Result
1.1.1	Management access	**Pass**
1.2.1	Command line configuration: add_sp_small	**Pass**
1.2.2	Command line configuration: add_sub_small	**Pass**
1.2.3	Command line configuration: del_sub_small	**Pass**
1.2.4	Command line configuration: del_sp_small	**Pass**
1.3.1	Establish PPPoE session	**Pass**
1.4.1	Block unauthorized access attempt: invalid password	**Pass**
1.4.2	Block unauthorized access attempt: invalid user	**Pass**
1.4.3	Block unauthorized access attempt: invalid VLAN	**Pass**
1.5.1	Time to restore 1 PPPoE session after BRAS reboot	**Pass**
1.6.1	Basic Forwarding	**Pass**
1.7.1	Basic QoS - Premium subscriber	**Pass**
1.7.2	Basic QoS - Economy subscriber	**Pass**
2.1.1	Command line configuration: add_sp_medium	**Pass**
2.1.2	Command line configuration: add_sub_medium	**Pass**
2.2.1	Establish 288 PPPoE sessions	**Pass**
2.3.1	Performance forwarding: downstream to 288 PPPoE clients	**Pass**
2.3.2	Performance forwarding: upstream from 288 PPPoE clients	**Pass**
2.3.3	Performance forwarding: upstream and downstream from/to 288 PPPoE clients	**Pass**
2.4.1	Time to restore 288 PPPoE sessions after BRAS reboot	**Pass**
2.5.1	Dynamic configuration: add a subscriber	**Pass**
2.5.2	Dynamic configuration: connect new subscribers to BRAS	**Pass**
2.5.3	Dynamic configuration: delete a subscriber	**Pass**
2.5.4	Dynamic configuration: delete service provider	**Pass**
2.6.1	QoS performance – medium configuration	**Pass**
3.1.1	Command line configuration: add_sp_large	**Pass**
3.1.2	Command line configuration: add_sub_large	**Pass**
3.2.1	Establish 1024 PPPoE sessions	**Pass**
3.3.1	Performance forwarding: downstream to 1024 PPPoE clients	**Pass**
3.3.2	Performance forwarding: upstream from 1024	**Pass**

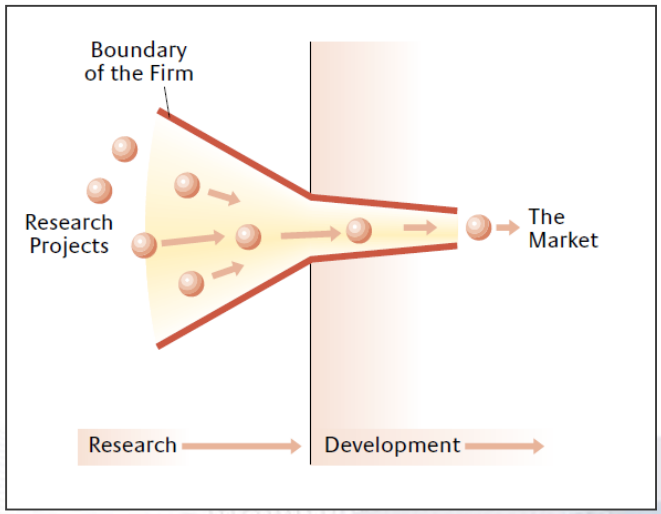
- Average 3 Million Packets Per Second per Logical Core for PPPoE processing.
  - Equivalent to 94 M PPS/97 Gbps per Blade = 1.5 G PPS/1.5 Tbps per 10 U chassis[1].
  - Test used 1024 PPP sessions & strict priority QoS
  - Test used an Intel® Xeon® E5655 @ 3.0 GHz, 8 physical cores, 16 logical cores (not all used).
- Scaled to 9K PPPoE sessions per vBRAS.
  - Support of 3 vBRAS per server.
- Subsequent BT research:
  - Implemented & testing software Hierarchical QoS.
  - Results so far show processing is still not the bottleneck.
  - Also tested vCDN performance & video quality.

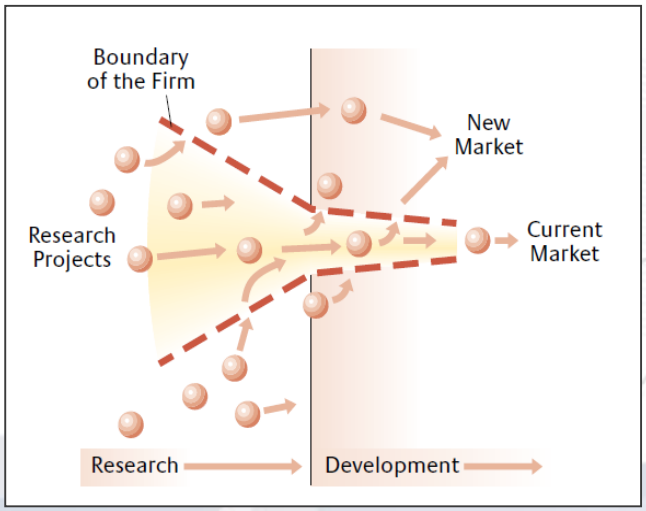
"Performance potential to match the performance per footprint of existing BRAS equipment."

[1] Using128 byte packets. A single logical core handles traffic only in one direction so figures quoted are half-duplex.
[2] http://www.btplc.com/Innovation/News/NetworkVirtualization.htm

Findings – Open Innovation (1)

- Application of Open Innovation model to address:
  - Rising costs of technology development.
  - Shorter product lifecycles.
  - Greater distribution of knowledge.
  - Engaging with customers much earlier in product development.
  - Sharing risk of technology innovation.
- NFV research will not be tightly bound within separate firms:





Findings – Open Innovation (2)

- Open Source and Open Innovation are not the same thing!
  - What is 'open' and what remains proprietary is key consideration as level of technology readiness advances.
  - Open Innovation requires decisions about business model development.
  - Where are the opportunities for new ventures within this new ecosystem, how will they be identified, and will there be significant first mover advantages?
  - Clear economic drivers for NFV but all firms are, or should be, addressing the challenge of how to capture the value (or savings) created but not at risk of disrupting the collaborative open innovation system as it evolves.
- Similarities to Human Genome Project (1990-2003)
  - Global scale, multi partner project mapping the human genome – creating an open platform for pharma industry to use for drug development.
  - Development of actual products / medicines / compounds remained more closed and competitive. Genome map became the common "platform".
  - Significant global growth in bioscience startups, incubators and accelerators.
  - High level of collaborations & acquisitions between big-pharma and VC funded startups.
  - Reshaped entire pharma industry around open innovation approach.

Next Steps – Japanese Survey Candidates

- Seeking additional Japanese network operators and service providers who are interested in participating with the survey.
  - Interview can be conducted in person or remotely.
  - All results will be anonymised.
  - Participants will have early and full access to the findings and conclusions.

Next Steps – Survey Findings and Conclusions

- Publications (late 2013)
  - Survey findings and conclusions.
  - Identification of techno-economic areas for further research.
- Conferences, either:
  - "MPLS & SDN Washington"
    - November, 2013
    - Washington, US.
  - Or, "SDN Congress"
    - October, 2013
    - Prague, Czech Republic.

Thank You!

Any comments or questions are welcome.

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