Recent Advances and Future Challenges for Network Function Virtualization Infrastructure

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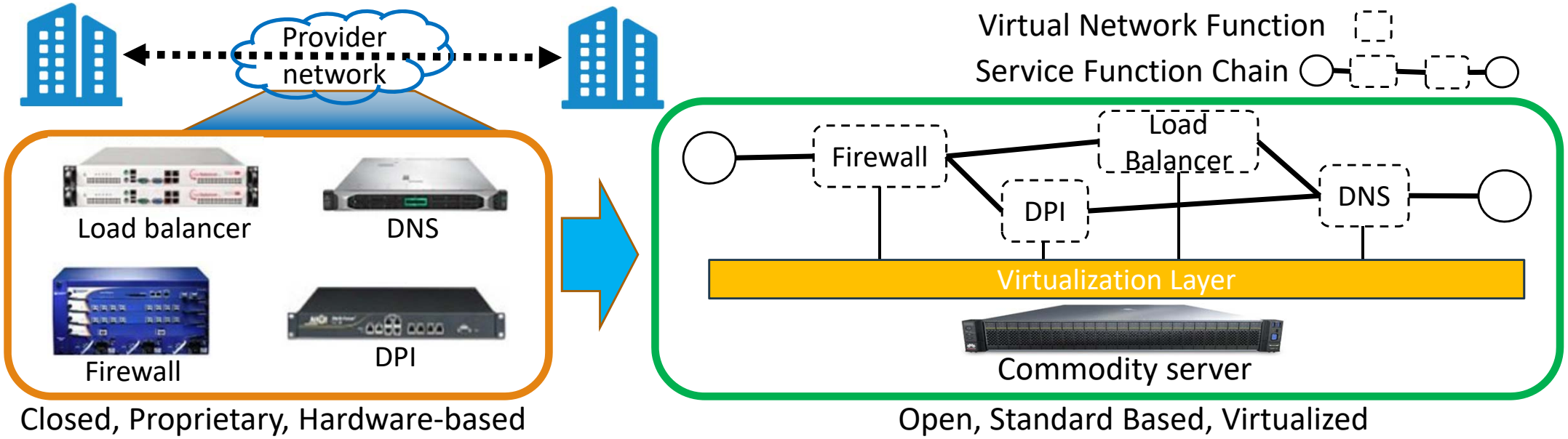
Outline

- Introduction & Background
  - NFV terminology, ETSI NFVI Architecture
- Advances & Challenges
  - VNF Resource Allocation Problem
  - Could-native Network Function
  - Other Applications: SDN, 5G, IoT
- Conclusion

Network Function Virtualization (NFV)

Definition: a **network architecture** concept that uses the technologies of IT **virtualization** to virtualize entire classes of **network functions** into building blocks that may connect, or chain together, to create communication and network **services**.



Benefits of NFV (Virtualization)

Use network resources without worry about where it is physically located, how much it is, how it is organized.

- ✓Orchestration: Manage thousands of devices
- ✓Flexibility: Change network architecture & behavior on the fly
- ✓Automation: Seamless deployment of new services
- ✓Scalability: Change size and quantity based on user demand
- ✓Performance & Efficiency: optimize resource utilization
- ✓Openness: full choice of modular plug-ins

Benefits of NFV for Network Operator

NFV has become a crucial technology for future network services to achieve goals of network optimization and cost reduction for network service providers:

- ✓Reducing the need for hardware and equipment
- ✓Avoiding vendor lock-in
- ✓Simplifying network operations
- ✓Achieving greater CAPEX (Capital Expenditure) and OPEX (Operating Expense) efficiency
- ✓Economical maintenance costs

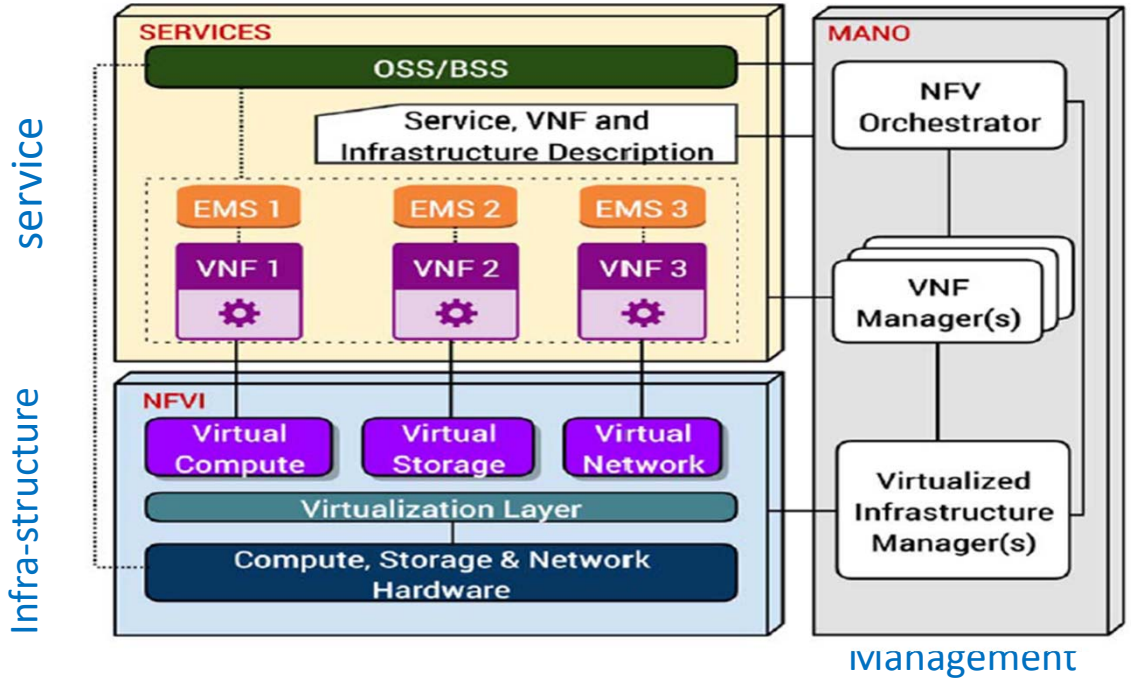
Network Functions Virtualization Infrastructure (NFVI)

The totality of all hardware and software components that build the environment where NFVs are deployed.

- How to virtualize network functions?
- How to deploy network functions?
- How to orchestrate network resources?
- How to manage network services?
- How to support service operations?

ETSI NFVI Architecture

Standard and Architecture defined by European Telecommunications Standards Institute



Source: "Resource Allocation in NFV: A Comprehensive Survey", Juliver Gil Herrera and Juan Felipe Botero, IEEE TRANSACTIONS ON NETWORK AND SERVICE MANAGEMENT, VOL. 13, NO. 3, SEPTEMBER 2016

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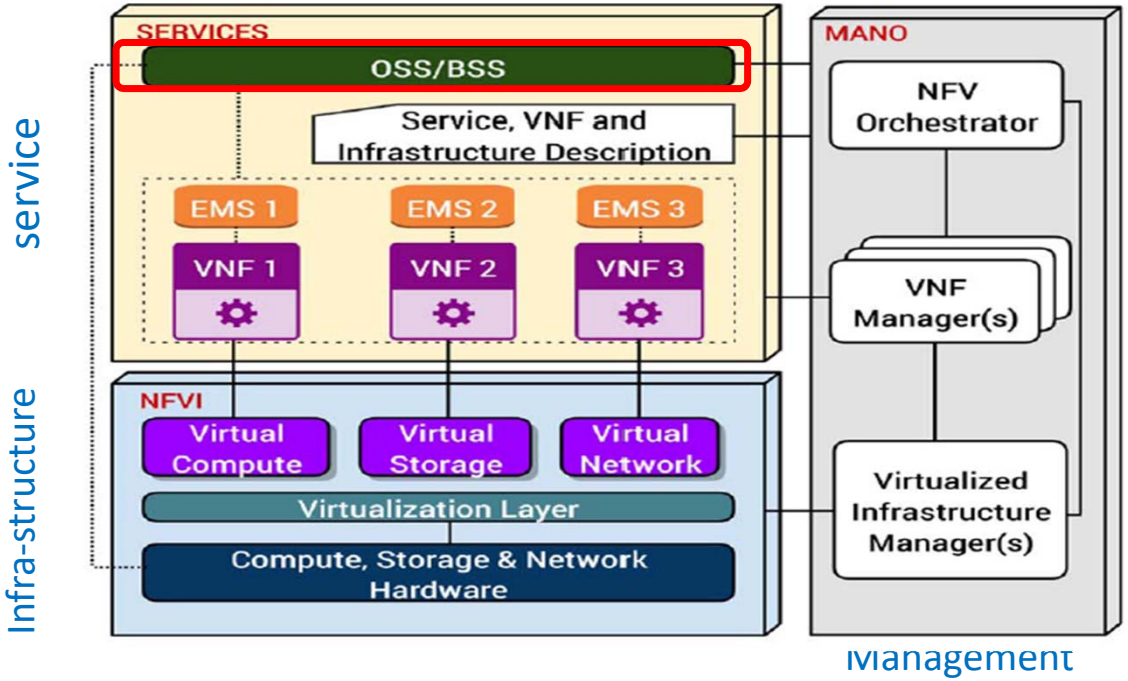

- Operation Support Subsystem (OSS)
  - network management, fault management, configuration management and service management
- Business Support Subsystem (BSS)
  - customer management, product management and order management

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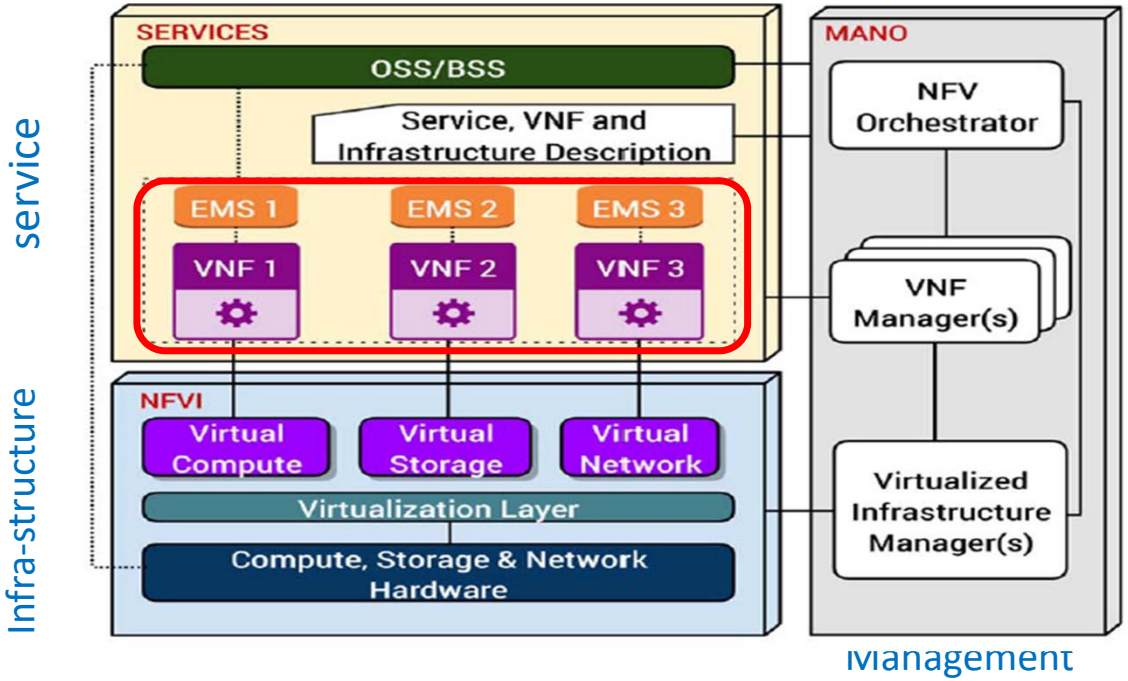

- Virtualization Network Function (VNF)
  - The basic block in NFV Architecture
  - It virtualized network function
- Element Management System (EMS)
  - Responsible for the functional management of VNF
  - Fault, Configuration, Accounting, Performance and Security

Source: "Resource Allocation in NFV: A Comprehensive Survey", Juliver Gil Herrera and Juan Felipe Botero, IEEE TRANSACTIONS ON NETWORK AND SERVICE MANAGEMENT, VOL. 13, NO. 3, SEPTEMBER 2016

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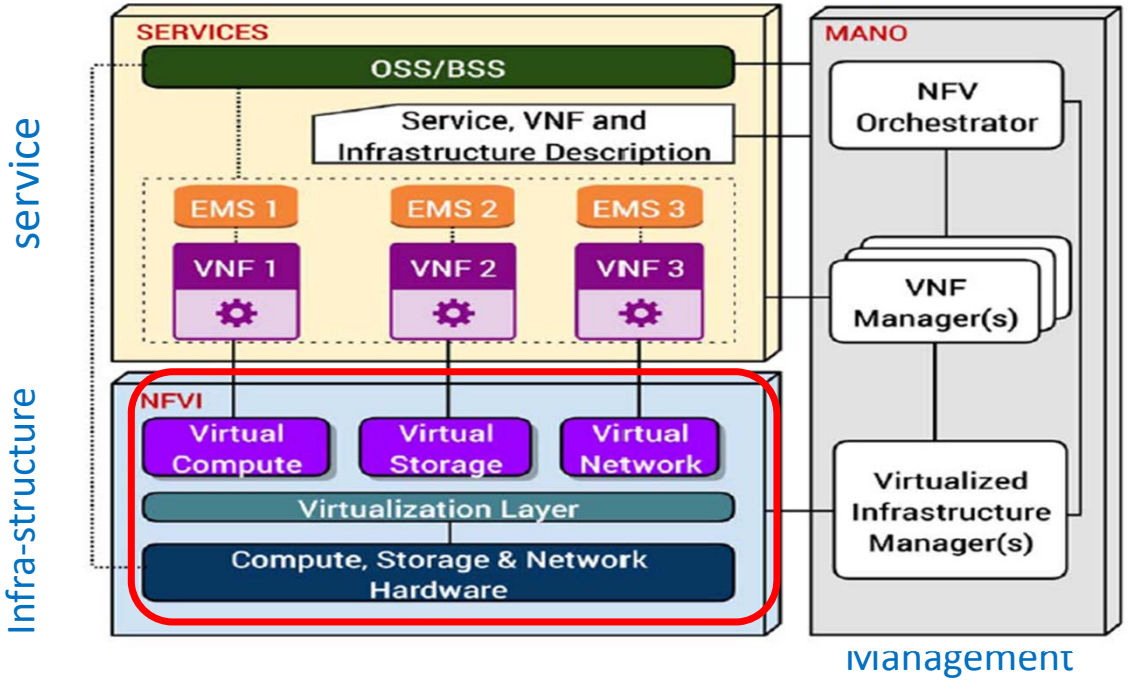

- VNF Infrastructure (NFVI)
  - Build up the environment for deploying VNF
    - Hardware Resources
    - Virtualization Layer
    - Virtual Resources

Network Domain Specific Cloud Platform & Infrastructure with greater challenges in **SECURITY** and **PERFORMANCE**

Source: "Resource Allocation in NFV: A Comprehensive Survey", Juliver Gil Herrera and Juan Felipe Botero, IEEE TRANSACTIONS ON NETWORK AND SERVICE MANAGEMENT, VOL. 13, NO. 3, SEPTEMBER 2016

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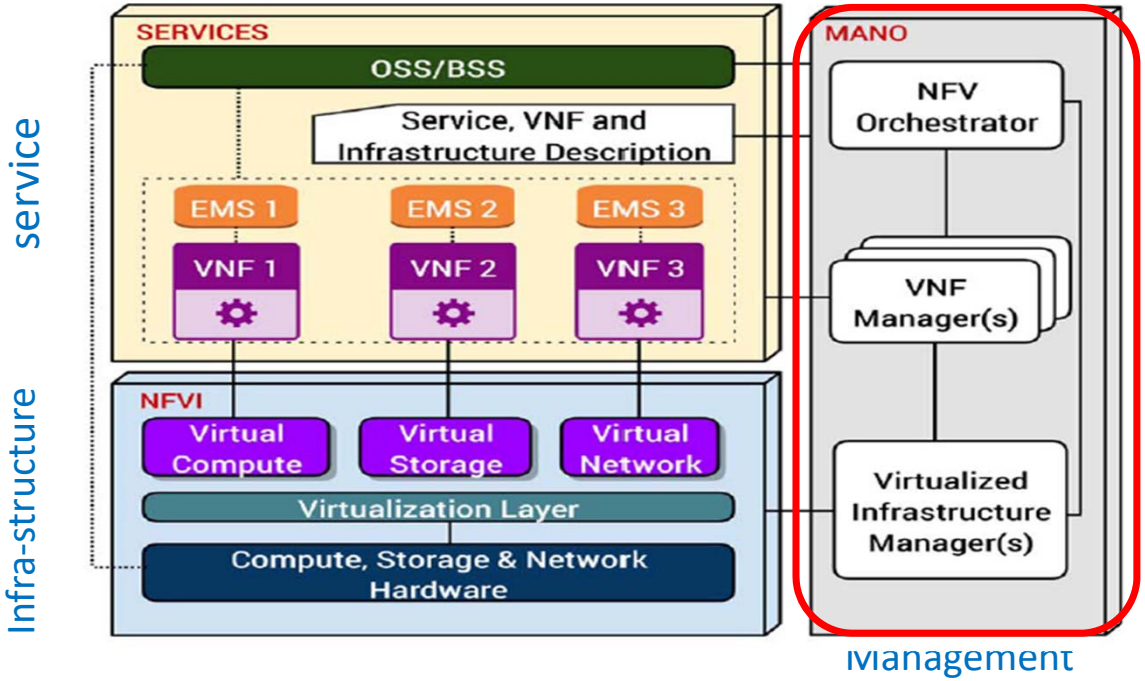

- Management and Orchestration (MANO)
  - Virtualized Infrastructure Manager(s): functionalities to control and manage the interaction of a VNF with resources
  - VNF Manager(s): VNF life cycle management from installation to termination
  - Orchestrator: orchestrate infrastructure and resource for realizing network services

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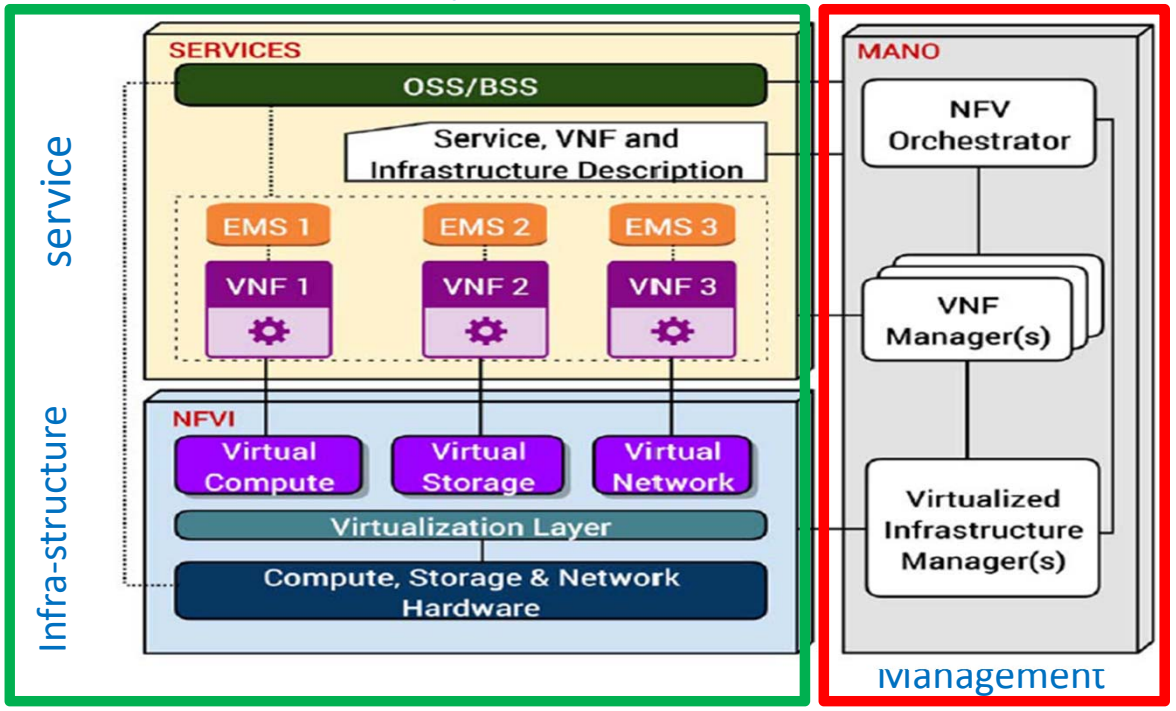
Industry
- Service
- Operation
- Infrastructure

Cloud-native Network Function



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Academia
- Algorithm
- Strategy
- Optimization

VNF Resource Allocation & Placement

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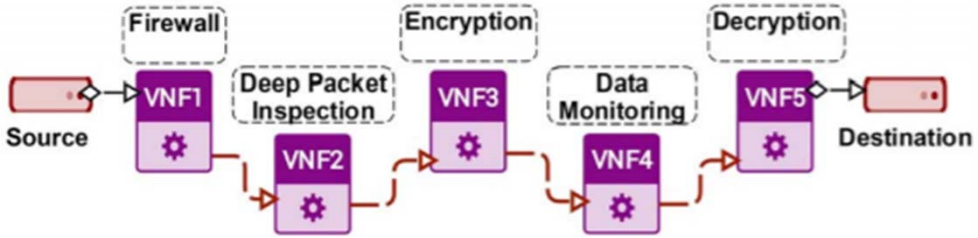
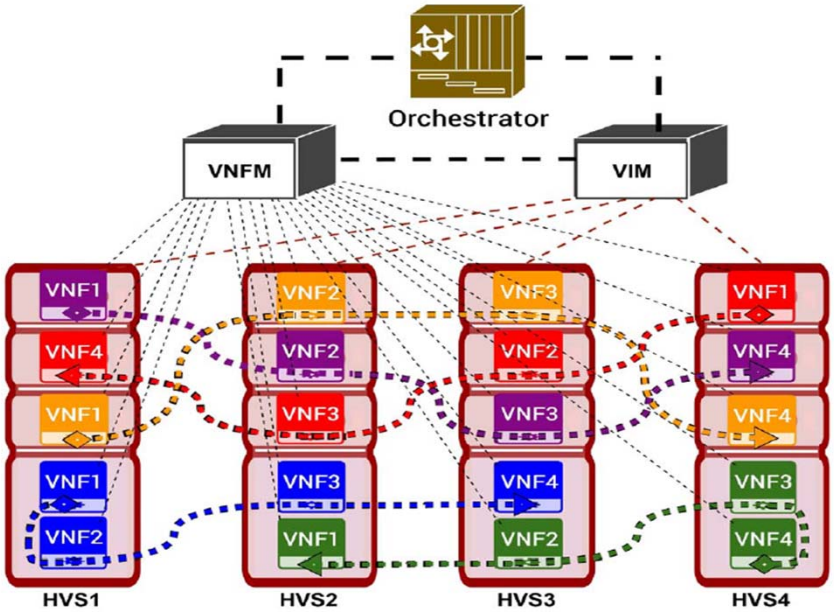
VNF Resource Allocation Problem

How to allocate and manage the resources for processing the user requests of a set of Service Function Chains (SFC)?

- Minimize service delay
- Maximize resource utilization
- Satisfy both resource & service constraints



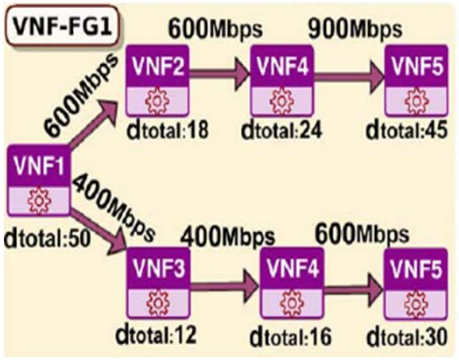


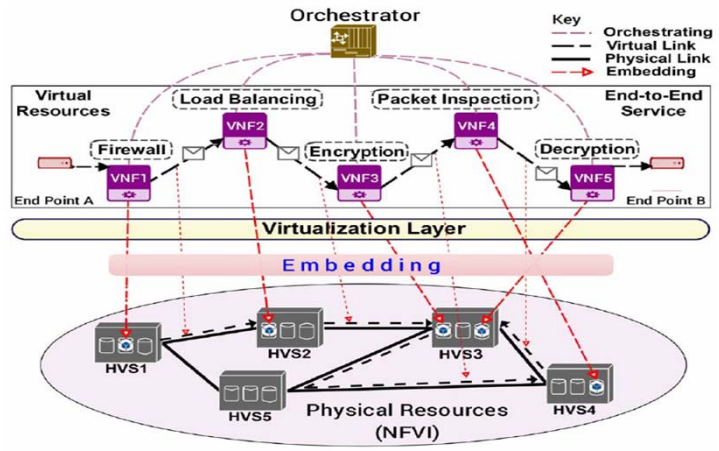
efficient allocation

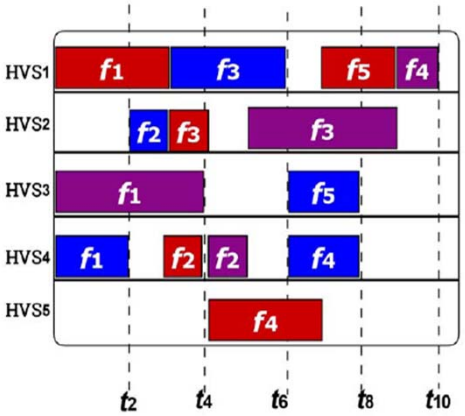
virtual service requests → physical network infrastructure

VNF Resource Allocation Problem

- A complete solving of resource allocation in NFV should consider these 3 steps:







Chain Composition | Forwarding Graph Embedding | Request Scheduling

"Resource Allocation in NFV: A Comprehensive Survey", Juliver Gil Herrera and Juan Felipe Botero, IEEE TRANSACTIONS ON NETWORK AND SERVICE MANAGEMENT, VOL. 13, NO. 3, SEPTEMBER 2016

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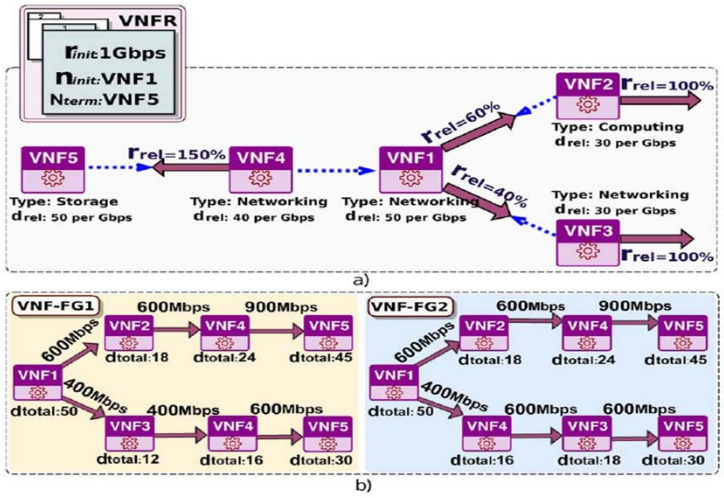

Chain Composition

- Exploits the flexibility introduced by virtualization to dynamically compose chains of VNFs
- The bandwidth demands of the links and the capacity demands of the nodes can be dynamically changed
- The order of the VNFs is also flexible

"Resource Allocation in NFV: A Comprehensive Survey", Juliver Gil Herrera and Juan Felipe Botero, IEEE TRANSACTIONS ON NETWORK AND SERVICE MANAGEMENT, VOL. 13, NO. 3, SEPTEMBER 2016

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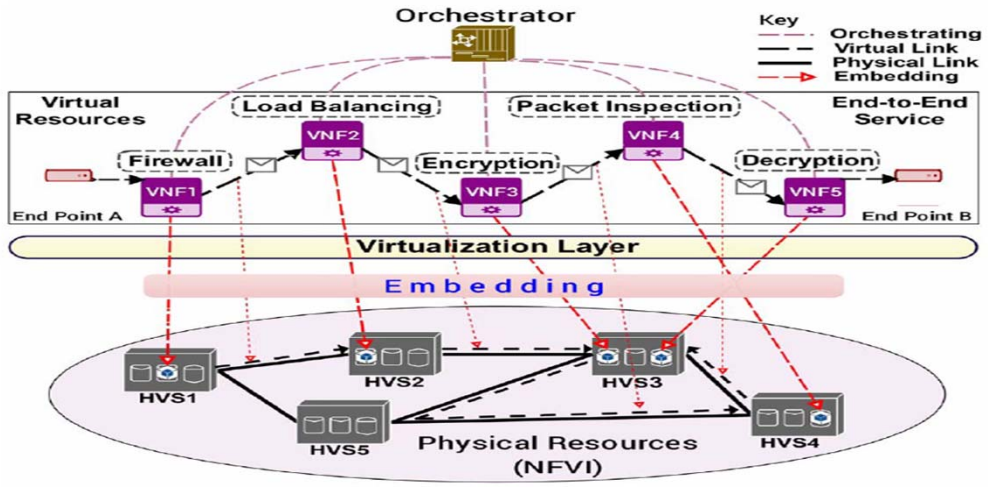

Forwarding Graph Embedding

Known as Virtual Network Embedding or VNF Placement Problem:

- How many VNF instances are required
- Where to allocate these VNFs
- How much resource is provisioned on a node
- What is the route between VNFs

"Resource Allocation in NFV: A Comprehensive Survey", Juliver Gil Herrera and Juan Felipe Botero, IEEE TRANSACTIONS ON NETWORK AND SERVICE MANAGEMENT, VOL. 13, NO. 3, SEPTEMBER 2016

VNF Placement Problem

The most critical, challenged and extensively-studied problem in MANO
- Significantly impact resource usage & service quality
- NP-Complete problem
- Must deal with frequent and bursty traffic variation

Objectives
- Maximize service providers' revenue: number of accepted SFCs
- Minimize service operation cost: resource and energy consumption
- Minimize reconfiguration cost: VNF migration, traffic rerouting, service interruption

Constraints
- Service quality: service chain end-to-end delay
- Limited resources: node capacity, link bandwidth
- Routing feasibility: flow conservation constraint

VNF Placement Problem

Approach:

- Define models
  - Resource/energy consumptions, service revenue/quality
- Formulate ILP (Integer Linear Programming) problems
  - Formulations are varied according to objectives, constraints, workload characteristics, VNF definitions
- Propose heuristic/greedy algorithms
  - Place VNFs of a SFC in a shortest path between ingress and egress routers
  - Reuse deployed VNFs to reduce base resource consumption
  - Apply metaheuristic search optimization strategies, like GA, PSO, ACO, tabu search
- Rely on traffic prediction or traffic/service monitoring to trigger reconfiguration proactively or reactively.

VNF Resource Allocation Problem

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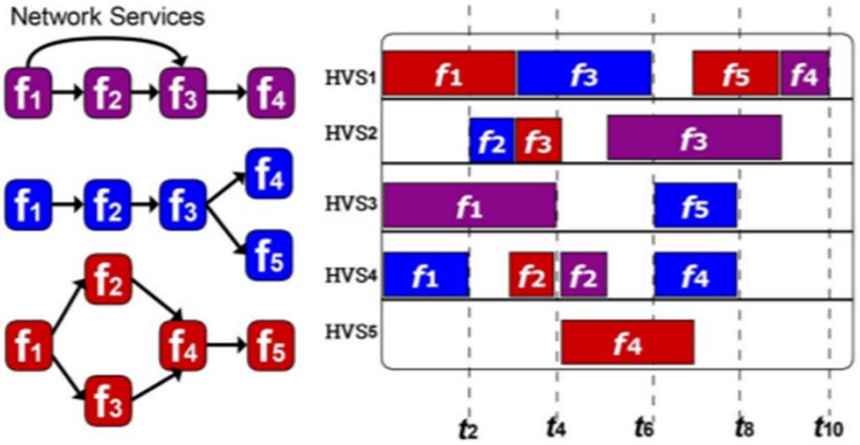

Request Scheduling

Find the time slot to process the packets/requests of each network service:

- What should be the order between SFCs?
- How to deal with the dependency among the service functions of a SFC?
- How to satisfy service requirement (e.g., delay)

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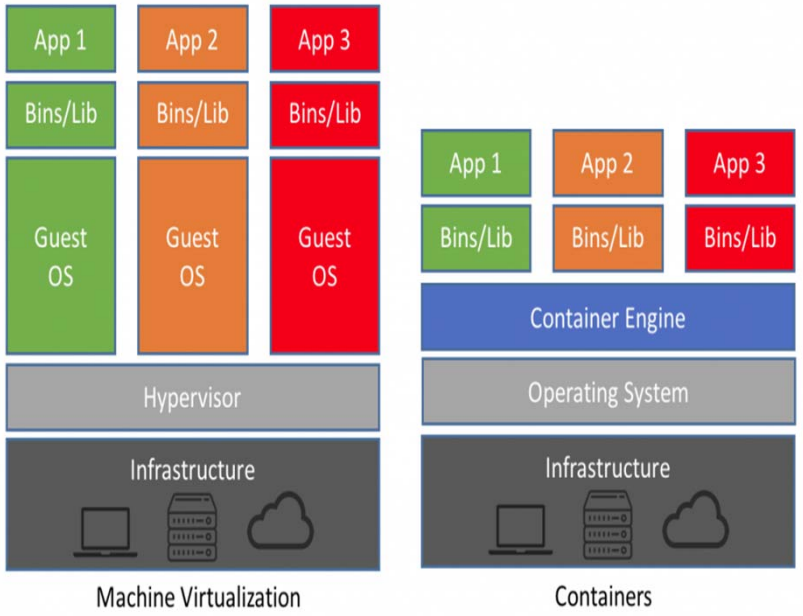
CNF: Cloud-Native/Container Network Function

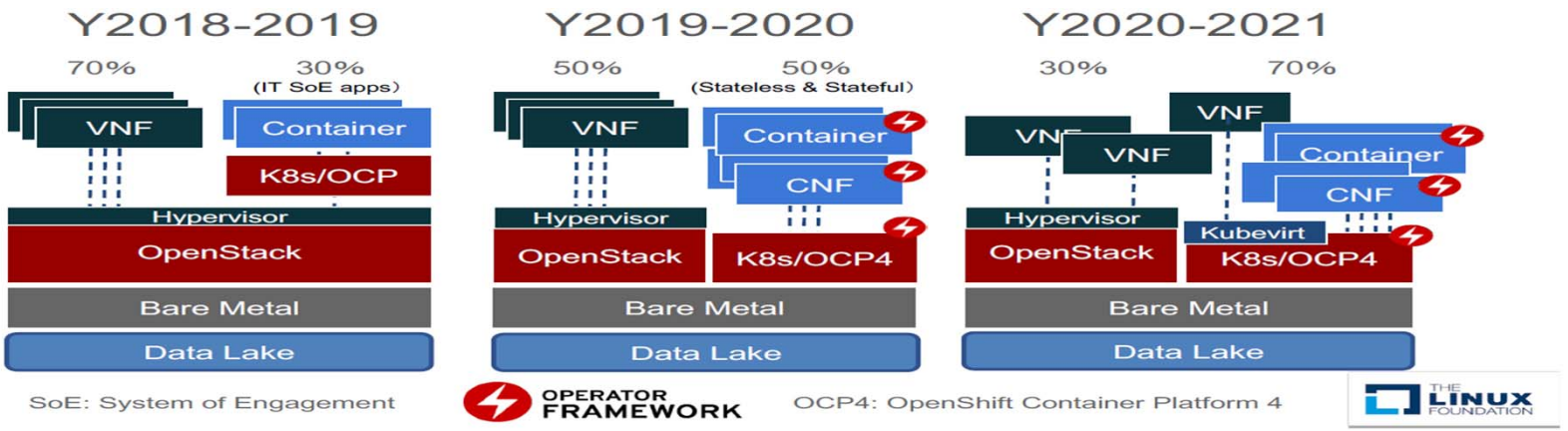
CNF: a software-implementation of a network function, which runs inside a **linux container instead of virtual machine**

- ✓**Higher** deployment **density** ➔ higher utilization & cost saving
  - Host hundreds of containers on a single machine
- ✓**Lower** virtualization **overhead** ➔ better performance
  - Nearly identical to Native performance
- ✓**Faster** resource **management** ➔ better agility
  - Start, create, replicate or destroy containers in seconds
- ✓Enabling new software architecture
  - **Microservice architecture**



CNF: Cloud-Native/Container Network Function

- The platform of NFV is migrating from virtual machine to container
- Hybrid virtualization infrastructure has also been proposed to ensure **isolation** and **security**
  - Orchestrator with ability to manage both VNF and CNF, e.g., Kubevirt
  - Lightweight VM, e.g., amazon fire cracker



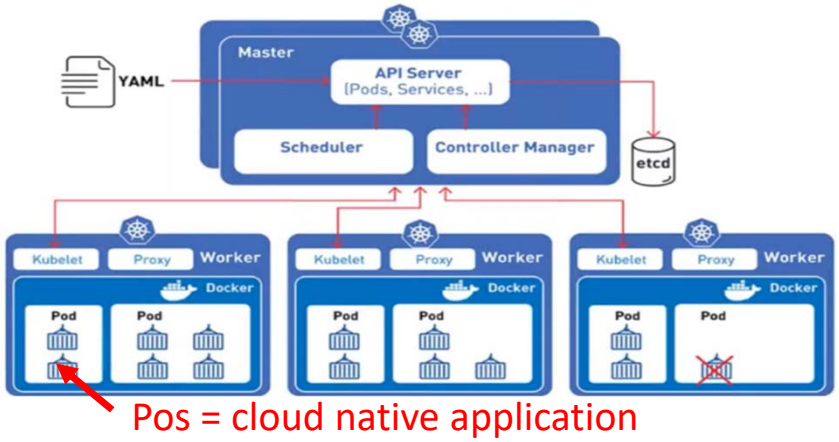
Kubernetes: Container Orchestrator

A portable, extensible, open-source platform for managing containerized workloads and services.

- The linux kernel of distributed systems
- Abstract away the underlying hardware and provide a uniform interface for applications
- Designed for loosely-coupled, distributed, elastic, microservices

Originated from Google's container cluster managers, Borg and Omega.

The most popular choice for container orchestration and cloud-native computing.



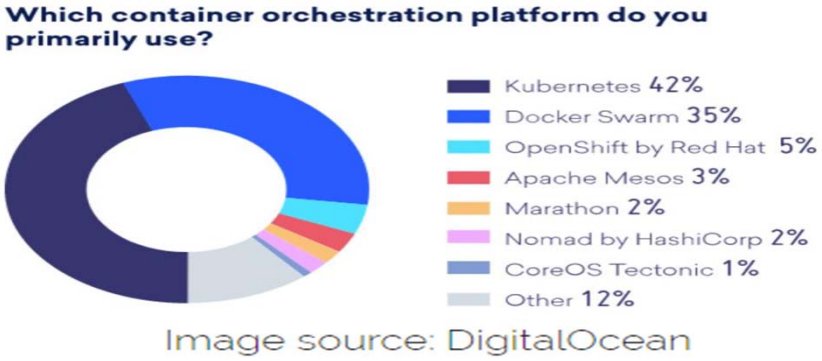
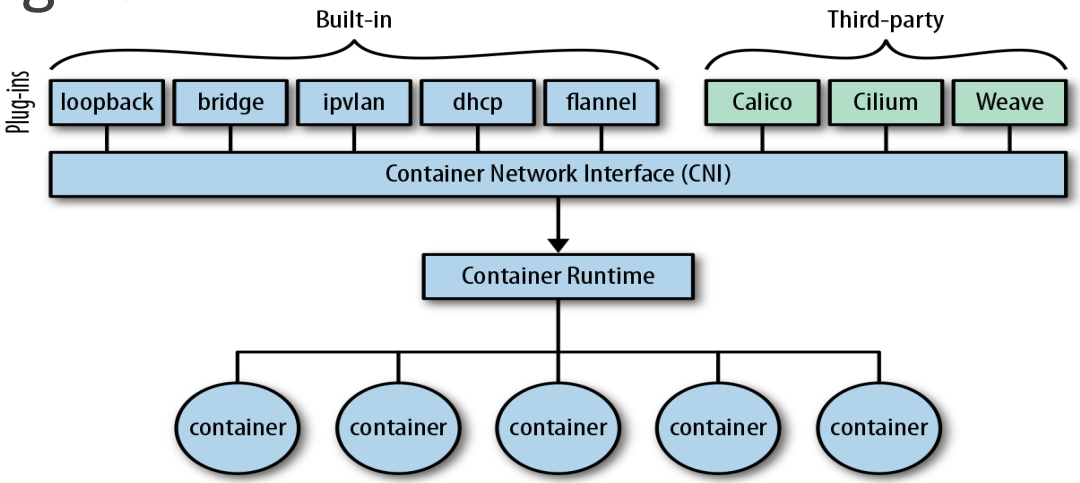


Image source: DigitalOcean

K8S Container Network Interface (CNI)

- **CNI** of Kubernetes: It consists of a specification and libraries for writing plug-ins to configure network interfaces in Linux containers.
- Compatible CNI Network Plugins:
  - ✓ Calio
  - ✓ Cillium
  - ✓ Flannel
  - ✓ GCE
  - ✓ Multus
  - ✓ OpenVSwitch
  - ✓ Kube-Router
  - ✓ Weave

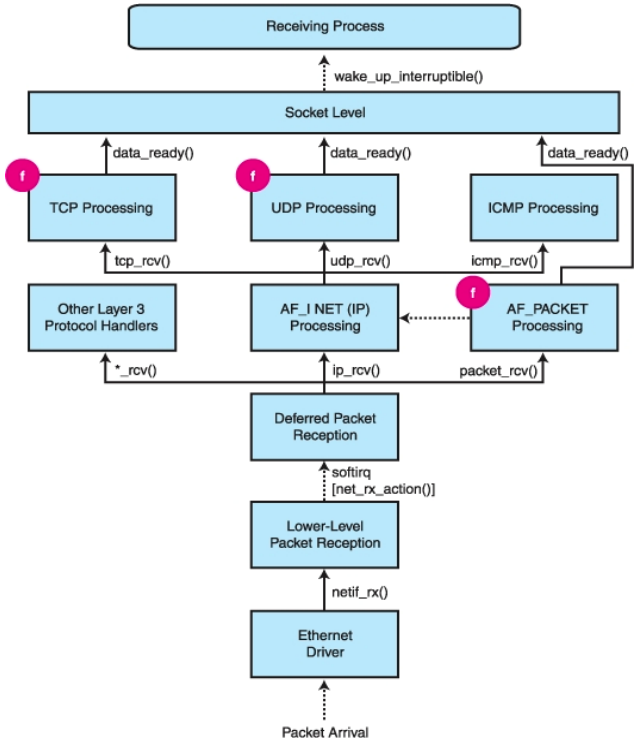


Performance Challenge

The network performance on NFV refers to the efficiency of packet processing

Network performance impacts by migrating special-purpose application-specific integrated circuit (ASIC) to common-off-the-shelf (COTS) hardware

Key performance indicator such as throughput and latency, affecting the overall end-to-end application performance



Linux Packet Processing Flow

Network Accelerating Solutions

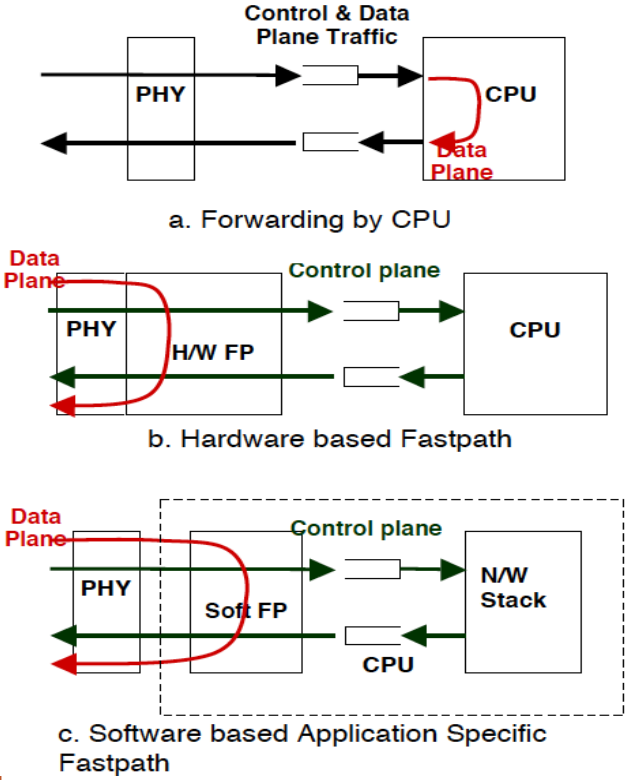
Hardware

- network processor units (NPUs)
- graphics processing units (GPUs)
- field programmable gate arrays (FPGAs)
- smart NICs (sNICs)

Software

- CPU pinning
- Zero-copy
- Batch processing
- NUMA-aware
- Lockless Parallelism
- eBPF

Most of the software tuning are functioning on user space to minimize OS kernel & context switch overhead



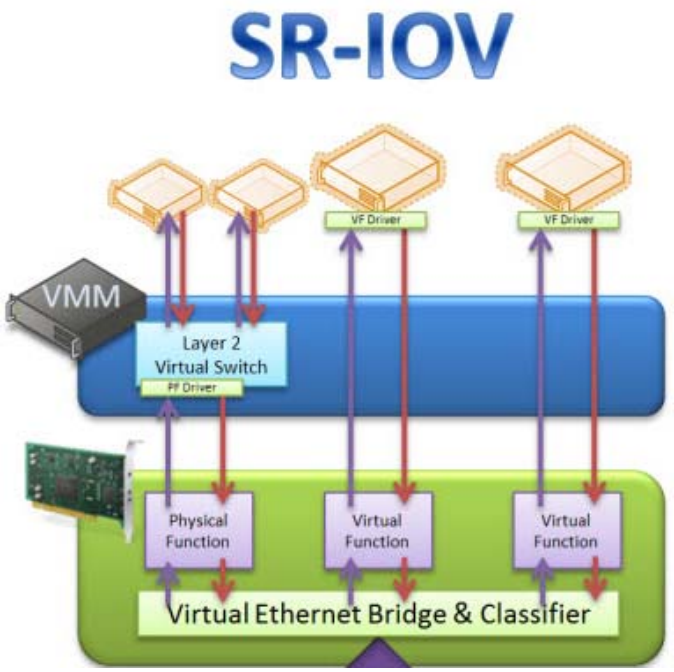
Hardware-Support Acceleration: SR-IOV

SR-IOV (Single Root Input/Output Virtualization) is a specification that allows the isolation of PCI Express resources between different users.

Each resource has Virtual Functions (VF) associated and each VM (Virtual machine) can only access the physical resource via its own allocated VF.

Strength

- Industry standard: SR-IOV is the long-established industry standard for virtualizing PCIE devices.
- Isolation: VFs ensure each VM is isolated from other –memory is secured and not shared.
- Efficiency: it minimizes context-switching overheads.



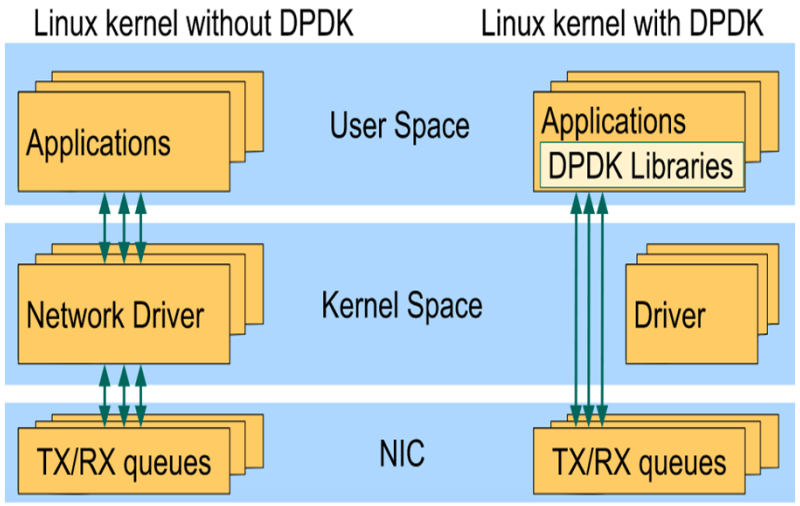
User Space Acceleration: DPDK & VPP (Vector Packet Processing)

DPDK is the Data Plane Development Kit that consists of libraries to accelerate packet processing workloads

- It offloads TCP packet processing from the operating system kernel to processes running in user space.
- It accesses devices via polling to eliminate the performance overhead of interrupt processing.

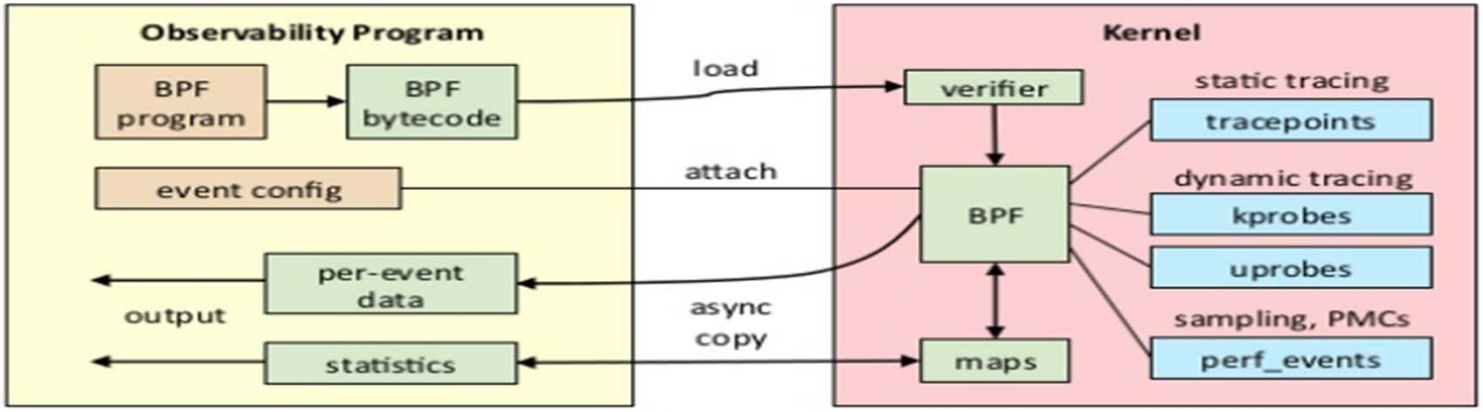
FD.IO (Fast data – Input/Output) VPP is the open source version of Cisco's Vector Packet Processing (VPP) technology

- Performance improvement over scalar processing
- Based on the DPDK library



Kernel Space Acceleration: eBPF (extended Berkeley Packet Filter)

- It is a feature in modern Linux kernels that allows you to write mini-programs that are attached to low-level hooks in the Linux kernel.
- Because eBPF runs inside the Linux kernel, it doesn't require changes to the application code or container configuration.
- Both **Calico** & **Cilium** uses eBPF to enhance security, performance, manageability of CNF



VNF to CNF is Challenging

Container packaging requires further rearchitecting of network function software

- **State is inextricably tied into the code:** Stateless processing is the most important feature in cloud native architecture. But in traditional application architectures, all state is stored locally and elements of state are accessed or updated by individual instructions throughout the body of the code.
- **Monolithic applications are hard to de-compose**: While legacy codebases typically show a high degree of modularity in the form of function calls and subroutines, these modules rarely offer natural boundaries for decomposition to loosely coupled **microservices** due to mutual dependencies on shared data structures.

Source: “There's No Easy Evolution Path from VNF to CNF” by STEVE GLEAVE

VNF to CNF is Challenging

Container packaging requires further rearchitecting of network function software

- **Procedural configuration management is very different to declarative**:
  - Container orchestrator (e.g., Kubernetes) is based on declarative configuration which requires holistic consistency checking of the entire configuration before any change is applied.
  - Tradition application is based on procedural configuration management where consistency checking is applied in a stepwise manner.

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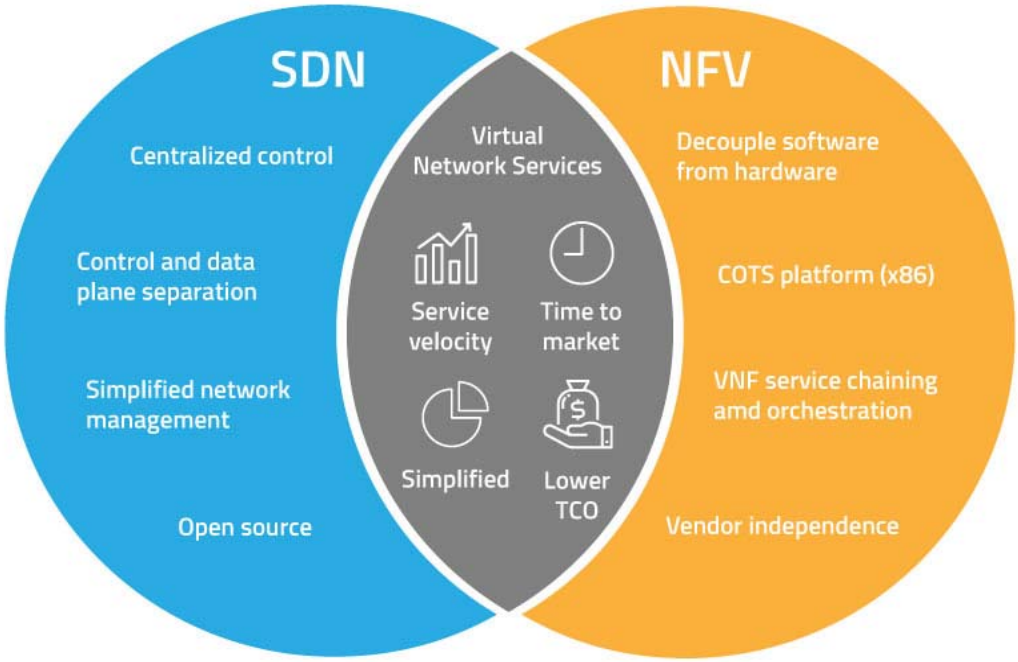
NFV vs. SDN

Software-Defined Network (SDN):

- manages networks by separating the **control plane** from the **forwarding plane**

Network Functions Virtualization (NFV):

- decouples network functions from **proprietary hardware appliances** and delivers equivalent **network functionality**

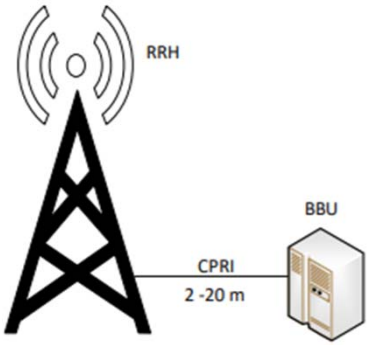


https://www.redeemsystems.com/sdnnfv.php

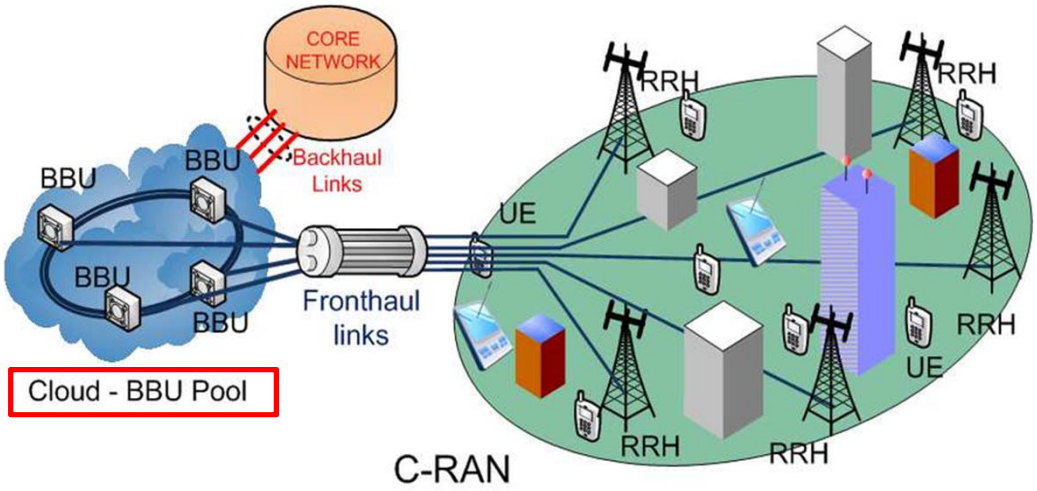
The Role of NFV in 5G / IoT

Cloud-RAN (C-RAN)

- a centralized, cloud computing-based architecture for radio access networks
- allow a low cost, high reliability, low latency and high bandwidth interconnect network in the BBU (Base Band Unit) pool
- **BBU pool can be managed by SDN / NFV technologies**



Traditional LTE RAN

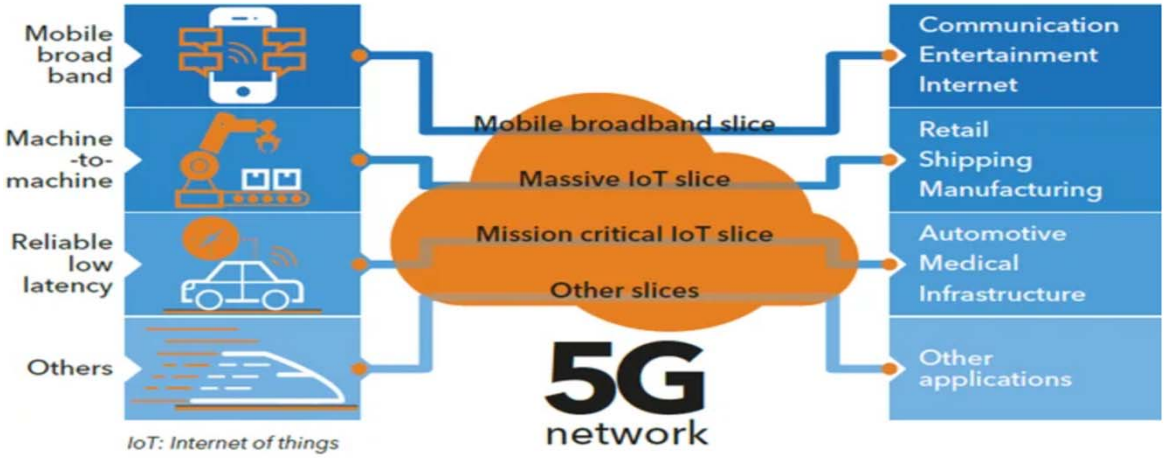


"Coordinated Multipoint (CoMP) Transmission Design for Cloud-RANs with Limited Fronthaul Capacity Constraints" in IEEE Transactions on Vehicular Technology 2015

The Role of NFV in 5G / IoT

Network Slicing

- The use of network virtualization to divide single network connections into multiple distinct virtual connections that provide different amounts of resources to different types of traffic
- NFV allow fast and flexible network slicing deployment and service management



Source: ITUNews

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Conclusion

- VNF has emerged as a crucial technology for future network services
  - achieve goals of network optimization and cost reduction
- Many challenges and open questions remain:
  - Research communities focus more on Management and Orchestration (MANO)
  - Industry companies focus more on infrastructure, architecture and standard
- CNF has already drawn growing interests
  - Microservice architecture, fast deployment, smaller memory footprint
  - Hybrid (CNF+VNF) environment can be expected in the future.
- VNF/CNF will combine with other technologies (SDN, 5G, Cloud) to power future applications in various domains, such as IoT, autonomous cars.

Publications

- Chi-Chen Yang and Jerry Chou, “A Hybrid Virtual Network Function Placement Strategy for Maximizing the Profit of Network Service Deployment over Dynamic Workload”, in the Proceedings of the 4th International Workshop on Systems and Network Telemetry and Analytic (SNTA), June 2021.
- Yong-Xuan Huang and Jerry Chou, “Evaluations of Network Performance Enhancement on Cloud-native Network Function”, in the Proceedings of the 4th International Workshop on Systems and Network Telemetry and Analytic (SNTA), June 2021
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Thank
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