Distributed applications: A challenge for systems, networks, and application development

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NFV & SDN

- What is Network Function Virtualization?
- What is Software-Defined Networking?

NFV: Ingredients

- Functions
  - Physical
  - Virtual
  - Typically, with management interface
  - In an executable form

} Virtual Network Function

Virtual Deployment Unit

- Services
  - Consist of functions, traversed in certain order
  - Service chain, forwarding graph, …
  - Typically, with management interface

- Infrastructure
  - Virtualized by a hypervisor

- Orchestration

ManO Framework

NFV: A definition attempt

- The ability to run functions inside a network
- Typical functions process data flows
- The idea to restructure code running inside a network
  - From monolithic blobs to individual components
  - Flexibly composed into services

SDN: Ingredients

- Switches
  - With flow tables
- Flows
- Control

SDN: A definition attempt

- Making flow tables controllable from the outside via a standardized API
- Concentrating control
  - From individual switches to few / a single controller
- A programming model
  - Or: a family of programming models, imposed by the particular controller framework

SDN is ***not*** ...

- Revolutionary: MPLS
- OpenFlow
- Central control
- A guaranteed market success
- Limited to specific networks (e.g., data centres, cloud networks)
- White-box switching
  - White-box switch: Hardware without a default operating system

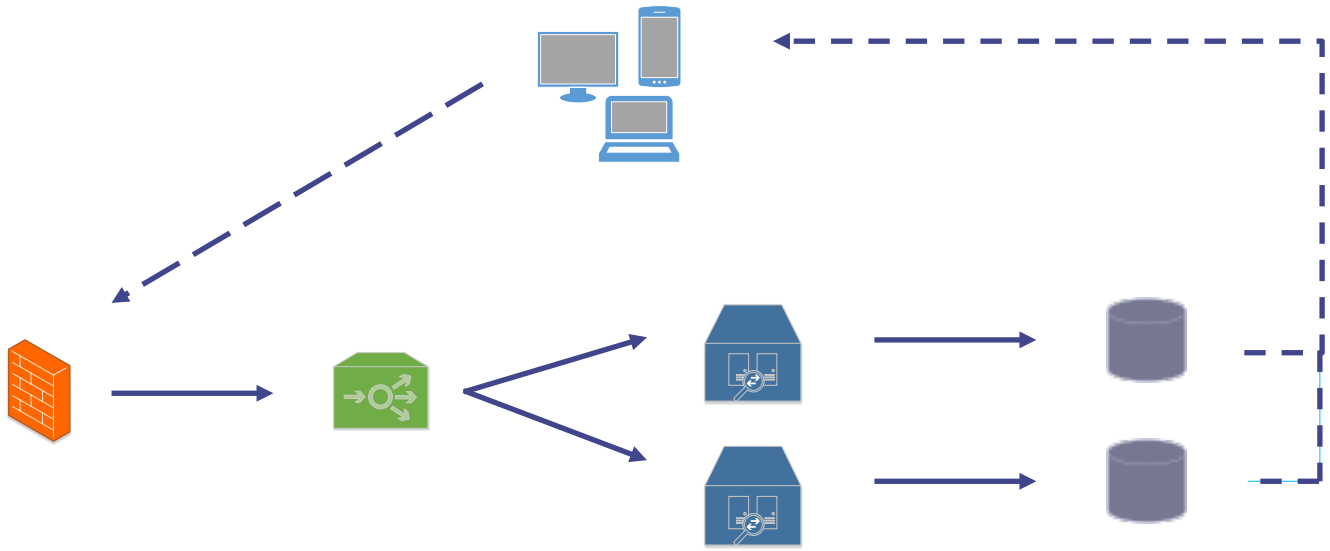
Why?

- Why NFV? Why SDN?

- Business models?

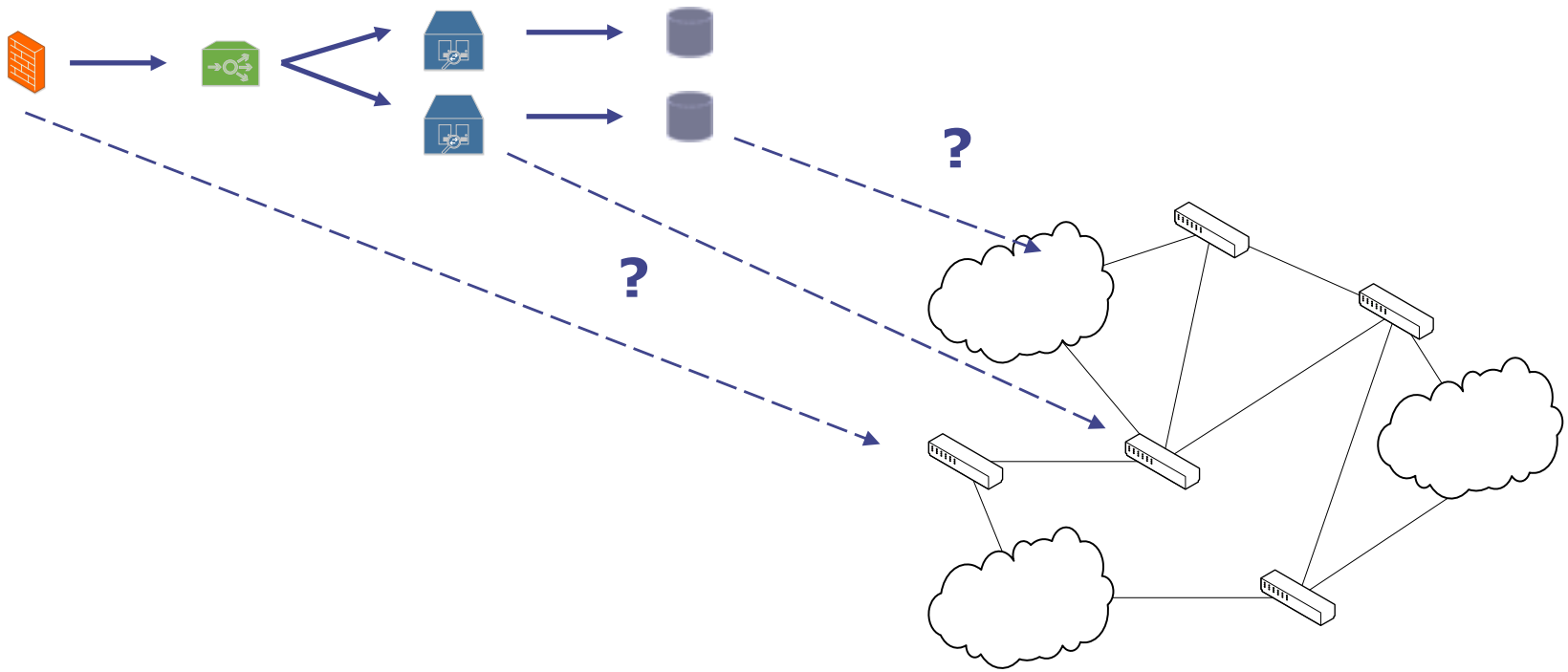
Look at many functions: services

- Isolated network functions the exception
- Rather: data flows via several network functions
- Simplest case: a chain
  - E.g.: A firewall, then a DPI, then a CDN
- More sophisticated: arbitrary acyclic graph
  - **Network function forwarding graph**



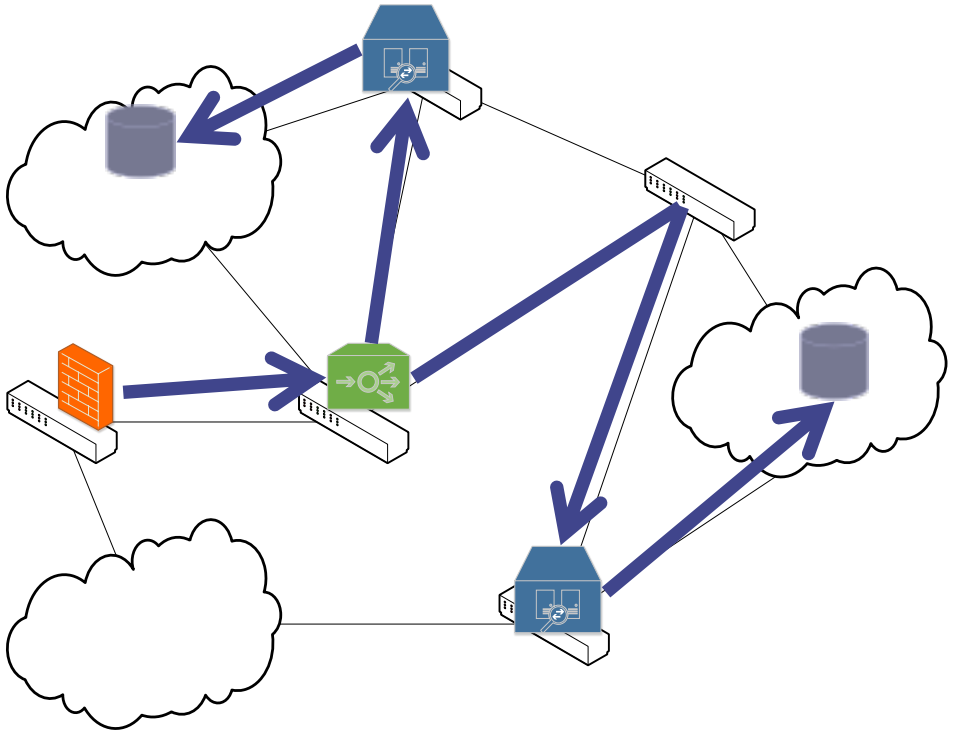
Placement

- Given a forwarding graph: On which actual nodes to execute which function?
  - Dealing with many graphs? Reuse functions? ...?



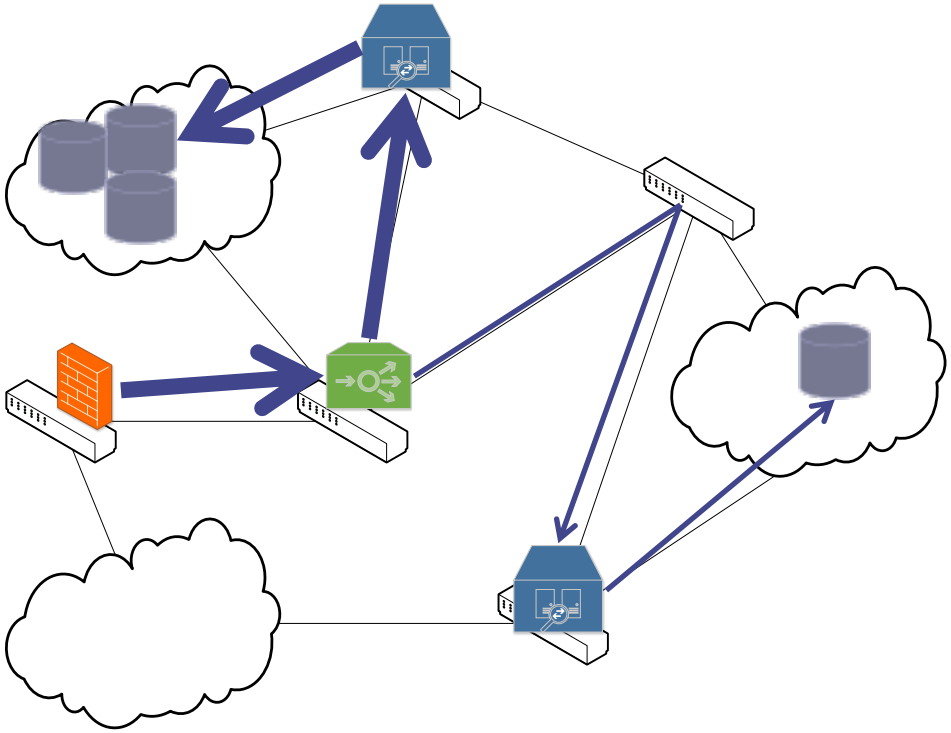
Deployment

- Suppose placement is solved
- How to instantiate VMs, set up paths?
  - Software-Defined Networking!



Scaling

- Suppose monitoring tells us that KPIs not met
  - Throughput low, latency high, ...
- Scale: Add virtual network functions, re-route, ...



So far: Network functions

- Network functions: Working on a flow of packets

- Other functions?
  - Examples?
  - Deployment?

Broadening the scope: Distributing data centers

- Common rationale: Economy of scale
  - Build huge data centers to safe money
  - But results in only a few centers
- Consequence: data centers far away from users
  - Fine for many applications
  - Critical for some: interactive, gaming, content distribution, streaming, ...
- Have some local functionality close to users?
  - Smaller centers, widely distributed
  - More expensive, more suitable?

Distributed Cloud Computing

- DCC pioneered in late 2000s, under different names
  - Distributed Cloud Computing
  - Carrier cloud
  - In-network cloud
  - Nano data centers
  - Fog & mist computing ….
- Many commonalities with NFV
  - Different emphasis: end-user applications vs. network-oriented features
  - Convergence? Open question …

Expectations for services?

? Scalability

? Dependable

? Cost-efficient

? Maintainable

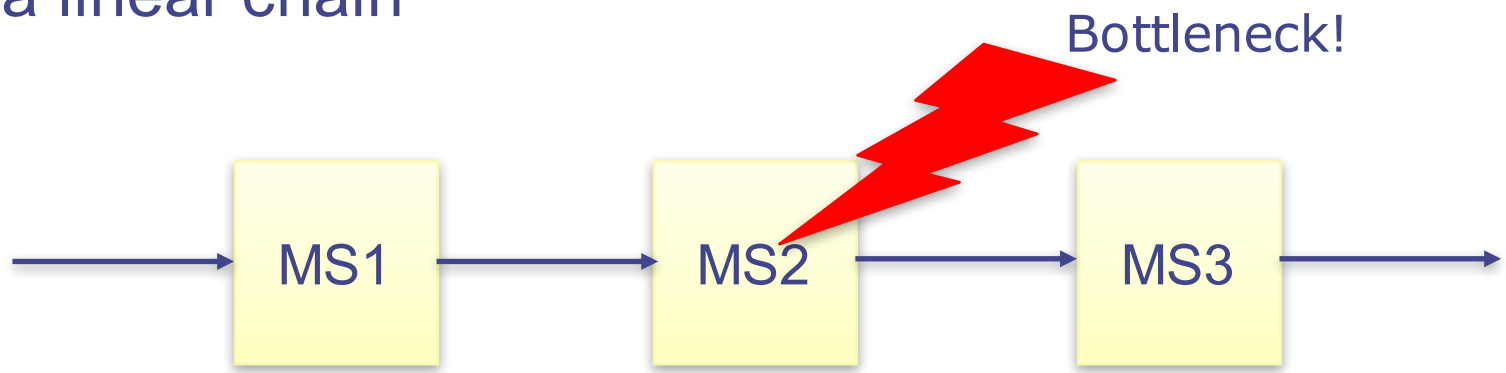
Common pattern: Service out of services, loosely coupled

- Construct a service out of smaller services
  - Independently runnable
  - Focused on a single functionality
- **Loosely coupled**, well defined, simple interfaces

- ***Microservices***
  - Recursive pattern: Chop up services into smaller services
    - E.g.: data analysis

Scalable microservices: Example

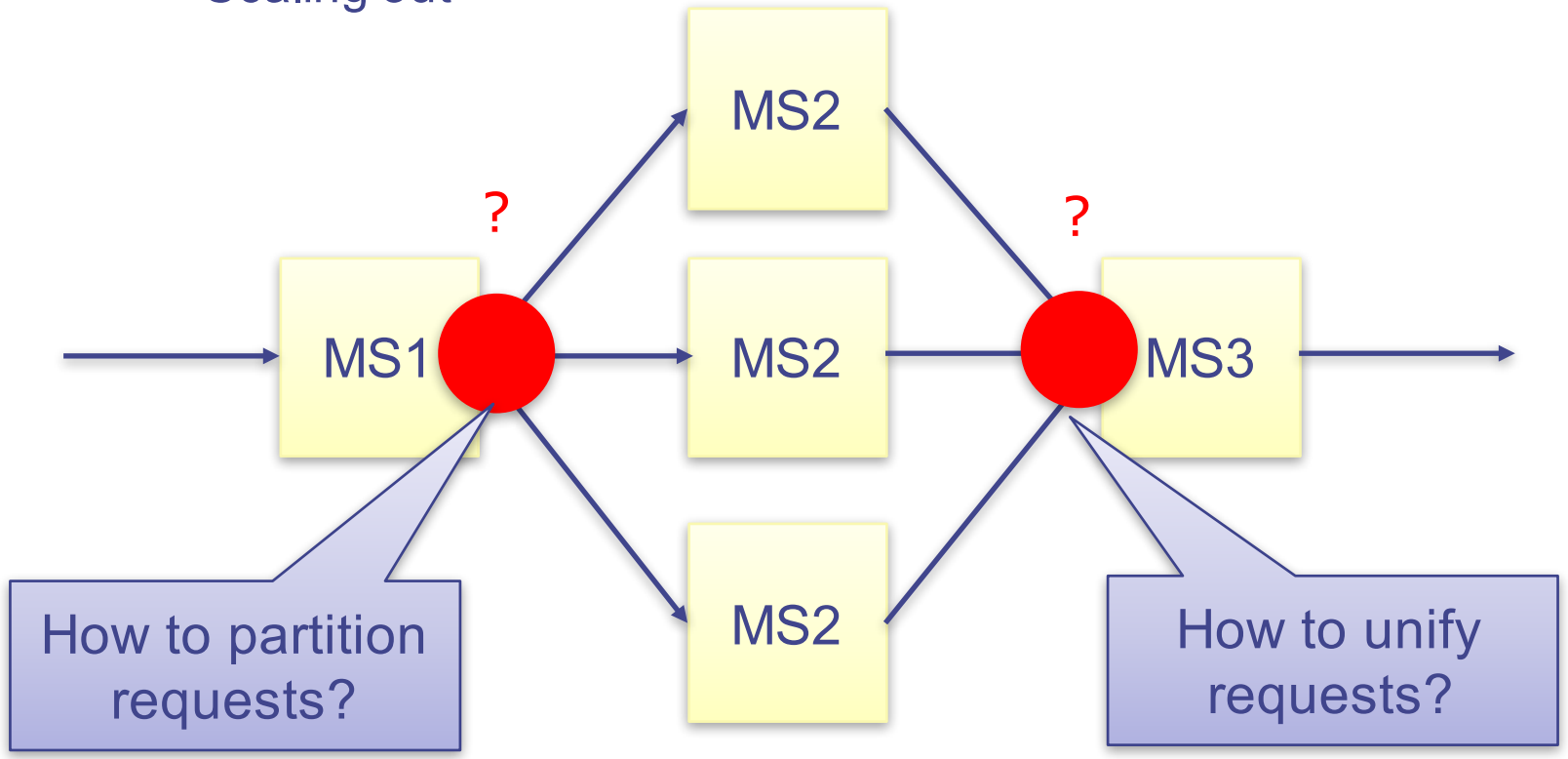
- Simple example: Service consists of three microservices, in a linear chain



- Each microservice: stateless, can process each request in isolation
- Computation per request on a standard machine:
  - MS1, MS3: 10 milliseconds
  - MS2: 100 milliseconds
  - Maximum throughput: 10 requests/second

Scalable microservices: Dealing with bottlenecks

- Options for MS2?
  - Buy a faster machine – only helps up to a point
    - "Scaling up"
  - Run multiple instances of MS2
    - "Scaling out"



Microservices: Challenges

- When to run how many instances of which service doing which work?
  - Buzzword: Stateless, autoscaling, load balancing
- How to deal with crashing services?
  - Buzzword: Automatic restart
- How to organize dependable, efficient message exchange between individual services?
  - Buzzword: Message queueing
- Stateful services?
  - Buzzword: Database

Same, same?

- Differences and commonalities?
  - NFV vs. DCC?
  - Microservice as pattern common to both?

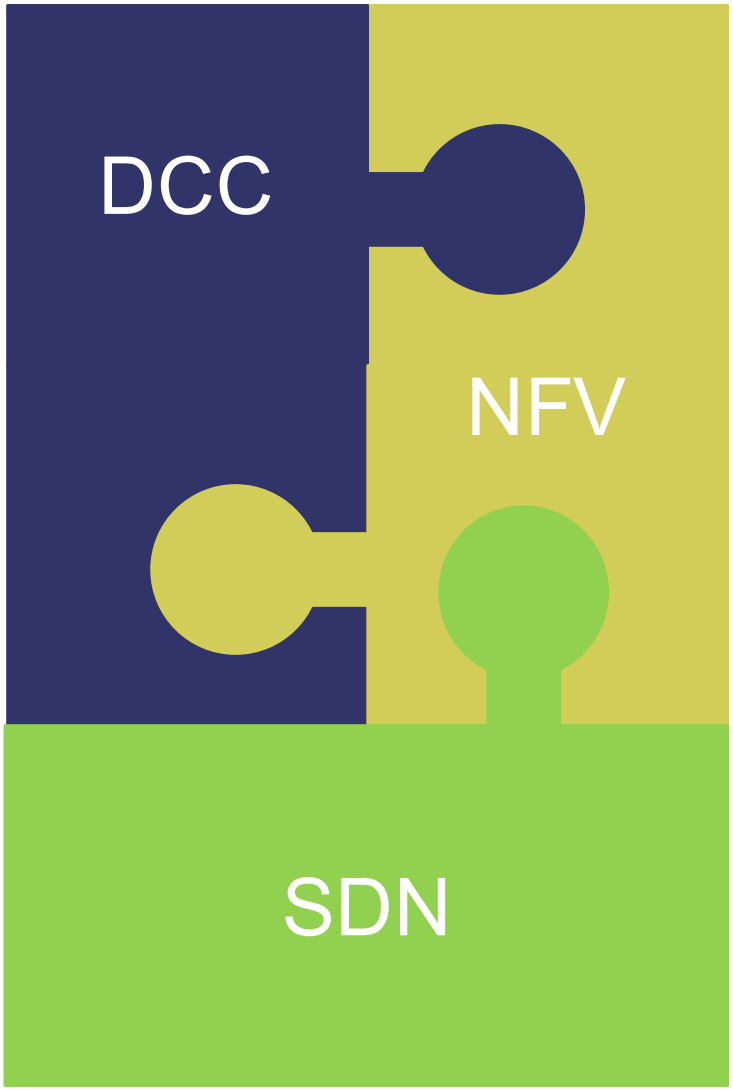
- Is there a difference between “network services” and “IT services”?
  - An inherent one?
  - One due to current architectures?

Hard-core VNF interpretation

- VNFs are transparent on an IP level
  - Transparent for source and destination
  - Must not modify Layer 3 addresses
  - Implies: only use Layer 2 interfaces
  - Cannot use L3 forwarding
  - Need to move traffic towards VNFs/put VNFs in the path

- Why? Consequences?
  - Eases reuse of existing code bases for functions
  - Makes shunting of traffic between VNFs more difficult
    - SDN to the rescue
  - Introduces a difference between “ordinary” and “network” services

Mid-term goal: Merge NFV, DCC, SDN

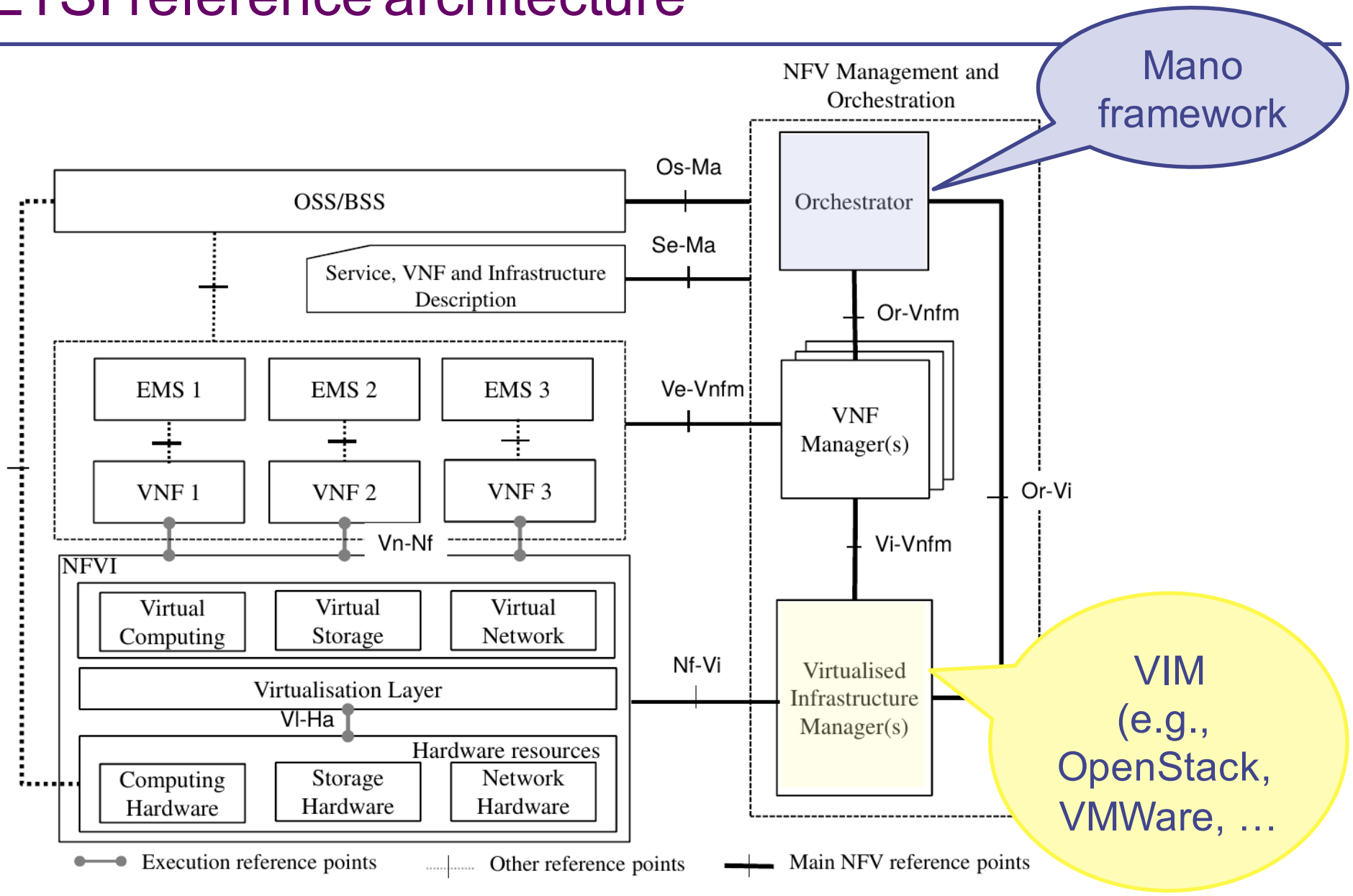


NFV reference architecture

- And for completeness: the ETSI NFV architecture

- IETF: Service function chaining
  - Substantially quite similar, just different terminology

ETSI reference architecture



Network Services as Forwarding Graphs of VNFs

- In the end, we want to build services meaningful for a user
  - In the network, end-to-end
  - Examples: virtual private network, mobile voice, …
  - This goes beyond the purview of a single VNF
- Goal: combine multiple VNFs into a *network service*
  - Executed by the compute domain, interconnected by the network infrastructure domain

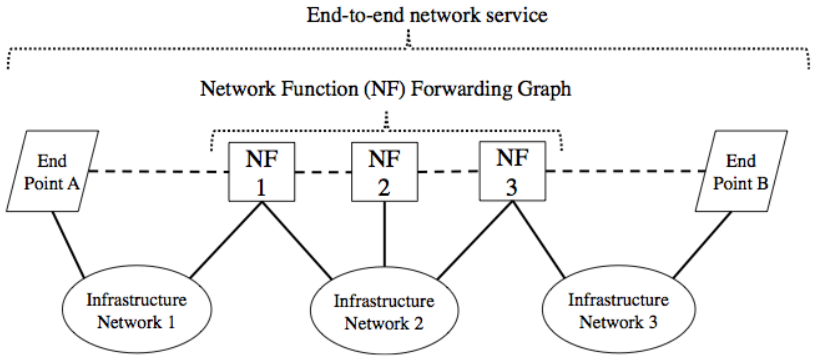


Figure 2: Graph representation of an end-to-end network service

- Typically: Order matters!
  - A service needs several functions, working on a data flow in a certain order
  - Expressed as a ***forwarding graph***

Forwarding graphs: Recursion allowed

- A VNF inside a forwarding graph can be constructed using a forwarding graph!

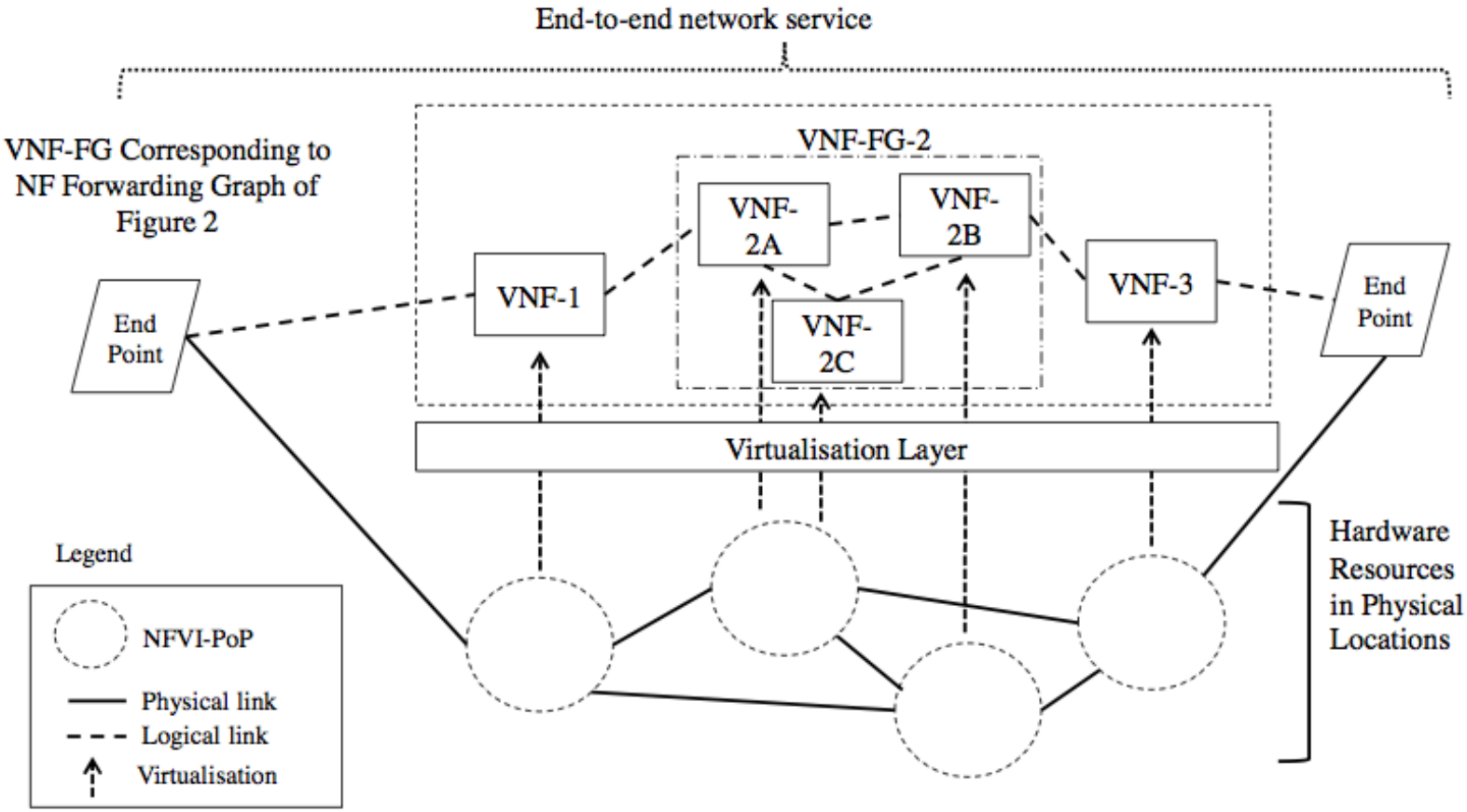


Figure 3: Example of an end-to-end network service with VNFs and nested forwarding graphs

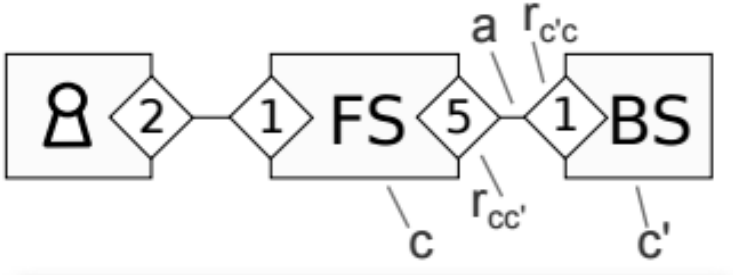
Goal: Deploy an NFV service

- Decide:
  - Which instances of which VNF are needed
  - Where to run which instance
  - How to connect instances together

- Required knowledge?
  - Structure of service
  - Offered load and infrastructure capabilities
  - VNF quantification: How many resources to deal with how much traffic, at which quality
  - Hence: ***quantitatively annotated templates***

Annotated templates

- Simple example: Annotate edges in a service by *multiplicity:*
  VNF instance
  can handle so many instances
  of the previous stage

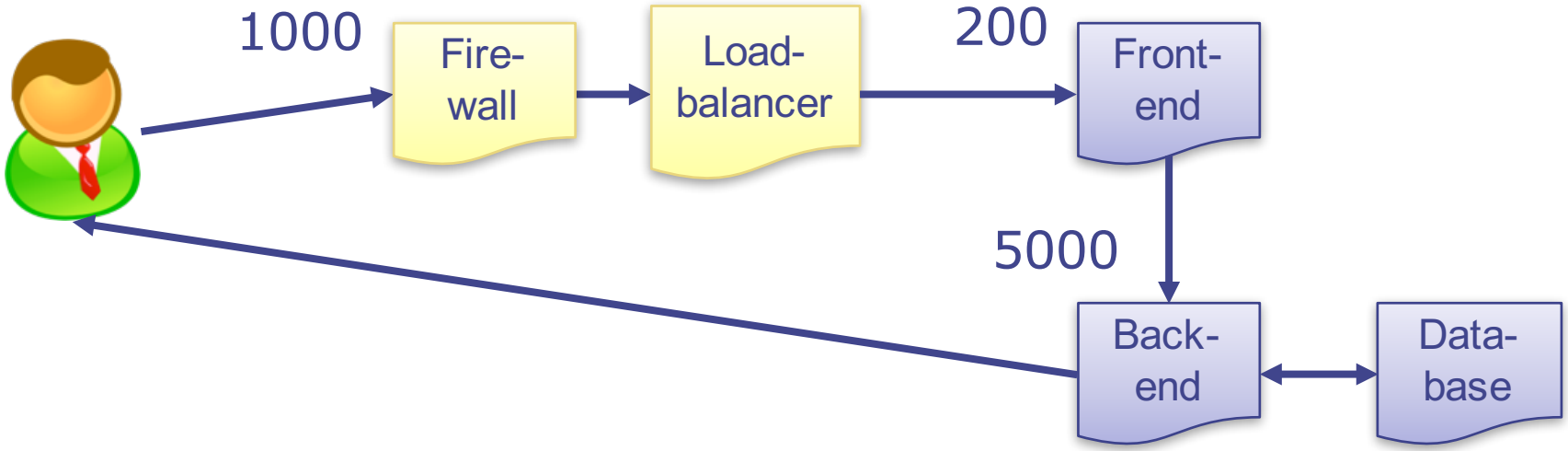


- Better: State tuples of
  (offered load, used resources, quality, produced load)
  - Can be used by ManO framework to scale and place
  - … and manage lifecycles (shutdown!)

- From where to get annotations?
  - Developers, testing while onboarding, monitor during operation

Templates, as they should be

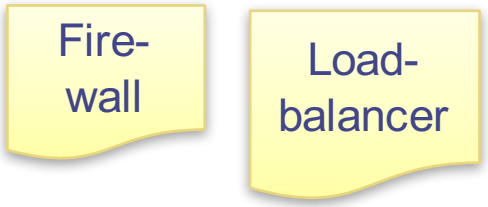
- **Quantitative** annotations
  - From profiling
- Scaling options
- …



Services?

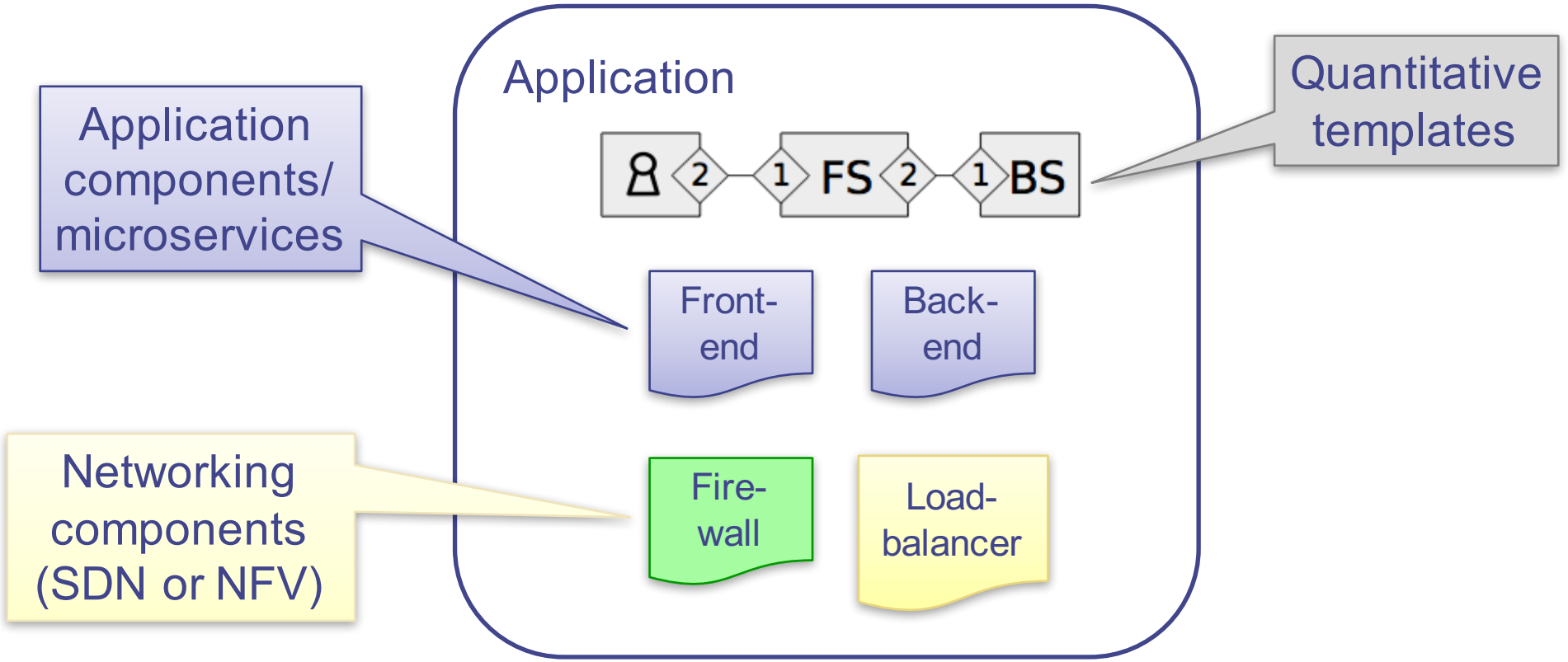
- “Ordinary” application boxes?

- “Network” functions?



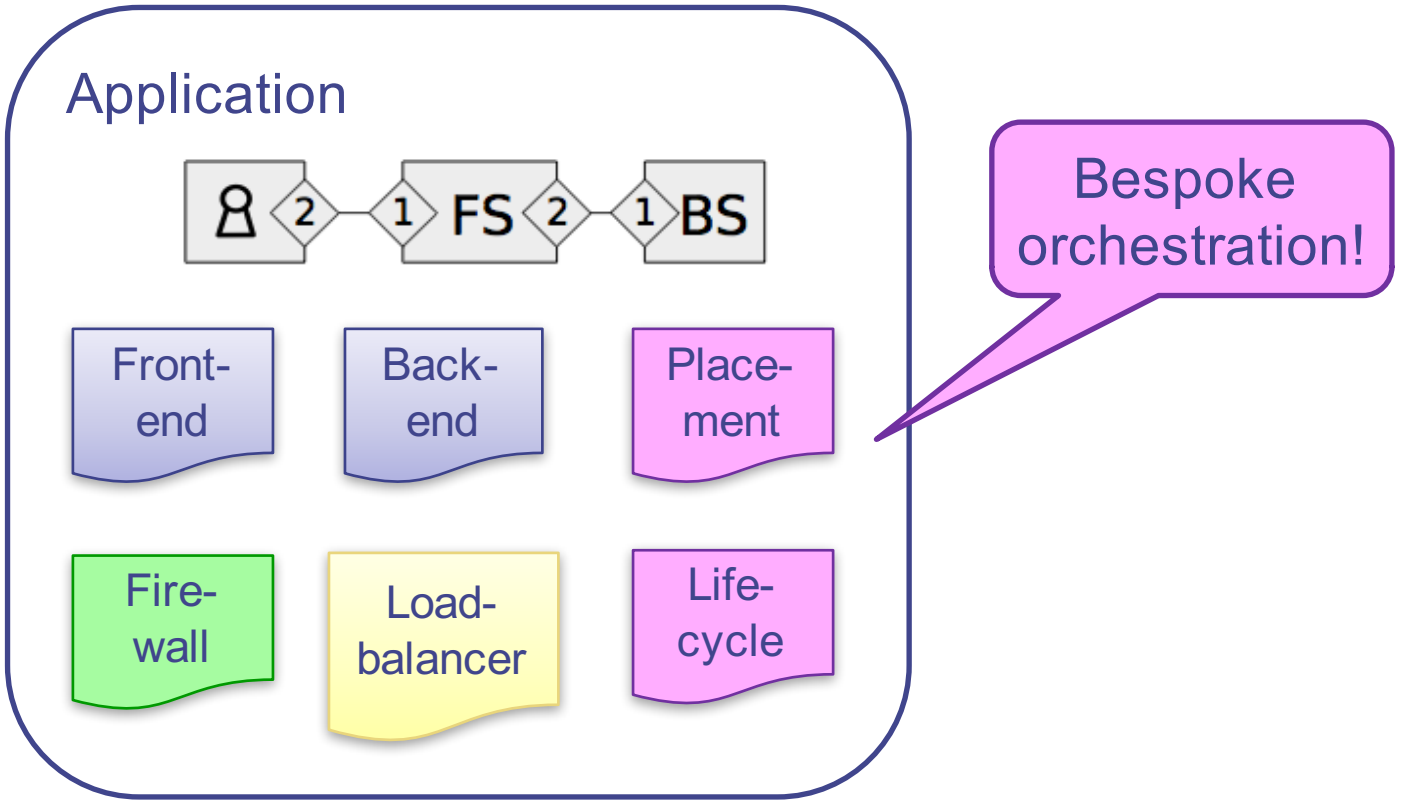
Applications become more complex

- **Application =**
  Actual application + networking



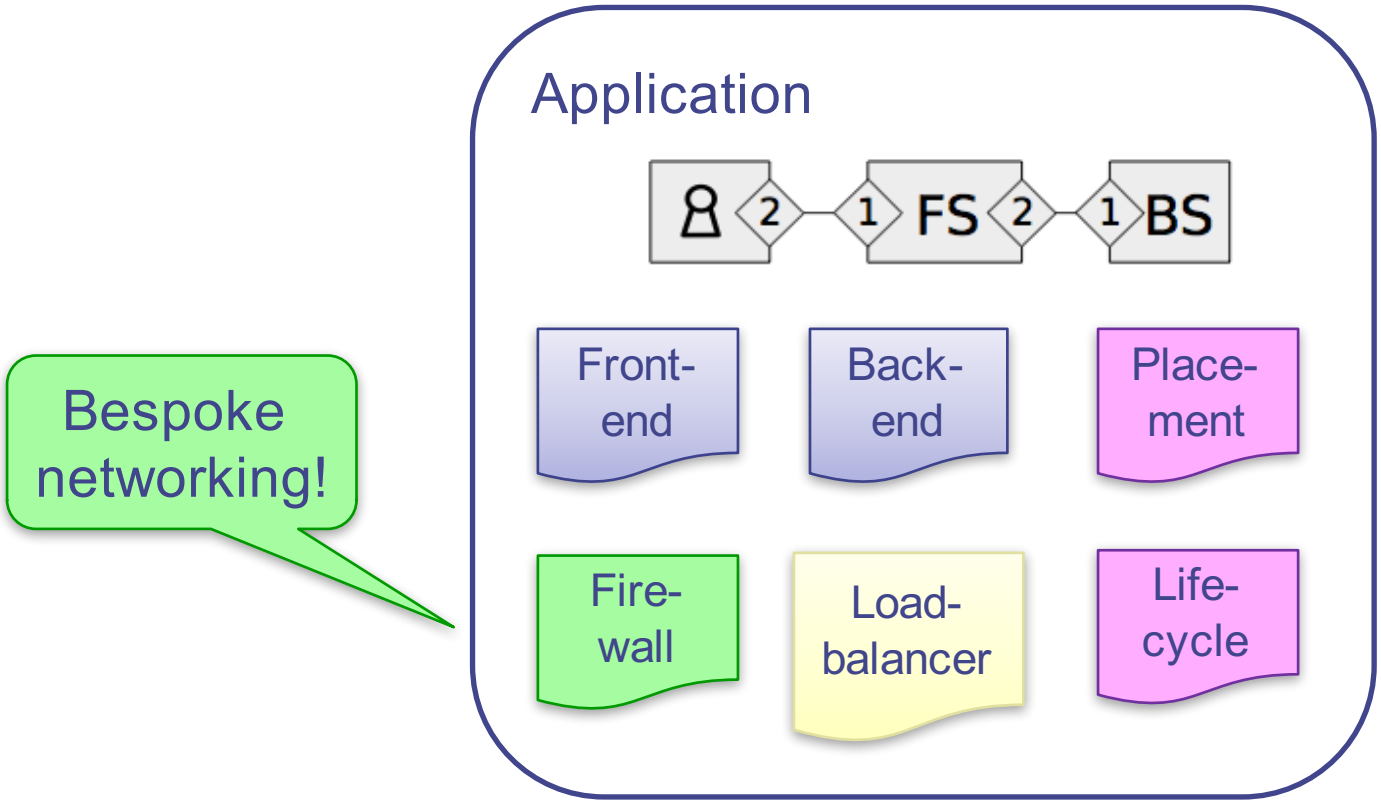
Developer knows best!

- **Application =**
  Orchestration + actual application + networking
  - UNIFY, SONATA, ...

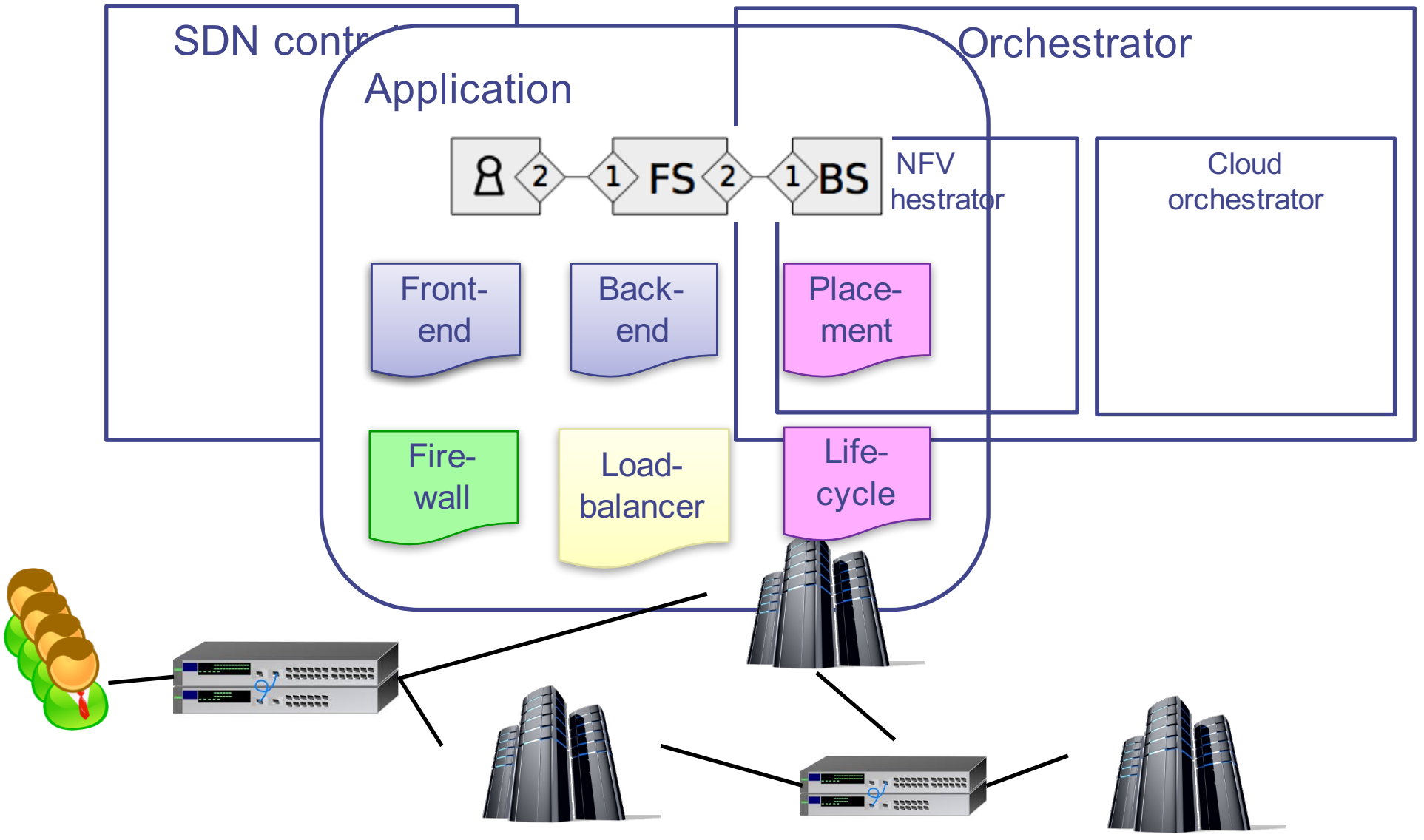


Reality check: Networking

- Networking: SDN controller applications
- Create network topology for application
- Developer support? Legacy?



High-level architecture



- Time permitting: Some discussions on algorithmic aspects in NFV orchestration

Hands-on!

- How to experiment with NFV, orchestration, …?
- Typical requirements
  - Reproducible experiments
  - Easy to use
  - Captures relevant parts of real-life infrastructure
  - Cheap (!)
- Compare: Mininet for SDN
- Concrete requirements?
  - Run executables at multiple locations, patch them into chains

A Mininet-based testbed for NFV: Containernet/Medicine

- Based on: M. Peuster, H. Karl, and S. van Rossem. **"MeDICINE: Rapid Prototyping of Production-Ready Network Services in Multi-PoP Environments."** in IEEE Conference on Network Function Virtualization and Software Defined Network (NFV-SDN), 2016.
  - https://github.com/containernet/containernet

- Walk-through demo: https://github.com/sonata-nfv/son-tutorials/blob/master/upb-containernet-emulator-summerschool-demo/README.md

https://goo.gl/uGjR3r

Walkthrough steps

1. Start containers in a Mininet network
    1. containernet as such
2. Multi-pop version: Start multiple containers at a single location
    1. son-emu
    2. Interface similar to OpenStack Nova
3. Build chains among containers
4. Define a service package
    1. Using Sonata's service definitions
5. Add a (highly simplified) Sonata ManO
6. Upload a service
7. Test the running service

Step 0: Start the virtual machine

- Download: http://www.peuster.de/SONATA/sonata-emulator-demo-vm-2017.ova
  - about 5 GB
- Or use the provided instances
- Login
  - Username and password: sonata
- Open terminal

Containers in Mininet?

- Mininet host: Basically just a process
  - Limits what you can do as VNF experiments
- Expectation?
- Hands-on!

Start containers in Mininet

- Similar to adding Mininet hosts to topology
- See ~/demo/topologies/containernet_example1.py

```
# add containers to topology
d1 = net.addDocker('d1', ip='10.0.0.251',
                   dimage="ubuntu:trusty")
d2 = net.addDocker('d2', ip='10.0.0.252',
                   dimage="ubuntu:trusty")

# connect containers to switches
net.addLink(d1, s1)
net.addLink(d2, s2)
```

- Start this file:
  sudo python ~/demo/topologies/containernet_example1.py

Use containers in Mininet/containernet

- Play around with topology:

```
containernet> dump
containernet> d1 ifconfig
containernet> d2 ifconfig
containernet> d1 ping -c3 d2
containernet> d1 ping -c3 h1
containernet> h1 ls
containernet> d1 ls
```

- Play with the containers (second terminal!):

```
docker ps
docker attach mn.d2
<enter>
<enter>

root@d2> top
```

Why Multi-PoP experiments?

- Represent and simplify data centres
  - Inside data centre: Big-switch abstractions
- Provide control over data centres
  - Akin to OpenStack Nova, e.g.
- Expectation?
- Hands-on: Get it to work!

Chaining?

- So far: VNFs running individually, not connection yet
  - No automatic learning switch in place
- Set up chaining: Put entries into flow tables

- Expectation?

- Hands-on!
  - Try to hook up the VNFs

From individual, chained containers to packages

- Actual deployment in an NFV context: service package
  - Describes: which functions, how connected, how scaled, …
  - Unit of deployment, passed to a MANO framework
- Expectation?
- Hands-on!
  - Try it: Start a SONATA gatekepper in the emulator, create a package, upload and startup package in gatekeeper

Thoroughly missing so far…

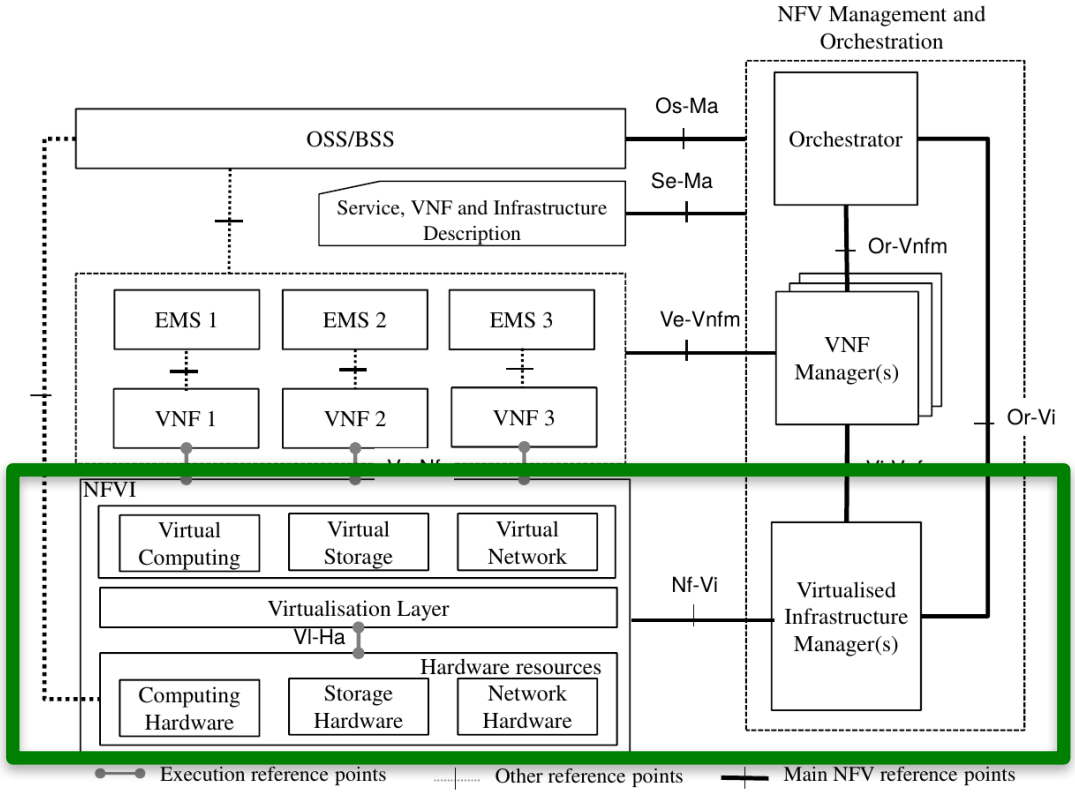
- Agreed-upon benchmark scenarios!
- Load generators!
  - At (at least) two abstraction levels
    - Generating new service request with service duration
    - Generating load for individual services
- Collaborators welcome!

Conclusion

- NFV still an active research and innovation area
  - Lot's of conceptual/architectural, algorithmic/optimization, systems work still necessary
- Ability to test in practice so far limited
  - Some steps to overcome that: Containernet/Medicine
  - Down the road: For developers and operators?
- Missing: Benchmarks!

Open source activity: OpNFV

- Initiative for an open-source NFVI/NFVI-Manager (including Nf-Vi interface)
- Public release available



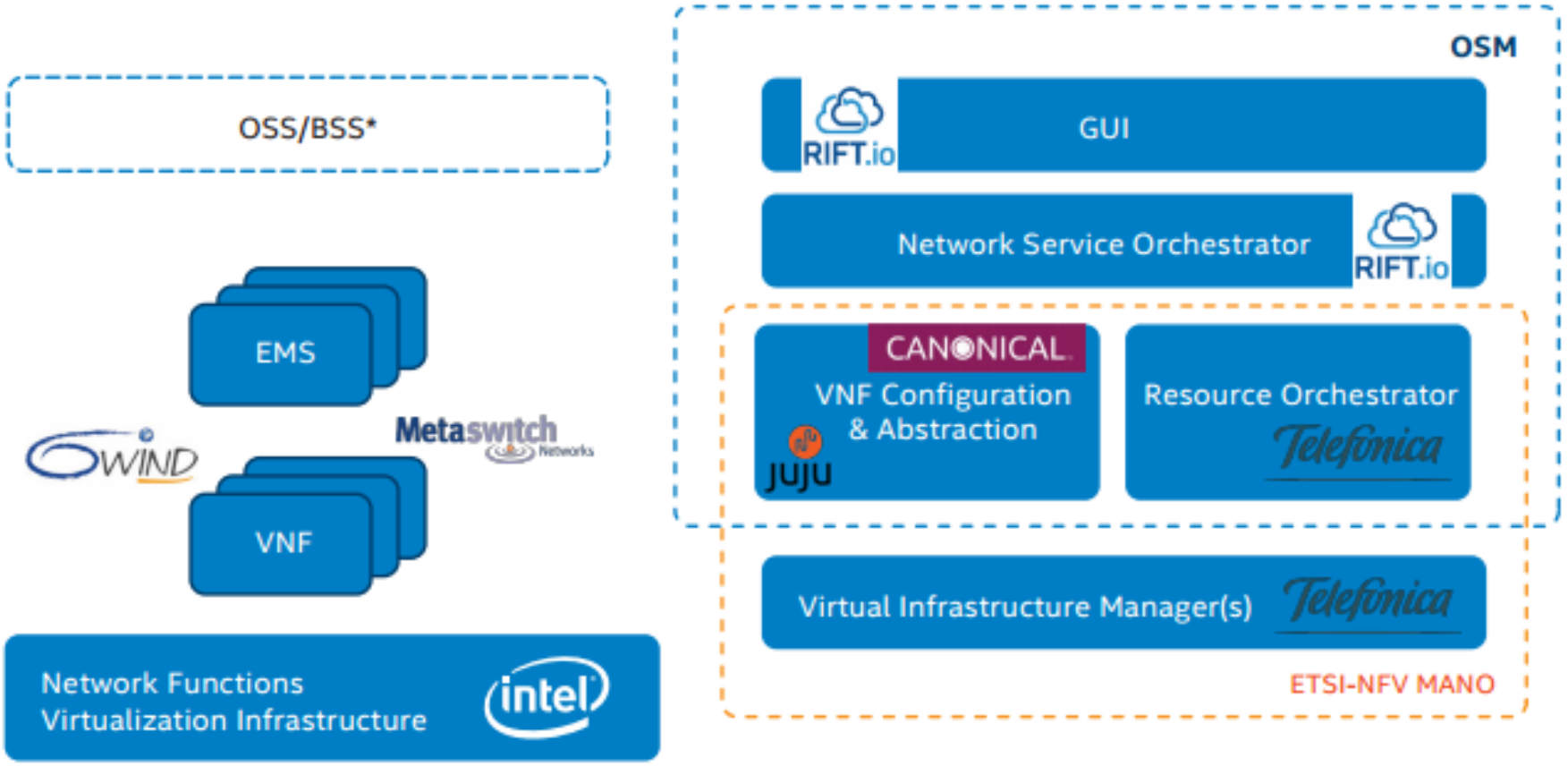
Initial OpNFV focus

https://www.opnfv.org/software/technical-overview

OpenSourceMano (OSM)

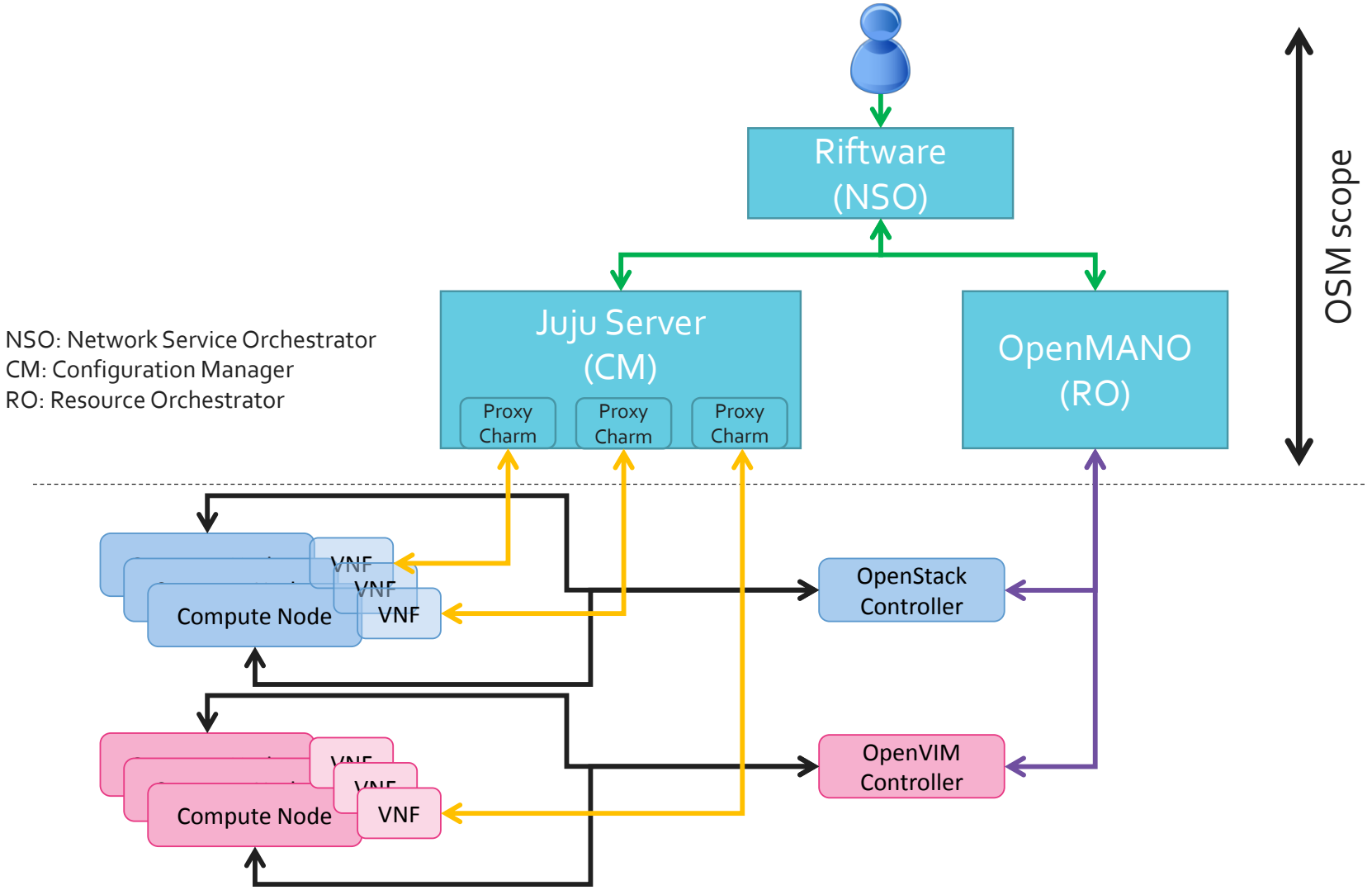
- Open-source Management / Orchestration framework
  - https://osm.etsi.org
  - Current release: https://osm.etsi.org/wikipub/index.php/OSM_Release_TWO
  - Aligned with ETSI reference architecture
  - UPB: member!

OSM high-level architecture



https://osm.etsi.org/wikipub/images/d/d4/OSM%2816%29000018r1_MWC16_architecture_overview.pdf

OSM high-level architecture



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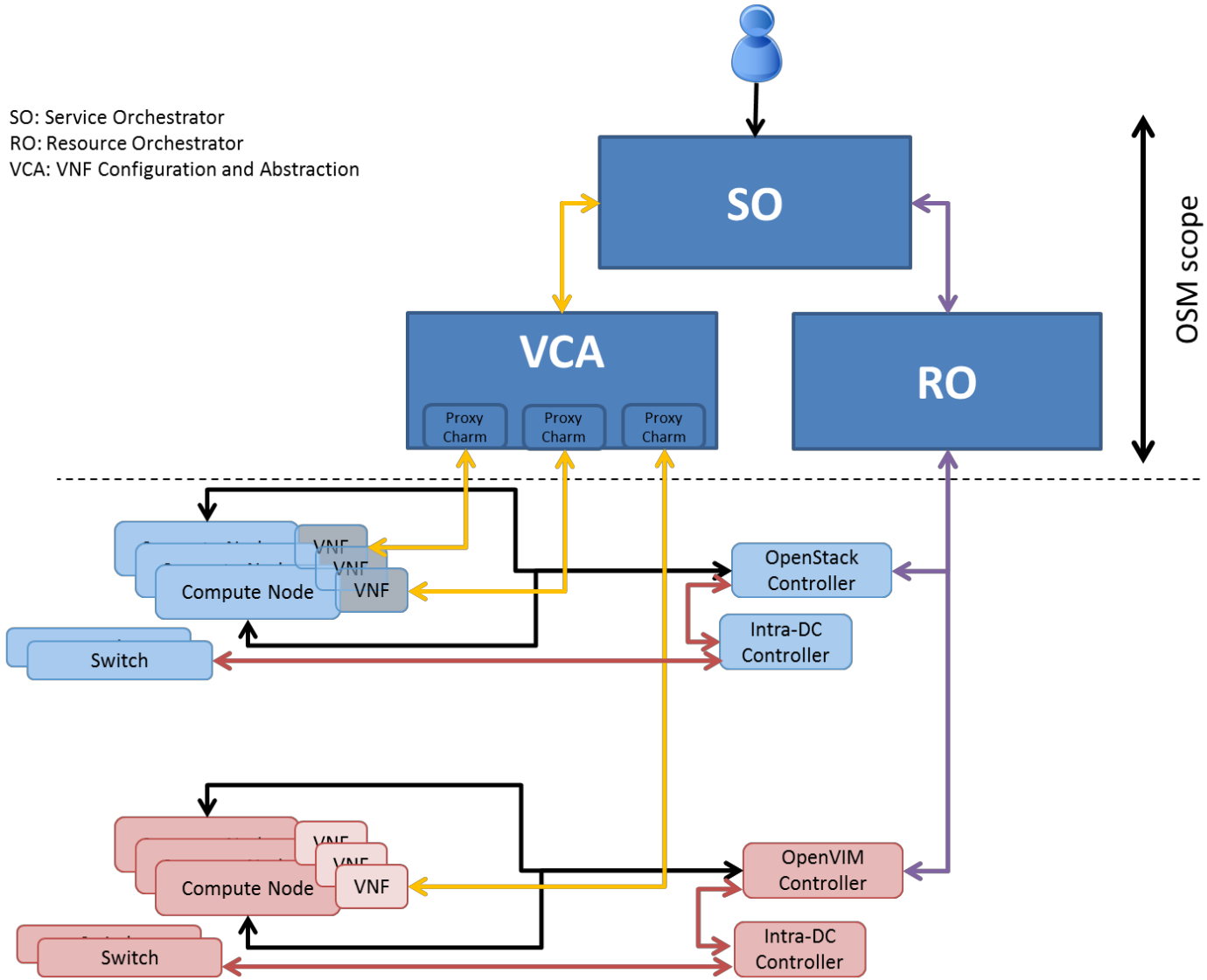
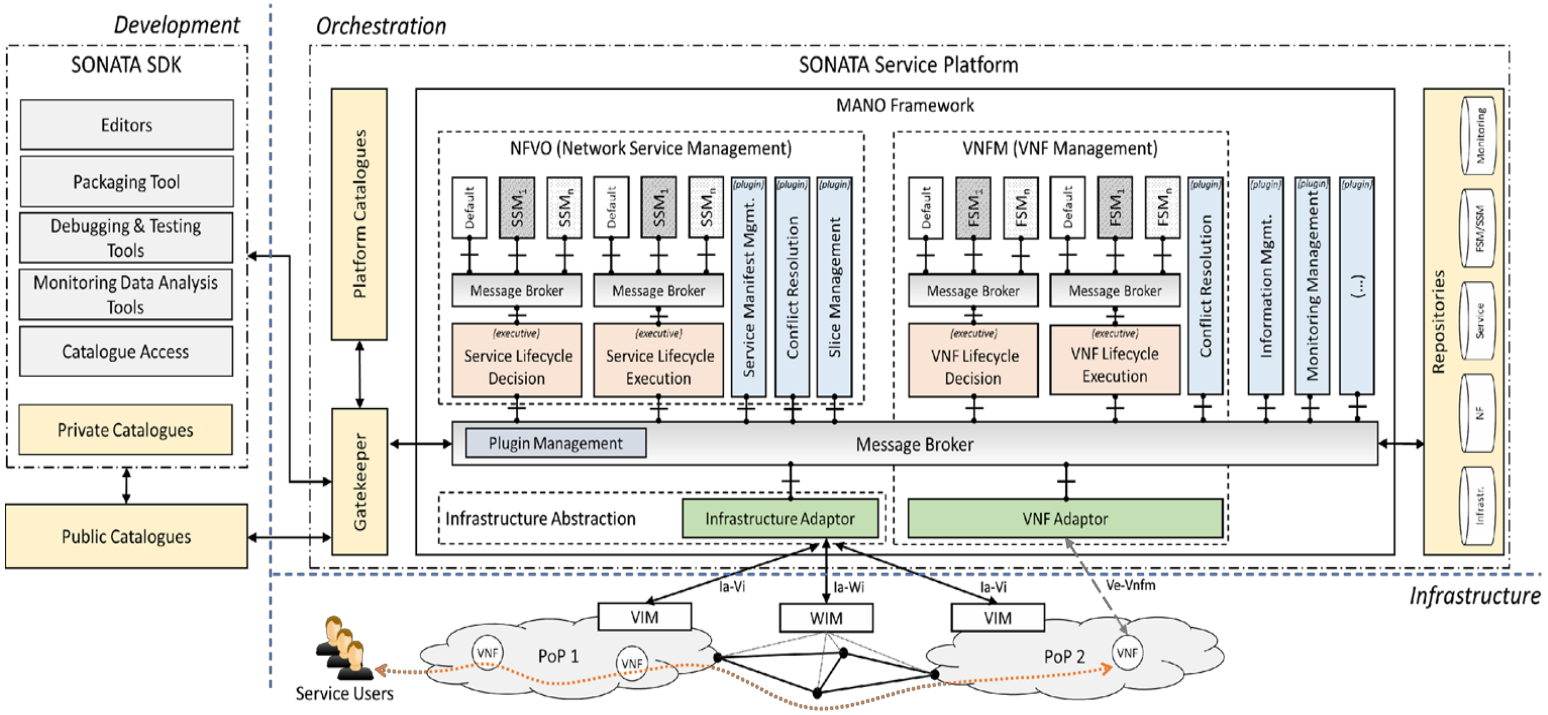


https://osm.etsi.org/wikipub/images/4/4d/OSM%2816%29000077r1_OSM_2_Tech_briefing_-_OSM_Release_ONE_installation.pdf

Sonata Mano frmework

- Sonata 5G-PPP http://sonata-nfv.eu
- Claim to fame: Unparalleled flexibility
  - Functions and services can bring along their own management functionality
  - Executed by ManO framework



References, further reading

- European Telecommunication Standards Insitute (ETSI), Industrial Study Group on Network Function Virtualization (ISG NFV), http://www.etsi.org/technologies-clusters/technologies/nfv
  - With various important white papers on reference architecture, use cases, terminology (see “Specifications” tab on that web page)
  - Especially: https://portal.etsi.org/nfv/nfv_white_paper2.pdf
- Vendor-specific white papers:
  - HP: http://www.hp.com/hpinfo/newsroom/press_kits/2014/MWC/White_Paper_NFV.pdf,
  - Alcatel Lucent: http://www.tmcnet.com/tmc/whitepapers/documents/whitepapers/2013/9377-network-functions-virtualization-challenges-solutions.pdf
- Service chaining surveys
  - http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=6702549
  - http://www.ewsdn.eu/previous/presentations/Presentations_2013/EWSDN-2013-v10a.pdf
- Papers for this chapter: Two mendeley groups
  - https://www.mendeley.com/groups/6764011/distributedcloudcomputing/
  - https://www.mendeley.com/groups/6763981/networkfunctionvirtualization/