The Role of PCE in an SDN World

Adrian Farrel – Old Dog Consulting
adrian@olddog.co.uk

Daniel King – Lancaster University
d.king@lancaster.ac.uk
What shall we talk about?

• The Path Computation Element (PCE)
  • What it is and where it comes from
  • How it is being used and what are the future plans

• SDN and NFV
  • What do we mean with these terms?
  • Is there a need for path computation?

• Application-Based Network Optimization (ABNO)
  • An “all-embracing” architecture or SDN and NFV
  • Where does PCE fit in ABNO?
  • What further work is needed?

• ABNO-centric implementations and research
The PCE – A short history

• PCE: Path Computation Element - “An entity (component, application, or network node) that is capable of computing a network path or route based on a network graph and applying computational constraints.” from RFC 4655

• That means that a PCE is a *functional component* in an abstract architecture.
  • It’s purpose is to determine paths through a network
  • It operates on a topology map (the Traffic Engineering Database – TED)
    • Nodes and links == connectivity graph
    • Node constraints and link constraints == metrics and capabilities
    • Learned from the routing protocol in the network, or from the inventory database, or direct from the network nodes
  • It can be realised as a component of an existing device (NMS, router, switch) or as a dedicated server (or virtualised service)

• Benefit of identifying PCE as a separate service...
  • Offload CPU-heavy computations
    • Provide advanced and sophisticated algorithms
  • Coordinate computation across multiple paths
  • Operate on an enhanced TED

• Primary initial purpose was for Traffic Engineered MPLS LSPs
  • Rapidly picked up for optical transport networks
Deployment Models for PCE

• The Path Computation Client (PCC) may be co-located with the PCE or separate
Deployment models can be seen as theology

• How you choose to use PCE depends on how you like to operate your network

• There is a range of theologies
  – There is one God who sees and controls everything
  – There is a single God who answers prayer, but you have free choice
  – There are many gods each with different responsibilities
  – We all contain an element of God

• PCE can be placed in a number of places
  – In a central provisioning server (NMS)
  – In a dedicated computation server
  – There may be multiple PCEs with different capabilities in different parts of the network
  – The PCE function can be distributed into the routers
The PCE Protocol (PCEP)

- The PCE architecture originates in the IETF
  - The main focus of the IETF is to specify protocols
- PCEP is the request/response protocol for accessing the services of a PCE
  - Session-based carried over TCP
- Like PCE, PCEP had a very narrow purpose
  - Simple path computation request/response for MPLS-TE LSPs
- Initial proposals and early implementations
  - Used RSVP-TE Path messages
    - It is “kind of obvious”: that is exactly what we will signal
    - Just use the TCP session to give context to the usage
    - It really worked
  - But was that really extensible?
    - Even in the MPLS-TE context we needed multiple extensions
    - RSVP has a lot of baggage
- Result:
  - A new container protocol and re-use of RSVP objects
The PCE – some more history

- Packet networks have not been a roaring success for PCE
  - Initially, only Cisco implemented
  - It is implemented and deployed
  - Main use cases are
    - Dual-homed IGP areas
    - Centrally controlled TE domains

- There is a huge amount of research and experimentation
  - More than 20 projects funded by the EU have PCE as a core component
  - A number of operators have in depth experimentations

- Commercial and Open Source Implementations
  - Software stacks from Metaswitch and Marben
    - But these are PCEP implementations, not full PCEs
  - Several Open Source implementations exist
  - Hardware vendors
  - Network operators

- The best take-up for PCE so far is in optical networks
Evolution

• PCE evolved very quickly after it was invented
• Advanced PCEP encodings for non-packet environments
• PCEP extensions for coordinated path computations
  • Path protection
  • Network re-optimisation
• Cooperating PCEs for multi-domain applications
• Applicability to sophisticated services such as point-to-multipoint
• Hierarchical PCE for selection of paths across multiple domains
• And evolution continues today
Cooperating PCEs

- The first “interesting” problem for PCE was inter-domain TE
  - “A domain is any collection of network elements within a common sphere of address management or path computation responsibility.” RFC 4655
  - An IGP area or an Autonomous System
  - An optical island

- Nodes in one network cannot see into other networks
  - PCEs must ask each other for advice

1. I want to reach the Egress
2. Thinks… “Route through A looks best”
3. How should I reach the Egress?
4. Thinks… “Route through D would be best”
5. I want to reach the Egress
Hierarchical PCE

• How do I select a path across multiple domains?
• Parent PCE (pPCE) has
  • An overview topology showing connectivity between domains
  • Communications with each Child PCE (cPCE)
• Parent can selectively and simultaneously invoke children to assemble an end-to-end path
The Stateful PCE

- The “classic” PCE uses network state stored in the TED
  - This information may be gathered from the network
    - Passive participation in the IGP
    - Export from the network using BGP-LS
  - Or it may be gathered by “other mechanisms” (RFC 4655)
    - Inventory, management systems, configuration export

- There is also transitory per-computation state in the PCE
  - This allows bulk computation or “Please compute a path considering this other LSP”

- A Stateful PCE is aware of other LSPs in the network
  - A PCE could retain knowledge of paths it previously computed
  - Or it may gather information about LSPs as exported from the network
    - BGP-LS
    - PCEP
      - “Yes, I used that path you gave me”
      - “Here are some other LSPs I know about”

- A Stateful PCE is able to do more intelligent path computation
The Active PCE

• An Active PCE is able to advise the network
  • About more optimal paths
  • When congestion is a problem

• As far as the protocol is concerned, it is only a small step
  • The PCC can say “Please worry about these LSPs for me.”
    • Delegation of LSPs from the PCC to the PCE
  • The PCE can say “Here is a path you didn’t ask for.”
    • For delegated LSPs or for new LSPs

• This enriches PCEP
  • From a request/response protocol
  • To become *almost* a configuration / provisioning protocol

• Architecturally it is “interesting”
  • PCEP used to be the language spoken by the computation engine (PCE)
  • Now it is the language spoken by the network management system (NMS) that has a computation component
    • That doesn’t make it wrong. It does make it different

• It also opens up PCEP as an SDN protocol as we will see later
New Networks and PCE

• New IETF effort: SPRING Working Group
  • Source Packet Routed Networking
  • Path through the network is predetermined for each packet
  • Path is encoded in the packet header as a series of hops
  • Some form of path computation is required
    • Could be as simple as SPF
    • May achieve load balancing
    • Might assign flows to different quality paths (delay, jitter, reliability, etc.)

• Service Function Chaining
  • Another new IETF effort: SFC Working Group
  • A Service Function Chain is an ordered list of service functions and servers
    • That means some form of path computation is necessary

• Deterministic wireless networks
  • For example Timeslotted Channel Hopping (TSCH) - IEEE802.15.4e
  • Path planning is an important aspect of operating these networks

• PCE is being investigated as a tool for these new networks
  • What that really means is that PCEP extensions are being proposed
What do we mean by “SDN”?

- **Software**
  - It’s all software!
  - We are looking for automation
  - Tools and applications

- **Driven or Defined**
  - Does it matter?

- **Networks**
  - Management of forwarding decisions
  - Control of end-to-end paths
  - Whole-sale operation of network

- The goals of commercial SDN networks
  - Make our networks better
  - Rapidly provide cool services at lower prices
  - Reduce OPEX and simplify network operations
  - Enable better monitoring and diagnostics
  - Make better use of deployed resources

- Converged services are the future
- Converged infrastructure is the future

- There is a significant element of centralisation
Bringing PCE to the SDN Feast

- PCE is an essential element for planning services in any network
- An Orchestrator cannot orchestrate without determining how traffic will flow through the network
  - And that means that an Orchestrator needs path computation function
  - Whether the PCE is built into the Orchestrator or lives as a separate component is an implementation choice
- A Controller cannot control more than a single node without determining how traffic will flow through a set of nodes
  - And that means that a Controller may need path computation function
  - Whether the PCE is built into the Controller or lives as a separate component is an implementation choice
PCEP as an SDN Protocol

- It is a simple step beyond an Active, Stateful PCE
  - Instead of suggesting LSPs, a PCE can provision LSPs
- Now PCEP can be seen as a full-scale provisioning protocol
  - I can provision anything for which I might have asked for a path
    - End-to-end LSPs
    - A fragment or segment of an LSP
    - The forwarding instructions on a single node
- Now PCE can be integral to the SDN components
  - I can use PCEP as an SDN Controller protocol
  - And/or as the Orchestrator-to-Controller protocol
- This raises the question of “competition” with OpenFlow which we will address later
Can we define “NFV”? 

• Operators use a variety of proprietary appliances to provide network functions when delivering services

• Deploying a new network function often requires new hardware components
  • Integrating new equipment into the network takes space, power, and the technical knowledge
  • This problem is compounded by function and technology lifecycles which are becoming shorter as innovation accelerates

• The concept of virtualization is well-known and has been used for many years
  • Operating system virtualization (Virtual Machines)
  • Computational and application resource virtualisation (Cloud Computing)
  • Link and node virtualisation (Virtual Network Topologies)
  • Data Center Virtualisation (Virtual Data Center)

• Network Function Virtualization
  • Virtualize the class of network function
  • Replace specialist hardware with instances of virtual services provided on service nodes in the network
  • Enables high volume services and functions on generic platforms

• Virtualizing network connectivity for services and applications is just another facet of NFV
SDN & PCE as enablers for Network Virtualization

- Consider Transport SDN as an example
  - Integrates Packet, TDM, and Optical Layer into a single converged network
  - Requires centralized control functions including resource computation
  - Uses southbound control interface

![Diagram of Transport SDN controller and associated domains]

- Control Functions:
  - Resource Computation
  - Resource Setup
  - Resource Performance Monitoring
  - Resource Resiliency
  - Re-optimisation

- Access Domain
- Converged packet-optical core domain
- Access Domain

End-to-End connection
Harnessing the Unicorn

• We’ve established that PCE is a wonderful thing
• We know that SDN and NFV offer a bright future for networking
• How do we bring PCE fully into the picture and make it work for us?
Building a Functional Architecture

• The purpose of a functional architecture is to decompose a problem space
  • Separate distinct and discrete functions into separate components
  • Identify the functional interactions between components

• An architecture is not a blue-print for implementation!
  • Components are abstract functional units
  • They can be realized as separate software blobs on different processors
  • Or they can all be rolled into one piece of spaghetti code
  • And they can be replicated and distributed, or centralized

• A protocol provides a realization of the interaction between two functional components
  • You only need to use it when the components are separated

• There have been many useful attempts to document architectures for SDN and NFV

• Our work has tried to present a wider picture
  • Address a range of network operation and management scenarios
  • Encompass (without changing) existing profiles of the architecture
  • Embrace SDN and NFV without becoming focused or obsessed with them
  • Highlight existing protocols and components
Application-Based Network Operation (ABNO)

• Application-Based Network Operations
  • A PCE-based Architecture for Application-based Network Operations
  • draft-farrkingel-pce-abno-architecture

• Network Controller Framework
  • Avoiding single technology domain “controller” architecture
  • Reuse well-defined components and protocols
    • Discovery of network resources and topology management.
    • Routing and path computation
    • Multi-layer coordination and interworking
    • Policy Control
    • OAM and performance monitoring

• Support a variety of southbound protocols
  • Leveraging existing technologies, support new ones

• Integrate with defined and developing standards, across SDOs
ABNO – Functional Components

- "Standardized" components
- Policy Management
- Network Topology
  - LSP-DB
  - TED
  - Inventory Management
- Path Computation and Traffic Engineering
  - PCE, PCC
  - Stateful & Stateless
  - Online & Offline
  - P2P, P2MP, MP2MP
- Multi-layer Coordination
  - Virtual Network Topology Manager
- Network Programming and Signalling
  - ForCES
  - OpenFlow
  - Interface to the Routing System
  - PCEP
  - RSVP-TE

Figure 1: Generic ABNO Architecture
Compare ABNO with SDN Architecture

- A richer function-set based on the same concepts
- Enables the use of OpenFlow and other protocols
- There are implementation/deployment choices to be made

Minimum required for SDN controller of infrastructure

- Applications
  - Application-controller plane i/f
- Orchestrator
  - OpenFlow Northbound
- Controllers
  - OpenFlow

What is required for commercial deployment of SDN control platforms for real networks
ABNO Implementation and Research

• There are a number of experimental implementations of ABNO
  • Most notable was a demonstration of Packet-Transport Integration
    • Packet devices from Juniper Networks
    • Optical devices from Infinera
    • ANBO-based Transport SDN from Telefonica
    • Telefonica has also tested with ADVA and Ciena

• Multiple research projects examining the use of ABNO...
FP7 “IDEALIST” Project

• Industry-Driven Elastic and Adaptive Lambda Infrastructure for Service and Transport (IDEALIST) Networks
  • The work is partially funded by the European Community’s Seventh Framework Programme FP7/2007-2013 through the Integrated Project (IP) IDEALIST under grant agreement nº 317999.
  • [www.ict-idealist.eu](http://www.ict-idealist.eu)

• The network architecture proposed by IDEALIST is based on four technical cornerstones:
  • An optical transport system enabling flexible transmission and switching beyond 400Gbps per channel
  • Control plane architecture for multi-layer and multi-domain optical transport network, extended for flexi-grid labels and variable bandwidth.
  • Dynamic network resources allocation at both IP packet and optical transport network layer
  • Multilayer network optimization tools enabling both off-line planning, on-line network reoptimization in across the IP and optical transport network
    • These tools are called Adaptive Network Management (ANM)
    • They are based on the ABNO architecture
    • Implementations exist!
FP7 IDEALIST Findings - Articles & Input to SDOs

• Publications (just a few)
  • In-Operation Network Planning
    *IEEE Communications Magazine*
  • Experimental Demonstration of an Active Stateful PCE performing Elastic Operations and Hitless Defragmentation
    *ECOC European Conference on Optical Communications*
  • Planning Fixed to Flexgrid Gradual Migration: Drivers and Open Issues
    *IEEE Communications Magazine*
  • Dynamic Restoration in Multi-layer IP/MPLS-over-Flexgrid Networks
    *IEEE Design of Reliable Communication Networks (DRCN)*
  • A Traffic Intensity Model for Flexgrid Optical Network Planning under Dynamic Traffic Operation
    *OSA Optical Fiber Communication (OFC)*

• Standards Input
  • Unanswered Questions in the Path Computation Element Architecture
  • A PCE-based Architecture for Application-based Network Operations
Other FP7 Projects with ABNO

- **FP7 OFERTIE** ([www.ofertie.org](http://www.ofertie.org)) Enhances the OFELIA testbed facility to allow researchers to request, control and extend network resources dynamically

- **FP7 DISCUS** ([www.discus-fp7.eu](http://www.discus-fp7.eu)) Distributed Core for unlimited bandwidth supply for all Users and Services

- **FP7 CONTENT** ([www.content-fp7.eu](http://www.content-fp7.eu)) Convergence of Wireless Optical Network and IT Resources in Support of Cloud Services

- **FI-PPP XIFI** ([www.wiki.fi-xifi.eu](http://www.wiki.fi-xifi.eu)) Creating a multi-DC community cloud across Europe
  - Flexible User Interface
  - Federated Cloud and Service Management
  - Dynamic Network Management
  - Resource Monitoring
TOUCAN

- Towards Ultimate Convergence of All Networks (TOUCAN)
- A UK funded project for 5 years from August 2014
- Academic Leadership
  - Lancaster, Heriot Watt, Edinburgh, and Bristol Universities
- Technology Partners
  - BT, Plextek, NEC, Samsung, JANET, and Broadcom
- Technology agnostic architecture for convergence based on SDN principles
  - Facilitate optimal interconnection of any network technology domains, networked devices and data sets with high flexibility, resource, and energy efficiency
  - Widely diverse networking technologies
    - Fiber-optic core
    - DSL, GigE
    - GSM/LTE
    - WiFi
    - Sensors
  - Service driven control with on demand delivery across virtualised infrastructure
  - Optimization based on capacity, connectivity, spectrum utilization, resource allocation and energy efficiency
  - Commoditisation of network and IT hardware devices
  - Exploit notion of adaptivity and programmability for optimal IT resource and workload allocation
- Investigating ABNO architecture as a cornerstone
The PACE Project

• Next Steps in PAth Computation Element (PCE) Architectures
• FP7 Coordination and Support Action
• Education and dissemination of PCE concepts
  • Tutorials, papers, knowledge base, outreach
• Development and applicability of new uses of PCE
  • Including SDN and NFV through support of ABNO
• Consolidate and coordinate existing (OpenSource) PCE developments
• http://www.ict-pace.net/
  • Funding from the European Union's Seventh Framework Programme for research, technological development and demonstration through the PACE project under grant agreement number 619712
ABNO and Research - Next Steps

• The research community is already embracing ABNO
• That should lead to important feedback
  • What is not clear in the architecture?
  • What pieces are missing or wrong?
  • How well do implementations behave?
  • How is PCE integrated into the whole?
    • What new PCE algorithms are needed?
    • How does PCEP need to be enhanced?
  • What new network types can be managed?
  • How can NFV, SFC, and network slicing be operated?
  • What are the security, management, and economic implications?
ABNO and Industry / Standards

• draft-farrkingel-pce-abno-architecture will soon be published as an RFC
  • It is informational and not a mandatory standard
    • It leaves a number of interfaces unspecified
      • For example, service request interface
    • It presents too many choices
  • Next steps
    • Applicability statements to show how to profile ABNO for specific environments
      • A few are captured in the draft
      • More (such as SDN) could be documented
    • New requirements documents and protocol specifications to fill the gaps

• This work will be done in coordination with industry
  • What do people really want to build and deploy?
 Assertions

- PCE is here to stay as a functional component of SDN
- Implementing PCE as a distinct unit enables
  - Scaling
  - Load-balancing
  - Rapid advancement of algorithms
- That means PCEP is a necessary protocol for accessing PCE
- PCEP can be used as a “provisioning protocol”
  - Most clear use in circuit-switched networks (MPLS-TE, GMPLS, ...)
  - Jury is out on the use of PCEP as a per-node control protocol
- SDN should be seen as a critical part of a wider view of network operation
- Re-use of components and protocols makes sense
- The ABNO architecture embraces SDN and factors it into the bigger picture
References

- The PACE project “PCE Primer”

- Path Computation Element Tutorial
  http://www.olddog.co.uk/Farrel_PCE_Tutorial.ppt

- IETF's PCE Working Group
  https://datatracker.ietf.org/wg/pce/documents/

- RFC 4655, “A Path Computation Element (PCE)-Based Architecture”
  https://www.rfc-editor.org/rfc/rfc4655.txt

- RFC 5440, ”Path Computation Element Communications Protocol”
  https://www.rfc-editor.org/rfc/rfc5440.txt

- RFC 6805, ”Hierarchical PCE”
  https://www.rfc-editor.org/rfc/rfc6805.txt

  https://www.ietf.org/id/draft-farrkingel-pce-abno-architecture

  https://www.ietf.org/id/draft-ietf-pce-questions

- “PCE: What is It, How Does It Work and What are its Limitations?”

- “In-Operation Network Planning”

- “Towards a carrier SDN: an example for elastic inter-datacenter connectivity”
  Optics Express, 2014.

- “PCEP - A Protocol for All Uses? How and when to extend an existing protocol”
  PACE Workshop, 2014.

- “A Survey on the Path Computation Element (PCE) Architecture”
  IEEE Communications Surveys and Tutorials, 2013.

- “Using the Path Computation Element to Enhance SDN for Elastic Optical Networks (EON)”
  iPOP Tokyo, 2013.
Questions?

Follow-up

adrian@olddog.co.uk
d.king@lancaster.ac.uk