



Fog-computing versus SDN/NFV and Cloud computing in 5G

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Fog-computing versus SDN/NFV and Cloud computing in 5G



Acknowledgement

This overview is compiled, based on several public documents belonging to different authors and groups, on Wireless/4G/5G networking, Cloud Computing, SDN, NFV, Fog Computing, etc. : conferences material, studies, research papers, standards, projects, overviews, tutorials, etc. (see specific references in the text and Reference list).



Fog-computing versus SDN/NFV and Cloud computing in 5G



Motivation of this talk

Facts:

- **Internet and Telecom convergence** → **Integrated networks: Future Internet**
- **Novel services and communication paradigms**
- **Content/media oriented communications, Social networks Internet of Things, M2M and Vehicular communications, etc.**
- **Novel, emergent technologies** are changing networks and services architectures :
 - *Advances in wireless technologies: 4G-LTE, LTE-A, WiFi*
 - *Evolution to 5G*
 - *Support technologies*
 - *Cloud Computing*
 - *Software Defined Networks (SDN)*
 - *Network Function Virtualization (NFV)*
 - *Fog/Edge Computing*



Fog-computing versus SDN/NFV and Cloud computing in 5G



Motivation of this talk (cont'd)

Mobile Traffic and Mobile Video

Source: http://www.cisco.com/c/en/us/solutions/collaterals/service-provider/visual-networking-index-vni/white_paper_c11-520862.html



Cisco Forecasts 24.3 Exabytes per Month of Mobile Data Traffic by 2019

Source: CISCO



Mobile Video Will Generate More Than 69 Percent of Mobile Data Traffic by 2019

Source: CISCO

Source CISCO

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Fog-computing versus SDN/NFV and Cloud computing in 5G



Motivation of this talk (cont'd)

- **Specific aspects in wireless/mobile environment** (having impact on 4G, 5G architectures and technologies)
 - the limited spectrum and bandwidth, interference
 - time- and location-dependent wireless link characteristics
 - radio resource management and allocation
 - mobility issues
 - heterogeneous RATs, terminal features
 - how to obtain higher capacity networks

- Main topic of this tutorial :
 - **Summary presentation of solutions to develop 5G networking and services - based on concepts and cooperating - support technologies as:**
 - **Cloud computing**
 - **Software Defined Networking**
 - **Network Functions Virtualization**
 - **Fog/Edge computing**



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1. **5G Vision and Architectures**
2. **Software Defined Networking (SDN) and Network Function Virtualization (NFV)**
3. **Cloud Computing Architectures in 5G**
4. **SDN and NFV in 5G**
5. **Fog Computing in 5G**
6. **Mobile Edge Computing**
7. **Open research topics**
8. **Conclusions**



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2. **Software Defined Networking and Network Function Virtualization**
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1. 5G Vision and Architectures



- **Key Drivers, Requirements, Technologies**
- Driving factors for cellular network evolution 3G → 4G → 5G
 - Device, Data, and Data transfer rates
 - continuous growth in wireless user devices, data usage
 - desired: better quality of experience (QoE)
 - ~ 50 billion connected devices will utilize the cellular network services until 2025 → high increase in data traffic
- **Current State-of-the-art solutions are not sufficient !**
- Three views for 5G:
 - **user-centric** (uninterrupted connectivity and comm. services, smooth consumer experience)
 - **service-provider-centric** (connected intelligent transportation systems, road-side service units, sensors, and mission critical monitoring/tracking services)
 - **network-operator-centric** (scalable, energy-efficient, low-cost, uniformly-monitored, programmable, and secure communication infrastructure)
- Consequence: three main 5G features
 - **Ubiquitous connectivity**: devices connected ubiquitously ; uninterrupted user experience
 - **Zero latency** (~ few ms): for life-critical systems, real-time applications, services with zero delay tolerance.
 - **High-speed Gigabit connection**



1. 5G Vision and Architectures



- **Key Drivers, Requirements, Technologies**
- **5G disruptive capabilities**
 - **x 10 improvement in performance** : capacity, latency, mobility, accuracy of terminal location, reliability and availability.
 - **simultaneous connection of many devices** + improvement of the terminal battery capacity life
 - **lower energy consumption** w.r.t. that today 4G networks; energy harvesting
 - **Better spectral efficiency**
 - help **citizens to manage their personal data**, tune their exposure over the Internet and protect their privacy
 - **reduce service creation time** and facilitate integration of various players delivering parts of a service
 - built on **more efficient hardware**
 - **flexible and interworking in heterogeneous** environments



1. 5G Vision and Architectures



- **Key Drivers, Requirements, Technologies (cont'd)**
 - **Additional requirements (and objectives) :**
 - **sustainable** and **scalable** technology
 - **cost reduction** through human task automation and hardware optimization
 - **ecosystem** for technical and business innovation
 - **Application fields:**
 - network solutions and vertical markets:
 - automotive, energy
 - food and agriculture
 - city management, government
 - education
 - healthcare, manufacturing
 - public transportation
 -



1. 5G Vision and Architectures



- **Key Drivers, Requirements, Technologies (cont'd)**
 - **5G - evolution of mobile *broadband networks* + *new unique network and service capabilities*:**
 - It will ensure *user experience continuity* in various situations
 - high mobility (e.g. in trains)
 - very dense or sparsely populated areas
 - regions covered by heterogeneous technologies
 - 5G -key enabler for the Internet of Things, M2M
 - **Mission critical services :**
 - high reliability, global coverage and/or very low latency (currently they are handled by specific networks), public safety
 - **It will integrate: networking + computing + storage resources into one programmable and unified infrastructure**
 - optimized and more *dynamic usage* of all distributed resources
 - convergence of fixed, mobile and unicast/mcast/broadcast services.
 - support *multi tenancy models*, enabling players collaboration
 - leveraging on the characteristic of current *cloud computing*



1. 5G Vision and Architectures



- **Key Drivers, Requirements, Technologies (cont'd)**
- **5G Key technological characteristics**
 - Heterogeneous set of integrated air interfaces
 - Cellular and satellite solutions
 - Simultaneous use of different **Radio Access Technologies (RAT)**
 - Seamless handover between heterogeneous RANs
 - Ultra-dense networks with numerous small cells
 - Need new interference mitigation, backhauling and installation techniques.
- **Driven by SW**
 - unified OS in a number of PoPs, especially at the edge of the network
- To achieve the required performance, scalability and agility it will rely on
 - **Software Defined Networking (SDN)**
 - **Network Functions Virtualization (NFV)**
 - **Mobile Edge Computing (MEC)**
 - **Fog Computing (FC)**
- **Ease and optimize network management** operations, through
 - cognitive features
 - advanced automation of operation through proper algorithms
 - Data Analytics and Big Data techniques -> monitor the users' QoE



1. 5G Vision and Architectures



- **5G Key Requirements**

- **Summary of 5G figures (very) for ambitious goals:**
 - **1,000 X in mobile data volume** per geographical area reaching a target ≥ 10 Tb/s/km²

 - **1,000 X in number of connected devices** reaching a density ≥ 1 M terminals/km²

 - **100 X in user data rate** reaching a peak terminal data rate ≥ 10 Gb/s

 - **1/10 X in energy** consumption compared to 2010

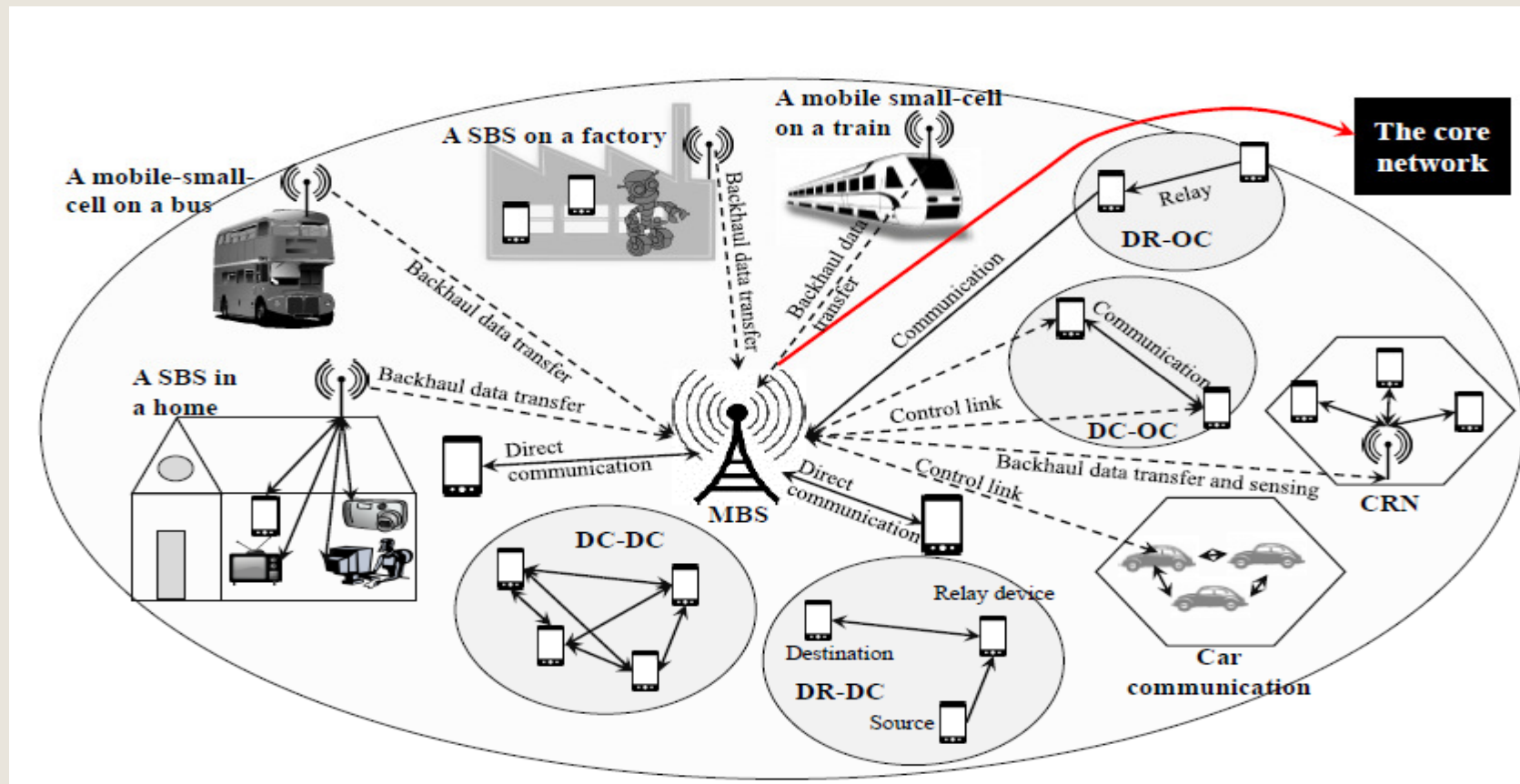
 - **1/5 X in E2E latency reaching 5 ms** for e.g. tactile Internet and radio link latency reaching a target ≤ 1 ms for e.g. Vehicle to Vehicle communication

 - **1/5 X in network management** OPEX

 - **1/1,000 X in service** deployment time reaching a complete deployment in ≤ 90 minutes

5G Generic Architecture

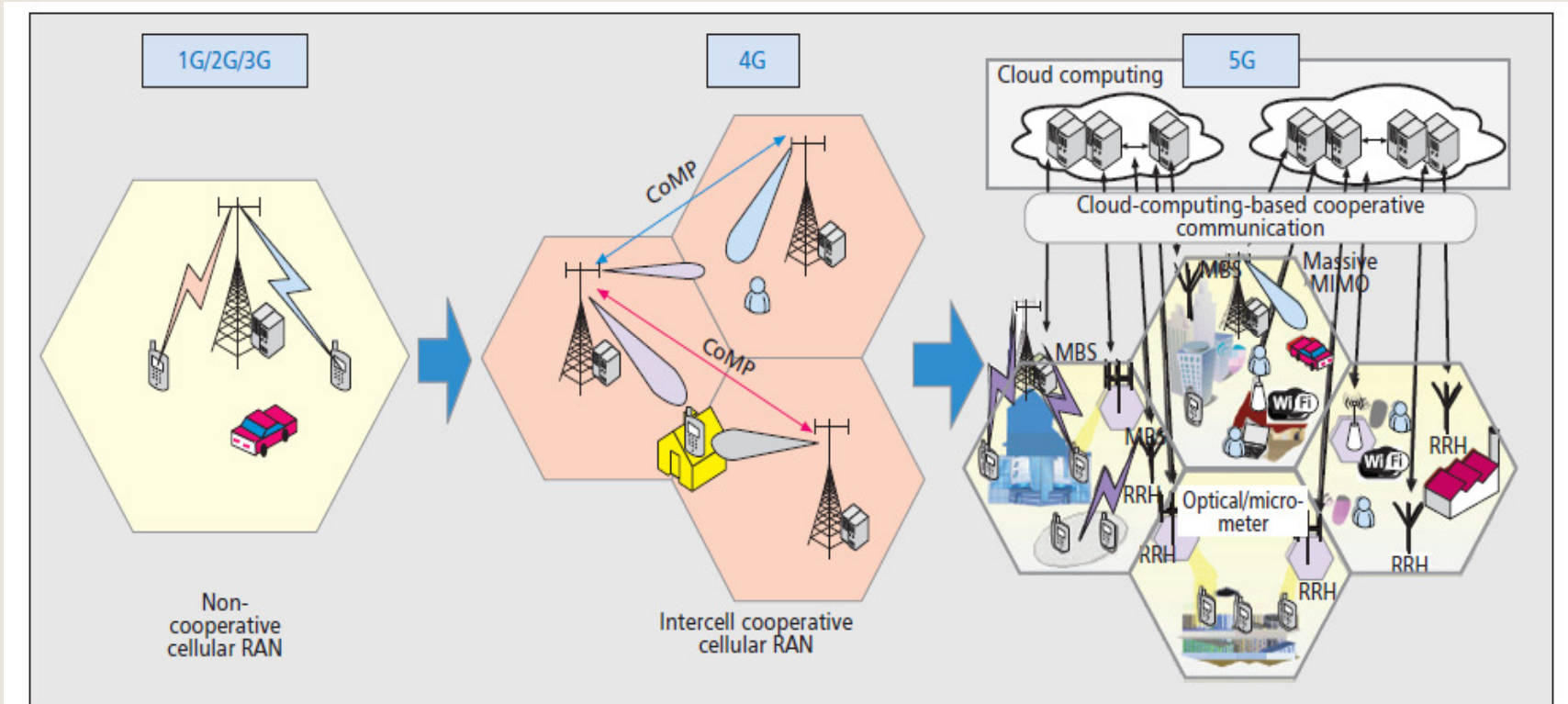
- multi-tier arch. : small-cells, mobile small-cells, and D2D- and CRN-based comm.



Source: Panwar N., Sharma S., Singh A. K. 'A Survey on 5G: The Next Generation of Mobile Communication'. Accepted in Elsevier Physical Communication, 4 Nov 2015, <http://arxiv.org/pdf/1511.01643v1.pdf>

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- **Example: Cellular systems evolution towards 5G H-CRAN**
 - Novel proposal for 5G architecture : **H-CRAN Heterogeneous Cloud Radio Access Networks**



RRH – Remote Radio Head; CoMP - coordinated multi-point; MBS Macro Base Station

Source: M. Peng, et al., "Heterogeneous cloud radio access networks: a new perspective for enhancing spectral and energy efficiencies," *IEEE Wireless Commun.*, Dec. 2014

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1. 5G Vision and Architectures



- 5G: Why SDN, NFV, Cloud technologies in 5G?

	Architecture and technology			
	SDN	NFV	Cloud computing	Fog/ Edge computing
5G Challenge/Problem				
High capacity	X		X	X
Scalability and flexibility	X	X	X	X
User centricity			X	X
Programability	X	X	X	X
Self-healing infrastructures	X		X	X
Heterogeneity of RATs	X	X	X	X
Interference mitigation			X	
Low latency				X
Energy saving			X	X
Flexible management	X	X	X	X
Wide range of supported services	X	X	X	X



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2. **➡ Software Defined Networking (SDN) and Network Function Virtualization (NFV)**
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8. **Conclusions**



2. Software Defined Networking and Network Function Virtualization



- **2.1 SDN main objectives and features**

- **Recent industry/research effort - results:**
 - **SDN** –new networking architecture
 - **Open Networking Foundation** (ONF- non-profit industry consortium) → several OpenFlow I/F specs for SDN

- **Promises for enterprises, data centres, carriers :**
 - higher programmability, automation, and network control
 - highly scalable, flexible networks
 - fast adaptation to changing business needs

- **SDN objectives:**
 - **Control Plane (CPI) and Data Plane (DPI) separation**
 - A centralized logical control and view of the network
 - underlying network infrastructure is abstracted from the applications
 - **common APIs**
 - Open I/Fs between the CPI (controllers) and DPI elements.
 - Network programmability: by external applications including network management and control
 - Independency of operators w.r.t. network equipment vendors
 - Technology to be used in Cloud data centers as well in WANs
 - Increased network reliability and security

 - **OpenFlow** : typical (“vertical”) protocol DPI ---CPI

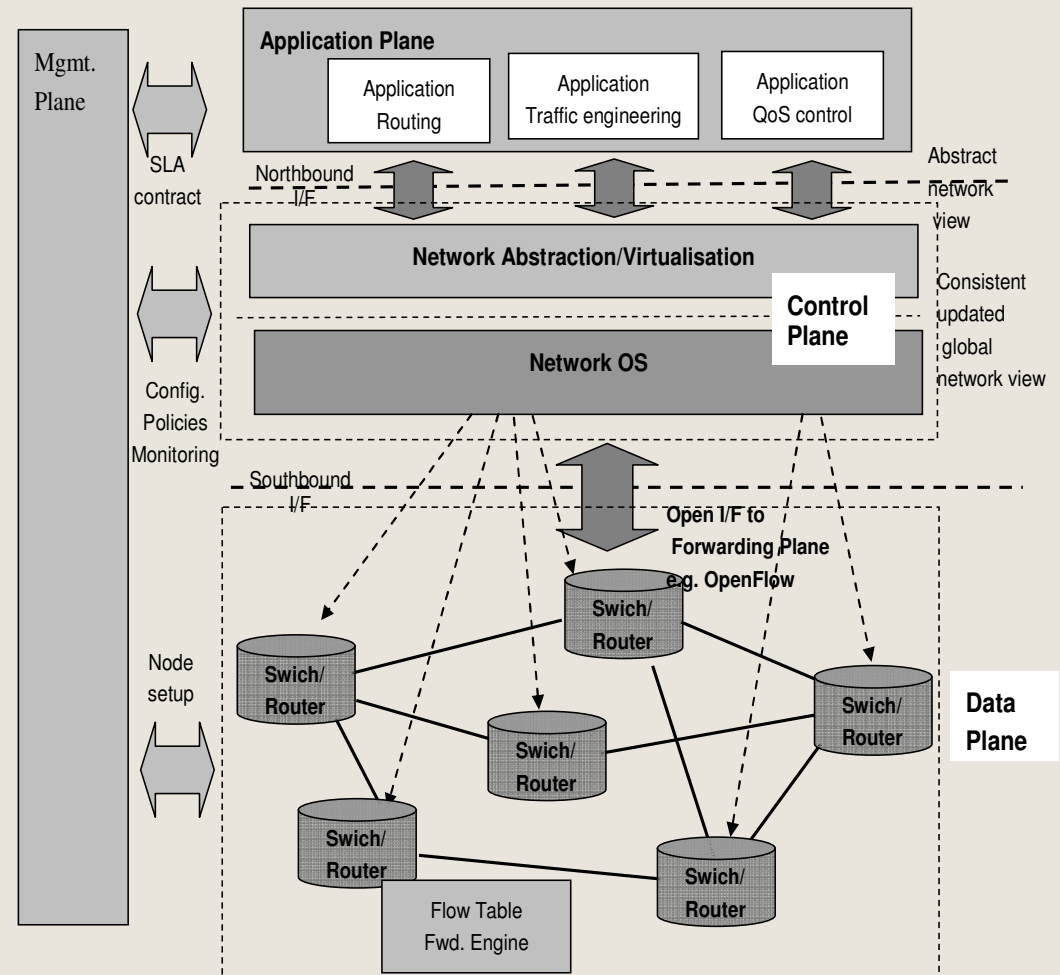
2.2 SDN Basic Architecture

Network OS:

- Distributed system that creates a consistent, updated network view
- Executed on servers (controllers) in the network
- Examples: NOX, PoX, ONIX, HyperFlow, Floodlight, Trema, Kandoo, Beacon, Maestro,..

SDN controller uses forwarding abstraction in order to:

- Collect state information from forwarding nodes
- Generate commands to forwarding nodes





2. Software Defined Networking and Network Function Virtualization



■ 2.3 Network Function Virtualization

- **NFV objectives:**
 - Improved capital efficiencies vs. dedicated HW implementation solutions, by:
 - Using COTS computing HW to provide **Virtualized Network Functions (VNFs)** through **SW virtualization techniques**
 - Sharing of HW and reducing the number of different HW architectures
- **Improved flexibility in assigning VNFs to HW**
 - better scalability
 - decouples functionality from location
 - enables time of day reuse
 - enhance resilience through **Virtualization**, and facilitates resource sharing
- **Rapid service innovation** through SW -based service deployment
- Common automation and operating procedures ⇒ **Improved operational efficiencies**
- **Reduced power consumption**
 - (migrating workloads and powering down unused HW)
- **Standardized and open I/Fs:** between VNFs infrastructure and mgmt. entities



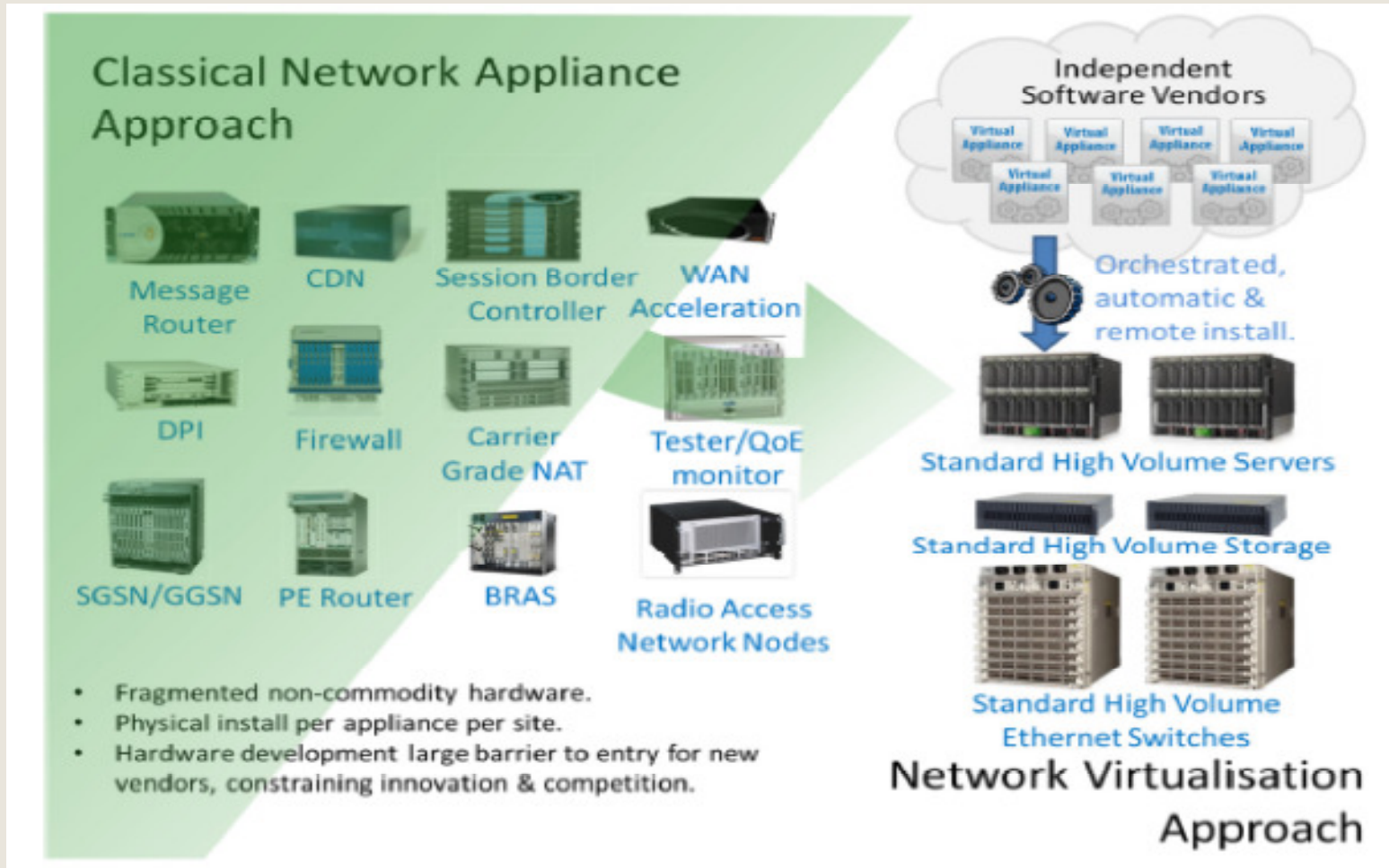
2. Software Defined Networking and Network Function Virtualization (NFV)



- **2.3 Network Function Virtualization (cont'd)**
- Network services are provisioned differently w.r.t current networks practice
- **Decoupling SW from HW**
 - network element is no longer a collection of integrated HW@SW entities
⇒ they may *evolve independently*
- **Flexible network function deployment:**
 - The SW/HW detachment allows to reassign and share the infrastructure resources
 - HW and SW can perform different functions at various times
 - The pool of HW resources is already in place and installed at some **NFVI-PoPs** ⇒ the actual NF SW instantiation *can be automated*.
 - leverages the different cloud and network technologies currently available
 - helps NOs to *faster deploy new network services* over the same physical platform.
- **Dynamic operation**
 - network function are performed by *instantiable SW components* ⇒
 - greater flexibility to scale the actual VNF performance in a dynamic way
 - finer granularity, for instance, according to the actual traffic

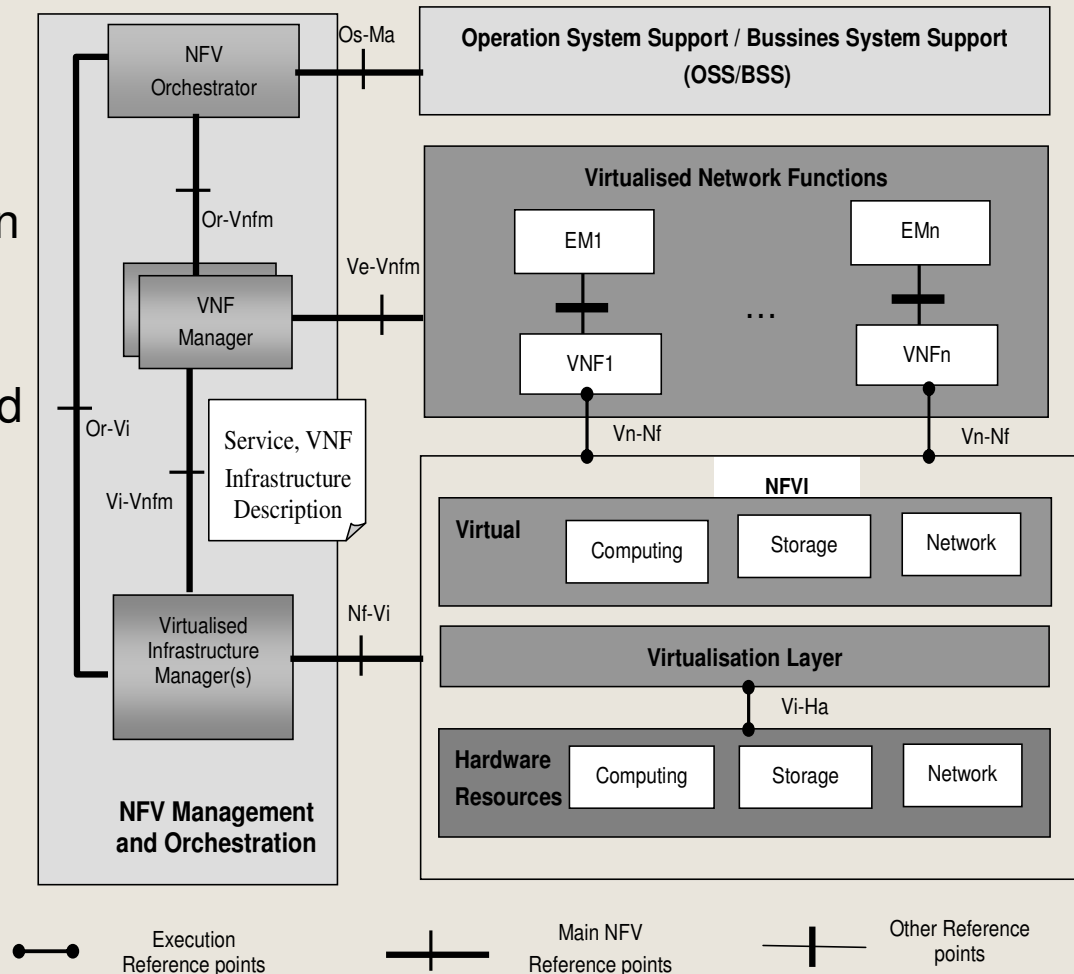
2. Software Defined Networking and Network Function Virtualization

- 2.3 Network Function Virtualization (cont'd)
 - NFV vision (source : ETSI)



2. Software Defined Networking and Network Function Virtualization

- **NFV Architecture**
- **High level view of NFV framework**
- **Working domains**
- **VNF**, as the SW implementation of a NF
- **NFV Infrastructure (NFVI)** includes the PHY resources and how these can be virtualized
 - NFVI supports the execution of the VNFs.
- **NFV Management and Orchestration (NFV-MANO)**
 - orchestration and lifecycle management of physical and/or SW resources
 - NFV MANO focuses on all virtualization-specific management tasks



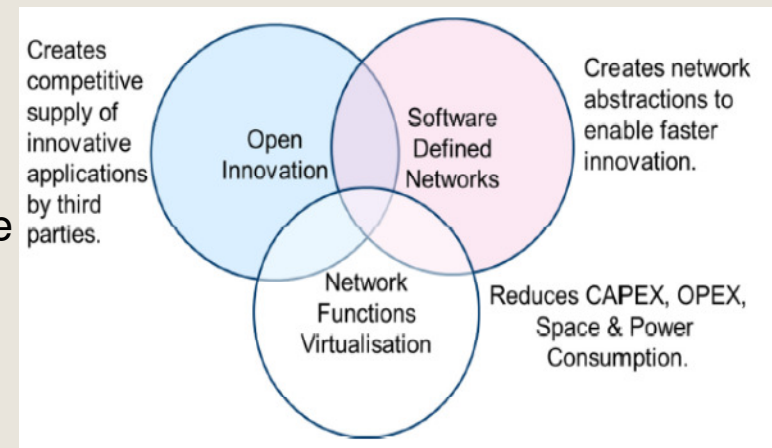


2. Software Defined Networking and Network Function Virtualization



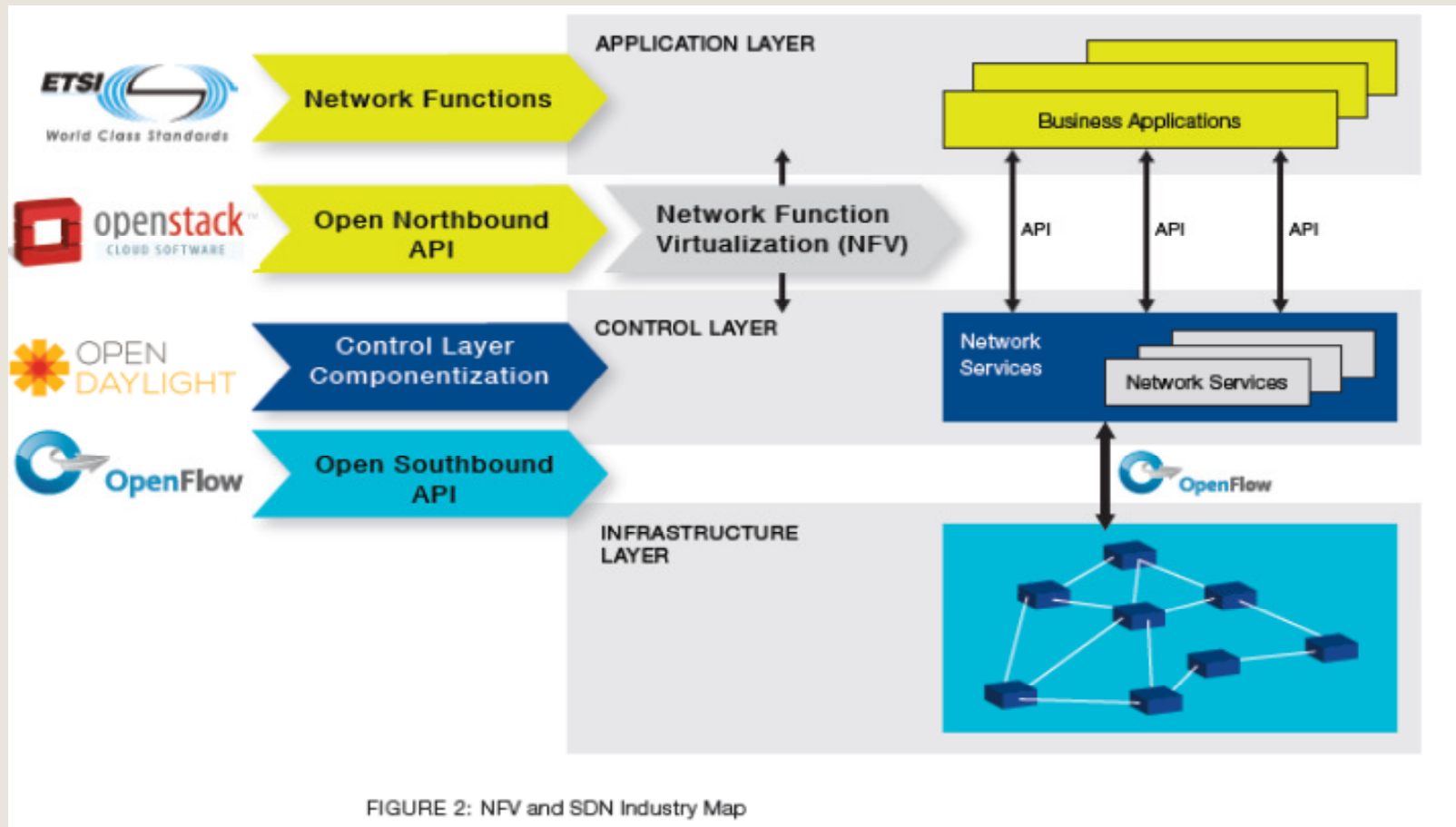
■ 2.3 NFV- SDN cooperation

- SDN/NFV : **complementary technologies**
 - Both build on the rapid evolution of IT and cloud technologies
- SDN features as:
 - separation CPI/DPI
 - ability to abstract and program network resources
- **fit nicely into the NFV paradigm** ⇒
 - SDN can play a significant role in the orchestration of the NFV Infrastructure resources (both physical and virtual) enabling : provisioning and configuration of network connectivity and bandwidth
 - automation of operations
 - security and policy control
- The SDN controller maps to the overall concept of network controller identified in the NFV architectural framework



2. Software Defined Networking and Network Function Virtualization

- **NFV SDN-Cooperation**
- ONF: NFV and SDN – industry view on architecture
- *Source: ONF*

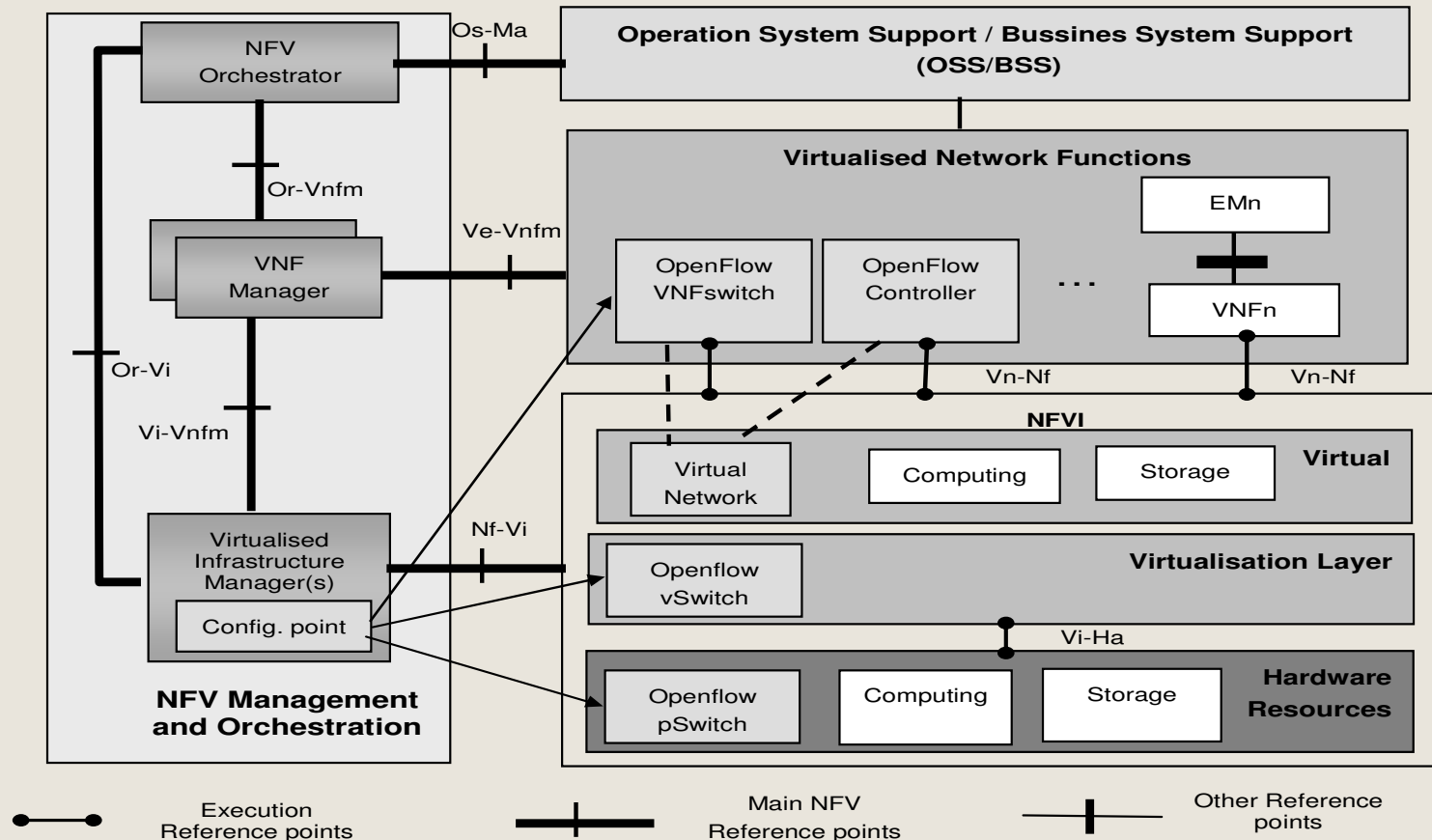


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2. Software Defined Networking and Network Function Virtualization (NFV)

- SDN and Network Function Virtualization

Source: "SDN and OpenFlow World Congress", Frankfurt, October 15-17, 2013





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3. Cloud Computing Architectures in 5G



- Cellular systems evolution towards 5G (cont'd)
 - CRAN Cloud Radio Access Networks- solution proposed for 5G
 - CRAN (interest from academia and industry)
 - large number of low-cost **Remote Radio Heads (RRHs)**, randomly deployed and connected to the **base band unit (BBU)** pool through the fronthaul links
 - **Advantages:**
 - **RRHs closer to the users** → higher system capacity, lower power consumption
 - the **baseband processing centralized at the BBU pool** → cooperative processing techniques to mitigate interferences
 - exploiting the resource pooling and statistical multiplexing gain → efficiency in both energy and cost
 - **Drawbacks:**
 - **the fronthaul constraints have great impact on worsening perf. of CRAN, and the scale size of RRHs**
 - accessing the same BBU pool is limited and could not be too large due to the implementation complexity
 - Note: many architectures are proposed by different mobile operators, manufactories, researching institutes → an unified CRAN for 5G is still not straightforward



3. Cloud Computing Architectures in 5G



- **Cellular systems evolution towards 5G (cont'd)**
 - **H-CRAN Heterogeneous Cloud Radio Access Networks**
 - HetNet
 - **Low Power Nodes (LPN)** (e.g., pico BS, femto BS, small BS , etc.) are key components to increase capacity in dense areas with high traffic demands.
 - **High power node (HPN)**, e.g., macro or micro BS) combined with LPN to form a HetNet
 - **Problem: too dense LPNs - >interferences, → need to control interferences**
 - Method : advanced DSP techniques
 - **4G solution: The coordinated multi-point (CoMP)**
 - (-) in real networks because CoMP performance gain depends heavily on the backhaul constraints
 - **Conclusion: cooperative processing capabilities is needed in the practical evolution of HetNets**



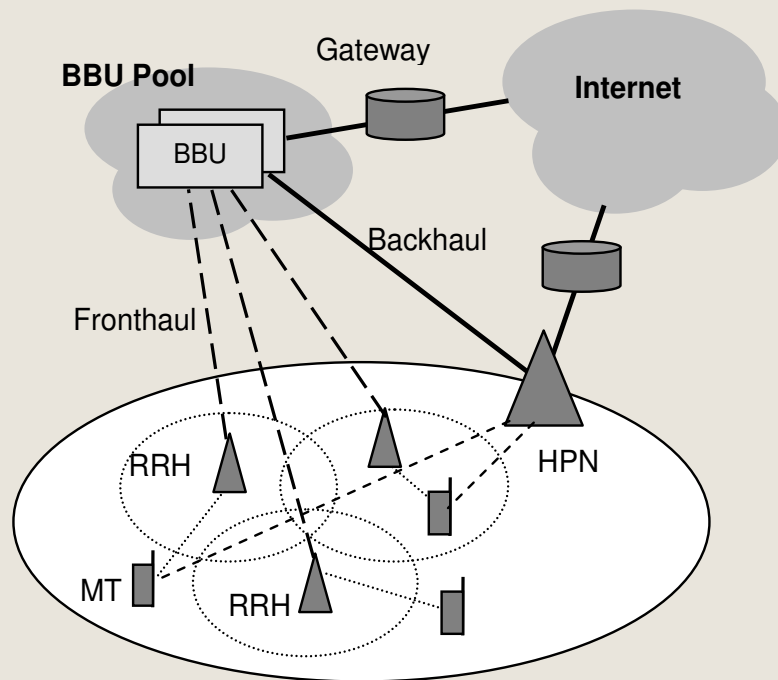
3. Cloud Computing Architectures in 5G



■ H-CRAN (cont'd)

- Notes:
 - In 1G, 2G, 3G: cooperative processing is not needed ← the inter-cell interference can be avoided by utilizing static frequency planning or CDMA
 - 4G - OFDM-based: **intercell interference is severe** → intercell or inter-tier cooperative processing through CoMP is critical
- **H-CRAN-based 5G system**
 - **Cloud computing based cooperative processing and networking techniques** are proposed to tackle the 4G challenges **alleviating inter-tier interference and improving cooperative processing gains**
 - the HPNs are enhanced with massive multiple antenna techniques and simplify LPNs through **connecting them to a “signal processing cloud” with high speed optical fibers**
 - The **baseband datapath processing + LPNs radio resource control** are moved to **the cloud server**
 - cloud computing based cooperation processing and networking gains are fully exploited
 - operating expenses are lowered
 - energy consumptions of the wireless infrastructure are decreased

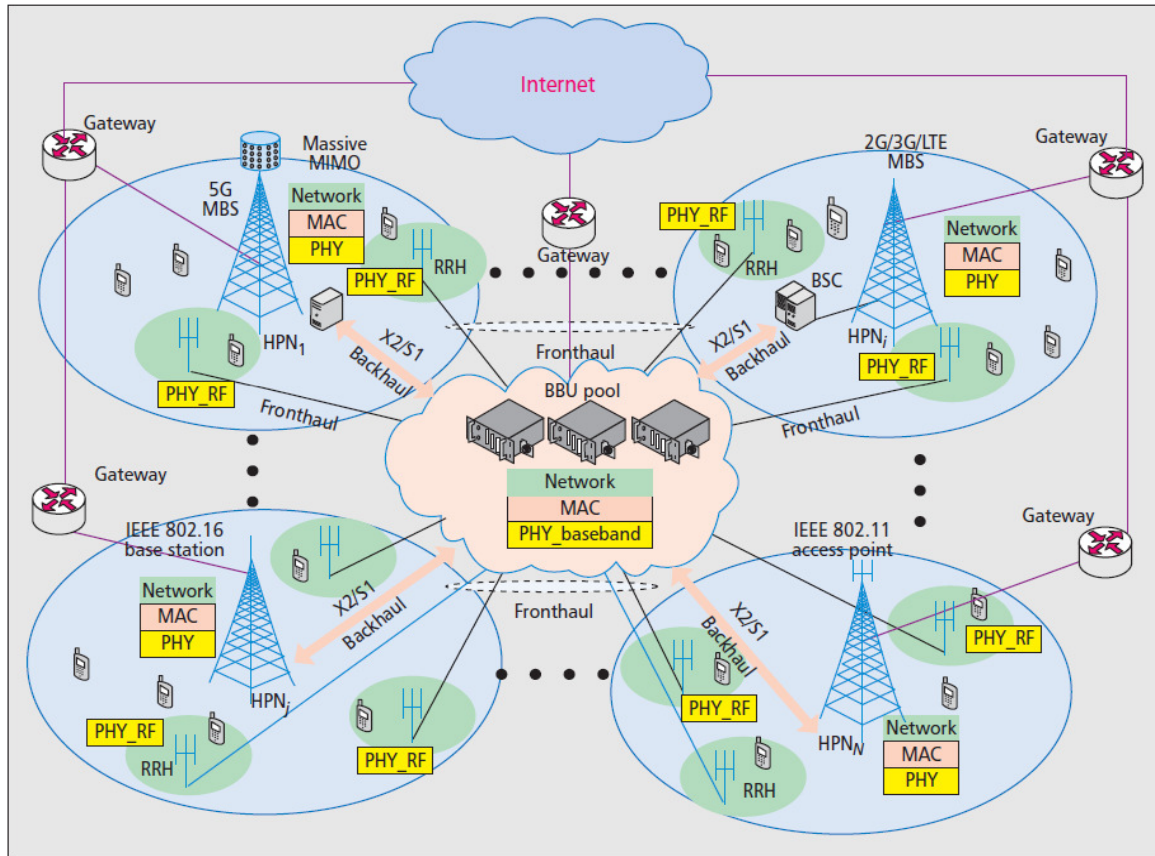
- **5G System Architecture in H-CRAN approach**
- Simplified H-CRAN architecture



RRH – Remote Radio Head;
 HPN – High Power Node
 LPN- Low Power Node
 BBU- baseband (processing) unit

RRHs include only partial PHY functions ;
 The model with these partial functionalities is denoted as PHY_RF

5G System Architecture in H-CRAN approach



RRH – Remote Radio Head;
X2/S1 – 3G imported interfaces
HPN – High Power Node
LPN- Low Power Node
BBU- baseband (processing) unit
BSC- Base Station Controller (2G/3G)
MIMO – Multiple Inputs – Multiple Outputs
LTE – Long Term Evolution (4G)

Source: M. Peng, et al., "Heterogeneous cloud radio access networks: a new perspective for enhancing spectral and energy efficiencies," *IEEE Wireless Commun.*, Dec. 2014

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3. Cloud Computing Architectures in 5G



- **Cellular systems evolution towards 5G (cont'd)**
 - **5G HetNet Solution (details)**
 - **Increase the capacity of cellular networks in dense areas with high traffic demands**
 - Key components in **HetNets: Low Power Nodes (LPN)** which serve for the pure “data-only” service with high capacity
 - **Advantages:**
 - **HetNets decouples the control plane and user plane**
 - LPNs only have a very simple control plane, while the control channel overhead and cell-specific reference signals of LPNs can be fully shifted to **Macro Base Stations (MBSs)**
 - **Drawbacks:**
 - **an underlaid structure that MBSs and LPNs reuse the same spectral resources → severe inter-tier interferences**
 - it is critical to suppress interferences through advanced DSP by adopting the advanced **Coordinated Multi-point (CoMP)** transmission and reception technique to suppress both intra-tier and inter-tier interferences.



3. Cloud Computing Architectures in 5G



■ H-CRAN (cont'd)

■ H-CRAN-based 5G system (details)

- **The RRHs : relay** (by compressing and forwarding) the received signals from UEs to the **centralized baseband unit (BBU)** pool through the wired/wireless fronthaul links
 - There is a **high number of RRH** with low energy consumption
 - Perform only the front RF and simple symbol processing
 - Other important baseband PHY processing and procedures of the upper layers are **executed jointly in the BBU pool**
- **The joint decompression and decoding are executed in the BBU pool**
- HPNs are still critical in C-RANs to
 - guarantee **backward compatibility** with the existing cellular systems
 - support **seamless coverage** since RRHs are mainly deployed to provide high capacity in special zones
- The HPNs, help the **convergence of** multiple **heterogeneous radio networks**
 - **all system control signaling is delivered wherein.**

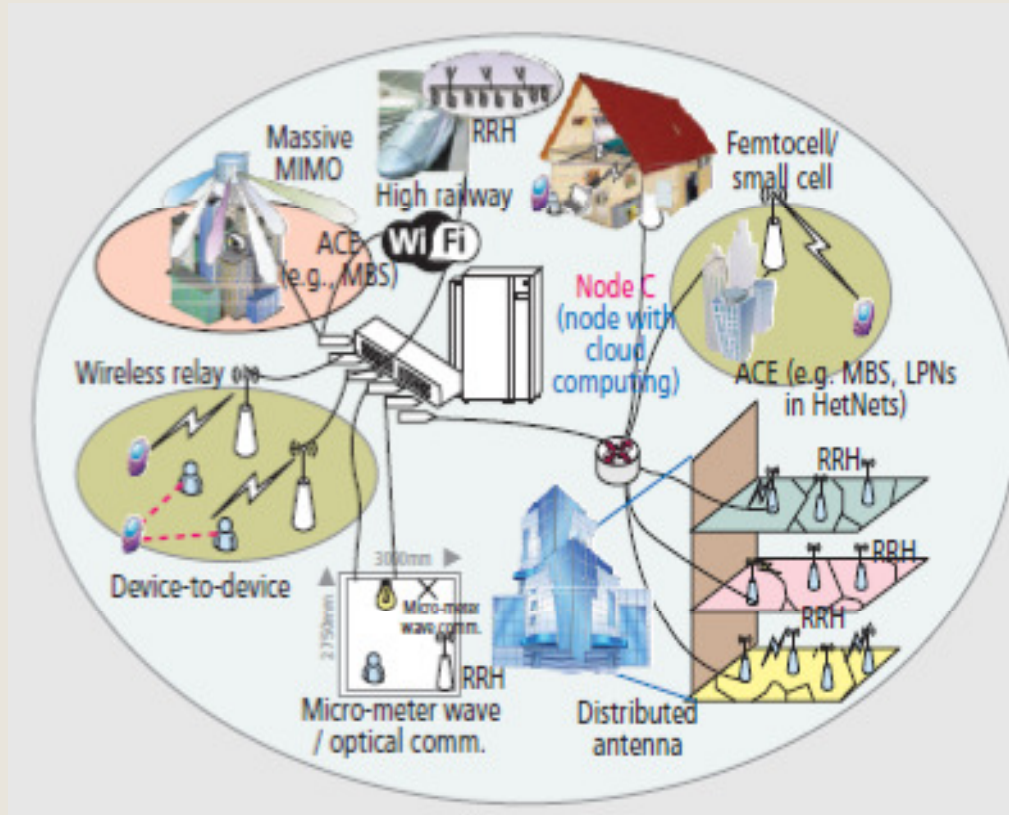


3. Cloud Computing Architectures in 5G



- **5G System Architecture in H-CRAN approach (cont'd)**
 - The I/Fs :[**BBU pool – HPNs**] → **mitigate the cross-tier interference** RRHs - HPNs through centralized CC-based cooperative processing techniques.
 - The data and control I/F (BBU pool – HPNs) are S1 and X2, respectively
 - **H-CRAN supported services: voice and data**
 - voice service admin - HPNs
 - high data packet traffic is mainly served by RRHs.
 - Participation of HPNs → H-CRAN alleviates the front-haul requirements
 - The control signaling and data symbols are decoupled in H-CRANs.
 - Favours a SDN-like approach
 - **All control signaling and system broadcasting data are delivered by HPNs to UEs**
 - which simplifies the capacity and time delay constraints in the (BBU pool – RRHs) fronthaul links
 - and makes RRHs active or sleep efficiently to decrease energy consumption
 - burst traffic or instant messaging service with a small amount of data can be supported efficiently by HPNs

- 5G System Components in H-CRAN approach



Cloud computing technologies → on_demand resource processing, storage, and network capacity wherever needed

Software-defined air interfaces and networking technologies are integrated → the flexibility to create new services and applications

RRH – Remote Radio Head;
 ACE - Ancestral Communication Entity i.e. :
 MBSs, micro BSs, pico BSs, etc.)
 HPN – High Power Node
 MIMO – Multiple Inputs –Multiple Outputs

Source: M. Peng et al., "System Architecture and Key Technologies for 5G Heterogeneous Cloud Radio Access Networks," *IEEE, Network*, vol. 29, no. 2, Mar. 2015, pp. 6–14.

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3. Cloud Computing Architectures in 5G



- **5G System Components in H-CRAN approach**
- **H-CRANs uses CC + heterogeneous convergence technologies**
- **New entity Node C (Node with CC)**
 - ~ to 3GPP BS evolution
 - has to converge different RANs for comm. entities (ACEs, i.e. MBSs, micro BSs, pico BSs, etc.)
 - processing and network functionalities in the PHY and upper layers for the newly designed RRHs
- **1. Node C works to converge ACEs**, it is ~ convergence GW, to execute:
 - the cooperative **multiple-radio resource managements** (CM-RRM)
 - **media independent handover (MIH)** functionalities
 - Can play role of **of traditional (RNC)** and BS controller (BSC)
- **2. Node C is used to manage RRHs**: it acts as the BBU pool, which is inherited from CRANs.
- Node C has powerful computing capabilities to execute large scale cooperative:
 - signal processing in the PHY
 - networking in the upper layers
- **RRHs mainly provide high speed data transmission** ; no CPI in hot spots
 - The control channel overhead and cell specific reference signals for the whole H-CRAN are delivered by ACEs.
 - UEs nearer to ACEs than RRHs are served by ACEs and called HUEs



3. Cloud Computing Architectures in 5G



- **5G System Components in H-CRAN approach**
- **5G H-CRAN = UEs, H-CRAN, and IoTs (details)**
 - Three architectural Planes:
 - **User/Data Plane (U)** carries the actual user traffic, related traffic processing
 - **Control Plane (C)** - control sgn. and resource allocation and traffic processing to improve SE and EE.
 - **Management Plane (M)**
 - administration and operation,
 - add/delete/update/modify the logic and interactions for the U and the C
 - **The H-CRAN architecture is software defined; it has attributes of SDN and CC**
 - overall system components – heterogeneous set:
 - User Equipments, IoT Devices
 - Network infrastructure – different technologies (MBS, microBS, picoBS, Access Points, Routers, etc.
 - Node C can play also the SDN controller role
 - **Applications (on top of SDN logical infrastructure)**
 - Management plane:
 - Self-organizing : Minimum drive test, Inter and Intra network SON
 - Resource cloudification: Cell association, user-centric scheduling, power control, load/handover control
 - Control plane: Cognitive processing: Underlaid, overlaid, hybrid
 - User Plane: Big data mining, Machine learning, traffic-driven and user-centric optimization

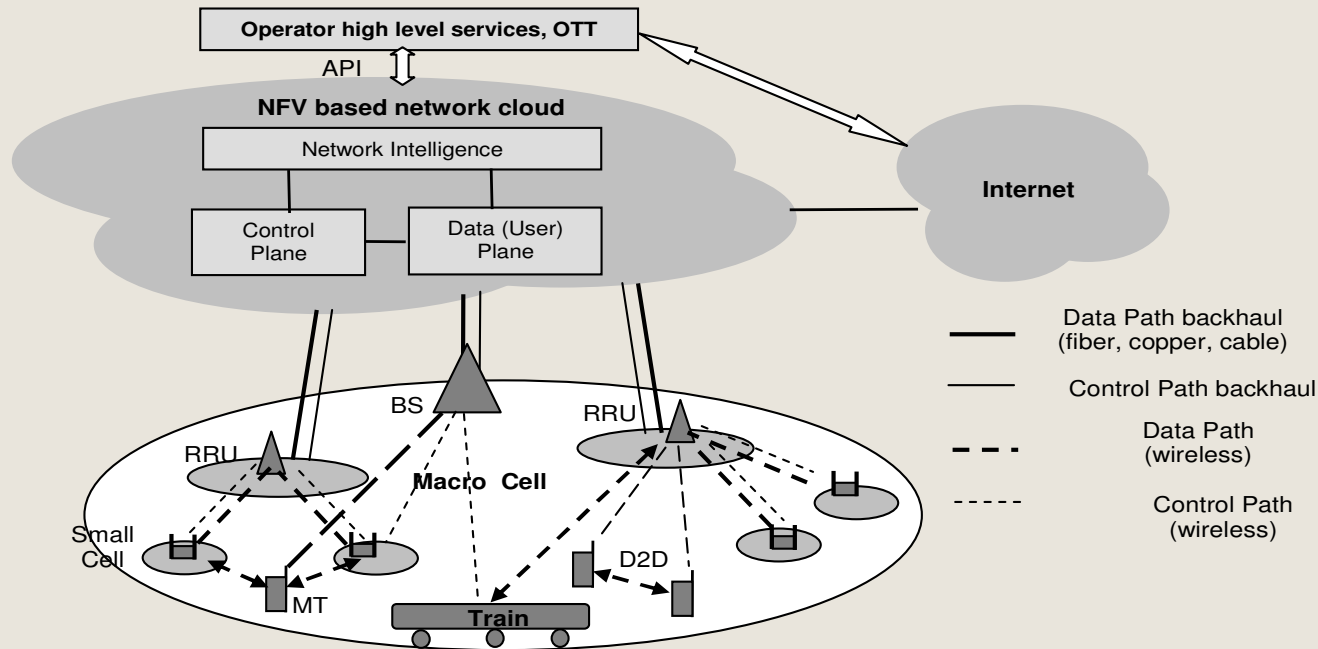


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■ Example 1: 5G network generic architecture [*]



RRU –Remote Radio Unit; D2D – Network controlled Device to Device;
 MTC – Machine type Communication; OTT- Over the Top; MT – Mobile Terminal;
 NFV- Network Function Virtualisation; API- Application Programmer Interface

[*] See Ref. : Agyapong P.K., Iwamura M., Staehle D., Kiess W., Benjebbour A. ' Design Considerations for a 5G Network Architecture'. *IEEE Communications Magazine*, November 2014, pp. 65-75



4. SDN and NFV in 5G



- **Example 1: 5G network generic architecture – details**
 - **Two logical network layers**
 - **Network cloud** - higher layer functionalities (different functions could be dynamically instantiated and scaled based on SDN/NFV)
 - **Radio Network (RN)** - a minimum set of lower layers L1/L2 functionalities
 - **Three main design concepts integrated:**
 - **NFV and SDN** with control/user plane split, to provide flexible deployment and management/operation;
 - **ultra-dense small cell deployments** (licensed/unlicensed spectrum), to support high capacity and data rate challenges
 - **the network data are used in the cloud**, to optimise resources usage and for QoS provisioning and planning.



4. SDN and NFV in 5G



- **Example 1: 5G network generic architecture – details (cont'd)**
 - **Characteristics/design solutions**
 - A redesigned stack integrates *Access Stratum (AS)* and *Non Access Stratum (NAS)*.
 - Splitting the Control/User (data) planes and using different frequency bands for coverage and capacity.
 - **Relaying and nesting configuration** - in order to support multiple devices, group mobility, and nomadic hotspots.
 - The **network intelligence is data-driven**, to optimise of the network resource planning and usage.
 - **Connectionless and contention-based access** is proposed with new waveforms for asynchronous access of massive numbers of *machine-type communications (MTC)*
 - connected cars, connected homes, moving robots, and sensors



4. SDN and NFV in 5G



- **Example 1: 5G network generic architecture – details (cont'd)**
 - **Characteristics/design solutions (cont'd)**
 - The NFV based network cloud is split into CPI and DPI (following the SDN principle) and a '*network intelligence- NI*' layer could be put on top of them.
 - **CPI** : mobility management, radio resource control, NAS-AS integration and security functions (e.g. authentication, etc.)
 - **DPI** (User Plane) assures the data flow paths between different RANs and to/from Internet.
 - e.g. gateway functions, data processing functions, mobility anchors, security control on the air interface, etc.
 - **NI**: services orchestration (traffic optimisation, QoS provisioning, caching control, etc.)
 - It can analyse the big data collected from the different components (core, RAN) and infer appropriate actions



4. SDN and NFV in 5G



- **Example 1: 5G network generic architecture – details (cont'd)**
 - **Characteristics/design solutions (cont'd)**
 - CPI and DPI instances can be seen as “data centers” having high amount of resources.
 - Each data centre can control one or several macrocells and/or RRUs
 - The DPI and CPL entities could be located close to BSs and also to RRUs, if some latency- critical services requirements should be met
 - The operator can deploy both large and small data centres to support specific service needs
 - BSs are more simple and more energy-efficient w.r.t. conventional 4G case



4. SDN and NFV in 5G



- **Example 1: 5G network generic architecture – details (cont'd)**
 - **Characteristics/solutions (cont'd)**
 - The network cloud allows for resource pooling, reducing over-provisioning and under-utilisation of network resources.
 - **SDN + NFV** -> dynamic deployment and scaling on demand of network functions.
 - the local data centres can borrow resources from each other (when traffic load is low)
 - they also can be enriched (installing new software) to support other apps
 - the cloud-computing model flexibility is present in the network cloud
 - **Open issue: decision on balancing between different allocation of functions and specifically how to incorporate small cells with NFV and SDN in a cost effective manner use in small cells in different frequency regimes**



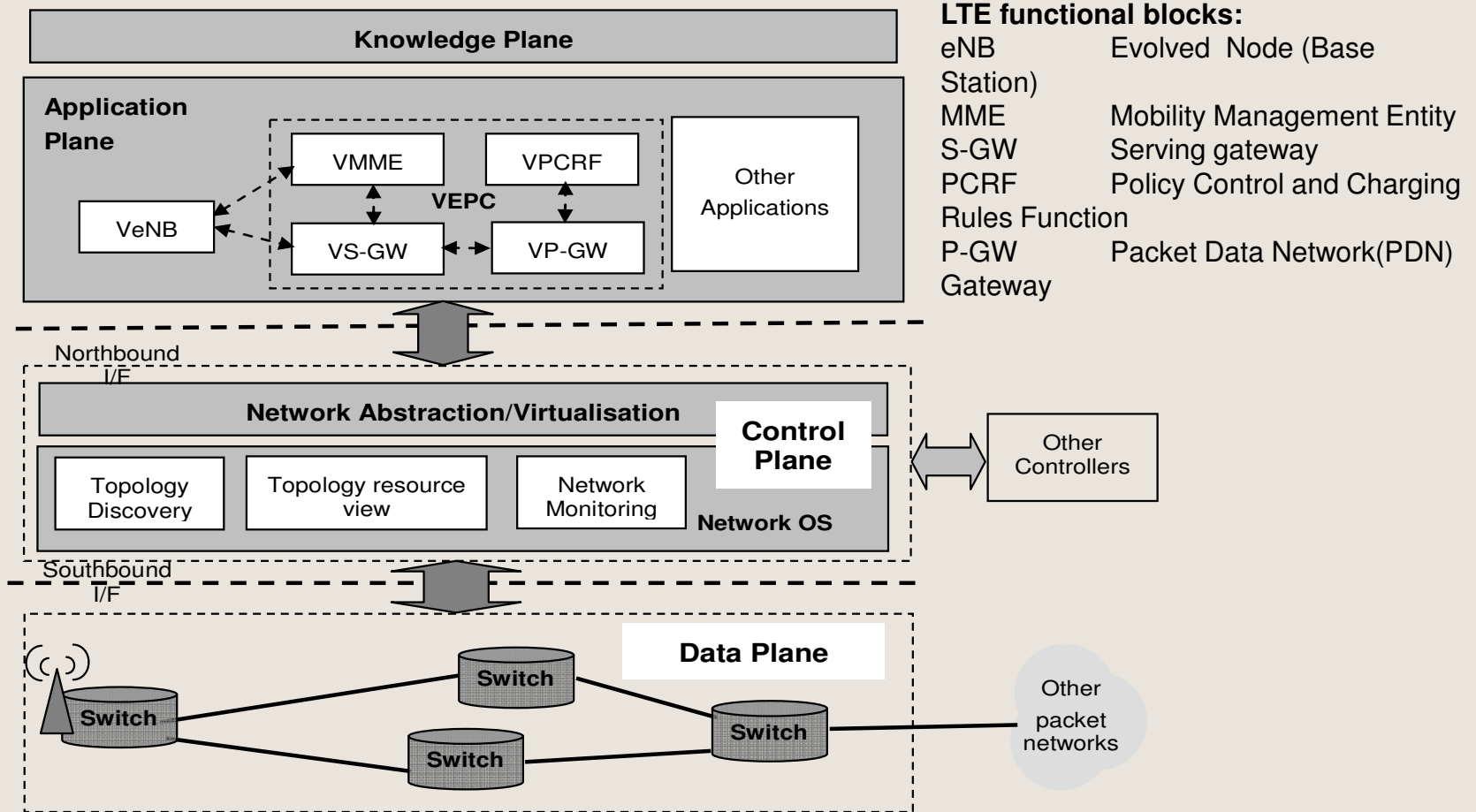
4. SDN and NFV in 5G



- **Example 2: Cellular SDN architecture (CSDN) [*]**
 - **CSDN is using the SDN and NFV principles**
 - **Goal** : to optimise the dynamic resource orchestration, by performing real-time context data gathering, analysis and then making intelligent decisions.
 - CSDN :forwarding, control, and network application **architectural planes**
 - The network and user information are collected from the mobile edge networks
 - used locally, or exported/ shared to other service providers, to enrich the set of services
 - A novel **Knowledge Plane** is added
 - to cooperate with network application plane
 - → **Mobile Services Provider (MSP)** can construct an intelligent vision upon its network and users' environment
 - New apps. or virtual functions can be implemented and instantiated
 - (e.g., optimised content distribution and caching, *Internet of Things (IoT)*, location based services, etc.)
 - and linked to the controller northbound interface

[*] Source ref.: Bradai A., Singh K., Ahmed T., and Rasheed T., 'Cellular Software Defined Networking: A framework'. *EEE Communications Magazine — Communications Standards Supplement*, June 2015, pp. 36-43

■ **Example 2: Cellular SDN architecture (CSDN) ([*])**



LTE functional blocks:

- eNB Evolved Node (Base Station)
- MME Mobility Management Entity
- S-GW Serving gateway
- PCRF Policy Control and Charging Rules Function
- P-GW Packet Data Network(PDN) Gateway

[*] Source ref.: Bradai A., Singh K., Ahmed T., and Rasheed T., 'Cellular Software Defined Networking: A framework'. *EEE Communications Magazine — Communications Standards Supplement*, June 2015, pp. 36-43



4. SDN and NFV in 5G



- **Example 2: Cellular SDN architecture (CSDN) – details**
 - The CSDN example is oriented towards the 4G LTE:
 - several functions can be implemented as VNFs at the CSDN application level, in a centralised cloud-based infrastructure
 - The sub-systems included in the architecture :
 - LTE Evolved Packet Core (EPC) and eNodeB (eNB)
 - The LTE virtualised network functionalities interact at the M&C level with the CSDN switches via the controller
 - **Data plane :**
 - CSDN switches of the ePC and its boundary is placed at the eNB
 - switches corresponding respectively to eNBs, Serving Gateway (S-GW) and Packet Data Network Gateway (P-GW)
 - Main **Control Plane** component: *Network Operating System (NOS)* and an abstraction/virtualisation layer



4. SDN and NFV in 5G



- **Example 2: Cellular SDN architecture (CSDN) – details**
 - Control Plane (CPI) SDN interfaces:
 - north I/F - to the Application Plane, south I/F to the DPI and east-west I/F towards other controllers.
 - **Virtual network functions (VNF)** are defined in the Application Plane, to execute the functions of UTRAN and EPC
 - VNFs, named **VeNB**, **Virtual Mobility Management Entity (VMME)** **VS-GW**, **VP-GW** and **Virtual Policy Control and Charging Rules Function (VPCRF)**,
 - + their corresponding switches in DPI (e.g. VeNB plus its CSDN switch correspond to eNB functionalities), perform the equivalent of LTE UTRAN and EPC functionalities
 - Other applications could be added to the Application Plane
 - **Open issues:**
 - wireless network, high number of users, scarce radio resources → fast real time response is required
 - **centralising all functions in the SDN controller is not scalable**
 - **further study for functions allocation balancing between a switch and a controller**



4. SDN and NFV in 5G



- **Example 2: Cellular SDN architecture (CSDN) – details**
 - **Open issues (cont'd)**
 - **How many controllers? One/several controller(s) per which network zone?**
 - Large networks -> need several controllers
 - How to distribute them geographically?
 - The controller placement multi-criteria problem is a NP-hard one...
 - maximize the controller-forwarder or inter-controller communication throughput
 - limit the controller overload (load imbalance)
 - fast recovery after failures (controllers, links, nodes).
 - **Data Plane:** Transforming the LTE specific functionalities in packet flow rules specific to SDN
 - **Real time response of the VMME ?**



4. SDN and NFV in 5G

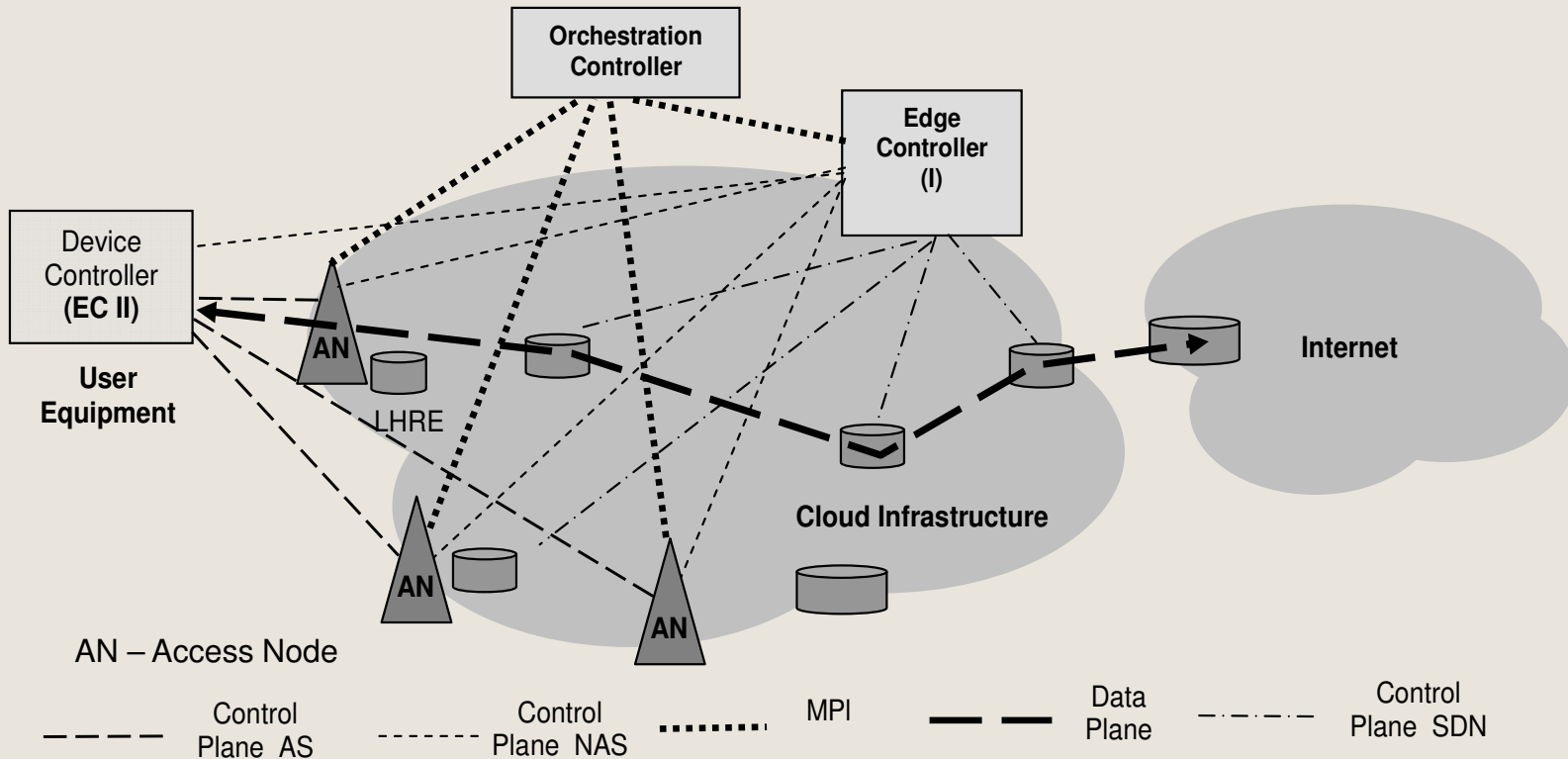


- **Example 3: 5G unified Control Plane and Data Plane [*]**
- 5G architecture based on **SDN, NFV and edge computing**
- **Three control levels: Device, Edge and Orchestration Controllers**,
 - fully decoupled from the DPI and implementing a unified security, connection, mobility and routing management for 5G networks
- The solution is **backward compatible to 3GPP** releases
 - SDN-based connectivity between VNFs (applications) enables carrier grade communication paths, by avoiding tunnelling
 - low E2E latency → appropriate for mission critical communications
 - flexible, reliable and dependable
- Implementation variants: *'centralised'* or *'distributed at the edge'*, depending on functional and non functional requirements of the supported services
- CPI and DPI logical network elements are decomposed into sets of applications or modules
 - modules can be dynamically instantiated in the cloud infrastructure according to network operation or service requirements.

[] Guerzoni R., Trivisonno R., Soldani D. 'SDN-Based Architecture and Procedures for 5G Networks'. 5GU 2014, November 26-27, Levi, Finland, DOI 10.4108/icst.5gu.2014.258052*

DataSys 2016 Conference May 22, 2016 Valencia, Spain

- Example 3: The 5G unified Control Plane and Data Plane [*]



AS – Access Stratum; NAS Non-Access Stratum; MPI – Management Plane; LHRE- Last Hop Routing Element

[*] Guerzoni R., Trivisonno R., Soldani D. 'SDN-Based Architecture and Procedures for 5G Networks'. 5GU 2014, November 26-27, Levi, Finland, DOI 10.4108/icst.5gu.2014.258052



4. SDN and NFV in 5G



- **Example 3: The 5G unified Control Plane and Data Plane – details**
- The *Device Controller (DC)* (located in the device) controls the PHY layer connectivity to the 5G network and handles AS functions such as access/network selection.
- Two types of *EDGE Controllers, (EC, (i) and (ii))*, implementing
 - Network Access Control; Packet Routing and Transfer
 - Radio Resource Management
 - Mobility and Connection Management ; Security
- The EC has similar functions to the AS/NAS 4G functions in eNodeB and MME
- The EC implementation is distributed over the cloud infrastructure, being composed of several interconnected *Control Applications (C-Apps)*
 - Each C-App performs a subset of functions, like:
 - Radio Access (RA), Authorization & Authentication (AA)
 - Admission Control (AC), Flow Management (FM), Mobility Management (MM), Connection (Session) Management (CM), Security (Sec).



4. SDN and NFV in 5G



- **Example 3: The 5G unified Control Plane and Data Plane – details (cont'd)**
- To fully separate the DPI/CPI also on the radio link, the RA App is split respectively into RAD /RAC applications.
- The DPI could be instantiated on a different **Point of Presence (PoP)**
- For some mission critical communications, the mobile devices might be required to support some AS/NAS functions; that is why two types, i.e.,
 - EC (i) – with C-Apps instantiated in the edge cloud infrastructures and
 - EC(ii) - implemented temporarily or permanently on a mobile device.
- The **Orchestration Controller (OC)** modules :
 - **Resource Orchestration (RO)**
 - **Topology Management (TM)** - has network mgmt. functions (similar to those of 4G)
- OC coordinates the utilisation of cloud resources (computational, storage and networking), allocating and maintaining the resources, to instantiate CPI and DPI
 - RO allocates PHY resources to instantiate EC Control Apps. i.e., it determines the embedding solution for the virtual CPI and DPI to be instantiated



4. SDN and NFV in 5G



- **Example 3: The 5G unified Control Plane and Data Plane – details (cont'd)**
- Data Plane (DPI):
 - SDN clean-slate architecture has been adopted
 - It did not define neither dedicated DPI network elements (e.g., 4G SGW and PGW), nor unique logical elements (e.g. mobility anchor points)
- **Advantages of the architecture:**
 - **reconfigurability** - one can dynamically instantiate logical architectures, implementing network functions, services and corresponding states in the optimal location within the cloud infrastructure
 - No more need of tunnelling protocols (common in 3GPP) (lower fwd. latency)
 - latency of forwarding paths could be reduced to almost zero by pro-actively configuring the SDN-based infrastructure (thus realising the “always-on” concept already present in 4G EPC)
 - **The proposed architecture, functions and procedures have the potential to become an important candidate solution for 5G**



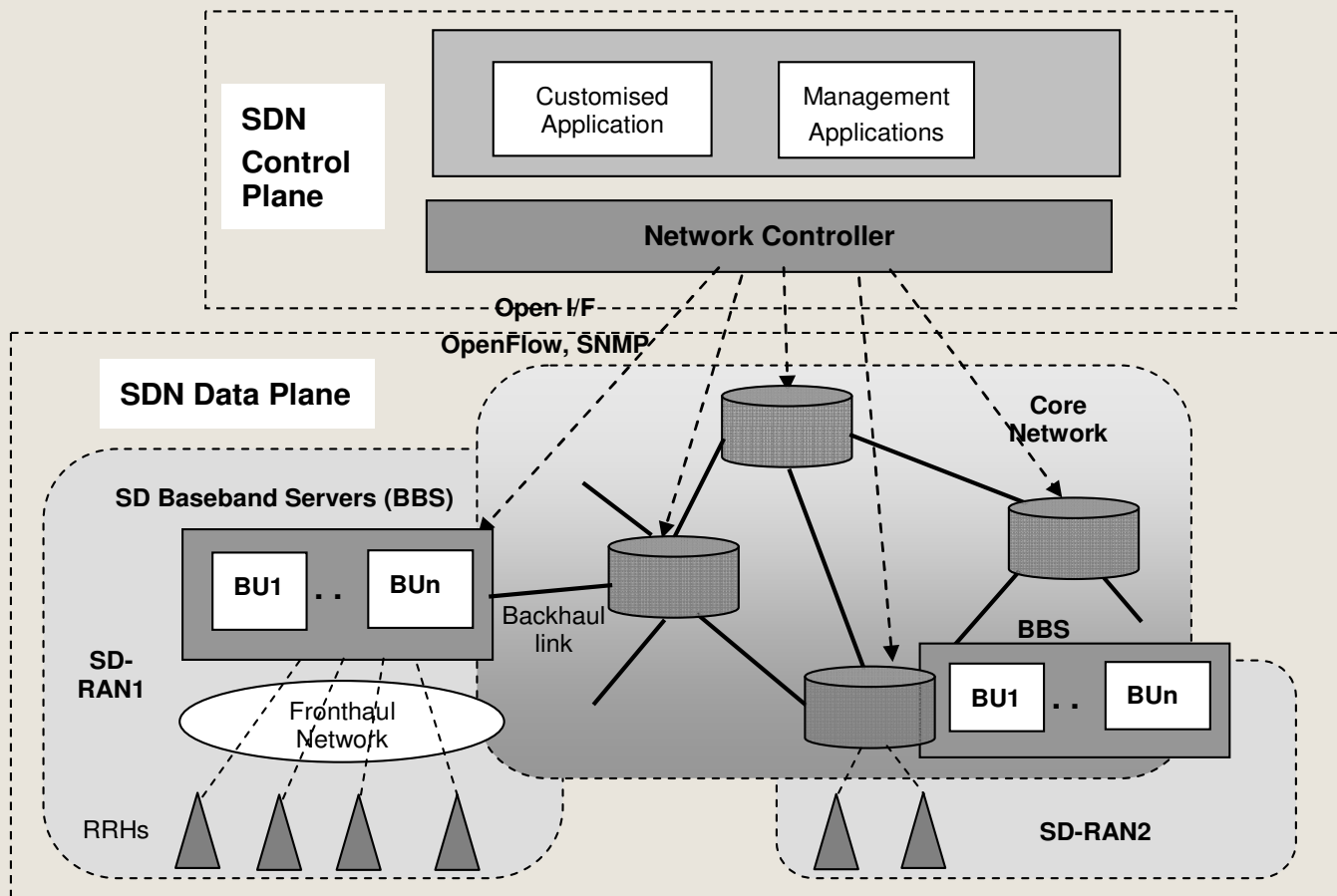
4. SDN and NFV in 5G



- **Example 4: SoftAir architecture ([*])**
- **SoftAir: a novel software-defined 5G architecture targeting NFV and cloudification and aiming to scalability, flexibility and resilience**
- Main characteristics: fine-grained BS decomposition, OpenFlow interfaces, mobility-aware control traffic balancing, resource-efficient network virtualisation, and traffic classification
- **SoftAir architecture : SDN Control Plane and Data Plane**
- DPI contains a complete network infrastructure: *Software Defined Core Network (SD-CN)* and *SD – Radio Access Network (SD-RAN)*
-
- The OpenFlow and SNMP protocols link the two planes
- SD-CN is composed by SD-switches, under CPI coordination

[*] Akyildiz I.F., Wang P., Lin S.C. 'SoftAir: A software defined networking architecture for 5G wireless systems', *Computer Networks* 85 (2015) pp.1–18.

- Example 4: Overall architecture of the SoftAir ([*])



Akyildiz I.F., Wang P., Lin S.C. 'SoftAir: A software defined networking architecture for 5G wireless systems', Computer Networks 85 (2015) pp.1–18.



4. SDN and NFV in 5G



- **Example 4: SoftAir architecture (cont'd)**
- SoftAir supports:
 - development of customised SDN applications, e.g., mobility management, QoS-based routing, billing policies, etc., in CPI
 - global management tools and network virtualization.
- Current field deployment have shown the SDN advantages (B4 - Google, SWAN - Microsoft, ADMCF - Huawei, etc.)
 - SD-CN can obtained important increase in link utilisation from 30–40 per cent to over 70 per cent
- Solutions for scalability (controller-to-[SD-CN] forwarders) communication
 - use of high performances controllers and/or
 - use multi-controller clusters and multi-threading technologies.
 - recent research : in large – scale SDN networks with in-band control channels, the controller-forwarder comm. delay can be minimised by using traffic balancing schemes, based on parallel optimisation theories.



4. SDN and NFV in 5G



- **Example 4: SoftAir architecture (cont'd)**
- SoftAir : mobility-aware and proactive control traffic balancing scheme, minimising the CPI-DPI delay by exploiting the SD-RAN mobile feature
 - the control traffic in SD-RAN is following some spatial and temporal patterns
- SoftAir supports:
- L1-L3 function virtualisation, performed in a distributed architecture
- The SD-BS is split into
 - hardware-only Radio Heads (RHs)
 - and software-implemented baseband units (these two components could be also remotely located).
- A fronthaul network (fiber/microwave) connects the *Remote Radio Heads (RRH)* to *Baseband processing Servers (BBS)* using standardised interfaces like
 - *Open Base Station Architecture Initiative (OBSAI)*
 - or *Common Public Radio Interface (CPRI)*
- Current standardisation effort Std.entities + industry to make the RRH-BBS technology independent.



4. SDN and NFV in 5G



- **Example 4: SoftAir architecture (cont'd)**
- SoftAir SD-RAN has some similarities to CRAN Architecture
- CRAN
 - focused on high-performance computing of baseband processing functions (mostly for L1 operations) at remote servers or data centers
 - (-) : **CRAN cannot achieve scalable PHY/MAC-layer cloudification and does not support network-layer cloudification as SD-CN does**
- SD-RAN
 - offers scalability, evolvability, and cooperativeness through fine-grained BS decomposition that overcomes fronthaul traffic burden
 - In SD-RANs partial baseband processing is done at the RRH (e.g., modem) while the remaining baseband functions (e.g., MIMO coding, source coding and MAC), are executed at the BBS



4. SDN and NFV in 5G



- **Example 4: SoftAir architecture (cont'd)**

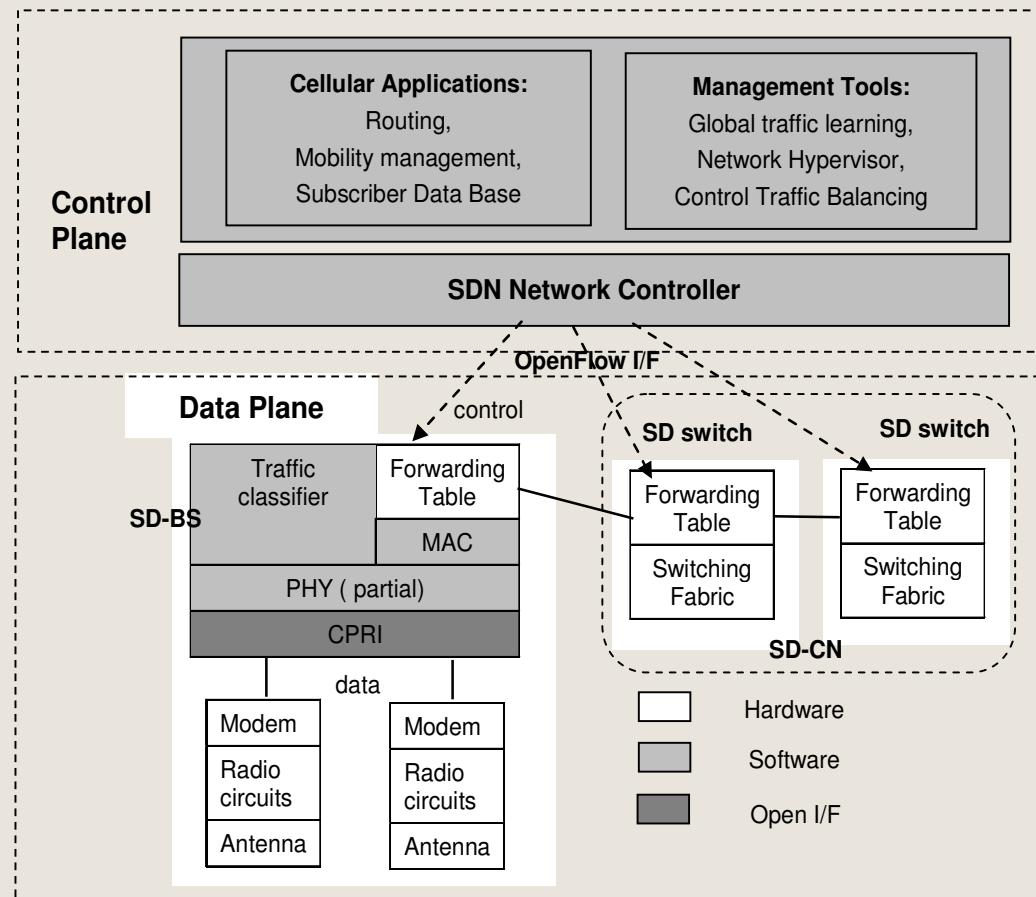
- **SoftAir functional split**
 - SD-RAN (has reduced data rate requirements) is scalable
 - It also can support cooperative gain
 - Is evolvable by allowing the aggregation of a large number of technology-evolving RRHs at BBS and CPRI-supported fronthaul solutions

 - BSs can be managed in SDN style via a unified interface, for different wireless standards (multi-technology capability)

 - Seamless vertical mobility is possible

 - **SoftAir network virtualisation**
 - multiple virtual networks (VNet) on the same PHY infrastructure
 - each VNet (slice) may independently adopt its L1/L2/L3 protocols
 - In SoftAir advanced solutions can be deployed on demand and dynamically allocated

- Example 3: Function cloudification in SoftAir system





4. SDN and NFV in 5G



- **Example 4: SoftAir architecture (cont'd)**
- The SoftAir NV enables a wide range of applications.
- Each *Mobile Virtual Network Operator (MVNO)* may use different wireless technologies (WiFi, WiMAX, LTE, small-cells, HetNets, etc.)
 - The virtual slices can be customised for different services and types of traffic flows - e.g., for QoS routing, E2E controlled performances, etc.
 - The slices isolation might accelerate the innovation, (in a slice, one can independently develop new protocols)
-
- SoftAir : **three types of hypervisors** (to realise virtualization):
 - high-level- network hypervisor
 - low-level
 - wireless hypervisors
 - switch hypervisors
- Thus SoftAir enables the E2E network virtualisation traversing both SD-RAN and SD-CN, realising a truly multi-service converged network infrastructure.



4. SDN and NFV in 5G



- **Example 4: SoftAir architecture (cont'd)**
- **SoftAir architecture advantages**
- RAN sharing - > CAPEX reduction
- Evolutionary adaptive arch. , due to DPI/CPI separation and DPI programmability
- SDN: DPI/CPI separation allows HW/SW infrastructures to evolve independently
 - For instance, novel RATs (e.g., mm-waves, full-duplex, massive MIMO, THz) can be adopted in hardware
 - CPI: Traffic engineering and network mgmt. optimisation solutions can be applied
- The cloud style and network virtualization creates possibility to offer **Infrastructure-as-a-Service (IaaS)** on top of the same physical network
 -
 - useful for emerging different network services, e.g., M2M, smart grid, MVNOs, OTT content services like Netflix video streaming, etc.



4. SDN and NFV in 5G



- **Example 4: SoftAir architecture (cont'd)**

- **SoftAir architecture advantages**
 - Distinct Service Providers (SP) can independently control, optimize, and customize the underlying infrastructure without owning it and without interfering with other SPs.

 - Network resources (e.g., spectrum), can be dynamically shared among SPs, e.g., Mobile Virtual Network Operators (MVNO)s.

 - A good spectral efficiency can be achieved, due to cooperativeness

 - Convergence of het-nets networks due to its open and technology-independent interfaces, → smooth transition among different RATs: WiFi, WiMAX, LTE, LTE-A, etc.



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6. Mobile Edge Computing
7. Open research topics
8. Conclusions



5. Fog Computing in 5G



- **Fog/Edge (FC) computing characteristics [*]:**
 - **Fog computing nodes (FCN)** are typically located away from the main cloud data centres, at the edge.
 - **Cloud computing on fog nodes** enables *low and predictable latency*
 - **FCNs**
 - are *wide-spread* and geographically available *in large numbers*
 - provide applications with *awareness of device geographical location* and device context.
 - *can cope with mobility of devices*
 - i.e. if a device moves far away from the current servicing FCN, the fog node can redirect the application on the mobile device to associate with a new application instance on a fog node that is now closer to the device.
 - *offer special services that may only be required in the IoT context* (e.g. translation between IP to non-IP transport)
 - Fog application code runs on FCNs as part of a distributed cloud application

[*] *Fog Computing and Mobile Edge Cloud Gain Momentum Open Fog Consortium, ETSI MEC and Cloudlets , Version 1.1 Guenter I. Klas Nov 22, 2015*



5. Fog Computing in 5G



- **Fog/Edge (FC) computing enabled applications [*]**
- **Data plane :**
 - **Pooling of clients idle computing/storage/bandwidth resources and local content**
 - **Content caching at the edge** and bandwidth management at home
 - **Client-driven distributed beam-forming**
 - **Client-to-client direct** communications (e.g., FlashLinQ, LTE Direct, WiFi, Direct, Air Drop)
 - **Cloudlets** (mobility-enhanced small-scale cloud data center located at the edge of the Internet) and micro data-centers
- **Control plane**
 - Over the Top (OTT) content management
 - **Fog-RAN: Fog driven radio access network**
 - **Client-based HetNets control**
 - Client-controlled Cloud storage
 - **Session management and signaling load at the edge**
 - Crowd-sensing inference of network states
 - Edge analytics and real-time stream-mining

[*] Source: M.Chiang, "Fog Networking: An Overview on Research Opportunities" December 2015, <https://arxiv.org/ftp/arxiv/papers/1601/1601.00835.pdf>



5. Fog Computing in 5G



- **FC provides**
 - light-weight cloud-like facility close of mobile users
 - users with a direct short-fat connection versus long-thin mobile cloud connection
 - customized and engaged location-aware services
- **FC is still new and there is lack of a standardized definition**
- **Comparison between Fog/Edge (FC) and Conventional Cloud Computing [*]:**

	Fog Computing	Cloud Computing
Target User	Mobile users	General Internet users.
Service Type	Limited localized information services related to specific deployment locations	Global information collected from world-wide
Hardware	Limited storage, compute power and wireless interface	Ample and scalable storage space and compute power
Distance to Users	In the physical proximity and communicate through single-hop wireless connection	Faraway from users and communicate through IP networks
Working Environment	Outdoor (streets, parklands, <i>etc.</i>) or indoor (restaurants, shopping malls, <i>etc.</i>)	Warehouse-size building with air conditioning systems
Deployment	Centralized or distributed in regional areas by local business (local telecommunication vendor, shopping mall retailer, <i>etc.</i>)	Centralized and maintained by Amazon, Google, <i>etc.</i>

[*] T H. Luan et.; al. , "Fog Computing: Focusing on Mobile Users at the Edge" [arXiv:1502.01815v3](https://arxiv.org/abs/1502.01815v3) [cs.NI] 30 Mar 2016



5. Fog Computing in 5G



■ C-RAN limitation in 5G context

- strong fronthaul network requirements (to access the centralised (BBU) pool)
- high bandwidth and low latency inter-connection fronthaul is necessary (expensive - in practice)

■ H-CRAN limitation in 5G context

▪ (+) H-CRAN solves some C-RAN problems

- user /data (DPI) and control planes (CPI) are decoupled
- in H-CRANs the centralized control function is shifted from the BBU pool (like in C-RANs) to the high power nodes HPN
- (HPNs) are mainly used to provide seamless coverage and CPI functions
- RRHs provide high speed data rate for DPI
- HPNs are connected to the BBU pool via the backhaul links for interference coordination

▪ (-) H-CRAN still has some challenges in practice

- popular location-based social applications → data traffic peaks over the fronthaul (RRHs <-->BBU pool) → high transient load for the fronthaul
- deploying of a high number of fixed RRHs and HPNs in H-CRANs to meet traffic peak requirements is not efficient (traffic is low for long time intervals)
- do not take full advantage of processing and storage capabilities in edge devices (e.g., RRHs and “smart” user equipments (UEs))



5. Fog Computing in 5G



- **Fog/Edge Computing in 5G context**
- extends the traditional cloud computing paradigm to the network edge
 - a high amount of storage, comm., control, configuration, measurement and management is performed at the network edge
- **collaboration radio signal processing (CRSP)** can not only be executed in H-CRANs centralized BBU pool, but also can be hosted at RRHs and even “smart” UEs
- UEs might download packets from closer points (UEs or RRHs)
- integration possibility of on-device processing and **cooperative radio resource management (CRRM)** on new types of “smart” UEs
- **Fog computing based RAN (F-RAN) architecture**
 - real-time CRSP and flexible CRRM at the edge devices
 - F-RANs can be adaptive to the dynamic traffic and radio environment
 - lower burden on the fronthaul and BBU pool
 - achievable user-centric objectives : adaptive technique among (D2D), wireless relay, distributed coordination, and large-scale centralized cooperation



5. Fog Computing in 5G



- **Fog/Edge Computing in 5G context**

- **Fog computing based RAN (F-RAN) architecture**
 - mobile FC and edge cloud can offer new services for information sciences and Internet of Things (IoT)
 - design of mobile fog as a programming model for large-scale, latency sensitive applications in the IoT
 - **FC in 5G environments- open research issue**

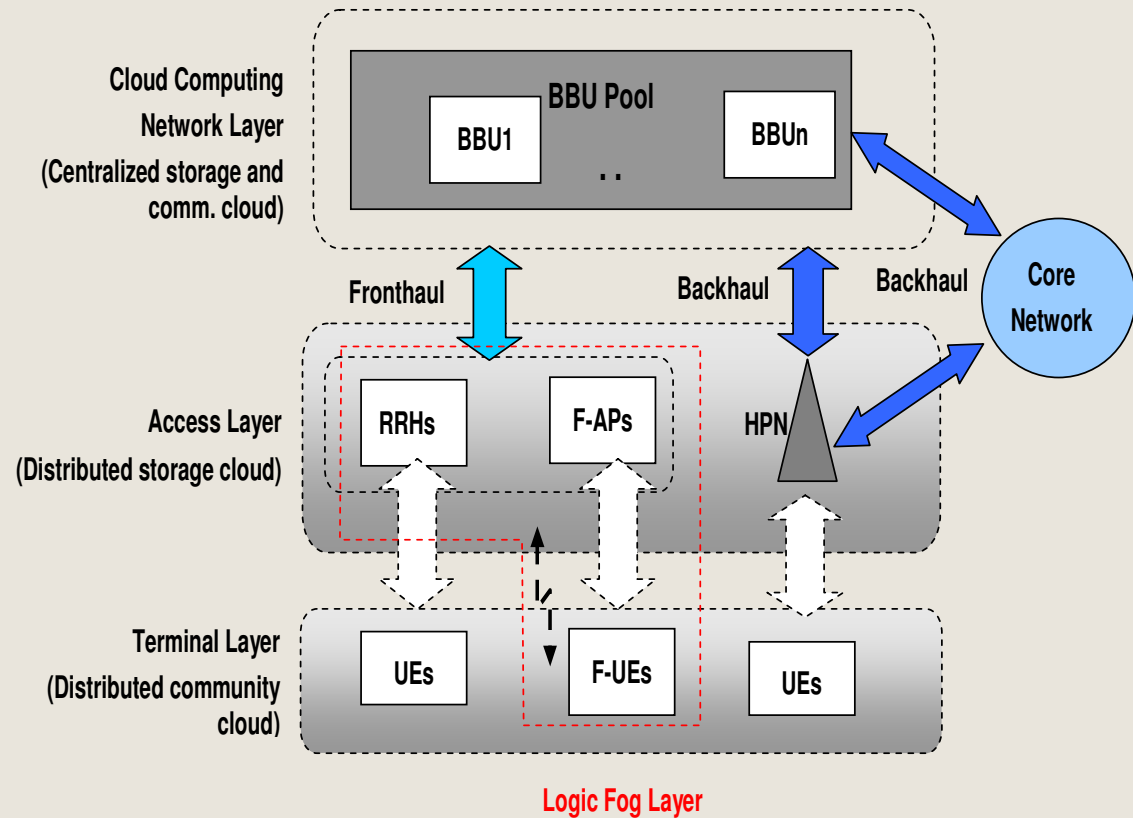
- **F-RAN architectures**
 - **three layers: cloud computing, network access and terminal layer**
 - F-RAN takes full advantages of the convergence of cloud computing, heterogeneous networking, and fog computing

 - The FC network is actually composed of
 - **F-APs** (residing in the network access layer) and
 - **F-UEs** (placed in the terminal layer)
 - F-UEs can inter-communicate (direct D2D mode or through additional F-UEs playing the role of mobile relays)
 - The network access layer is composed by F-APs, HPNs and RRHs

- F-RAN simplified architecture**

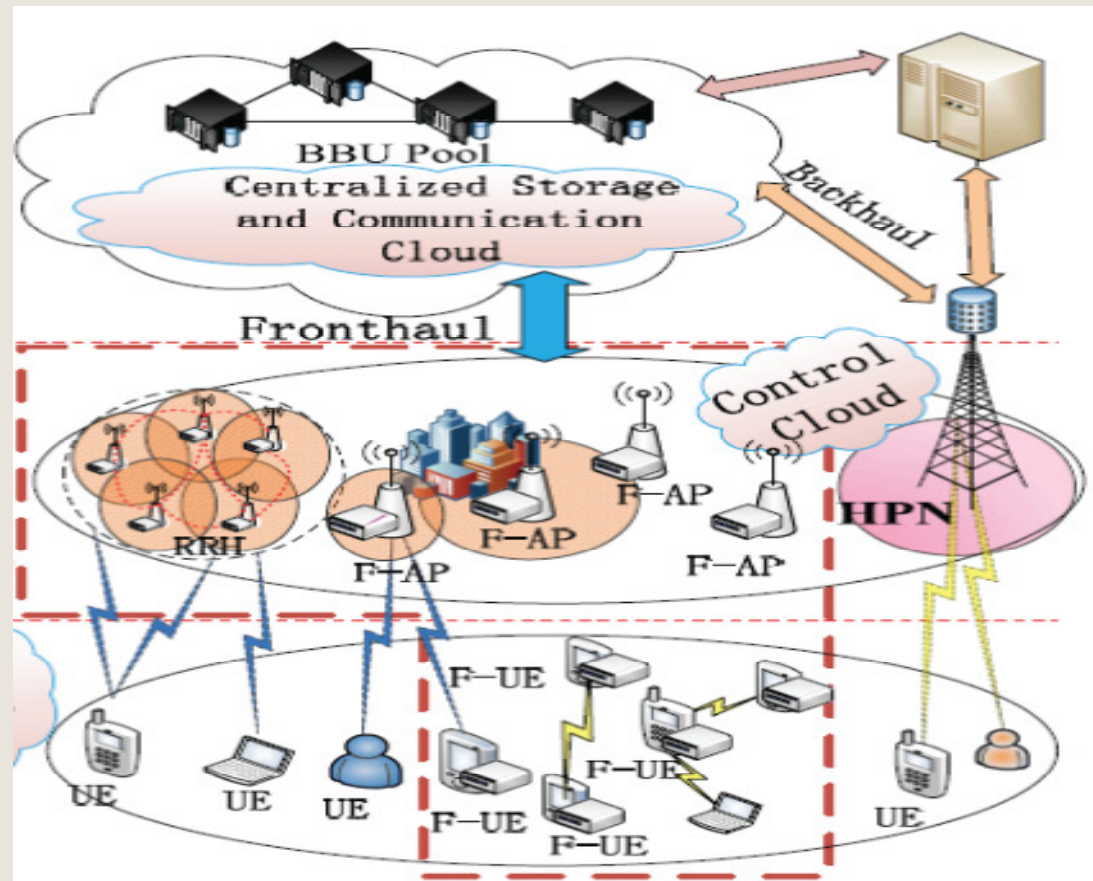
BBU – BaseBand Unit
 F-AP Fog Access Point
 RRH – Remote Radio Head
 HPN – High Power Node
 (Base Station)

 F-UE Fog capable user
 equipment



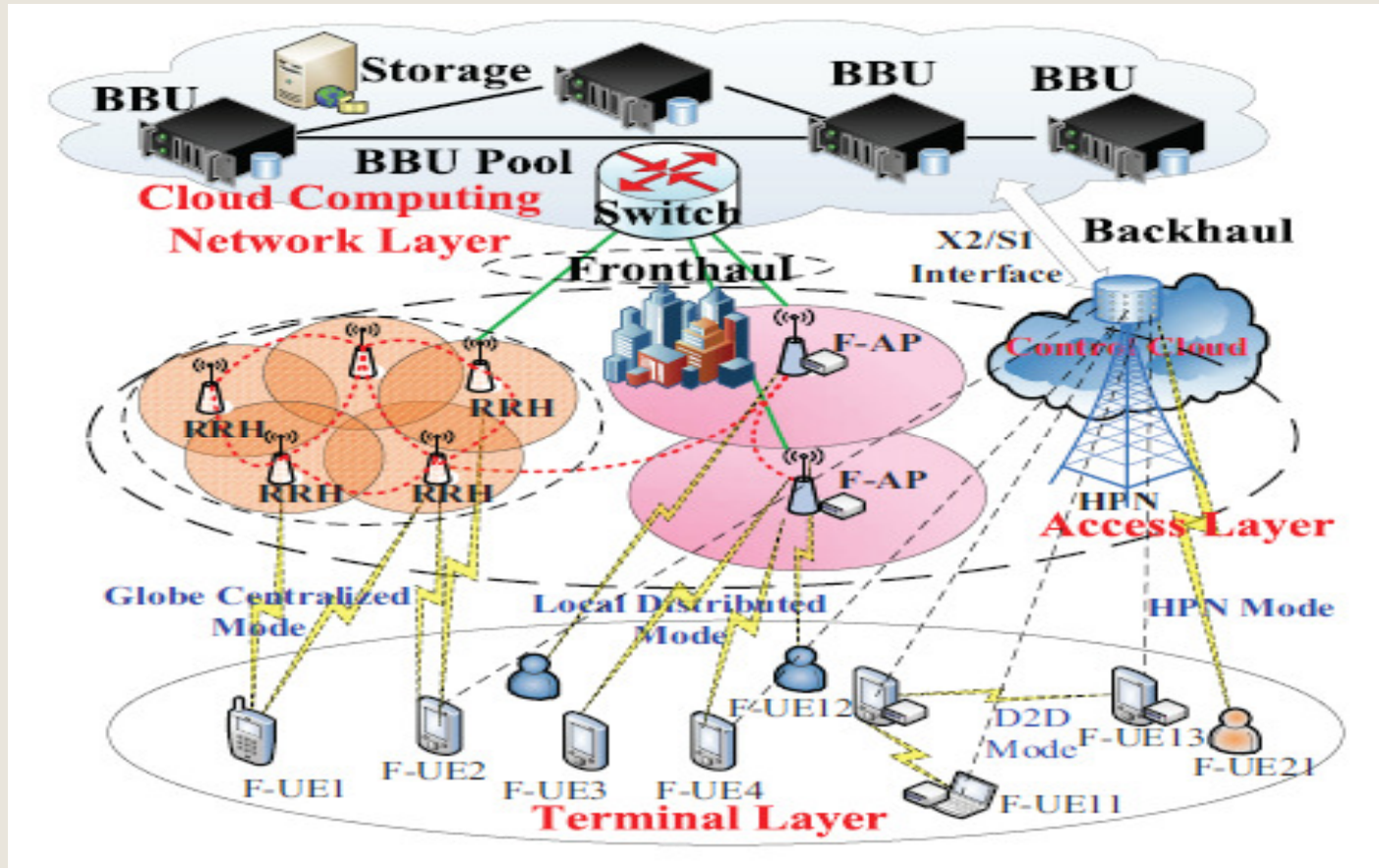
- F-RAN architecture- example

BBU – BaseBand Unit
 F-AP Fog Access Point
 RRH – Remote Radio Head
 HPN – High Power Node
 (Base Station)
 F-UE Fog capable user
 equipment



Source: M.Peng,S.Yan, K.Zhang, and C.Wang, "Fog Computing based Radio Access Networks:Issues and Challenges", IEEE NETWORK,2015, <http://arxiv.org/abs/1506.04233>

- F-RAN architecture- example (cont'd)



Source: M.Peng, S.Yan, K.Zhang, and C.Wang, "Fog Computing based Radio Access Networks: Issues and Challenges", IEEE NETWORK, 2015, <http://arxiv.org/abs/1506.04233>



5. Fog Computing in 5G



- **F-RAN Architecture features**
- F-APs
 - used in the Data Plane to forward and process the traffic data
 - communicate with BBU pool through the fronthaul links and HPN through backhaul links
- The signals over fronthaul links are large-scale processed in the BBU pool, while over the backhaul links only control information is exchanged between the BBU pool and HPN
- The BBU pool plays a similar role as in H-CRANs (can also make centralised caching)
- F-RAN alleviates the tasks of the BBU pool and fronthaul links, given that a large number of CRSP and CRRM functions are shifted towards F-APs and F-UEs
- F-APs and F-UEs may perform limited caching



5. Fog Computing in 5G



- **Architectures comparison: C-RAN, H-CRAN and F-RAN**
- **BBU pool and fronthaul burden:**
 - C-RAN –highest; H-CRAN – medium; F-RAN- lowest
- F-RAN : Lowest latency

- **Decoupling between the CPI and DPI : only in H-CRAN and F-RAN**

- **Caching and CRSP functions**
 - centralised in CRAN and H-CRAN
 - F-RAN- it can be mixed, i.e., centralised/distributed

- **CRRM functions**
 - centralised in CRAN
 - H-CRAN F-RAN : mixed solution can be used

- **Complexity**
 - CRAN or H-CRAN put high complexity in BBU pool and low complexity in RRHs and UEs
 - F-RAN exposes medium complexity in BBU pool, F-APs and F-UEs.



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6. Mobile Edge Computing



- **Why MEC?**
 - **MEC provides IT and cloud-computing capabilities within the RAN in close proximity to mobile subscribers**
 - MEC accelerates content, services and applications so increasing responsiveness from the edge

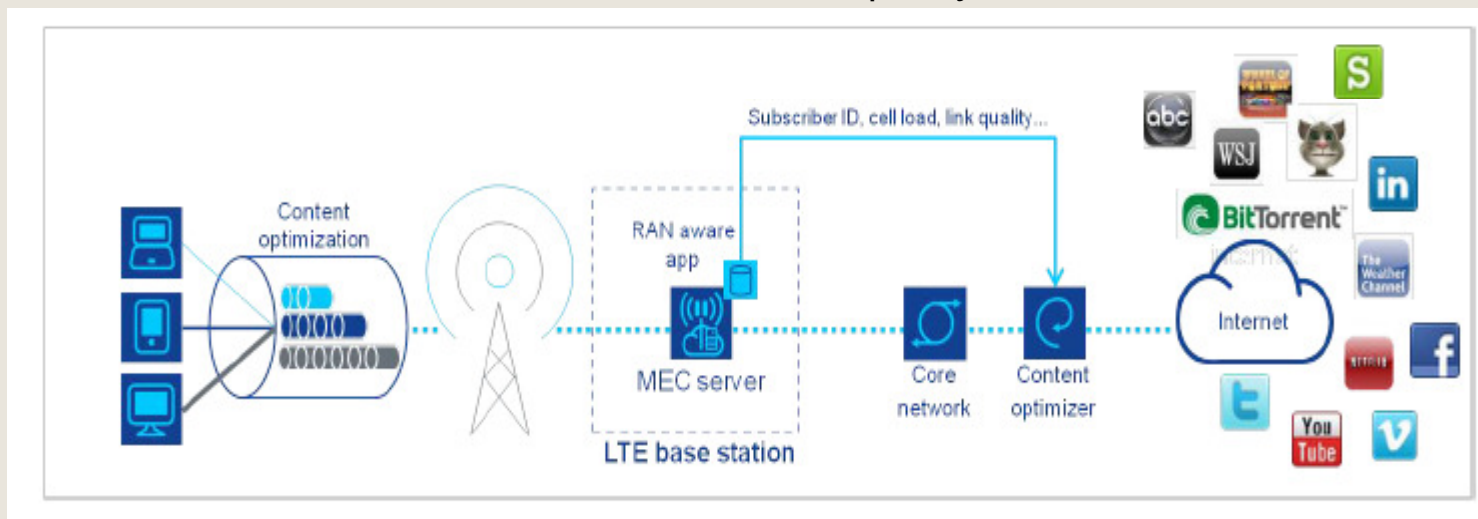
 - **Main standardization actors:** ETSI, 3GPP, ITU-T

 - RAN edge offers a service environment with **ultra-low latency and high-bandwidth** as well as **direct access to real-time radio network information**
 - (subscriber location, cell load, etc.) useful for applications and services to offer context-related services

 - Operators can open the radio network edge to **third-party partners**

 - **Proximity, context, agility and speed** can create value and opportunities for mobile operators, service and content providers, *Over the Top (OTT)* players and *Independent Software Vendors (ISVs)*

- **MEC Use Cases examples (content- oriented)**
 - **RAN-aware Content Optimization**
 - The application exposes accurate cell and subscriber radio interface information (cell load, link quality) to the **content optimizer**, enabling **dynamic content optimization**, improving QoE, network efficiency and enabling new service and revenue opportunities.
 - **Dynamic content optimization** enhances video delivery through reduced stalling, reduced time-to-start and ‘best’ video quality.

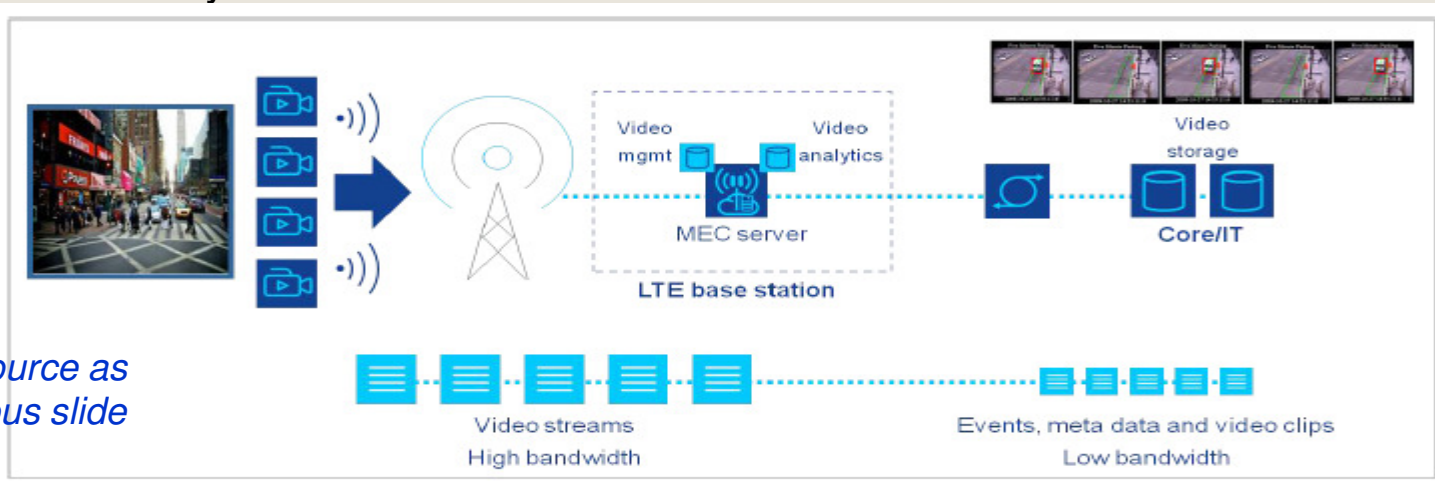


Source: https://portal.etsi.org/Portals/0/TBpages/MEC/Docs/Mobile-edge_Computing_-_Introductory_Technical_White_Paper_V1%2018-09-14.pdf
Mobile-Edge Computing – Introductory Technical White Paper

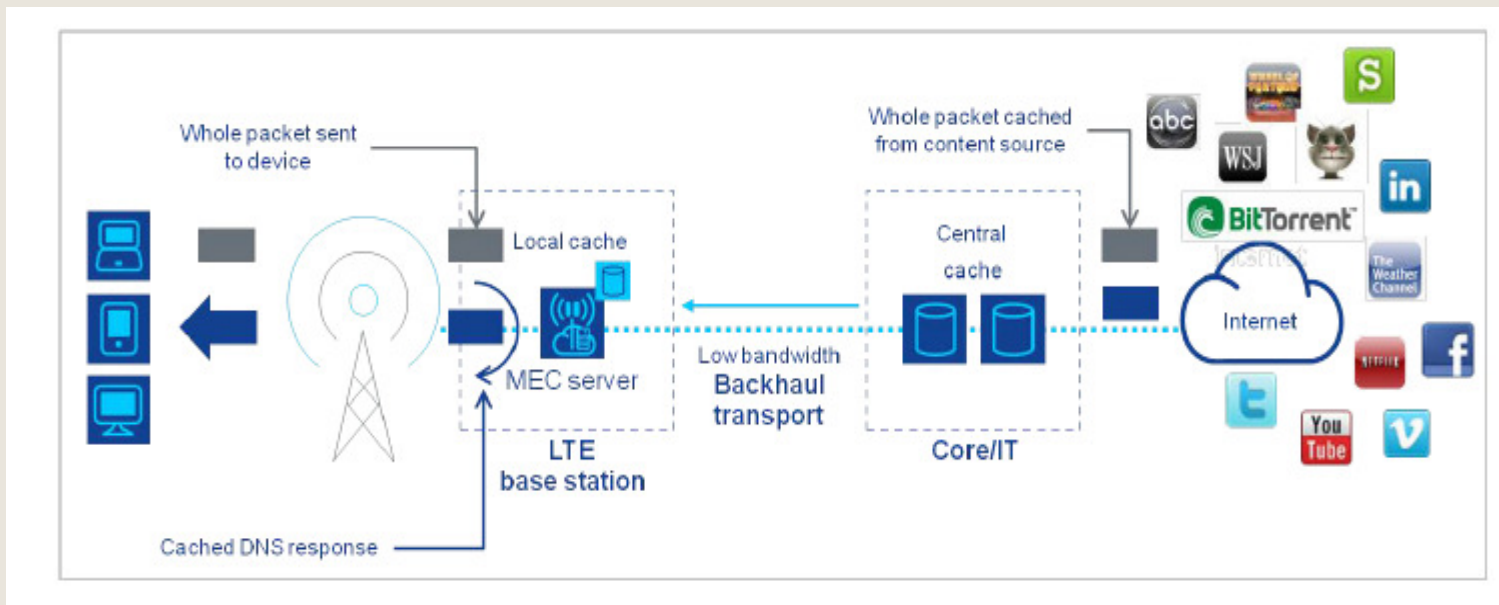
MEC Use Cases examples (content- oriented) (cont'd)

Video Analytics

- distributed video analytics solution: efficient and scalable mobile solution for LTE
- The **video mgmt.** application **transcodes and stores captured video** streams from cameras, received on the LTE uplink
- The **video analytics** application **processes the video data to detect and notify specific configurable events** e.g. object movement, lost child, abandoned luggage, etc.
- The application **sends low bandwidth video metadata** to the central operations and management server for database searches. Applications : safety, public security to smart cities

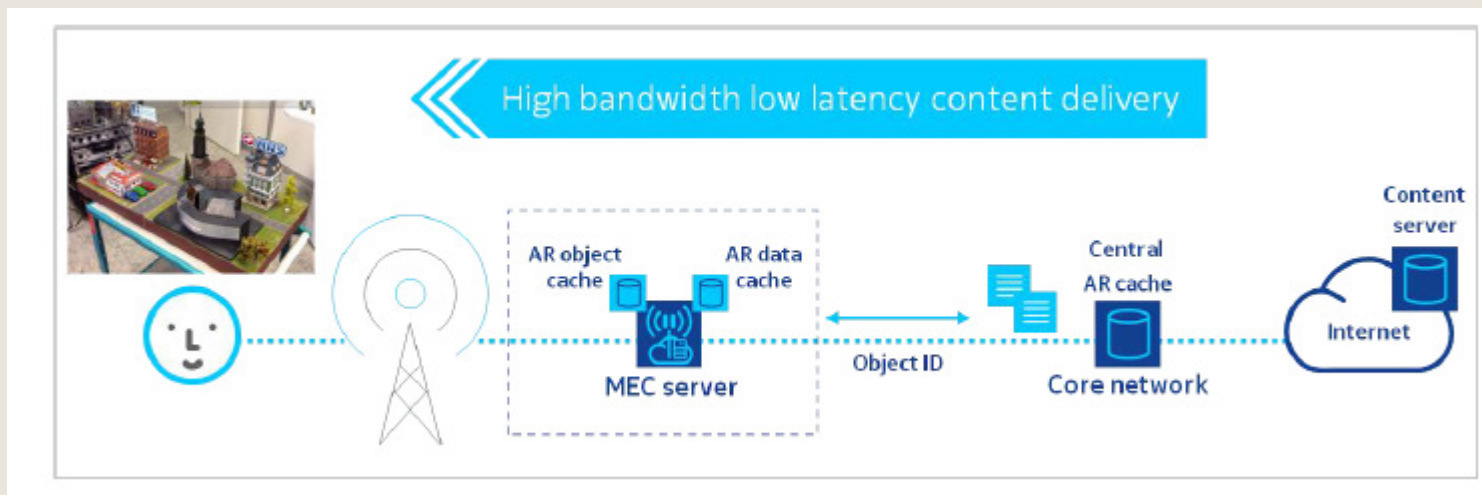


- **MEC Use Cases examples (content- oriented) (cont'd)**
 - **Distributed Content and DNS Caching**
 - A distributed caching technology can provide backhaul and transport savings and improved QoE.
 - Content caching could reduce backhaul capacity requirements by ~35%
 - Local DNS caching can reduce web page download time by ~20%



Same source as previous slide

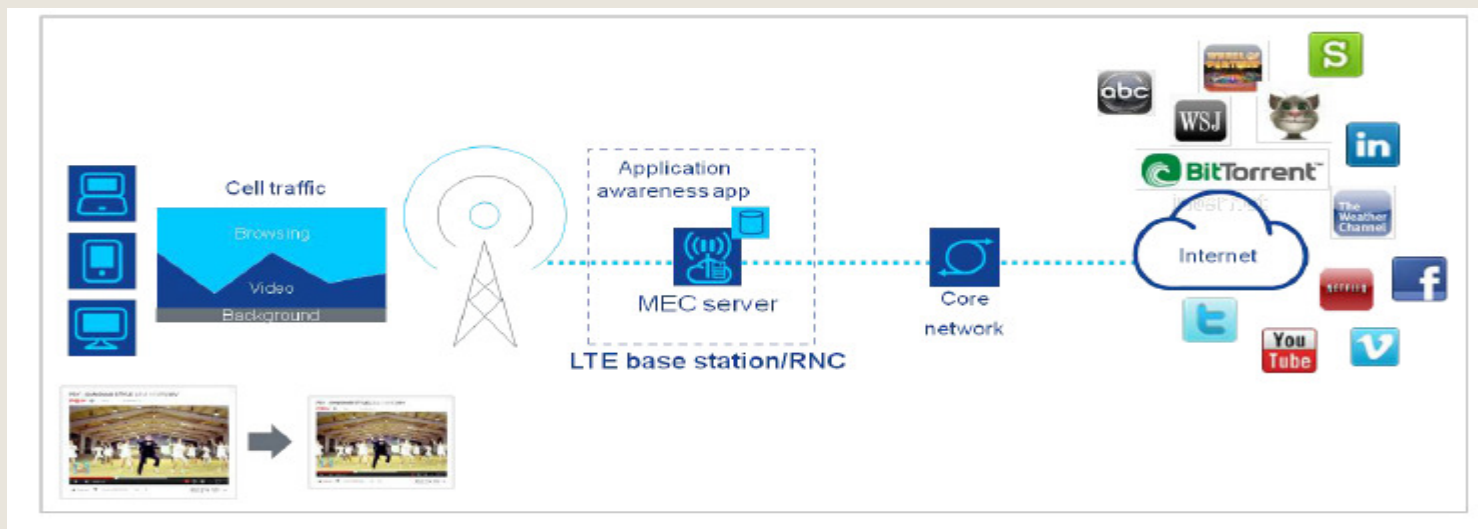
- **MEC Use Cases examples (content- oriented)**
- **Augmented Reality (AR) content delivery**
 - An AR application on a smart-phone or tablet - overlays augmented reality content onto objects viewed on the device camera
 - Applications on the MEC server can provide local object tracking and local AR content caching;
 - RTT is minimized and throughput is maximized for optimum QoE
 - Use cases: offer consumer or enterprise propositions, such as tourist information, sporting event information, advertisements etc.



Source: https://portal.etsi.org/Portals/0/TBpages/MEC/Docs/Mobile-edge_Computing_-_Introductory_Technical_White_Paper_V1%2018-09-14.pdf
 Mobile-Edge Computing – Introductory Technical White Paper

DataSys 2016 Conference May 22, 2016 Valencia, Spain

- **MEC Use Cases examples**
- **Application-aware cell performance optimization**
 - Applied for each device in real time can improve network efficiency and customer experience
 - It can reduce video stalling and increase browsing throughput.
 - Reduce latency
 - Provide independent metrics on application performance (video stalls, browsing throughput, and latency) for enhanced network management and reporting



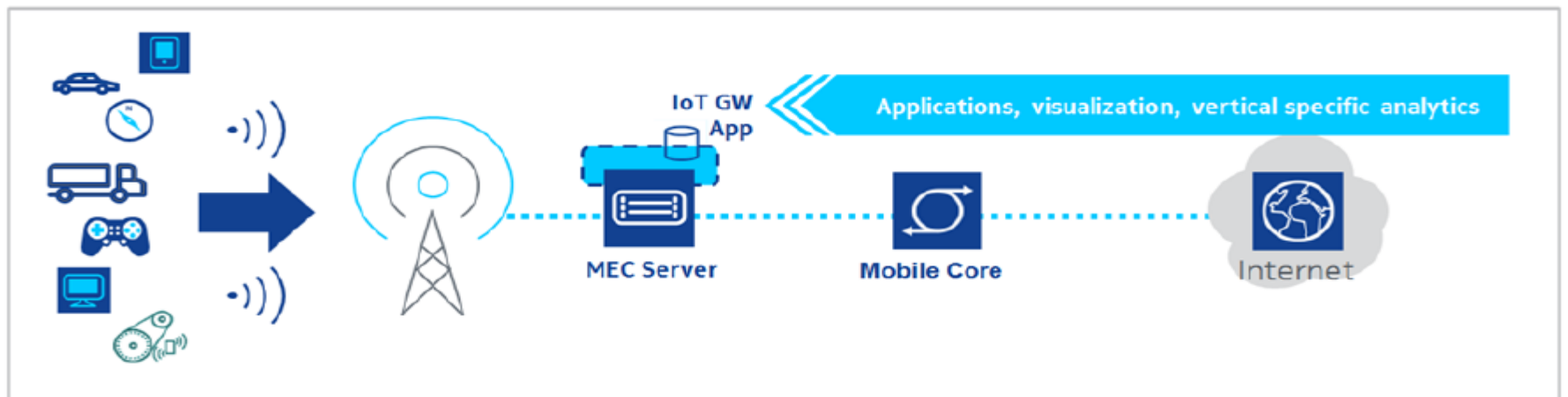
Source: https://portal.etsi.org/Portals/0/TBpages/MEC/Docs/Mobile-edge_Computing_-_Introductory_Technical_White_Paper_V1%2018-09-14.pdf
 Mobile-Edge Computing – Introductory Technical White Paper

DataSys 2016 Conference May 22, 2016 Valencia, Spain

- **MEC Use Cases examples**

- Internet of Things (IoT)

- IoT generates additional messaging on telecoms networks, and requires gateways to aggregate the messages and ensure security and low latency
- real time capability is required and a grouping of sensors and devices is needed for efficient service.
- IoT devices are often low in terms of processor and memory capacity → need to aggregate various IoT messages connected through the mobile network close to the devices
- This also provides an analytics processing capability and a low latency response time.

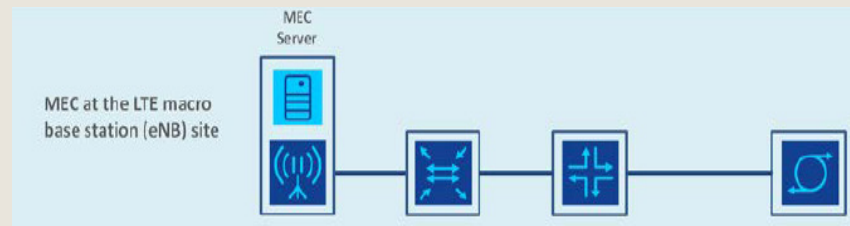


*Yun Chao Hu et.al., "Mobile Edge Computing A key technology towards 5G" ETSI White Paper No. 11
September 2015, ISBN No. 979-10-92620-08-5*

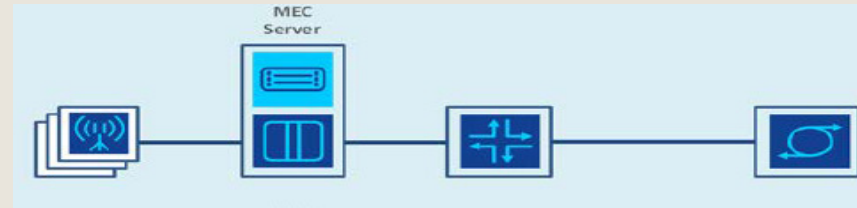
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- **Possible Deployment Scenarios (ETSI)**
 - The MEC server can be deployed in several variants
 - Note: the multi-technology (LTE/3G) cell aggregation site can be indoor or outdoor

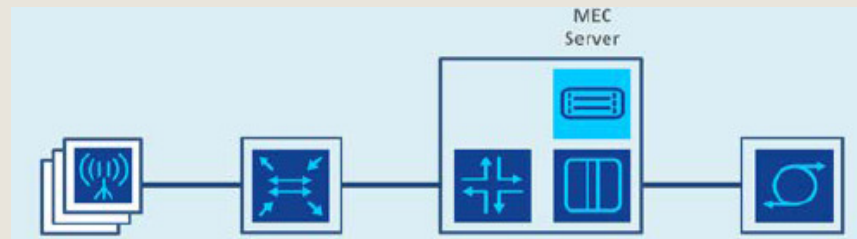
MEC at the LTE macro base station (eNB) site



MEC at the multi-technology (3G/LTE) cell aggregation site



MEC at the 3G Radio Network Controller (RNC) site





6. Mobile Edge Computing

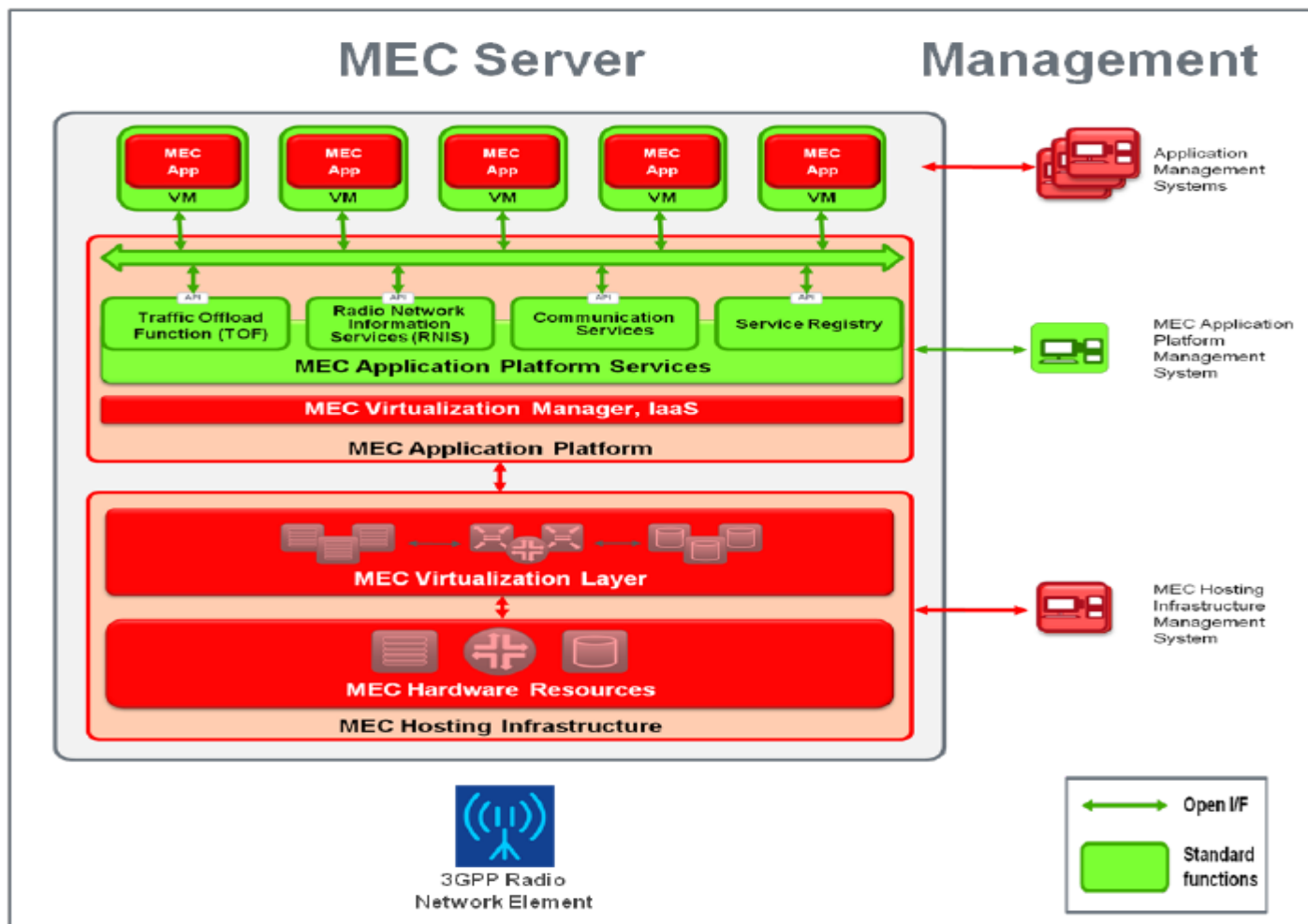


■ MEC Architectures

- MEC provides a **highly distributed computing environment** that can be used to deploy applications and services as well as to store and process content in close proximity to mobile users.
- Applications **can benefit from real-time radio and network information** and can offer a personalized and contextualized experience to the mobile subscriber.
- The **mobile-broadband experience is more responsive** and opens up new monetization opportunities. This creates an ecosystem where new services are developed in and around the BS
- **Key element : (MEC) IT application server** which is integrated in RAN (as above)
 - **The MEC server provides computing resources, storage capacity, connectivity, and access to user traffic and radio and network information**

5. Mobile Edge Computing

- MEC Platform Overview (*source: ETSI*)- *NFV inspired arch*





CONTENTS



1. 5G Vision and Architectures
2. Software Defined Networking (SDN) and Network Function Virtualization (NFV)
3. Cloud Computing Architectures in 5G
4. SDN and NFV in 5G
5. Fog Computing in 5G
6. Mobile Edge Computing
7.  Open research topics
8. Conclusions



7. Open research topics



- **SDN/NFV**
 - the **centralised SDN nature** → **bottlenecks** and thus can reduce the resilience and scalability
 - a **balance between centralised logical control and actual distributed infrastructure of controllers** should be found
 - **flat or hierarchical architecture of SDN control plane** – with multiple controllers should be adapted to 5G both in Core and RAN
 - the flat organisation of the SDN controllers does not provide an effective and flexible management solution for 5G networks to meet the requirements for resilience and scalability.
 - different **reconfiguration policies** should be applied to the network elements in a dense environment, at different time scales
 - due to the dynamicity and density of this network
 - this can also result in high signalling overhead



7. Open research topics



- **SDN/NFV (cont'd)**
 - RAN link quality is usually **unreliable and unstable**, interrupting temporarily the communication between the controller and its forwarders (if the controller communication channel uses in-band signalling),
 - isolated wireless networks problem to solve
 - 5G network **might have cells with particular configuration policies**, which should be considered in a differentiated way by the SDN controllers.
 - the **partition of functions to be implemented in each plane is still an open issue in the SDN/NFV/5G**, particularly in the RAN area.
 - the edge heterogeneity (including D2D, M2M, and V2V) -> very dynamic topologies -> **complexity in SDN and NFV functions planning**, increased by several distinct mobility models and hardware constraints
 - (e.g., the SDN controller should instruct the switches or network hypervisor which terminal node should forward packets)



7. Open research topics



■ SDN/NFV (cont'd)

- integrating SDN and NFV
 - the SDN programmability needs standardising the N/S interfaces between physical and virtual network functions that form a single network service chain.
- virtualisation might negatively impact the virtual LTE and Wi-Fi services -> the VNFs performance should be analysed (to decide about physical/virtual implementation option).
- standardisation of NFV/SDN is still in-progress
 - a unified cellular programmable interface for implementing SDN and NFV is under development, including a service chain through the integration of SDN and NFV



7. Open research topics



■ C-RAN/H-CRAN/Fog

- two major problems in both CRANs and H-CRANs
 - high transmission delay and heavy burden on the fronthaul
 - C-RAN s H-CRANs do not take benefit from processing and storage capabilities in edge devices, such as RRHs and even 'smart' mobile terminals / user equipments (UEs)
- use SDN style of control in F-RAN environment?
 - The combination of the MAC functions and L1 functions for edge devices in F-RANs is still not yet clarified
 - SDN is centralisation-based (for control), while the F-RAN has a distributed characteristic, based on edge devices
 - using SDN control for F-RANs-> need to carefully define slices to isolate the signal processing from resource management in edge devices, as to provide non-interfering networks to different coordinators.
- If SDN controllers are located in cloud computing network layer, -> control traffic overhead appears (CPI --DPI) to be transported over fronthaul links -> decreasing the advantages of F-RANs.



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7. Conclusions



- **5G networking and services – promising technology for a large range of applications**
- **Cloud, fog, SDN, NFV, MEC, virtualization** concepts and technologies can offer strong support in developing 5G architectures and implementations
- Significant effort still to be done to
 - Find the best architectural configuration in order to realize synergic cooperation between technologies and take the best benefits from their advantages
 - Explore further the SDN/NFV cooperation
 - Distributed & hierarchical architectures for both SDN & NFV
 - Function split and migration in both SDN and NFV
 - Explore hierarchical SDN control in 5G+NFV context
 - Orchestration and management
 - NFV
 - Evaluate real time response of the VNFs
 - Dynamic VNF moving properties in mobility context
 - MEC – promising technology: it can transform BSs into intelligent service hubs , capable of delivering highly personalized services directly from the very edge of the network while providing the best possible performance in mobile networks.



- Thank you !
- Questions?



List of Acronyms



■	ACE	Ancestral Communication Entity
■	AVC	Audio Video Conference
■	BBU	Baseband Processing Unit
■	BS	Base Station
■	BSC	Base Station Controller (2G/3G)
■	BSS	Business Support System
■	CC	Cloud Computing
■	CCN	Content Centric Neetworking
■	CDN	Content Delivery Network
■	CDNP	Content Delivery Network Provider
■	COTS	Commercial-off-the-Shelf
■	CoMP	Coordinated multi-point
■	CP	Content Provider
■	CRAN	Cloud RAN
■	DASH	Dynamic adaptive streaming over HTTP
■	DRM	Digital Rights Management
■	EMS	Element Management System
■	EPC	Evolved Packet Core
■	ETSI	European Telecommunications Standards Institute
■	FEC	Forward Error Correction
■	HCRAN	Heterogeneous CRAN
■	HPN	High Power Node
■	HSPA	High Speed Packet Access
■	HTTP	Hyper Text Transport Protocol
■	IaaS	Infrastructure as a Service



List of Acronyms (cont'd)



- IMS IP Multimedia System
- ISG Industry Specification Group.
- IT Information Technology
- LPN Low Power Node
- LTE Long Term Evolution
- MBMS Multicast Broadcast Media Service
- M&O Management and Orchestration
- MME Mobility Management Entity
- MIMO Multiple Inputs –Multiple Outputs
- NAT Network Address Translation
- NF Network Function
- NFV Network Functions Virtualization
- NFVI Network Functions Virtualization Infrastructure
- NO Network Operator
- NP Network Provider
- NS Network Service
- OSS Operations Support System
- PaaS Platform as a Service
- PoC Proof of Concept.
- RAN Radio Access Network
- RRH Remote Radio Head



List of Acronyms (cont'd)



- RNC Radio Network Controller
- RTP Real Time Protocol
- RTCP Real Time Control Protocol
- RTSP Real Time Streaming Protocol
- SaaS Software as a Service
- SDN Software Defined Network
- SDP Session Description Protocol
- SDO Standards Development Organisation
- SLA Service Level Agreement
- S/P-GW Serving and Packet Data Networks Gateway
- SP Service Provider
- TCP Transmission Control Protocol
- UDP User Datagram Protocol
- VM Virtual Machine
- VNF Virtual Network Function



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Backup slides





Network Function Virtualization



- **NFV Actors**
- **ETSI NFV Group**
 - **Global (operators-initiated) *Industry Specification Group (ISG)* under the auspices of ETSI**
 - ~200 members (2014)
 - –28 Tier-1 carriers (and mobile operators) & service providers, cable industry
- **Open membership**
 - ETSI members sign the “Member Agreement”
 - Non-ETSI members sign the “Participant Agreement”
- Operates by consensus (formal voting only when required)
- Deliverables: requirements specifications, architectural framework, PoCs, standards liaisons
- Face-to-face meetings quarterly.
- **Currently: four (4) WGs, two (2) expert groups (EGs), 4 root-level work items (WIs)**
 - WG1: Infrastructure Architecture
 - WG2: Management and Orchestration
 - WG3: Software Architecture
 - WG4: Reliability & Availability
 - EG1: Security
 - EG2: Performance &
- Network Operators Council (NOC): technical advisory body



Network Function Virtualization



- **NFV Actors**
- **Open Networking Foundation (ONF)**
 - Active also in NFV area
 - E.g. of document: “OpenFlow-Enabled SDN and Network Functions Virtualization,” 2014, see Refs.
- **Internet Research Task Force (IRTF)**
 - RFC 7426, Jan 2015: “Software-Defined Networking (SDN): Layers and Architecture Terminology” , see Refs.
 - proposes a common terminology for SDN layering and architecture based on significant related work from the SDN research community