The Role of SDN-NFV in Flexible Optical Networks:
Current Status, Challenges and Opportunities

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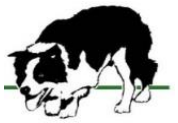
An opportunity for SDN & NFV
Variable bit-rate technology

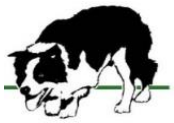
- Flexible and Elastic Optical Networks
  - Photonic Integrated Circuit (PIC) technology
    - Paving the path towards cost effective transmission schemes beyond 100Gbps.
  - Digital Coherent and SuperChannel technology solutions
    - Variable >100Gbps client signals and cost effective >100Gbps transponders
    - Capable of long reach up to 400Gbps without regeneration
  - Cost effective and flexible transponders
    - The Sliceable-Bandwidth Variable Transponder (SBVT).
      - Reduce bandwidth to extend reach
      - More spectrum to extend reach
      - More bandwidth over short reach
- FlexGrid
  - A variable-sized optical frequency range
  - ITU-T Study Group 15 (www.itu.int/rec/T-REC-G.694.1)

Leveraging
FlexGrid with SDN & NFV



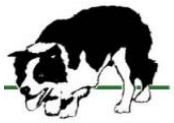
- The network architecture we developed is based on four technical cornerstones:
  1. An optical transport system enabling flexible transmission and switching up to, and beyond 400Gbps per channel.
  2. Hybrid control plane architecture for multi-layer and multi-domain optical transport network, extended for flexi-grid labels and variable bandwidth
  3. Dynamic network resources allocation at both IP and optical transport network. layer
  4. Leveraging Software Defined Networks and Network Functions Virtualisation paradigms
- Focus on standards-based development
  - Framework for GMPLS based control of Flexi-grid DWDM networks
  - Generalized Labels for the Flexi-Grid in LSC Label Switching Routers
  - GMPLS OSPF-TE Extensions in for Flexible Grid DWDM Networks
  - RSVP-TE Signaling Extensions in support of Flexible Grid
  - Extensions to PCEP for Hierarchical Path Computation Elements (H-PCE)
  - A YANG data model for FlexGrid Optical Networks

A Controller for
Optical Network Operations



- "SDN Controller" is a contentious term, it can have many different meanings:
  - Historically the term was derived from the network domain, technology and protocol mechanism
- SDN Controller wars are ongoing:
  - Operators have an expectation of standards-based technologies for deploying and operating networks
  - SDN controller vendors rarely provide multivendor interoperability using open standards
  - Provisioning should be a compelling feature of SDN, however many SDN controllers use non-standardised APIs
  - Recent Open Source initiatives tend to be vendor led
- Typically SDN controllers have a very limited view of topology, multi-layer and multi-domain scenarios are slowly being added
- Flexibility has been notably absent from most controller architectures both in terms of southbound protocol support and northbound application requests

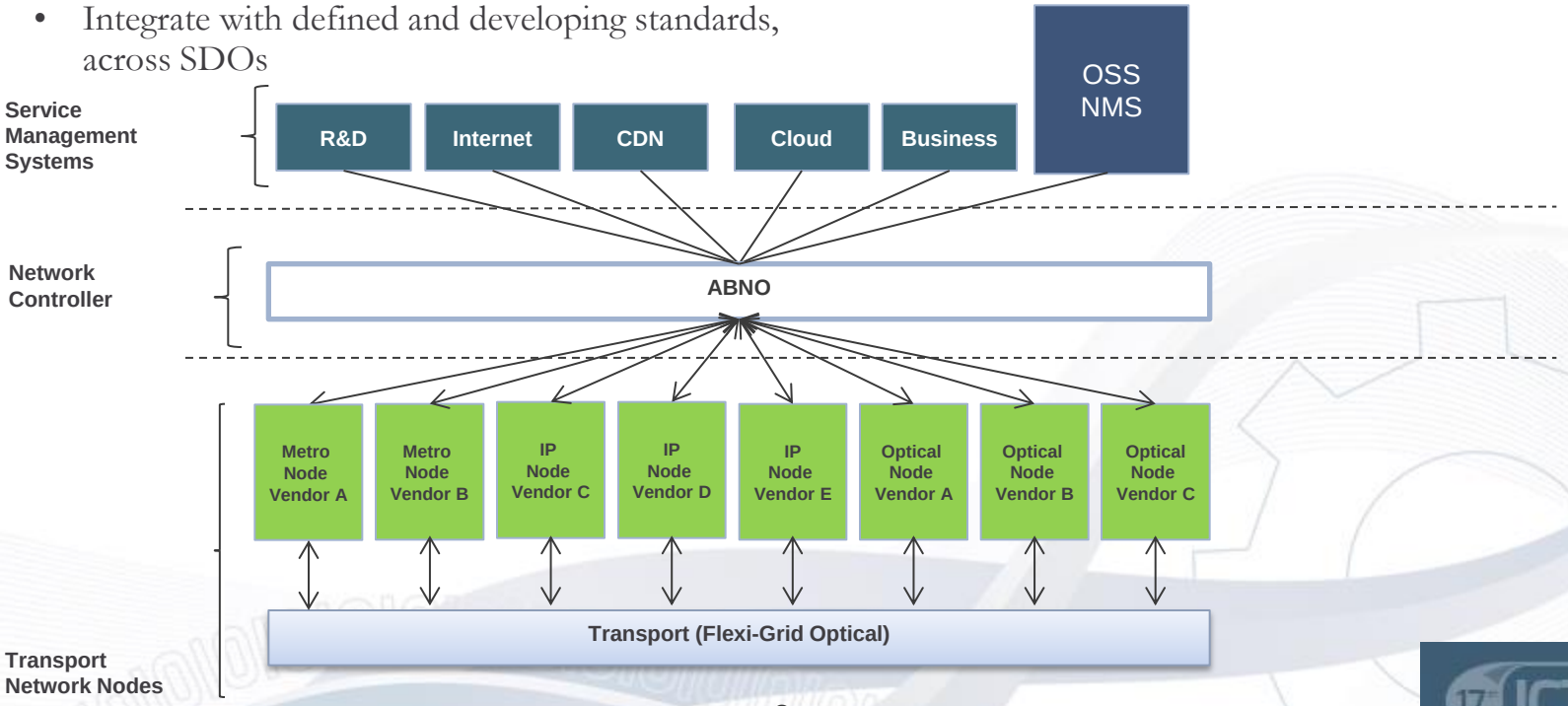
Decomposition of an Optical network controller



- Avoiding the mistake of a single "controller" architecture
  - As it encourages the expansion and use of specific protocols
- Discovery of network resources and topology management
- Network resource abstraction, and high-layer presentation
- Wavelength assignment and path computation
- Multi-layer coordination and interworking
  - Multi-domain & multi-vendor network resources provisioning through different control mechanisms (e.g., OpenFlow, ForCES)
- Policy Control
- OAM and Performance Monitoring
- Security & Resiliency
- A wide variety of southbound northbound protocol support
- Leveraging existing technologies
  - What is currently available?
  - Must integrate with existing and developing standards

What is an Application-Based Network Operation?

- Applications-Based Network Operations (ABNO - RFC7491)
  - A PCE-based Architecture for Application-based Network Operations https://tools.ietf.org/html/rfc7491
- Network Controller Framework
  - Avoiding single technology domain "controller" architecture
  - Reuse well-defined components
  - Support a variety of southbound protocols
    - Leveraging existing technologies, support new ones
- Integrate with defined and developing standards, across SDOs



ABNO for FlexGrid
Uses & Applications

- The network does not need to be seen any longer as a composition of individual elements
  - Applications need to be capable of interaction with the network.
- Support of the next generation of variable and dynamic optical transport characteristics
  - Multi-layer path provisioning
  - Network optimization after restoration
- Automated deployment and operation of services.
  - "Create a new transport connection for me"
  - "Reoptimize my network after restoration switching"
  - "Respond to how my network is being used"
  - "Schedule these services"
  - "Identify lease loaded links, and targets for future capacity planning"

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 Signaling & Programming
  - RSVP-TE
  - ForCES
  - OpenFlow
  - Interface to the Routing System
  - Emerging technologies: Segment Routing & Service Function Chaining

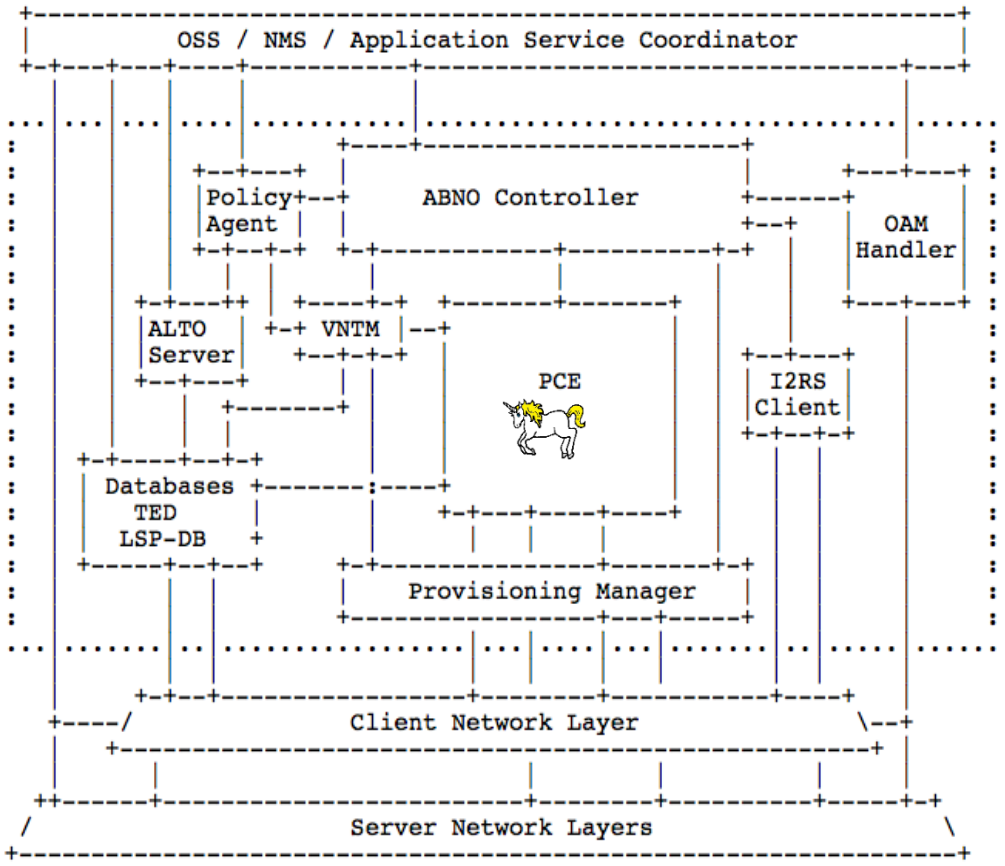
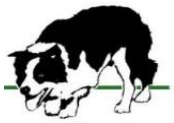
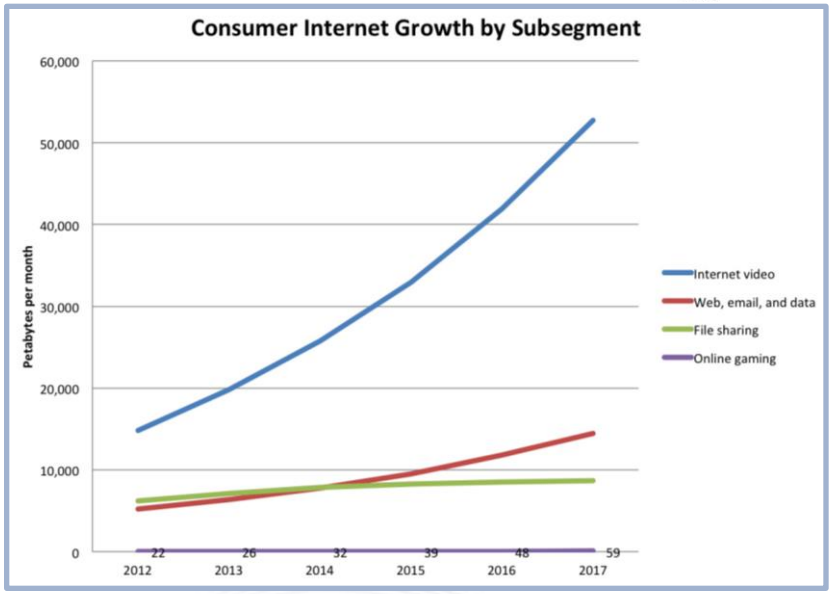


Figure 1: Generic ABNO Architecture

Is Content Delivery the "Killer Application" for SDN & NFV?



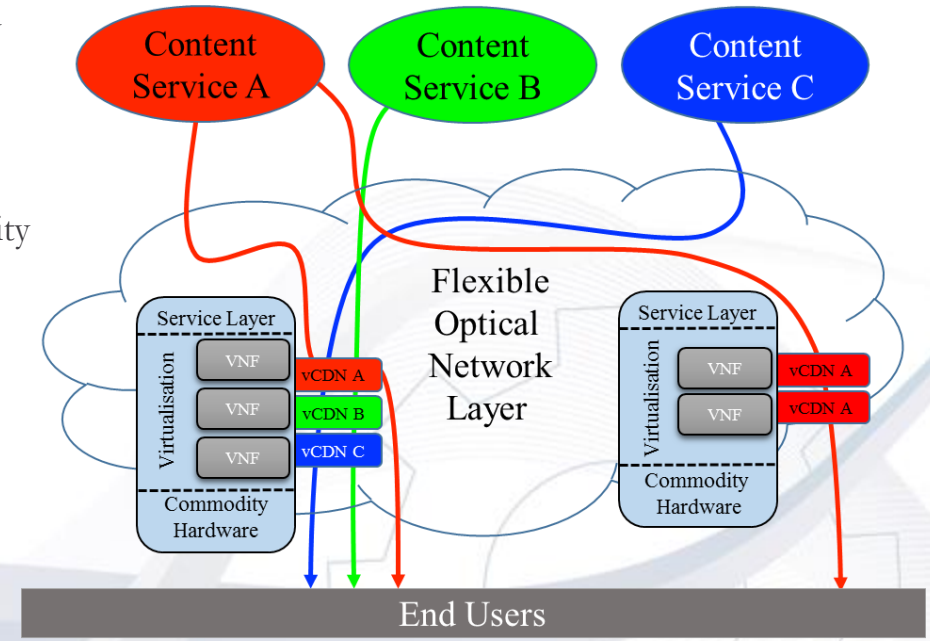
- Delivery of content, especially of video, is one of the major challenges of all operator networks due to massive growing amount of traffic.
- Complementary to the growth of today's Video Traffic
  - On-demand Content Services to internet end-users, with similar quality constraints as for traditional TV Service of Network Operators
  - Delivery of terrestrial transmissions over IP/optical networks
- Distribution of terrestrial transmissions:
  - Uncompressed: Serial Digital Interface (SDI)
  - Compressed: Motion JPEG



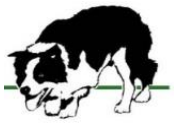
Name	Video	Bitrate
SD-SDI	480i/576i	270 Mbit/s
HD-SDI	720p/1080i	1.5 Gbit/s
3G-SDI	1080p	3 Gbit/s
6G UHD-SDI	4K 30fps	6 Gbit/s
12G UHD-SDI	4K 60fps	12 Gbit/s
24G UHD-SDI	4K 120fps	24 Gbit/s

SDN & NFV "Killer Application"
Content Distribution Network (CDN)

- Design principles require an efficient, reliable and responsive CDN
  - Fault-tolerant network with appropriate load balancing
  - Performance of a CDN is typically characterized by the response time (i.e. latency) perceived by the end-users
  - Slow response time is the single greatest contributor to users abandoning content and web sites and processes
  - The performance of a CDN is affected by
    - Distributed content location
    - Switching mechanism
    - Data replication and caching strategies
    - Reliable functions and network connectivity

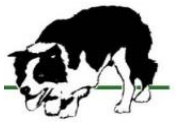


Blending SDN & NFV for the Virtualized CDN (vCDN)



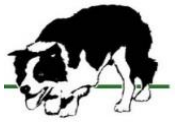
- SDN Network Control
  - Centralized control
  - Dynamic connectivity
  - Elastic bandwidth
- NFV Flexibility, Performance & Predictability
  - Performance: Mean Response Time, Latency, Hit Ratio Percentage, Number of Completed Requests, Rejection rate and Mean CDN load
  - Dimensioning: remaining stable whatever the use of virtualized HW resources for CDN components
  - Resource management: allow the right balance of network i/o to CPU power to storage i/o performance (e.g., RAM and HDD)
- Efficient use of resources (storage)
  - Fulfil specific storage density requirements, e.g. to cache a large catalog of popular content
- Deployment & Operational tools
  - Compliance of cache nodes with main monitoring and reporting requirements (e.g., JSON, YANG, SNMP, syslog, etc.) so that operator is able to manage different types of cache nodes together for a Delivery Service
- Content Management
  - Ability to select specific cached content (e.g., video/HTTP) and replicate/duplicate these selected content items during delivery via virtual switching to a Quality of Experience (QoE) virtualized function without degrading the overall performance of the virtualized CDN function

Yes, but.
Is it actually being used/developed?



- EC-Funded Projects investigating, using and/or developing ABNO
  - FI-PPP XIFI
  - FP7 OFERTIE
  - FP7 DISCUS
  - FP7 CONTENT
  - FP7 PACE (ict-pace.net) - Next Steps for the Path Computation Element
- Deployments and Code Availability
  - iONE, Universitat Politècnica de Catalunya (UPC) (OpenSource)
  - ANM, Telefonica (OpenSource)
  - Infinera (Closed Proof of concept)
- Publications & Standards
  - A PCE-Based Architecture for Application-Based Network Operations, IETF RFC7491
  - Unanswered Questions in the Path Computation Element Architecture, IETF RFC7399
  - "In-Operation Network Planning", IEEE Communications Magazine
  - "Adaptive Network Manager: Coordinating Operations in Flex-grid Networks", ICTON (IEEE)
  - "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)
  - **And many, many more…**

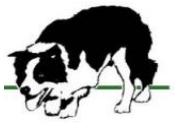
Future research and investigations
Where next?



- Commercializing ABNO for video distribution and storage
  - Ongoing re-use of components and protocols, and extending where necessary, makes sense
- Implementing a controller as a distinct unit with the SDN architecture provides a number of benefits:
  - Scaling
  - Load-balancing
  - Resilience
  - Multiple forwarding technology support (various optic flavours)
  - Rapid advancement of algorithms, the next disruptive wave of innovation will be Machine Learning (ML)
- Therefore, SDN should be seen as a critical part of a wider view of network operation
- However, gaps exist!

Assuming a basis for a controller

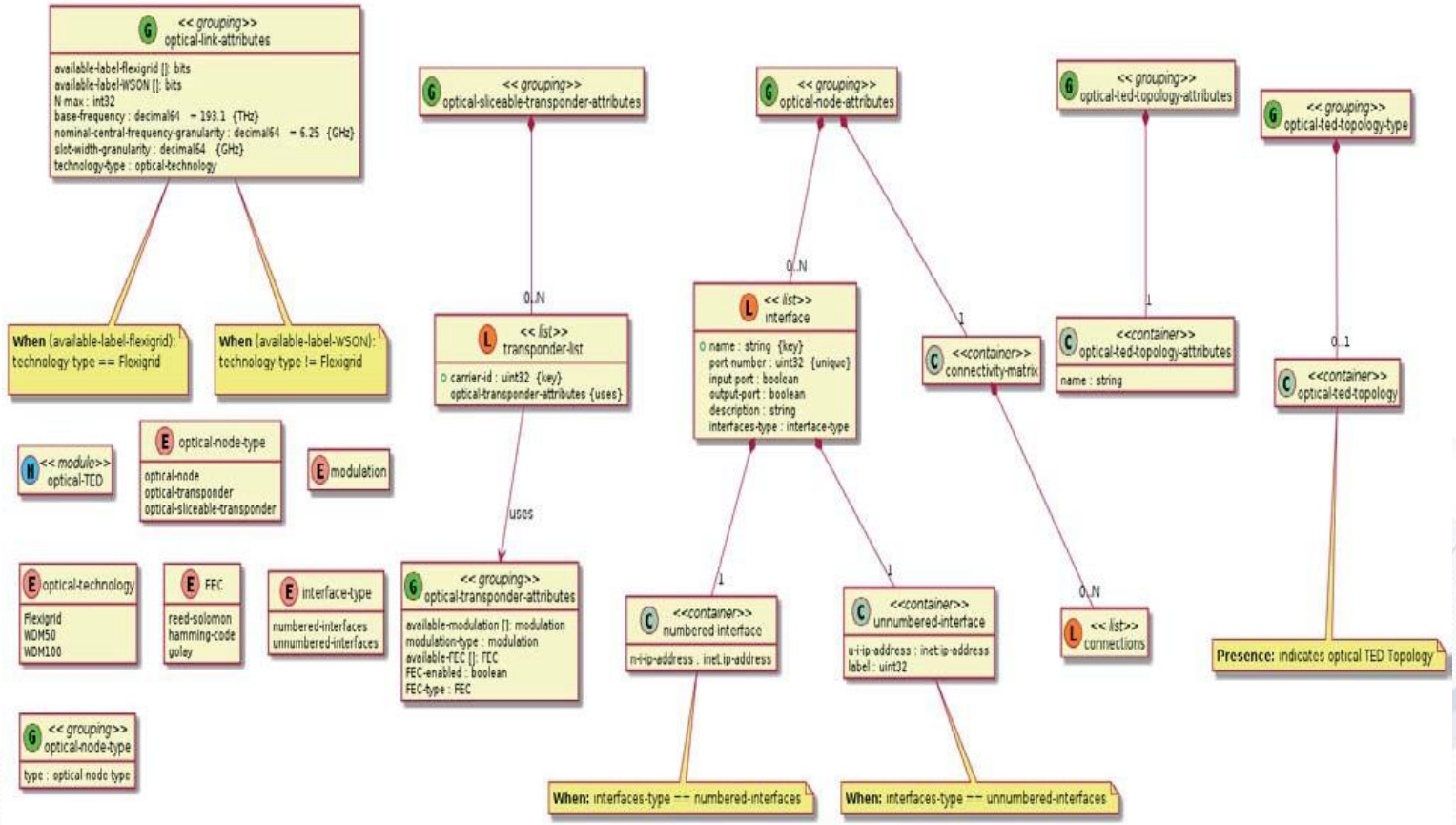
How to do we integrate into the orchestrator?



- Application specific orchestration layer needed
  - Can this ever be generalized to be application agnostic?
  - How might we define the service?
  - Are service information models are available?
- Optimization being performed in multiple layers
  - If using PCE, where should the PCE element(s) actually be located?
  - Is the PCE a candidate for Network Functions Virtualisation (NFV)?
  - How do we scale, load balance and ensure resilience for?
  - Speed at which path computations are provided
- Can paths be determined and provisioned any quicker?
  - How can we combine offline (planning) and online (real-time) requests?
- Multi-layer support (packet layer over flexible optical networks)
  - Placement of video services at both the packet and optical layer (bandwidth dependent)
- Application of Policy/Intent when computing computation paths and configuring equipment

Network Control
Optical network modeling

- Continue to develop YANG data and information models
  - Please see later presentation & paper.



Network Control
Resource Management & Optimisation

- Resource representation
  - Meta models for VNFs and infrastructure
- Consideration and operation of various optimisation goals:
  - Time
  - Performance
  - Cost
  - Reliability
  - Minimising the resource footprint
  - Power Consumption

Network Control
Service Level Agreement Management

- Translate consumer demands into a service and application definition
  - Encode performance qualities
  - Specify resource and QoS requirements
  - Mask resource details, queue data and current workload
- Combination and management of several SLAs relevant at various levels
  - High-level, human-readable SLAs
  - Technology SLAs within the middleware to guarantee service provisioning

Network Control
Performance Monitoring and Measurement

- Infrastructure analytics and visualisation
- Composite metrics
- Simulations and “what if” scenario testing
- Hardware performance monitoring

Thank You!

Any comments or questions are welcome.

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