Introduction to Network Function Virtualization (NFV)

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These slides and audio/video recordings of this class lecture are at:

http://www.cse.wustl.edu/~jain/cse570-13/

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1. What is NFV?
2. NFV and SDN Relationship
3. ETSI NFV ISG Specifications
4. Concepts, Architecture, Requirements, Use cases
5. Proof-of-Concepts and Timeline

Note: This is 4th module of four modules on OpenFlow, OpenFlow Controllers, SDN and NFV in this course.

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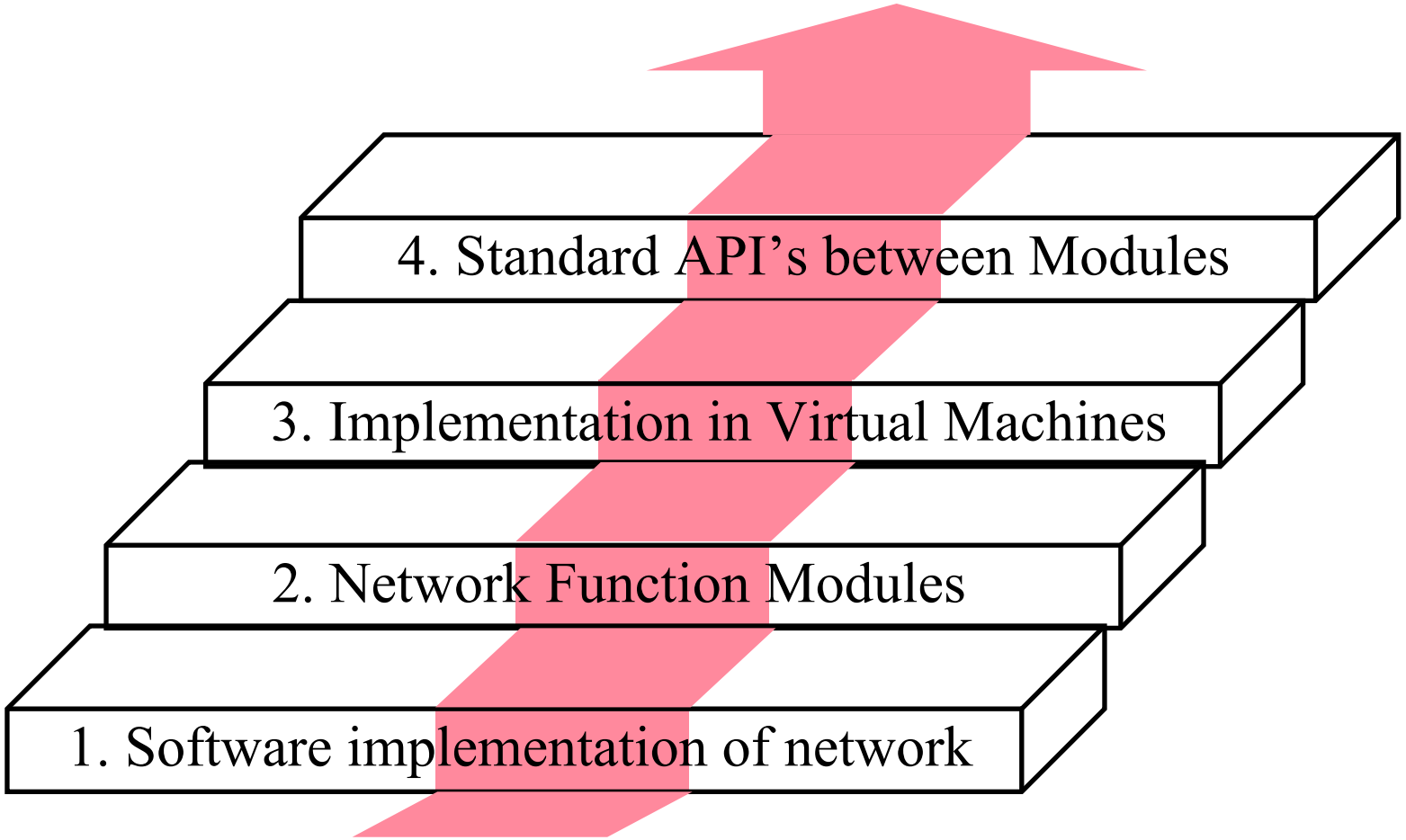
Four Innovations of NFV



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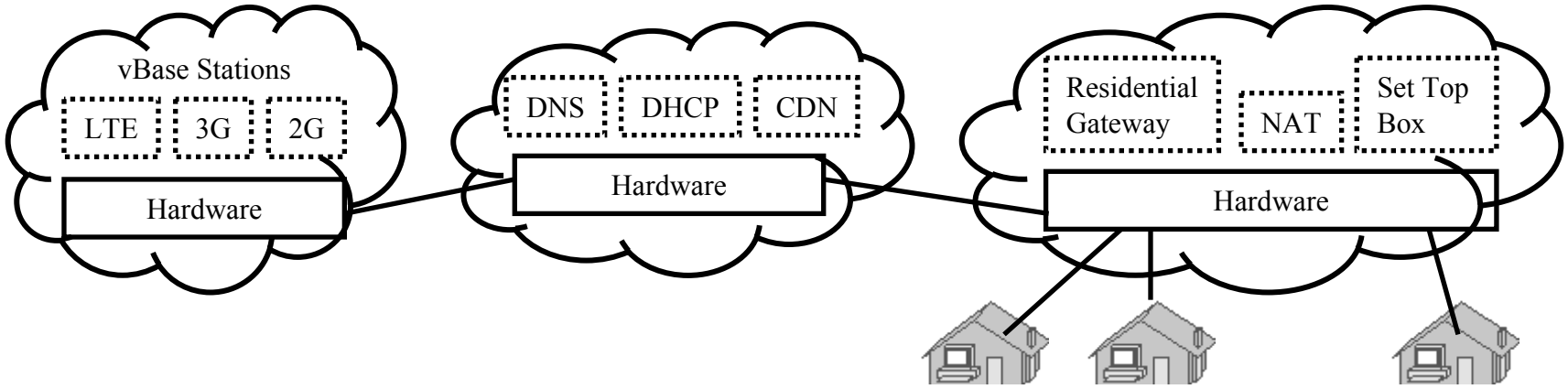
Network Function Virtualization (NFV)

1. Fast standard hardware ⇒ **Software based Devices**
   Routers, Firewalls, Broadband Remote Access Server (BRAS)
   ⇒ A.k.a. *white box* implementation
2. **Function Modules** (Both data plane and control plane)
   ⇒ DHCP (Dynamic Host control Protocol), NAT (Network Address Translation), Rate Limiting,



Ref: ETSI, "NFV – Update White Paper," Oct 2013, http://www.tid.es/es/Documents/NFV_White_PaperV2.pdf (Must read)

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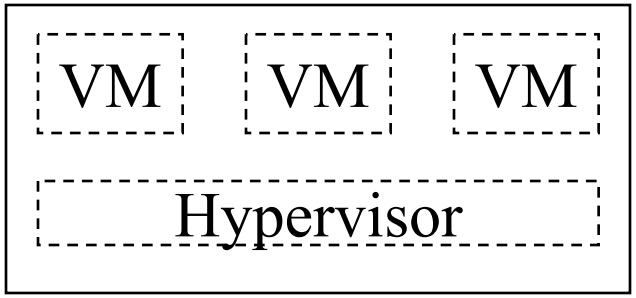
NFV (Cont)

3. **Virtual Machine implementation**
   ⇒ Virtual appliances
   ⇒ All advantages of virtualization (quick provisioning, scalability, mobility, Reduced CapEx, Reduced OpEx, …)



4. **Standard APIs**: New ISG (Industry Specification Group) in ETSI (European Telecom Standards Institute) set up in November 2012

Why We need NFV?

1. **Virtualization**: Use network resource without worrying about where it is physically located, how much it is, how it is organized, etc.
2. **Orchestration**: Manage thousands of devices
3. **Programmable**: Should be able to change behavior on the fly.
4. **Dynamic Scaling**: Should be able to change size, quantity
5. **Automation**
6. **Visibility**: Monitor resources, connectivity
7. **Performance**: Optimize network device utilization
8. **Multi-tenancy**
9. **Service Integration**
10. **Openness**: Full choice of Modular plug-ins

Note: These are exactly the same reasons why we need SDN.

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NFV and SDN Relationship

- Concept of NFV originated from SDN
  ⇒ First ETSI white paper showed overlapping Venn diagram
  ⇒ It was removed in the second version of the white paper
- NFV and SDN are complementary.
  One does not depend upon the other.
  You can do SDN only, NFV only, or SDN and NFV.
- Both have similar goals but approaches are very different.
- SDN needs new interfaces, control modules, applications.
  NFV requires moving network applications from dedicated hardware to virtual containers on commercial-off-the-shelf (COTS) hardware
- NFV is present. SDN is the future.
- Virtualization alone provides many of the required features
- Not much debate about NFV.

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Mobile Network Functions

- Switches, e.g., Open vSwitch
- Routers, e.g., Click
- Home Location Register (HLR),
- Serving GPRS Support Node (SGSN),
- Gateway GPRS Support Node (GGSN),
- Combined GPRS Support Node (CGSN),
- Radio Network Controller (RNC),
- Serving Gateway (SGW),
- Packet Data Network Gateway (PGW),
- Residential Gateway (RGW),
- Broadband Remote Access Server (BRAS),
- Carrier Grade Network Address Translator (CGNAT),
- Deep Packet Inspection (DPI),
- Provider Edge (PE) Router,
- Mobility Management Entity (MME),
- Element Management System (EMS)

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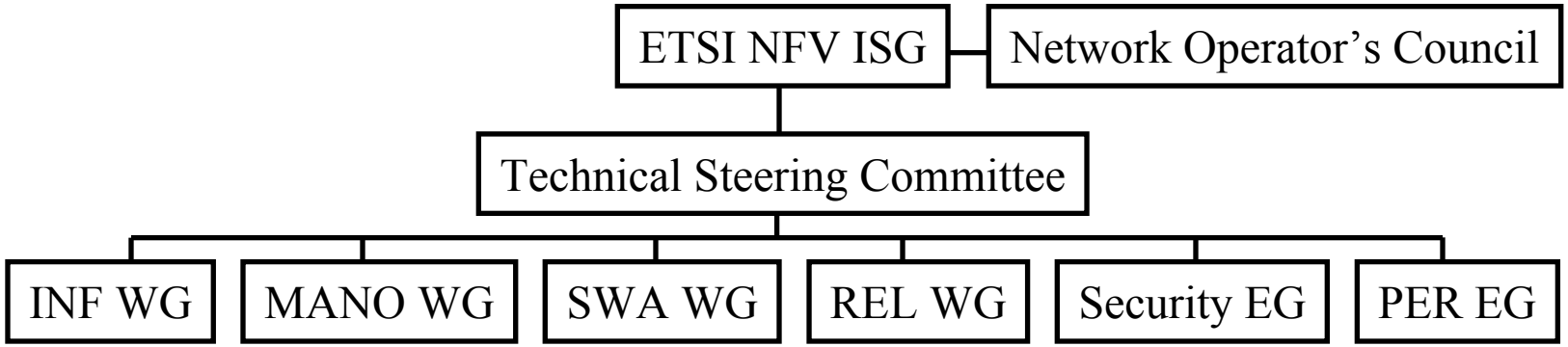
ETSI NFV ISG



- Industry Specification Group (ISG)'s goal is to define the requirements.
- Four Working Groups:
  - **INF**: Architecture for the virtualization Infrastructure
  - **MANO**: Management and orchestration
  - **SWA**: Software architecture
  - **REL**: Reliability and Availability, resilience and fault tolerance

Ref: M. Cohn, "NFV, An Insider's Perspective: Part 1: Goals, History, and Promise," Sep 2013, http://www.sdncentral.com/education/nfv-insiders-perspective-part-1-goals-history-promise/2013/09/

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ETSI NFV ISG (Cont)

- Two Expert Groups:
  - **Security** Expert Group: Security
  - **Performance and Portability** Expert Group: Scalability, efficiency, and performance VNFs relative to current dedicated hardware

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NFV Specifications

1. NFV Use cases (GS NFV 001)
2. NFV Architectural Framework (GS NFV 002)
3. Terminology for Main Concepts in NFV (GS NFV 003)
4. NFV Virtualization Requirements (GS NFV 004)
5. NFV Proof of Concepts Framework (GS NFV-PER 002)

Ref: ETSI, "Network Function Virtualization," http://www.etsi.org/technologies-clusters/technologies/nfv

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NFV Concepts

- **Network Function (NF):** Functional building block with a well defined interfaces and well defined functional behavior
- **Virtualized Network Function (VNF)**: Software implementation of NF that can be deployed in a virtualized infrastructure
- **VNF Set**: Connectivity between VNFs is not specified, e.g., residential gateways
- **VNF Forwarding Graph**: Service chain when network connectivity order is important, e.g., firewall, NAT, load balancer
- **NFV Infrastructure (NFVI)**: Hardware and software required to deploy, mange and execute VNFs including computation, networking, and storage.

Ref: ETSI, "Architectural Framework," Oct 2013, http://www.etsi.org/deliver/etsi_gs/NFV/001_099/002/01.01.01_60/gs_NFV002v010101p.pdf
Ref: ETSI, "NFV Terminology for Main Concepts in NFV," Oct 2013, http://www.etsi.org/deliver/etsi_gs/NFV/001_099/003/01.01.01_60/gs_NFV003v010101p.pdf
Ref: W. Xu, et al., "Data Models for NFV," IETF Draft, Sep 2013, http://tools.ietf.org/html/draft-xjz-nfv-model-datamodel-00

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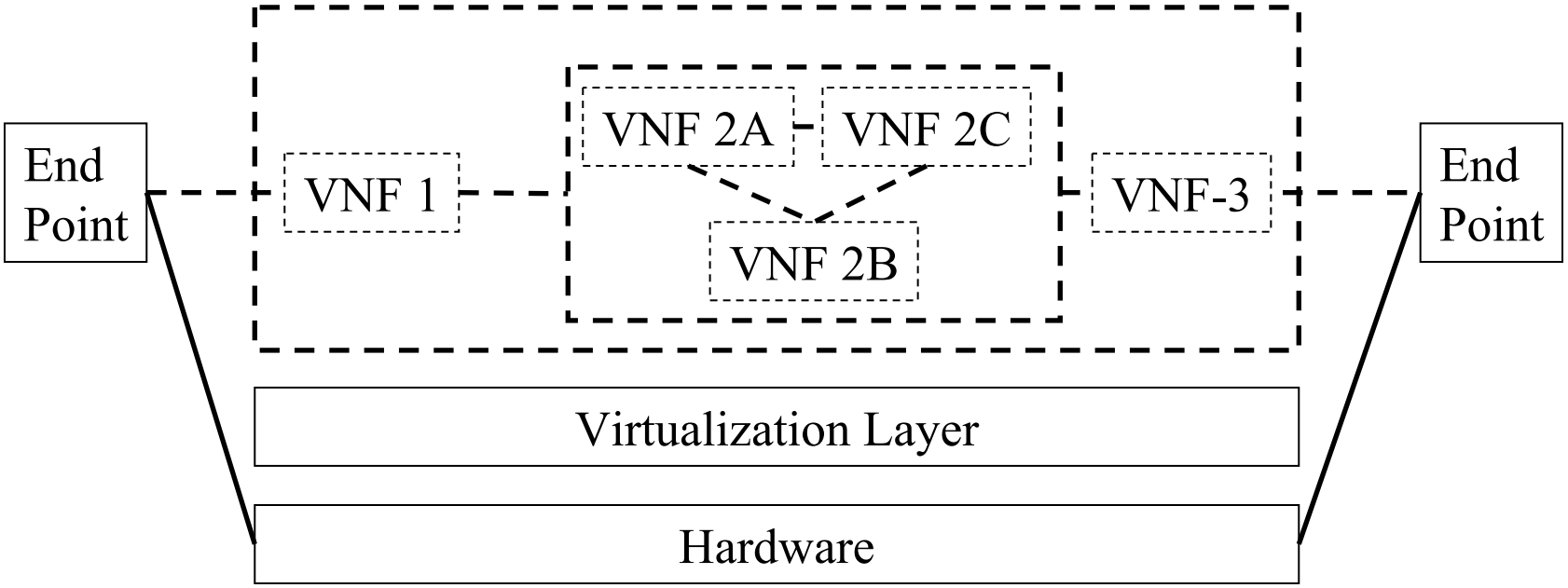
Network Forwarding Graph

- An end-to-end service may include nested forwarding graphs



Ref: ETSI, "Architectural Framework," Oct 2013,
http://www.etsi.org/deliver/etsi_gs/NFV/001_099/002/01.01.01_60/gs_NFV002v010101p.pdf

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NFV Concepts (Cont)

- **NFVI Point of Presence (PoP)**: Location of NFVI
- **NFVI-PoP Network**: Internal network
- **Transport Network**: Network connecting a PoP to other PoPs or external networks
- **VNF Manager**: VNF lifecycle management e.g., instantiation, update, scaling, query, monitoring, fault diagnosis, healing, termination
- **Virtualized Infrastructure Manager**: Management of computing, storage, network, software resources
- **Network Service**: A composition of network functions and defined by its functional and behavioral specification
- **NFV Service**: A network services using NFs with at least one VNF.

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NFV Concepts (Cont)

- **User Service**: Services offered to end users/customers/subscribers.
- **Deployment Behavior**: NFVI resources that a VNF requires, e.g., Number of VMs, memory, disk, images, bandwidth, latency
- **Operational Behavior**: VNF instance topology and lifecycle operations, e.g., start, stop, pause, migration, …
- **VNF Descriptor**: Deployment behavior + Operational behavior
- **NFV Orchestrator**: Automates the deployment, operation, management, coordination of VNFs and NFVI.
- **VNF Forwarding Graph**: Connection topology of various NFs of which at least one is a VNF

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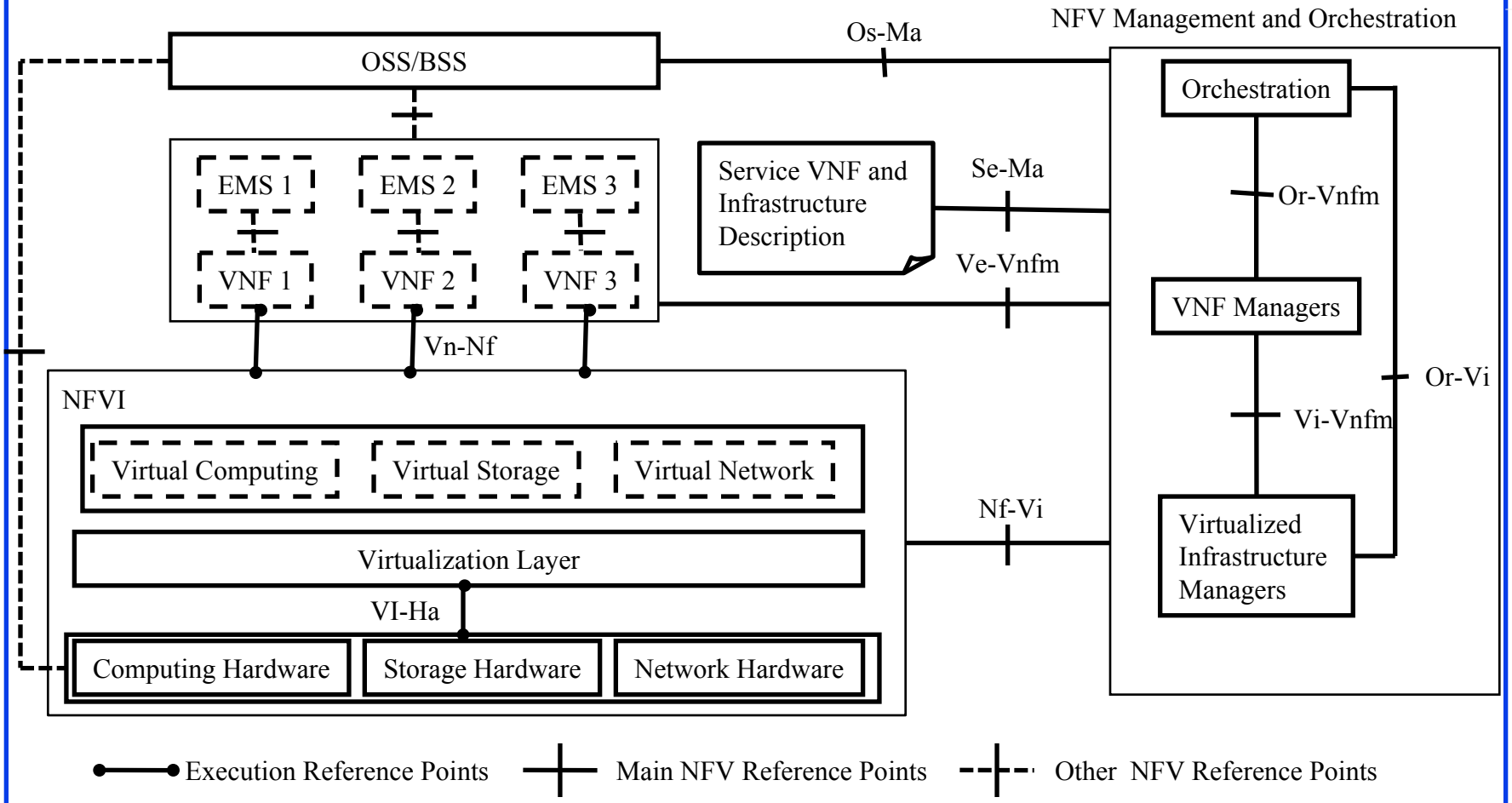
NFV Architecture



Ref: ETSI, "Architectural Framework," Oct 2013, http://www.etsi.org/deliver/etsi_gs/NFV/001_099/002/01.01.01_60/gs_NFV002v010101p.pdf

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NFV Reference Points

Reference Point: Points for inter-module specification

1. Virtualization Layer-Hardware Resources (**VI-Ha**)
2. VNF – NFVI (**Vn-Nf**)
3. Orchestrator – VNF Manager (**Or-Vnfm**)
4. Virtualized Infrastructure Manager – VNF Manager (**Vi-Vnfm**)
5. Orchestrator – Virtualized Infrastructure Manager (**Or-Vi**)
6. NFVI-Virtualized Infrastructure Manager (**Nf-Vi**)
7. Operation Support System (OSS)/Business Support Systems (BSS) – NFV Management and Orchestration (**Os-Ma**)
8. VNF/ Element Management System (EMS) – VNF Manager (**Ve-Vnfm**)
9. Service, VNF and Infrastructure Description – NFV Management and Orchestration (**Se-Ma**): VNF Deployment template, VNF Forwarding Graph, service-related information, NFV infrastructure information

Ref: ETSI, "Architectural Framework," Oct 2013, http://www.etsi.org/deliver/etsi_gs/NFV/001_099/002/01.01.01_60/gs_NFV002v010101p.pdf

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NFV Framework Requirements

1. **General**: Partial or full Virtualization, Predictable performance
2. **Portability**: Decoupled from underlying infrastructure
3. **Performance**: as described and facilities to monitor
4. **Elasticity**: Scalable to meet SLAs. Movable to other servers.
5. **Resiliency**: Be able to recreate after failure.
   Specified packet loss rate, calls drops, time to recover, etc.
6. **Security**: Role-based authorization, authentication
7. **Service Continuity**: Seamless or non-seamless continuity after failures or migration

Ref: ETSI, "NFV Virtualization Requirements,", Oct 2013, 17 pp.,
http://www.etsi.org/deliver/etsi_gs/NFV/001_099/004/01.01.01_60/gs_NFV004v010101p.pdf

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NFV Framework Requirements (Cont)

8. **Service Assurance:** Time stamp and forward copies of packets for Fault detection
9. **Energy Efficiency Requirements**: Should be possible to put a subset of VNF in a power conserving sleep state
10. **Transition:** Coexistence with Legacy and Interoperability among multi-vendor implementations
11. **Service Models**: Operators may use NFV infrastructure operated by other operators

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NFV Use Cases

- **Cloud**:
  1. NFV infrastructure as a service (NFVIaaS) like IaaS
  2. Virtual Network Functions (VNFs) as a service (VNFaaS) like SaaS
  3. VNF forwarding graphs (Service Chains)
  4. Virtual Network Platform as a Service (VNPaaS) like PaaS
- **Mobile**:
  5. Virtualization of the Mobile Core Network and IMS
  6. Virtualization of Mobile Base Station
- **Data Center**:
  7. Virtualization of CDNs
- **Access/Residential**:
  8. Virtualization of the Home environment
  9. Fixed Access NFV

Ref: ETSI, "NFV Use Cases," http://www.etsi.org/deliver/etsi_gs/NFV/001_099/001/01.01.01_60/gs_NFV001v010101p.pdf
Ref: M. Cohn, "NFV Insider's Perspective, Part 2: There's a Network in NFV – The Business Case for SDN," Sep 2013, http://www.sdncentral.com/education/nfv-insiders-perspective-part-2-theres-network-nfv-business-case-sdn/2013/09/

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NFV Proof of Concepts (PoCs)

ETSI has formed and NFV ISG PoC Forum.
Following modules have been demoed:

1. Virtual Broadband Remote Access Server (BRAS) by British Telecom
2. Virtual IP Multimedia System (IMS) by Deutsche Telekom
3. Virtual Evolved Packet Core (vEPC) by Orange Silicon Valley
4. Carrier-Grade Network Address Translator (CGNAT) and Deep Packet Inspection (DPI), Home Gateway by Telefonica
5. Perimeta Session Border Controller (SBC) from Metaswitch
6. Deep packet inspection from Procera

Most of these are based on Cloud technologies, e.g., OpenStack

Ref: M. Cohn, "NFV Group Flocks to Proof-of-Concept Demos," Aug 2013, http://www.sdncentral.com/technology/nfv-group-flocks-to-proof-of-concept-models/2013/08/

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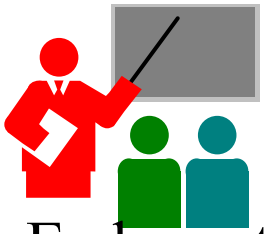
Summary



1. NFV aims to reduce OpEx by automation and scalability provided by implementing network functions as virtual appliances
2. NFV allows all benefits of virtualization and cloud computing including orchestration, scaling, automation, hardware independence, pay-per-use, fault-tolerance, …
3. NFV and SDN are independent and complementary. You can do either or both.
4. NFV requires standardization of reference points and interfaces to be able to mix and match VNFs from different sources
5. NFV can be done now. Several of virtual functions have already been demonstrated by carriers.

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Reading List

- ETSI, "NFV - Update White Paper," Oct 2013, http://portal.etsi.org/NFV/NFV_White_Paper2.pdf (must read)
- ETSI, "Network Function Virtualization," http://www.etsi.org/technologies-clusters/technologies/nfv
- ETSI, "Architectural Framework," Oct 2013, http://www.etsi.org/deliver/etsi_gs/NFV/001_099/002/01.01.01_60/gs_NFV002v010101p.pdf
- ETSI, "NFV Terminology for Main Concepts in NFV," Oct 2013, http://www.etsi.org/deliver/etsi_gs/NFV/001_099/003/01.01.01_60/gs_NFV003v010101p.pdf
- ETSI, "NFV Use Cases," http://www.etsi.org/deliver/etsi_gs/NFV/001_099/001/01.01.01_60/gs_NFV001v010101p.pdf
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- M. Cohn, "NFV Insider's Perspective, Part 2: There's a Network in NFV – The Business Case for SDN," Sep 2013, http://www.sdncentral.com/education/nfv-insiders-perspective-part-2-theres-network-nfv-business-case-sdn/2013/09/
- M. Cohn, "NFV Group Flocks to Proof-of-Concept Demos," Aug 2013, http://www.sdncentral.com/technology/nfv-group-flocks-to-proof-of-concept-models/2013/08/
- W. Xu, et al., "Data Models for NFV," IETF Draft, Sep 2013, http://tools.ietf.org/html/draft-xjz-nfv-model-datamodel-00
- CloudNFV, http://www.cloudnfv.com/page1.html
- Project Clearwater, http://www.projectclearwater.org/
- B. Briscoe, et al., "NFV," IETF, March 2012, http://www.ietf.org/proceedings/86/slides/slides-86-sdnrg-1.pdf
- Intel, "Open simplified Networking Based on SDN and NFV," 2013, 7 pp., http://www.intel.com/content/dam/www/public/us/en/documents/white-papers/sdn-part-1-secured.pdf
- J. DiGiglio, and D. Ricci, "High Performance, Open Standard Virtualization with NFV and SDN," http://www.windriver.com/whitepapers/ovp/ovp_whitepaper.pdf

Acronyms

- API Application Programming Interface
- BRAS Broadband Remote Access Server
- BSS Business Support Systems
- CapEx Capital Expenditure
- CDN Content Distribution Network
- CGNAT Carrier-Grade Network Address Translator
- CGSN Combined GPRS Support Node
- COTS Commercial-off-the-shelf
- DDIO Data Direct I/O Technology
- DHCP Dynamic Host control Protocol
- DPI Deep Packet Inspection
- EMS Element Management System
- ETSI European Telecom Standards Institute
- GGSN Gateway GPRS Support Node
- GPRS
- HLR Home Location Register
- IaaS Infrastructure as a Service

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Acronyms (Cont)

- IETF Internet Engineering Task Force
- IMS IP Multimedia System
- INF Architecture for the virtualization Infrastructure
- IP Internet Protocol
- ISG Industry Specification Group
- LSP Label Switched Path
- MANO Management and orchestration
- MME Mobility Management Entity
- NAT Network Address Translation
- NF Network Function
- NFV Network Function Virtualization
- NFVI Network Function Virtualization Infrastructure
- NFVIaaS NFVI as a Service
- NIC Network Interface Card
- OpEx Operational Expences
- OS Operating System

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Acronyms (Cont)

- OSS Operation Support System
- PaaS Platform as a Service
- PE Provider Edge
- PGW Packet Data Network Gateway
- PoC Proof-of-Concept
- PoP Point of Presence
- PSTN Public Switched Telephone Network
- QoS Quality of Service
- REL Reliability, Availability, resilience and fault tolerance group
- RGW Residential Gateway
- RNC Radio Network Controller
- SaaS Software as a Service
- SBC Session Border Controller
- SDN Software Defined Networking
- SGSN
- SGW Serving Gateway

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Acronyms (Cont)

- SIP Session Initiation Protocol
- SLA Service Level Aggrement
- SWA Software architecture
- TAS Telephony Application Server
- TMF Forum
- vEPC
- VM Virtual Machine
- VNF Virtual Network Function
- VNFaaS VNF as a Service
- vSwitch Virtual Switch
- VT-d Virtualization Technology for Direct IO
- VT-x Virtualization Technology

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