Content Distribution in Wireless/5G Environments

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InfoWare 2015 Conference October 12th,2015, Malta

Acknowledgement

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

An OTT-style content delivery system example are coming from the CHIST-ERA specific Research European Project DISEDAN:

***DI**stributed **SE**lection of content streaming source and **D**ual **A**daptatio**N**,*
2014-2015

Partners:

Warsaw University of Technology Warsaw, Poland (coordinator)
University Politehnica of Bucharest (UPB), Romania
LaBRI Lab, University of Bordeaux, Bordeaux, France

UPB Research Group (8 academics + PhD students + students)
Research on : network architectures, protocols, services (simulation, perf. evaluation, implementation), QoS, content delivery, resource management.
Participation to many FP5, FP6, FP7, and H2020 research projects
Recent interest: FI architecture, SDN, NFV, 5G

Content Distribution in Wireless/5G Environments

Motivation of this talk

Facts:

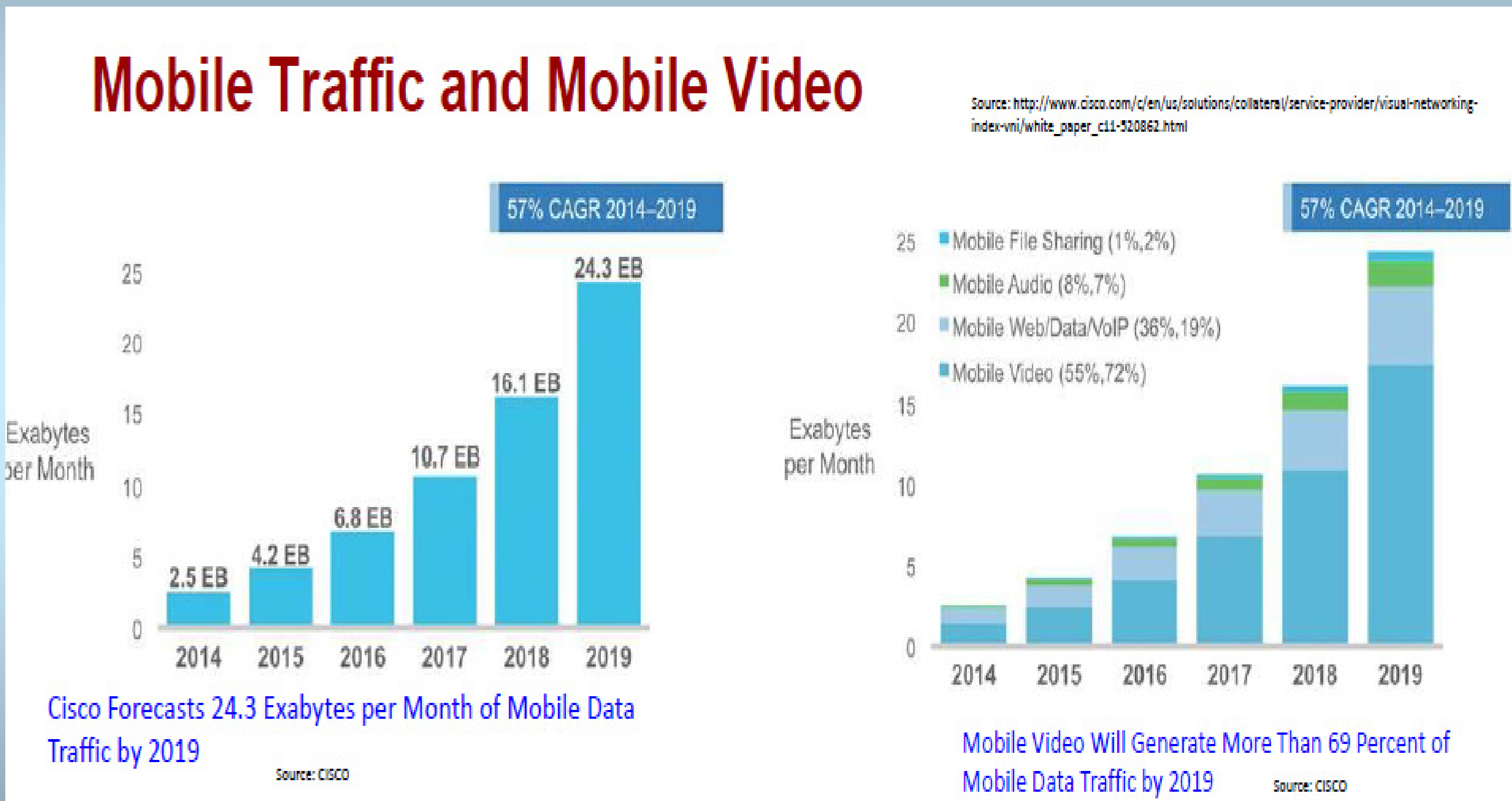
- **Internet and Telecom convergence → Integrated networks**: Future Internet

- **Content:** became the main information item exchanged between different actors, in the current and Future Internet
  - Many estimations: soon, content (live, pre-recorded, etc.- **especially video** and **media content**) will be ~ 80-90% of the total global traffic
- **High increasing ratio of mobility communications** needs (10 **3 in 5-6 years) and
  - strong orientation towards content-related services and applications
  - **content delivery over wireless technology- hot topic**

- **New emergent technologies** - changing networks and services architectures – influencing also content delivery:
  - ***Advances in wireless technologies: 4G-LTE, LTE-A, WiFi***
  - ***Evolution to 5G***
  - ***Cloud Computing***
  - ***Software Defined Networks (SDN)***
  - ***Network Function Virtualization (NFV)***
  - ***Over the Top solutions (OTT), combinations***
  - ***Content Oriented solutions – in networking and services: CDN/CON/CCN***

Content Distribution in Wireless/5G Environments

Motivation of this talk (cont'd)



Source CISCO

Content Distribution in Wireless/5G Environments

Motivation of this talk (cont'd)

- **Challenges in wireless/mobile environment** (having impact on content delivery services)
  - the limited spectrum and bandwidth in wireless
  - time- and location-dependent wireless link characteristics
  - radio congestion
  - potential handoff issues
  - heterogeneous device features and limitations, etc.

- Main topic of this keynote:
  - **What are the main needs (and solutions) in developing content-oriented services over wireless environment**
    - as to support a large ranges of user and provider requirements, for networks, services and applications
    - while leveraging high volume of traffic in high mobility conditions?
  - **Some sample architectures and solutions will be presented**

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1. Introduction: Content Delivery
2. 5G Vision and Architectures
3. Software Defined Networking and Network Function Virtualization
4. Content Delivery Architectures for 5G
5. Mobile Edge Computing
6. Example of a light OTT architecture
7. Conclusions

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2. **5G Vision and Architectures**
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6. **Example of a light OTT architecture**
7. **Conclusions**

1.Introduction: Content Delivery

- **Content Related Actors**
  - Content Provider (CP)
  - Content Services – offered by Cloud Providers (CS-CIP)
  - Advertiser (A), Broker (B)
  - (High Level) Service Provider – (HL)SP
  - Content Delivery Network - Provider (CDNP)
  - Network Provider/Operator (NP/NO/ISP)
  - Device/Client/Consumer (machine/human)
    - **Notes :**
      - ***Commercial actors can play combined roles***
      - **Novel terminology - *Prosumer* = producer and/or consumer of content**

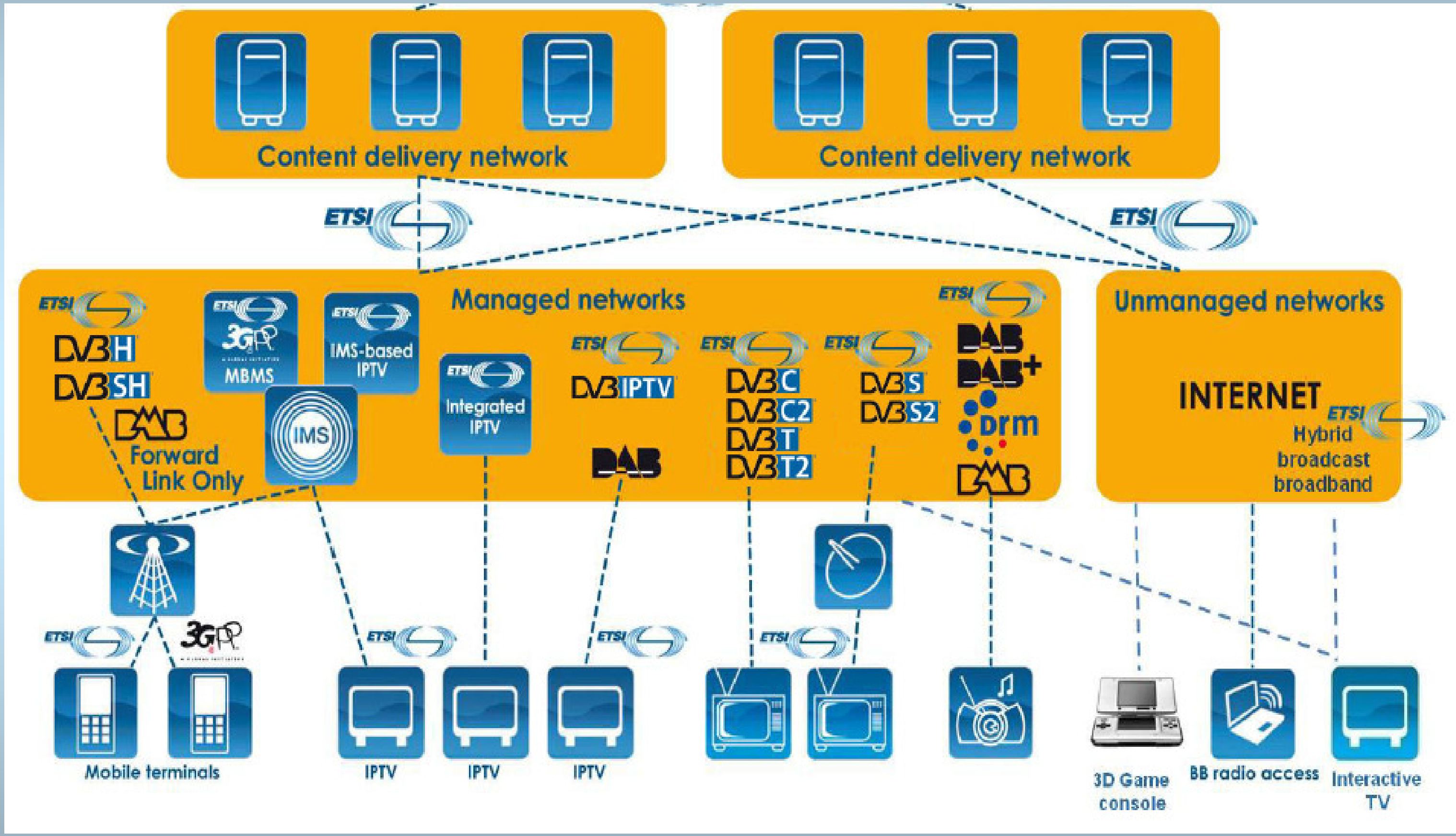
- **Digital Media Value chain**
  - **Content Creation**: Encoding, Encapsulation, Digital Rights Mgmt (DRM)
  - **Aggregation:** dynamic Ads
  - **Content Distribution** (through networks) : Media Protocols, IP transport, CDNs
  - **Content Consumption:** Client devices/terminals

1. Introduction: Content Delivery

- **Content processing and delivery aspects**
  - ***Managed and/or unmanaged* – point of view-** applied to
    - Content itself
    - Transport (through the network)
    - End devices/clients
  - **Real life**: a large range of offerings exist:
    - **Best Effort** ………………-> **Fully Managed** services
    - *YouTube, Netflix, HBO GO, Hulu………..Comcast, Deutsche Telekom, …*
  - **Different solutions → different complexity/cost/offered_quality**
    - Examples
      - **IPTV**: managed transport and delivery, guaranteed QoS/QoE, Linear+ VoD, Paid service
      - **Internet TV (working style: Over the Top –OTT)** : Best Effort delivery, no QoS guarantees (or weak), mostly on demand, pay or free services
  - **Different business models:** transactional, ad - supported, subscription (the last model usually involves SLAs to be established between parts)

1. Introduction: Content Delivery

- **ETSI View on Content/Media Delivery services**



Source: ETSI- "Content Delivery", http://www.etsi.org/images/files/ETSIClusterBrochures/clusters-content-delivery-Q32015.pdf

1. Introduction: Content Delivery

- **ETSI View on Content/Media Delivery services (cont'd)**
- **Is 5G relevant for broadcasters?**
  - Yes, if it will meet the Broadcasters' constraints w.r.t. content distribution
    - Free to air, no gatekeepers, broadcast QoS - independent of #viewers & location, brand visibility, ease of use, analytics to support targeted advertising.
    - Data monthly volume limits & tariffs are a limiting factor for distribution by a Mobile Network Operators (MNO)
  - Consumers would like to watch:
    - live TV – not just on large displays, but also on tablets and smart - phones
    - On-demand content (e.g. catch - up TV or subscription services) on all types of Devices
  - Still open issue: Broadcasting networks cannot deliver on-demand services, whilst current mobile networks cannot provide scalable delivery of high - quality video to large numbers of devices

Source: ETSI "WIRELESS MEDIA DISTRIBUTION BEYOND 2020", http://www.etsi.org/news-events/events/856-wireless-media-distribution-beyond-2020

1. Introduction: Content Delivery

- **ETSI View on Content/Media Delivery services (cont'd)**
- **Next steps for Convergence Standards:**
  - Media-network convergence
  - CDN and Cloud support
  - Optimising streaming / compression
  - Video roadmap options in 3GPP
  - Video Analytics
  - Multimode networks (including LTE and 5G focus)
  - Video delivery focus across ETSI for all activities and Sectors supported
  - IoT includes among others – video services

1. Introduction: Content Delivery

- **Basic characteristics of Media Delivery over IP networks**
  - **Broadcast, *push-based* streaming (DVB, MPEG2-TS)**
    - Dedicated architecture and corresponding infrastructure
    - Push content in unicast or multicast mode
    - Usually the network services are managed
    - Sender is initiator
    - Intelligent servers, dumb clients
    - Adaptation: explicit feedback loop, ARQs, stream/server switching or *server-based* real-time adaptation

    - **Protocols**
      - RTP -*Real-time Transport Protocol* (for media flow transport)
      - Control: RTSP, RTCP (sender/receiver reports), SDP, SAP … requires codec-specific payload formats
      - UDP - Transport protocol (simple, connection-less, unreliable)
      - STUN/TURN to solve NAT/Firewall problems

1. Introduction: Content Delivery

- **Basic characteristics of Media Delivery over IP networks**

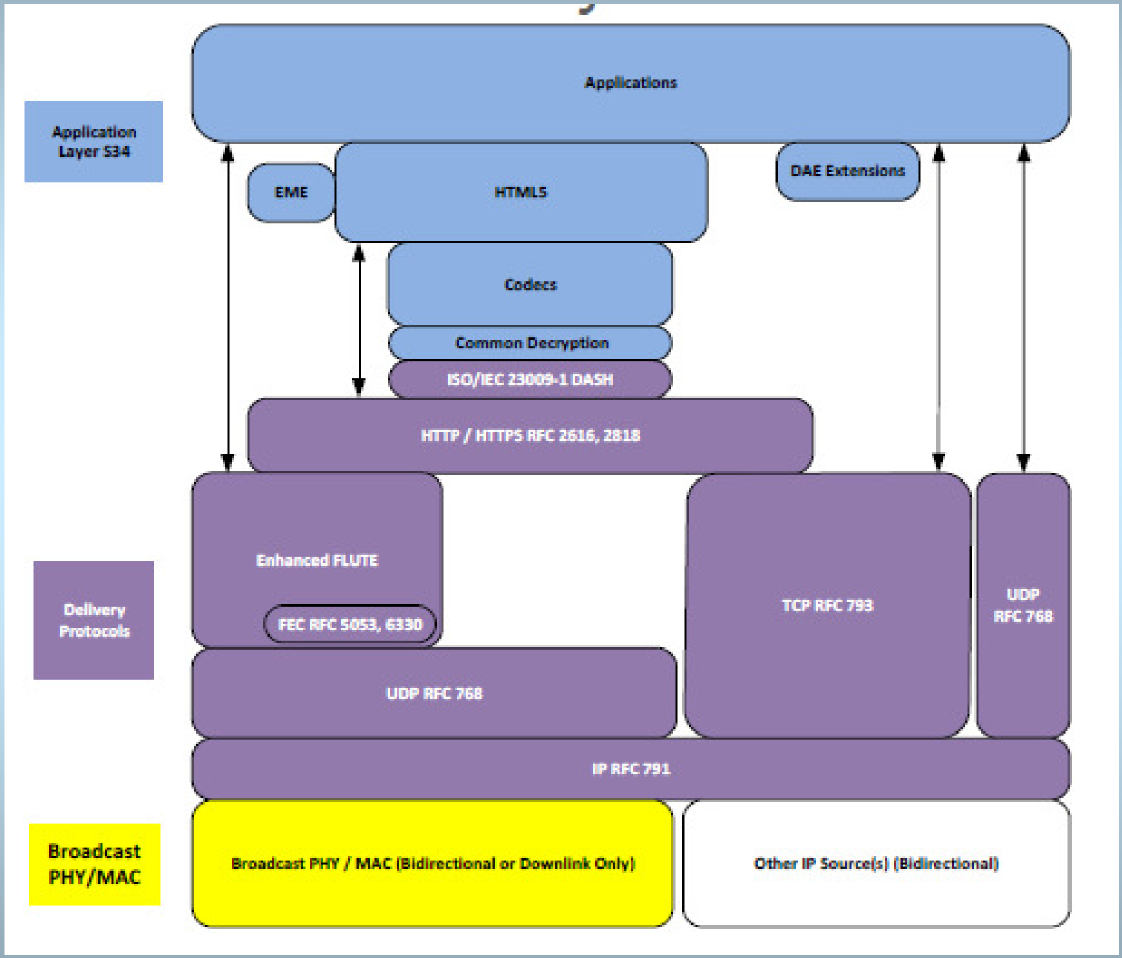
  - ***Pull-based* streaming**
    - Use of existing architecture and infrastructure for Web content (server, proxy, cache, CDN)
    - Unmanaged network service (usually)
    - Client is initiator (pull content in unicast mode)
    - Intelligent client, existing infrastructure, servers
    - Over the Top (OTT) streaming
    - Manifest and segments formats (MPEG-4 TS, ISOBMFF)
    - Adaptivity: driven by smart client decisions (need adaptation logic)
    - **Protocols**
      - Hypertext Transfer Protocol (HTTP): port 80 (no NAT/firewall issues)
      - TCP - Transport protocol (CO, reliable)

Source: T.Stockhammer, "3GPP Content Delivery Efforts", http://dashif.org/wp-content/uploads/2015/08/6e-3GPP-Content.pdf

1. Introduction: Content Delivery

- **3GPP Architectural Stack for Content Delivery**

- 3GPP specifies
  - MBMS and IP unicast
    - (HSPA, LTE, LTE-A)
  - DASH
  - 3GPP/ISO File format
  - AVC and HEVC
  - HE-AACv2
  - 3GPP Time Text
  - (HTML-5)
- 3GPP also supports
  - RTP
  - SMIL



Source: T.Stockhammer, "3GPP Content Delivery Efforts", http://dashif.org/wp-content/uploads/2015/08/6e-3GPP-Content.pdf

1. Introduction: Content Delivery

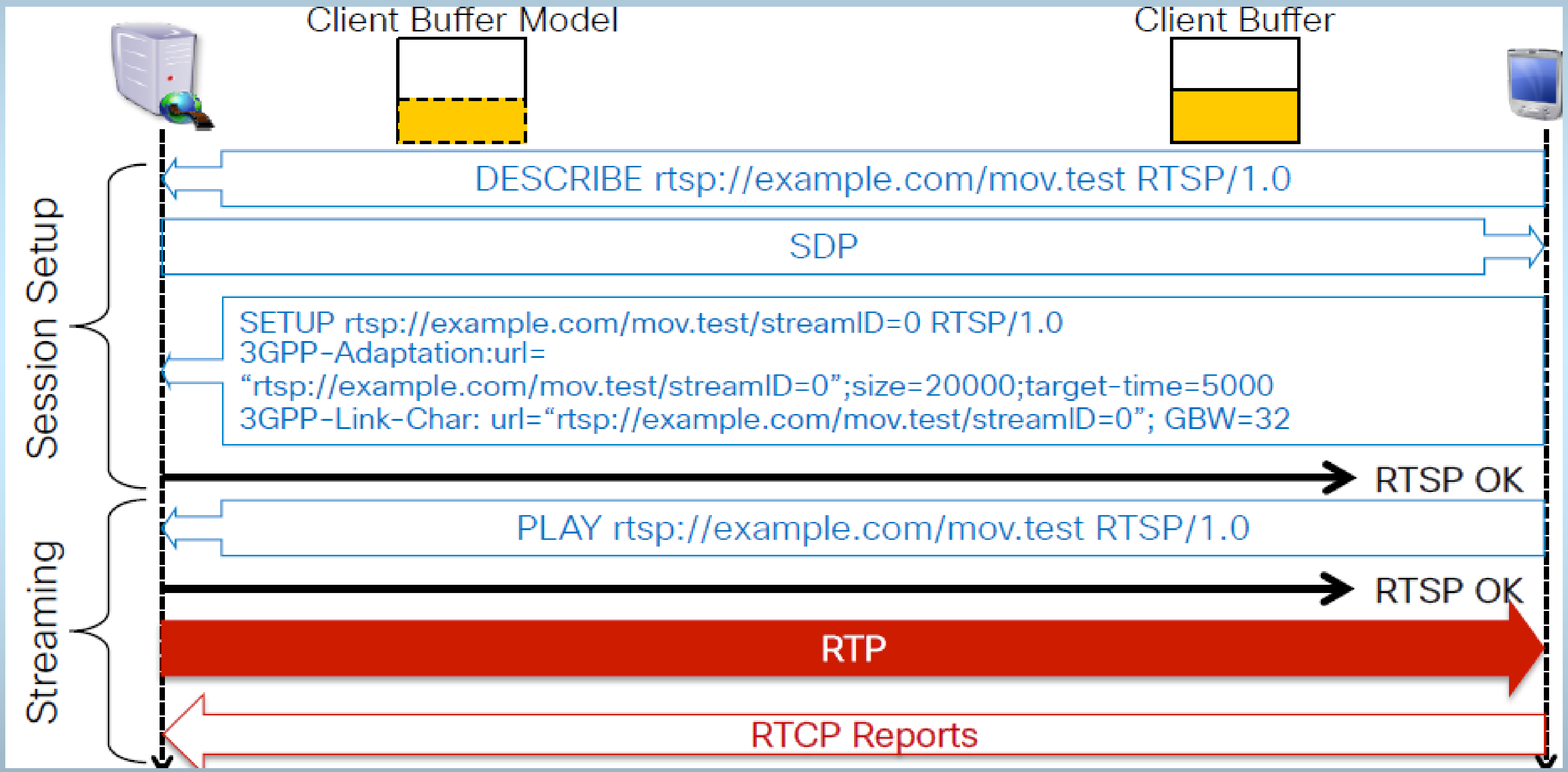
- **Architectural Stack for 3GPP Content Delivery** (cont'd)

- Notations:
  - 3GPP - 3rd Generation Partnership Project
  - MBMS – Multicast and Broadcast Media Services
  - HSPA – High Speed Packet Access
  - LTE/LTE-A – Long Term Evolution – Advanced (4G)
  - DASH – Dynamic Adaptive Streaming over HTTP
  - AVC – Audio Video Conference
  - HEVC - High Efficiency Video Coding
    - a successor to H.264/MPEG-4 AVC (Advanced Video Coding)
  - HE-AACv2 -High-Efficiency Advanced Audio Coding (HE-AAC)
  - (HTML-5) – v5 markup language used for structuring and presenting content on the WWW
  - RTSP - **Real Time Streaming Protocol** - protocol to control streaming media servers.

- 3GPP also supports
  - RTP- Real Time Protocol
  - RTCP- Real Time Control Protocol
  - SMIL- Synchronized Multimedia Integration Language- a markup language for describing multimedia presentations

1. Introduction: Content Delivery

- **Example 1: Video Delivery over RTSP - Push-Based**
  - 3GPP Packet-Switched Streaming Service (PSS)



Source: C.Timmerer, “Over the Top Content Delivery: State of the Art and Challenges Ahead”, 2015, http://www.slideshare.net/christian.timmerer

1. Introduction: Content Delivery

Evolution of Video Delivery over HTTP - Pull-Based

- **Progressive Download**
  - Server sends the media flow as fast as possible
  - Client has an input buffer
  - Client starts playout after a certain buffer fill (to accommodate jitter)

- **Pseudo streaming**
  - Server paces the transmission
  - Client can seek
  - Metadata are needed

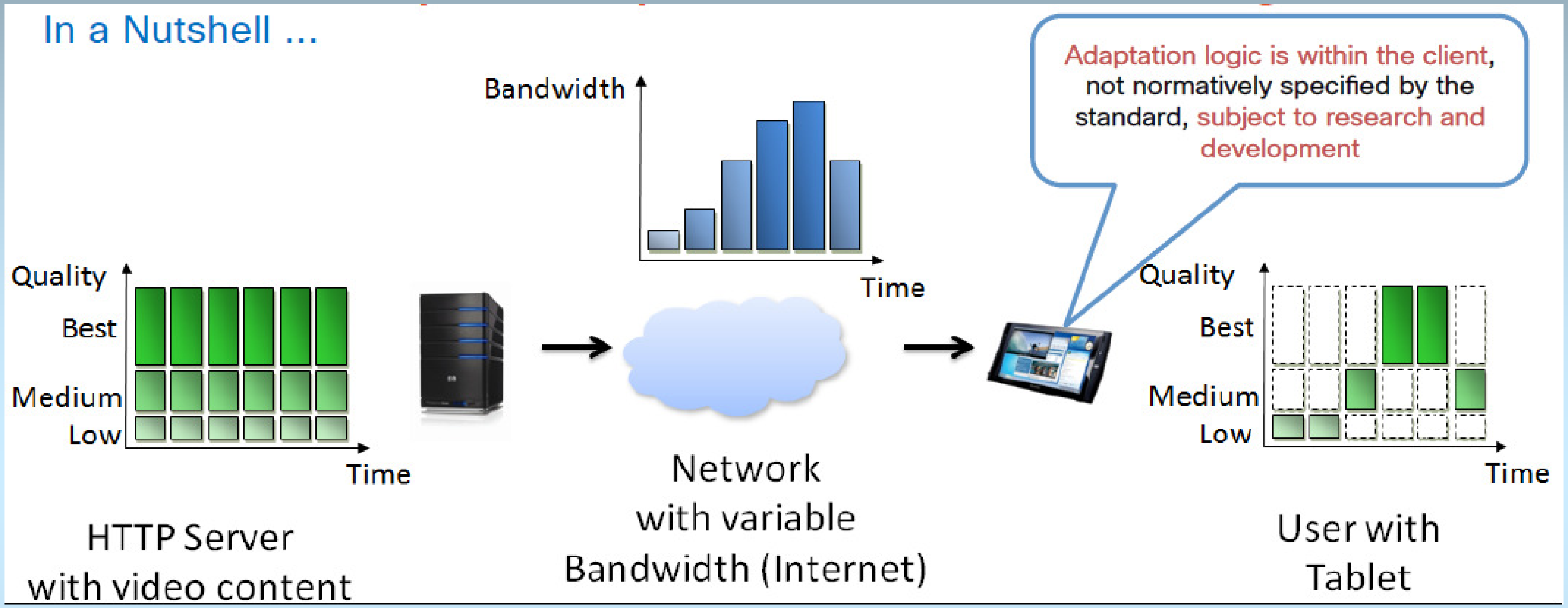
- **Adaptive Streaming**
  - Client requests small chunks of content
  - Adaptation is enabled
  - Live streaming and dynamic ads are supported

1. Introduction: Content Delivery

- **Example 2: Adaptive Streaming over HTTP principles**
  - Idea : Adapt Video flow transport to the network (Web) conditions
  - Imitation of Streaming via **Short Downloads**
    - Client downloads small video chunks to minimize bandwidth waste and maximize QoE
    - **Clients- track and monitor** consumption
  - **Adaptation to Network Dynamic** Conditions and Terminal Capabilities
    - paradigm : “any device, anywhere, anytime”
  - Improved **Quality of Experience (QoE)**
    - Enables faster start-up and seeking (compared to progressive download), and quicker buffer fills; Reduces skips, freezes and stutters
  - Use of well known **HTTP framework**
    - easy traversal of middle-boxes (e.g., NATs, firewalls)
    - cloud access, leverages existing HTTP caching infrastructure (estimates indicate - cheaper costs than CDN)

1. Introduction: Content Delivery

- **Adaptive Streaming over HTTP –principles –DASH- (cont'd)**

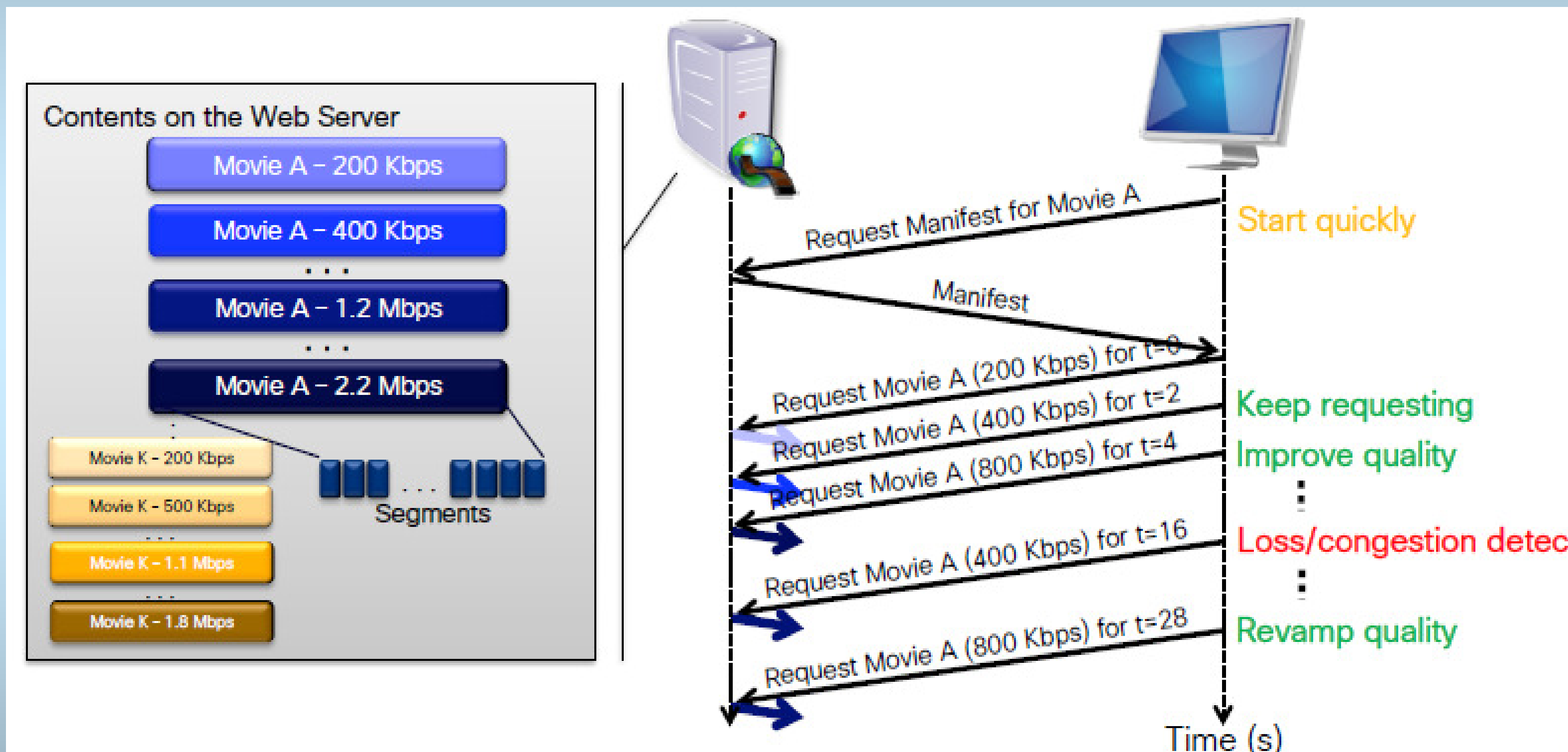


Source: C. Timmerer and C. Griwodz, "Dynamic adaptive streaming over HTTP: from content creation to consumption", Proc.of the 20th ACM Int'l Conf.on Multimedia (MM '12), Nara, Japan, Oct./Nov. 2012.

- **Examples of Adaptive Bit Rate Streaming technologies**
  - Dynamic Adaptive Streaming over HTTP (DASH)
  - Apple HTTP Live Streaming (HLS)
  - Microsoft Individualized-Integrated Book (IIB) Smooth Streaming
  - Adobe HTTP Dynamic Streaming

1. Introduction: Content Delivery

- **Over-The-Top – Adaptive Media Streaming- principles (cont'd)**
  - Multi-Bitrate Encoding and Representation Shifting



Source: C.Timmerer, "Over the Top Content Delivery: State of the Art and Challenges Ahead", 2015, http://www.slideshare.net/christian.timmerer

1. Introduction: Content Delivery

- **Problems of Adaptive Media Streaming-in wireless/mobile environment**

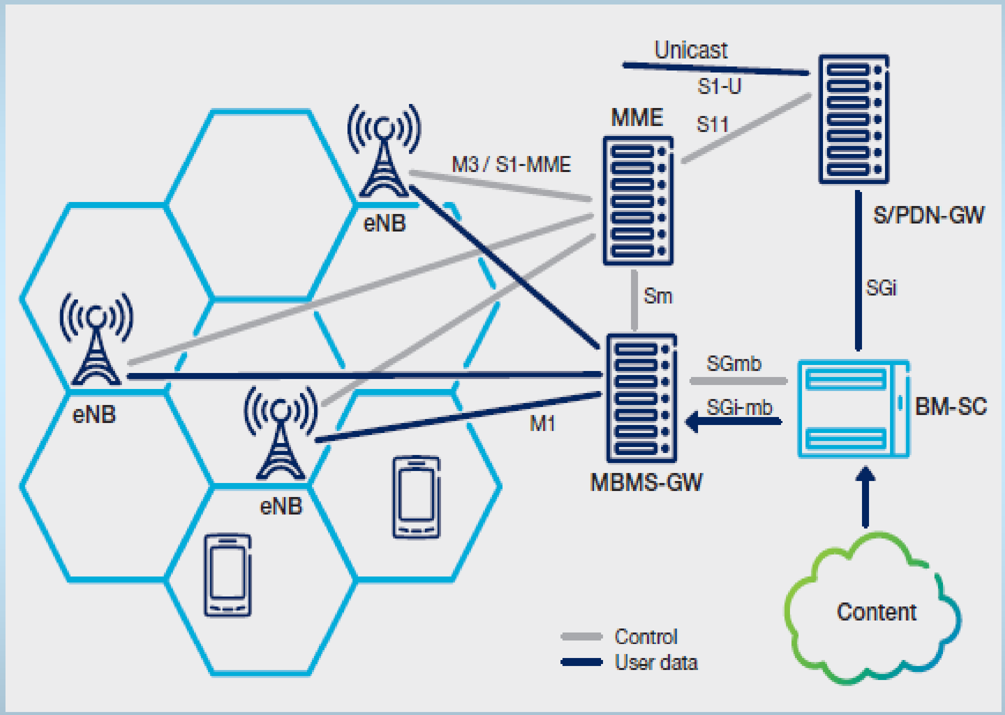
  - **network conditions vary** widely over time + mobility
    - Example: even within a single Netflix session, the measured throughput varies from 500 Kbits/s to 17 Mbits/s

  - **Estimating the network capacity** even for the near future is **challenging** in mobile video streaming
    - Inaccurate estimates can lead to degraded QoE

    - If **network capacity**
      - is **underestimated,** the user will receive the video with lower quality, even though the current network condition allows a higher quality of video to be delivered
      - is **overestimated** the player picks a video bit rate greater than network capacity→ video plays back faster than downloaded rate → video buffer depletion → video pauses.

1. Introduction: Content Delivery

- **LTE - Evolved Multimedia Broadcast Multicast Service (eMBMS) architecture - example**
  - **Broadcast Multicast Service Center (BM-SC)** - new network element of the LTE Broadcast-distribution tree
  - Generic files or MPEG-DASH live streams are carried across the BM-SC and made available for broadcast
  - BM-SC adds resilience to the broadcast (AL-FEC)
  - MBMS-GW forwards streams from the BM-SC to all eNBs
  - IP multicast is used on the M1 interface GW - eNBs
  - The GW routes MBMS session control signaling to the MMEs serving the area.



Source: T.Lohmar et al., "Delivering content with LTE Broadcast", Ericsson Review, Feb. 2013

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3. 5G Vision and Architectures

- **Key Drivers, Requirements, Technologies**
- **5G disruptive capabilities**
  - an **order of magnitude Improvement** in performance : more capacity, lower latency, more mobility, more accuracy of terminal location, increased reliability and availability.
  - connection of **many devices** simultaneously and to improve the terminal battery capacity life
  - **energy efficiency:** consume a fraction of the energy that a 4G networks consumes today; energy harvesting
  - **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

3. 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, healthcare, manufacturing
      - public transportation
      - and so forth

3. 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 and storage resources into one programmable and unified infrastructure**
    - **optimized** and more **dynamic usage** of all distributed resources
    - **convergence of fixed, mobile** and broadcast services.
    - support **multi tenancy models**, enabling players collaboration
    - leveraging on the characteristic of current **cloud computing**

3. 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)**

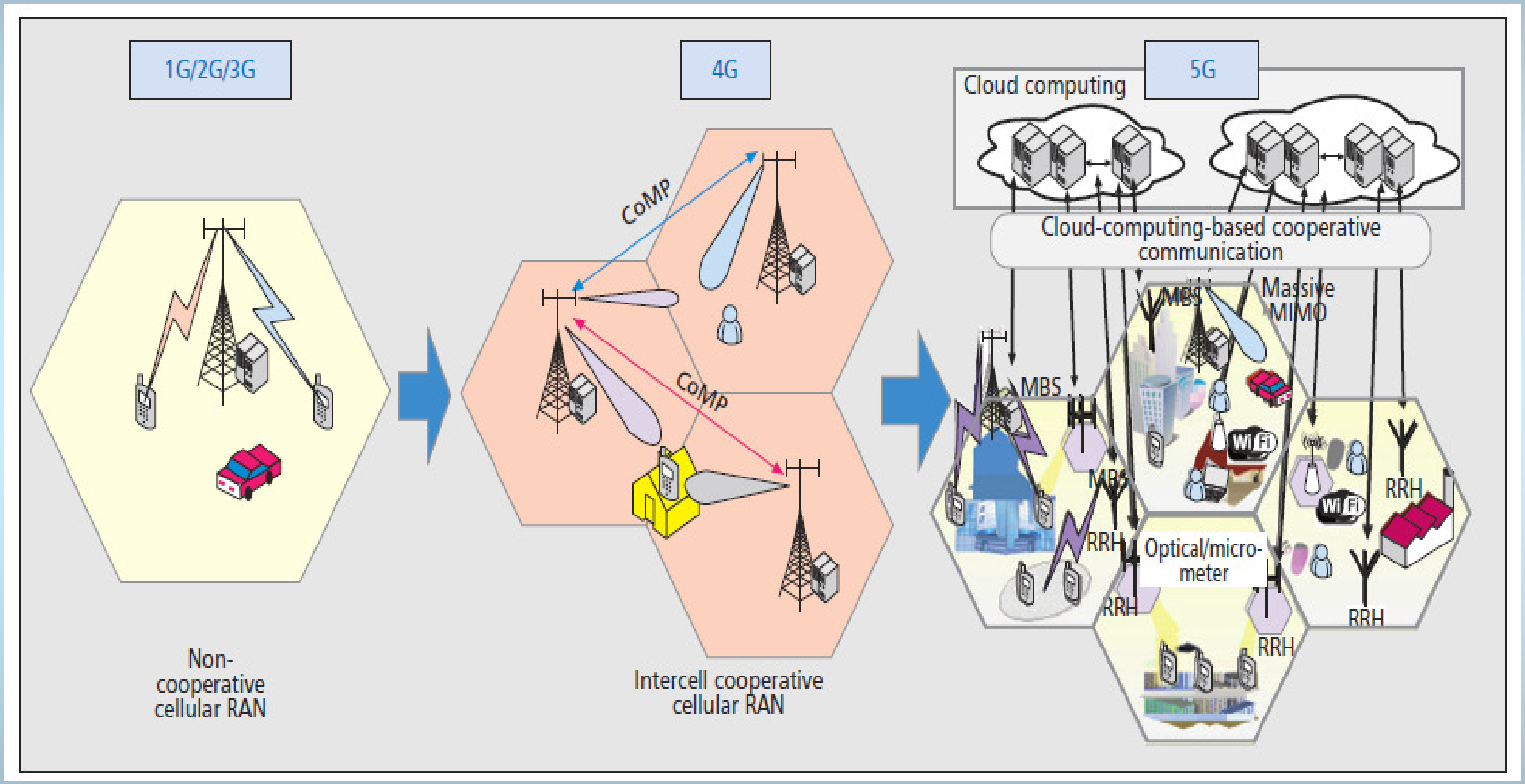
  - **Ease and optimize network management** operations, through
    - cognitive features
    - advanced automation of operation through proper algorithms
    - Data Analytics and Big Data techniques -> monitor the users' QoE

3. 5G Vision and Architectures

- **5G Key Requirements**
- **Summary of 5G figures (very) 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 ≥ 1M terminals/km2
  - **100 X in user data rate** reaching a peak terminal data rate ≥ 10Gb/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

3. 5G Vision and Architectures

- **Cellular systems evolution towards 5G**
  - 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

3. 5G Vision and Architectures

- **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. 5G Vision and Architectures

- **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

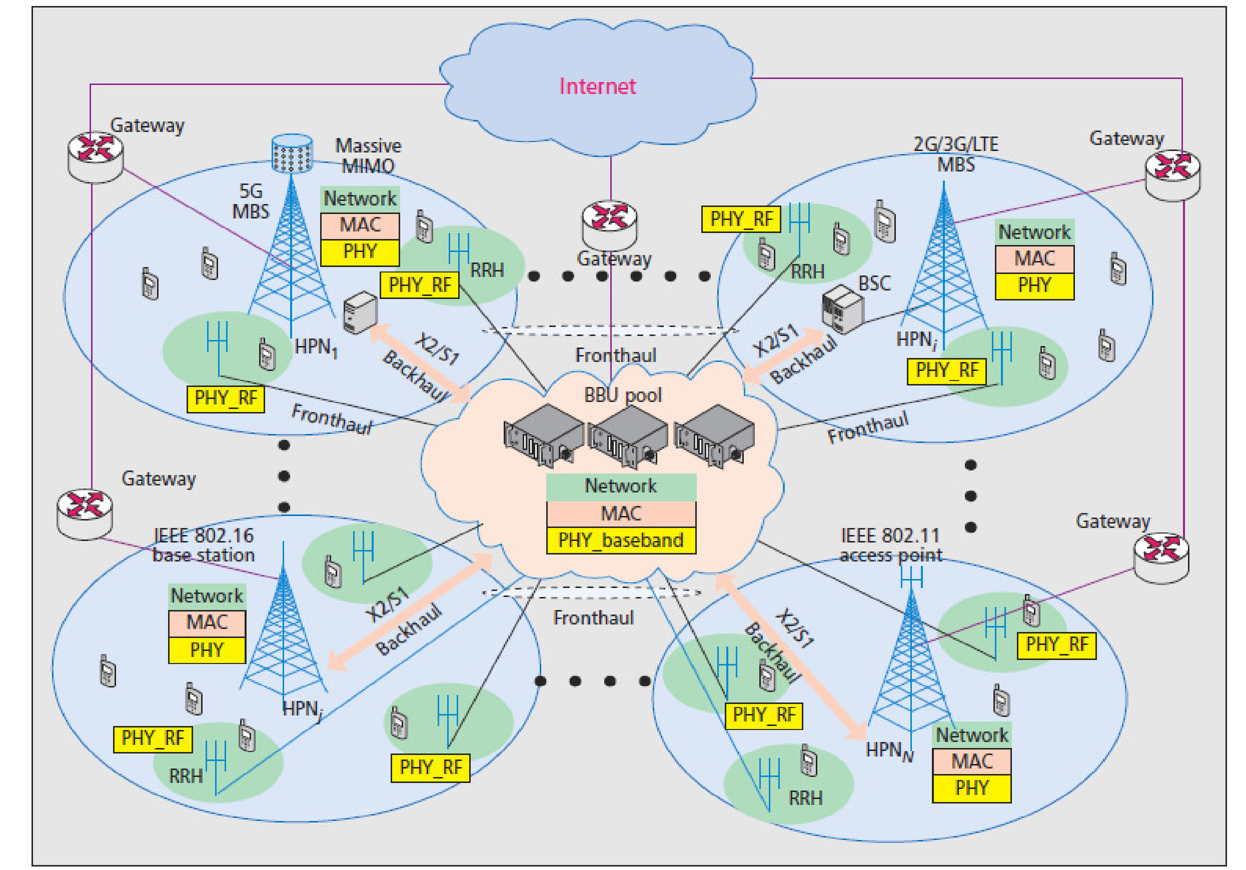
3. 5G Vision and Architectures

- **H-CRAN**
  - Notes:
  - 1G, 2G, 3G: cooperative processing is not demanded ← 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
    - It enhances the HPNs capabilities 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

3. 5G Vision and Architectures

5G System Architecture in H-CRAN approach

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



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

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)

3. 5G Vision and Architectures

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
    - adopting the advanced **Coordinated Multi-point (CoMP)** transmission and reception technique to suppress both intra-tier and inter-tier interferences.
  - Example : Report: the average spectral efficiency (SE) perf. gain from the uplink CoMP in downtown Dresden field trials was only ~ 20 percents with non-ideal backhaul
    - *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*

3. 5G Vision and Architectures

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
  - **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.
  - **RRHs in H-CRANs**
    - 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 BBU** pool is interfaced with HPNs to mitigate the cross-tier interference between RRHs and HPNs
    - through centralized cloud computing-based cooperative processing techniques

3. 5G Vision and Architectures

5G System Architecture in H-CRAN approach (cont'd)

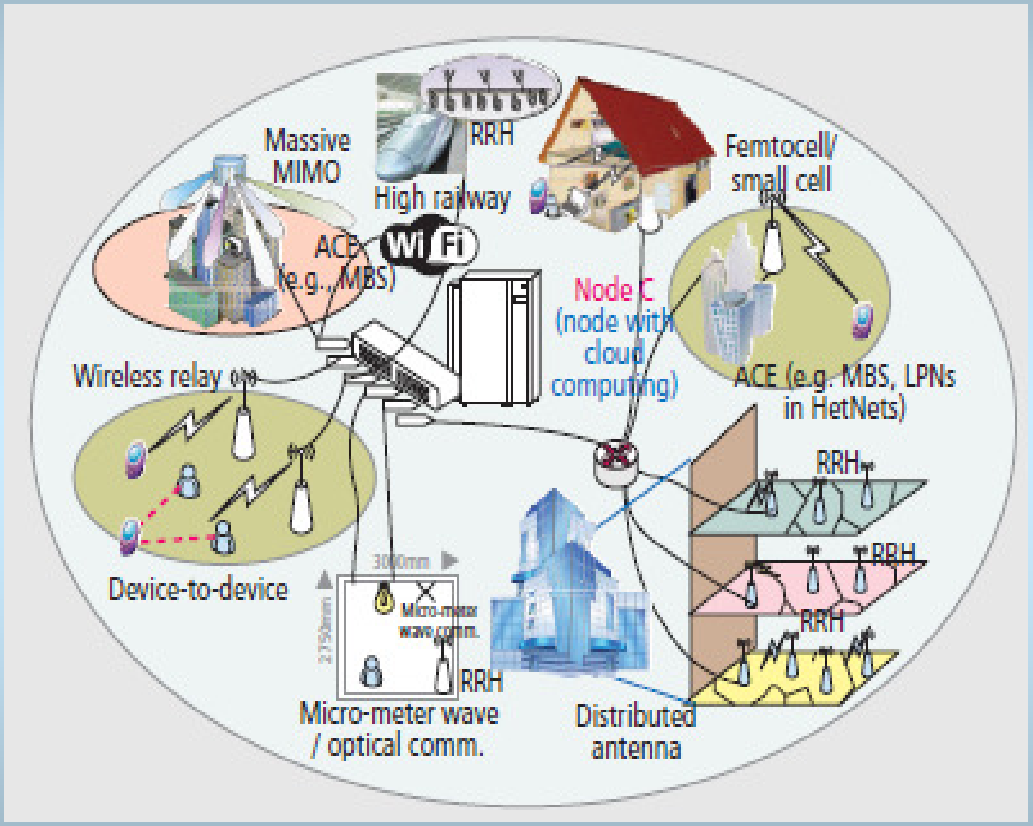
- The **BBU pool - HPNs I/Fs → mitigate the cross-tier interference** RRHs - HPNs through centralized CC-based cooperative processing techniques.
- The data and control I/F BBU pool - HPNs : S1 and X2, respectively

- **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 reqs
- 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

3. 5G Vision and Architectures

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.*

3. 5G Vision and Architectures

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 net 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 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. 5G Vision and Architectures

- **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, and modify the logic and interactions for the U plane and the C plane.
  - **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 cloudization: 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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7. Conclusions

3.1 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

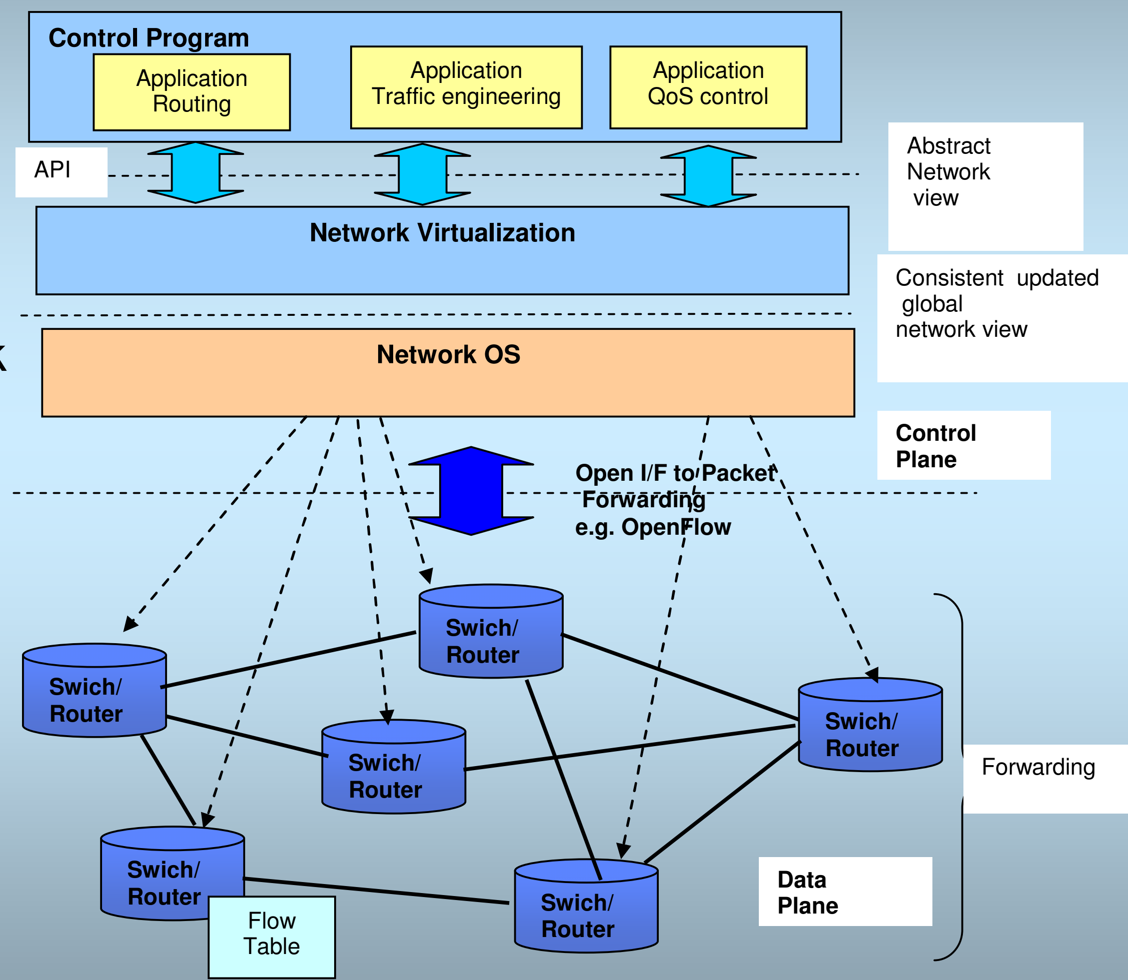
- **SDN objectives:**
  - **Control Plane (CPl) and Data Plane (DPl) separation**
  - A centralized logical control and view of the network
    - underlying network infrastructure is abstracted from the applications
    - common APIs
  - Open I/Fs between the CPl (controllers) and DPl elements.
  - Network 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 DPl CPl

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

3.2 SDN Basic Architecture

- **Network OS:**
  - Distributed system that creates a consistent, updated network view
  - Executed on servers (controllers) in the network
  - Examples: NOX, 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



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

3.2 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 $\Rightarrow$ **Improved operational efficiencies**

- **Reduced power usage**
  - (migrating workloads and powering down unused HW)

- **Standardized and open I/Fs**: between VNFs infrastructure and mgmt. entities

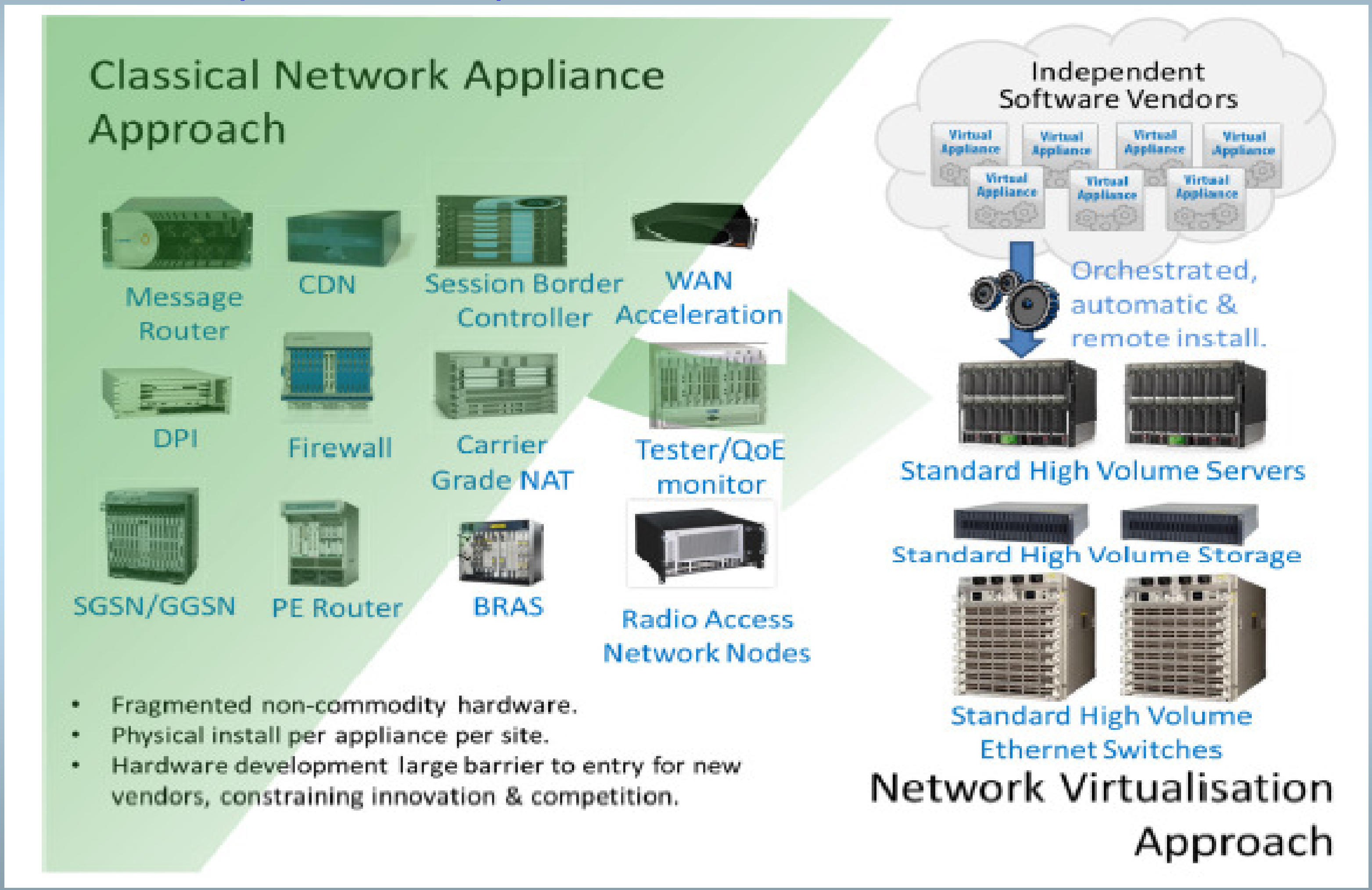
3. Software Defined Networking and Network Function Virtualization (NFV)

3.2 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

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

- **NFV vision** (source : ETSI)



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

- **NFV Architecture**

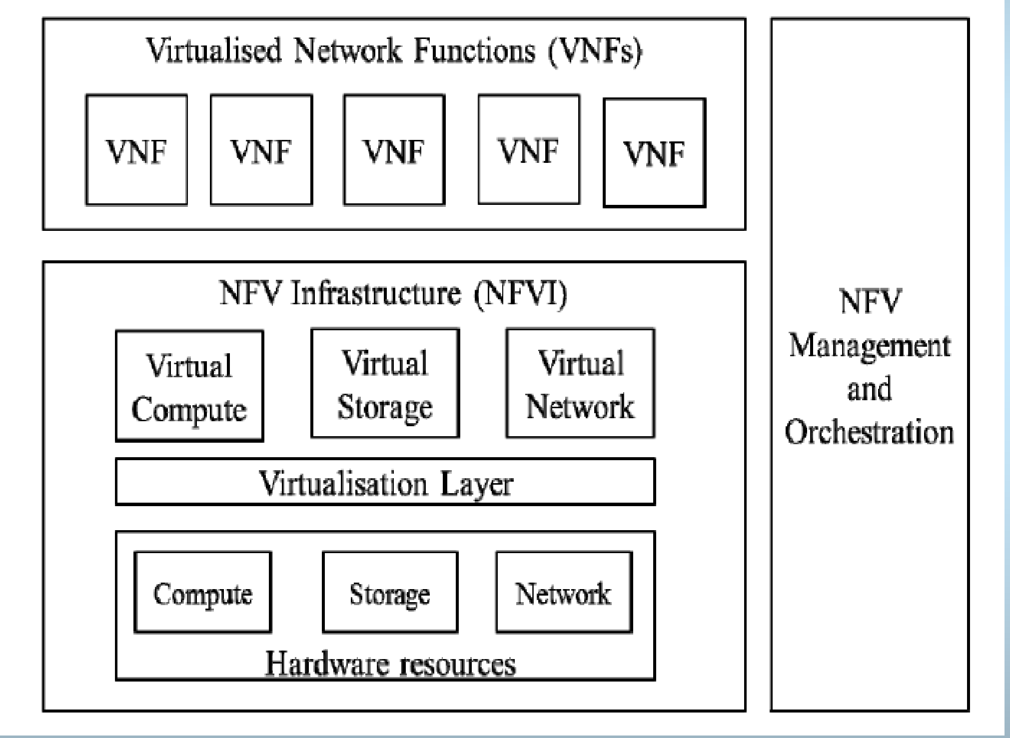
- **High level view of NFV framework**

- **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

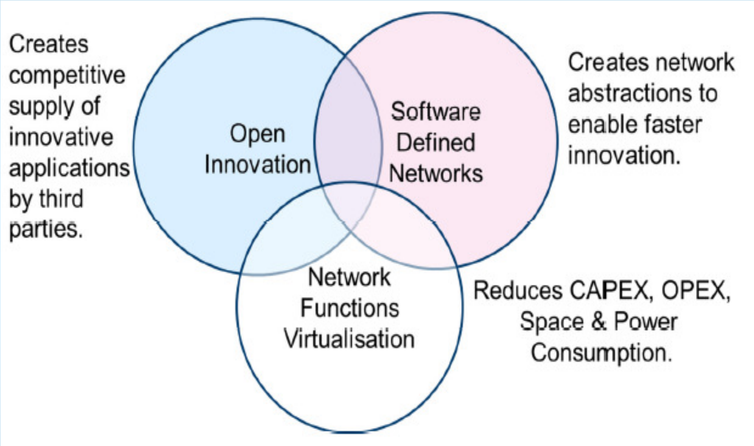
  - NFV MANO focuses on all virtualization-specific management tasks



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

3.3 NFV- SDN cooperation

- SDN/NFV recognized as **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



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

- NFV SDN-Cooperation
- ONF: NFV and SDN – industry view on

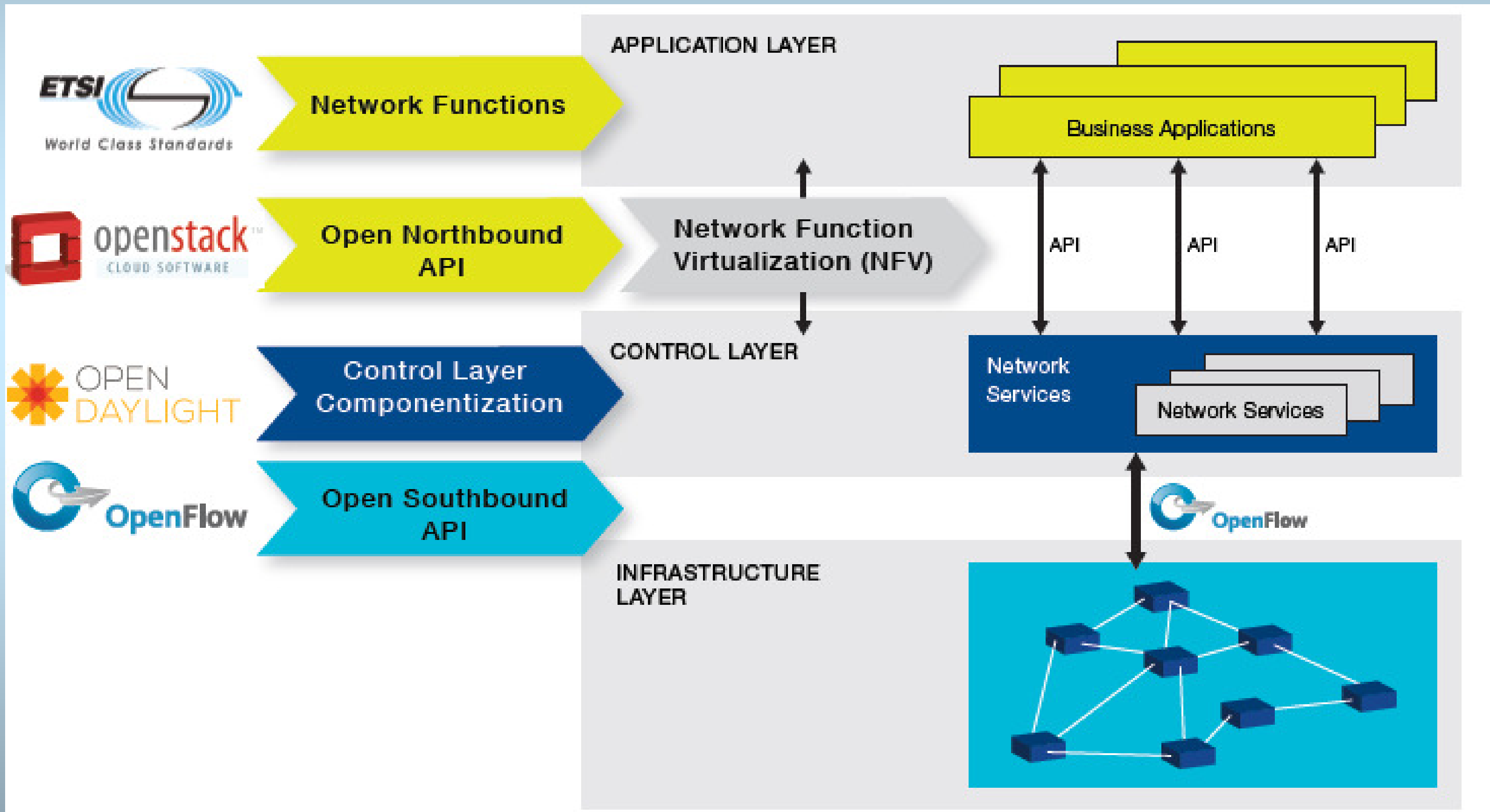
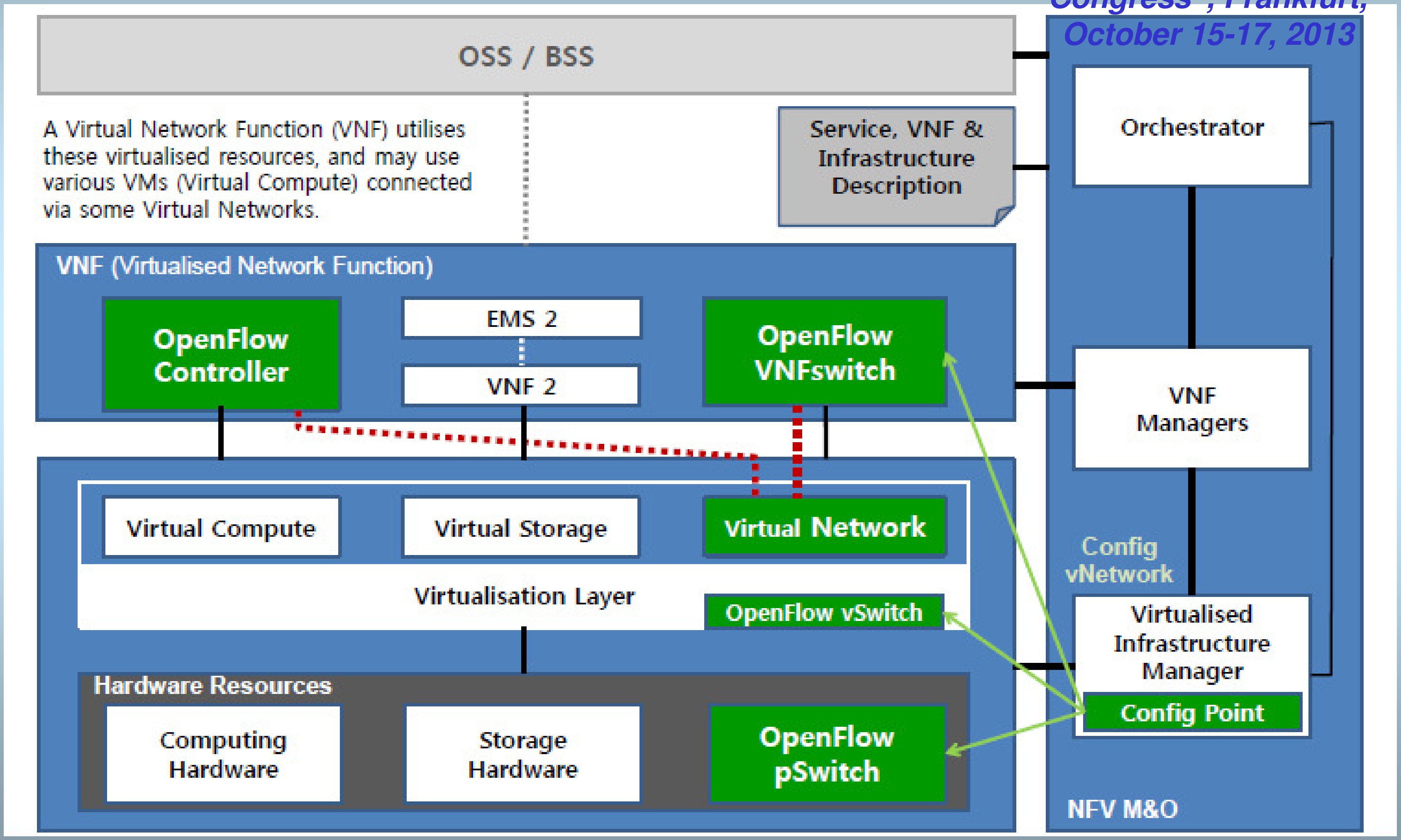


FIGURE 2: NFV and SDN Industry Map

3. 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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4. Content Delivery Architectures for 5G

Video Coding and transmission protocols

- **Encoding**
  - **Single-MUE case**: video encoder controls the information redundancy
  - **Multi-MUE case**: a video encoder takes into account different QoS requirements from the highly diversified mobile users.
  - **Multiple Description Coding (MDC), and Scalable Video Coding (SVC)** are utilized in current stds. (e.g. H.264/AVC and H.265/HEVC)
    - To adapt to the dynamic wireless transmission

      SVC: base layer and multiple enhancement layers with different priorities.

      MDC: Multiple descriptions of the source video are generated with equal priority, usually leading to more redundancy than those in SVC

- The SVC and MDC schemes can **adaptively generate video packets** from the same source (with different of intra- and inter-frame redundancy) - based on NSI information - to guarantee the delivery robustness
  - **More accurate NSI → allows less redundancy, but -> higher encoder computation task**

4. Content Delivery Architectures for 5G

- **Transmission**

  - The **HTTP/TCP** - and **RTP/UDP**-based protocols have been broadly adopted for video transmission in wired/wireless Networks

  - **Dynamic Adaptive Streaming (DASH),** an HTTP/TCP-based protocol, has been standardized
    - it can handle video packets with different priorities and thus is feasible to support video files encoded by SVC.

  - **MDC scheme is more suitable for UDP-based** protocols (no guarantee for delivery, ordering, or duplicate protection in UDP)
    - UDP based protocols could better support the congestion control by dropping video packets according to network states.

  - For both TCP- and UDP-based protocols, priority information for the video packets can be examined by **Deep Packet inspection (DPI),** which could be utilized by SP for QoS control.

4. Content Delivery Architectures for 5G

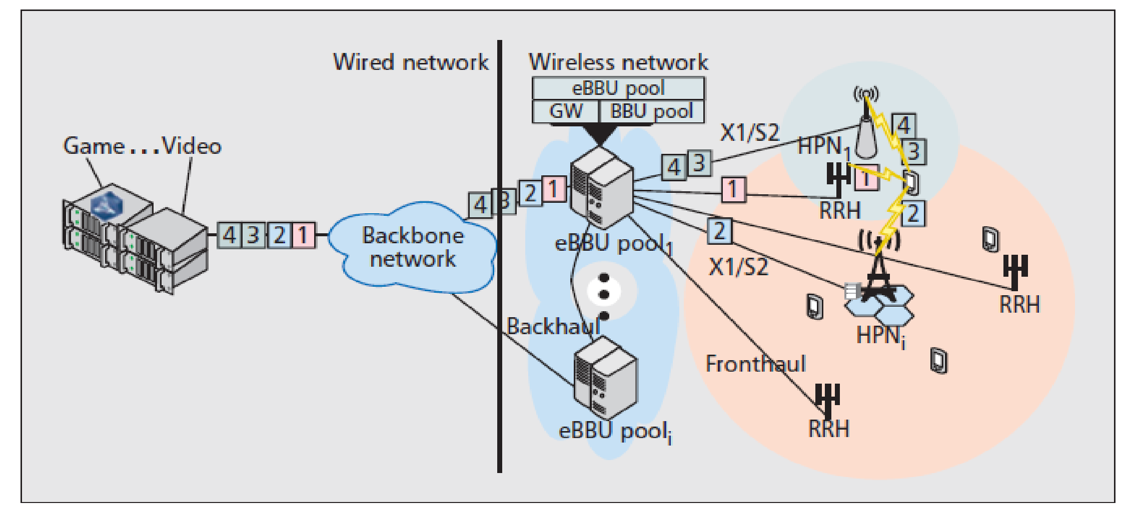
- **Conventional Delivery solutions**
  - Video packet **encoding and scheduling : at HS**
  - **Data predetermined paths** (via assigned RATs) to MUEs.
    - Equivalent : parallel pipeline trs. Model; each chosen RAT corresponds to a pipeline, with a **packet queue and a server.**
  - The path : HS → MUE : long delay for the feedback NSI → only certain quasi-static info is accessible to the HS → low perf. of adaptive flow control and video encoding
  - **"Out-of-order" issue at the MUE-** multi-RAT bottleneck → illustrates the importance of such NSI
    - Note : delivery delays by different RATs are usually unknown to the HS → reordering at MUE → MUE demultiplex operation issues for video packets and causes an out-of-order event -> retransmission for out-of-order packet → overhead on the network traffic.
    - Solution: increasing the MUE buffer size – but issues arise - due to the limit of TCP window size adjustment.
  - **Conclusion: the out-of-order issue is severe in the conventional het-nets without central control, due to the lack of perfect NSI in the RATs.**
  - Queuing model: ***n* independent *M*/*M*/1 queuing systems**, where *n* is the number of the RATs

4. Content Delivery Architectures for 5G

- **H-CRAN solution for video delivery**
  - promising technique in the upcoming 5G systems
  - It can jointly and efficiently **process, cache, and transmit** various videos
  - **- centralized baseband processing unit pool (BBU pool), controlling:**
    - multiple remote radio heads (RRHs)
    - multiple HPNs
  - **The BBU pool and RRHs are inherited from the CRAN**
    - A powerful centralized BBU (+) : caching video, scheduling data packets, and understanding the statistics of video traffic
    - Smart content caching (BBU is close to multiple RATs) release the traffic burden
  - Centralized coordination in a BBU → **video packets can be sent to MUEs in parallel via multiple RATs** (overall rate increase)
  - **BBU could schedule the video** packets into the matched RATs according to the required QoS
  - **BBU pool can be integrated with basic GW functions**, to control and schedule the video packets across multiple RATs → improved performance by globally managing the available resources across different RATs

4. Content Delivery Architectures for 5G

- **H-CRAN solution for video delivery (cont'd)**
  - Initial solutions : each RAT usually has its own GW ,
  - **Enhanced BBU (eBBU) pool = BBU pool and + GW**
  - GW : cover n x RATs
    - basic functions : packet buffering/inspection and routing/scheduling for multi-RAT. (2G, 3G, 4G, WLAN, RRH, etc.)
  - Possible evolution: **such a GW might replace the related network units, such as the Evolved Packet Core (EPC) in 4G**
  - The H-CRAN for one cell = various coexisting RATs + one eBBU pool.



M. SHENG, et.al., "Video Delivery in Heterogeneous CRANs : Architectures and Strategies", IEEE Wireless Communications , June 2015, pp.14- 21

H-CRAN solution for video delivery (cont'd)

- **Each cell has multiple RATs**; it is centrally controlled by one eBBU pool
- The eBBU pool
  - connected to all HPNs via data (S1) and control (X2) I/Fs
- **The eBBU pools in multiple neighboring cells are connected with a backhaul.**

- MUEs has access via HPNs or the RRHs, (RRH= an RF frontend and some basic symbol processing functionalities).

- RRHs are connected to the eBBU pool via high-speed optical fibers (i.e., the fronthaul) with the major

4. Content Delivery Architectures for 5G

- **Caching issues**
  - Traditional CDN use caching
  - **CDNs optimize content placement,** but not enough study on using it in wireless communications
  - **Wireless** system usually focuses on **delivery rates, agnostic to content.**
  - **Possible solution: joint design of content placement, access, and delivery for the heterogeneous wireless networks**
  - **Examples of key components** :
    - **1. Multi-level popularity:** content is divided the into different levels of popularity based on statistical knowledge of user requests
    - **2.Multi-level caching:** APs have caching capabilities and use them to locally cache content based on popularity
    - **3.Multi-level access:** dynamically allocate user access to APs, based on popularity of requested content
    - **4. Broadcast delivery:** Use the PHY broadcast property to serve multiple (distinct) requests simultaneously, by enabling coded-multicasting opportunities.
  - Note: In H_CRAN the eBBU Pool could play also caching role

4. Content Delivery Architectures for 5G

- **Caching in H-CRAN**
- Variants: **No eBBU Pool caching**
  - **The eBBU pool is directly connected to the RATs**
  -
  - The eBBU pool can easily obtain their online NSI and utilize it in the packet scheduling (multi-RAT scheduler) → delivery perf. is better (e.g. addressing the previously discussed out-of order issue)
  - The priorities of different video packets (e.g., those generated by SVC) or QoS requirements from multiple MUEs may also affect the scheduling at the eBBU pool
    - Example: higher priority assigned to the 4G while those with lower priority are sent to a WLAN
  - Queuing model: as an ***M*/*M*/*n*** queuing system
  - **The H-CRAN with packet scheduling → better delivery performance than conventional heterogeneous networks with only HS scheduling**

4. Content Delivery Architectures for 5G

- **Caching in H-CRAN**
- **H-CRAN**
- Variants: **eBBU Pool Caching**
  - The demanded **video can be cached at the local eBBU** pool, based on the technology of content awareness caching for 5G networks
    - reduced traffic from original HS
  - **Both the video encoding and transmission can be adapted to the online NSI of multiple RATs.**
  - The **eBBU pool works as the SP** with the units encoding the source video, controlling the frame rate, and managing the pre-caching content and buffering in MUEs.
  - **More accurate online NSI→ the encoding redundancy and the size of pre-caching content could be minimized** → saves the scarce spectrum resource.
    - More accurate NSI at the eBBU pool → reduced encoding redundancy can be used

4. Content Delivery Architectures for 5G

- Performance of different video delivery architectures
  - *Source: M. SHENG, et.al., "Video Delivery in Heterogeneous CRANs : Architectures and Strategies", IEEE Wireless Communications , June 2015, pp.14- 21*

Architecture	Encoding	Scheduling	Out of order	Performance
Without H-CRAN	HS	HS	Bad	Bad
H-CRAN without caching	HS	eBBU pool	Good	Good
H-CRAN with caching	eBBU pool	eBBU pool	Best	Best

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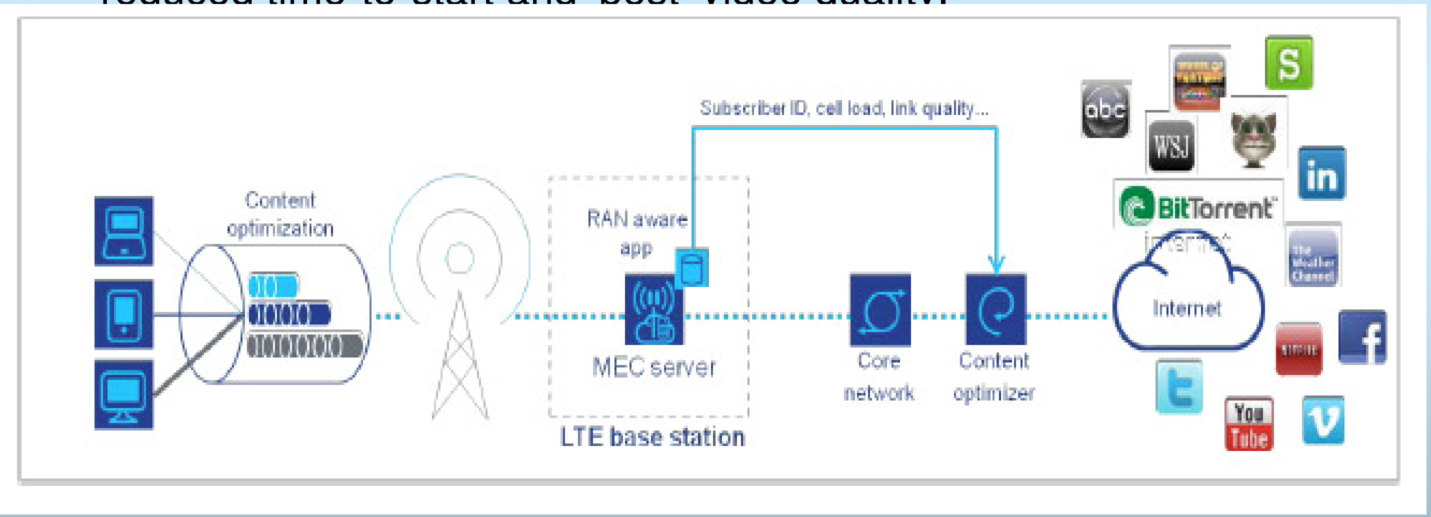
5. Mobile Edge Computing

- **Why MEC?**
  - **MEC provides IT and cloud-computing capabilities within the RAN in close proximity to mobile subscribers**
  - **Main standardization actors:** ETSI, 3GPP, ITU-T
  - MEC accelerates content, services and applications so increasing responsiveness from the edge
  - 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)*

5. Mobile Edge Computing

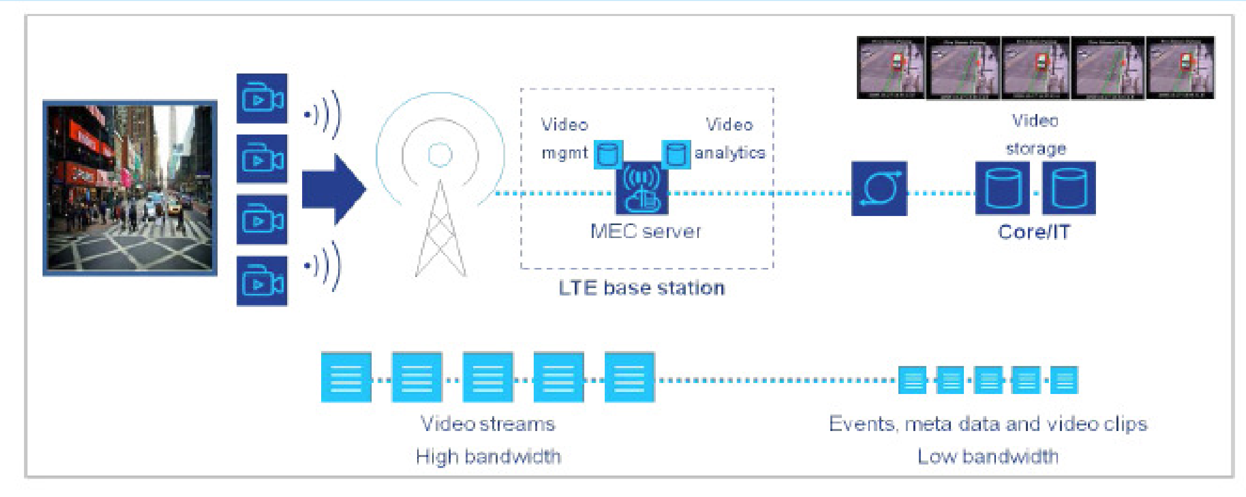
- **MEC Use Cases examples (content- oriented)**
  - **RAN-aware Content Optimization**
    - The application exposes accurate cell and subscriber radio interface information (cell load, link quality) to the content optimizer, enabling dynamic content optimization, improving QoE, network efficiency and 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

5. Mobile Edge Computing

- **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



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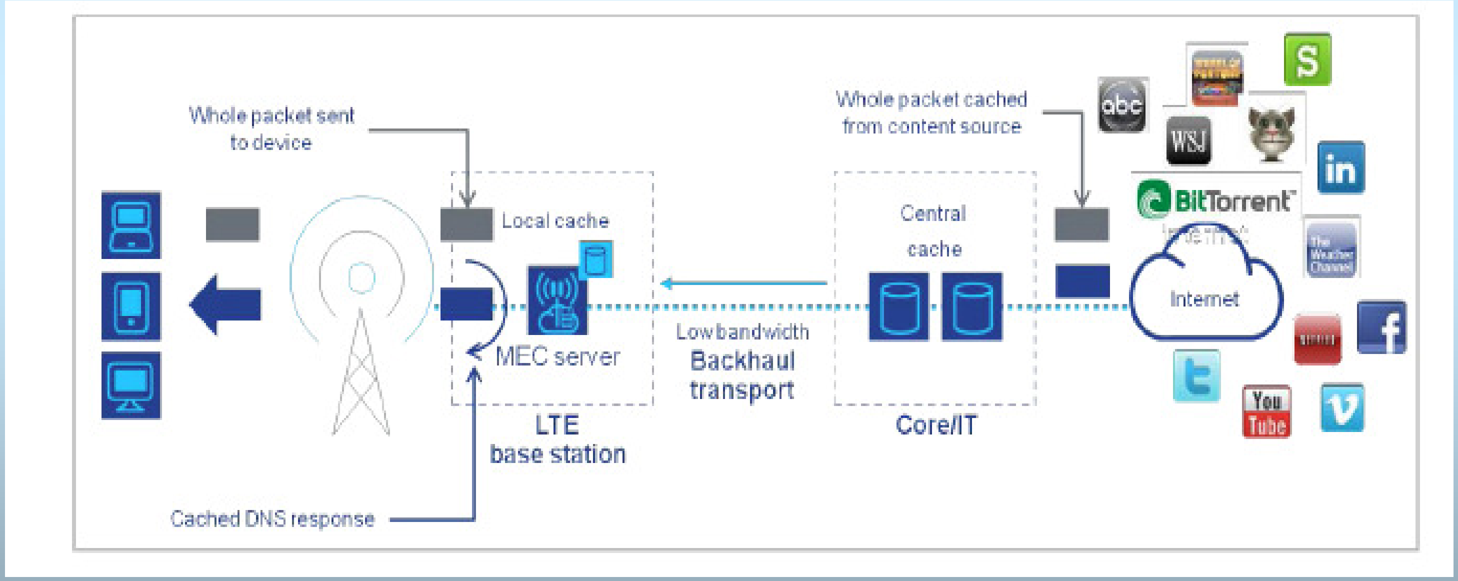
MEC Use Cases examples (content- oriented) (cont'd)

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%



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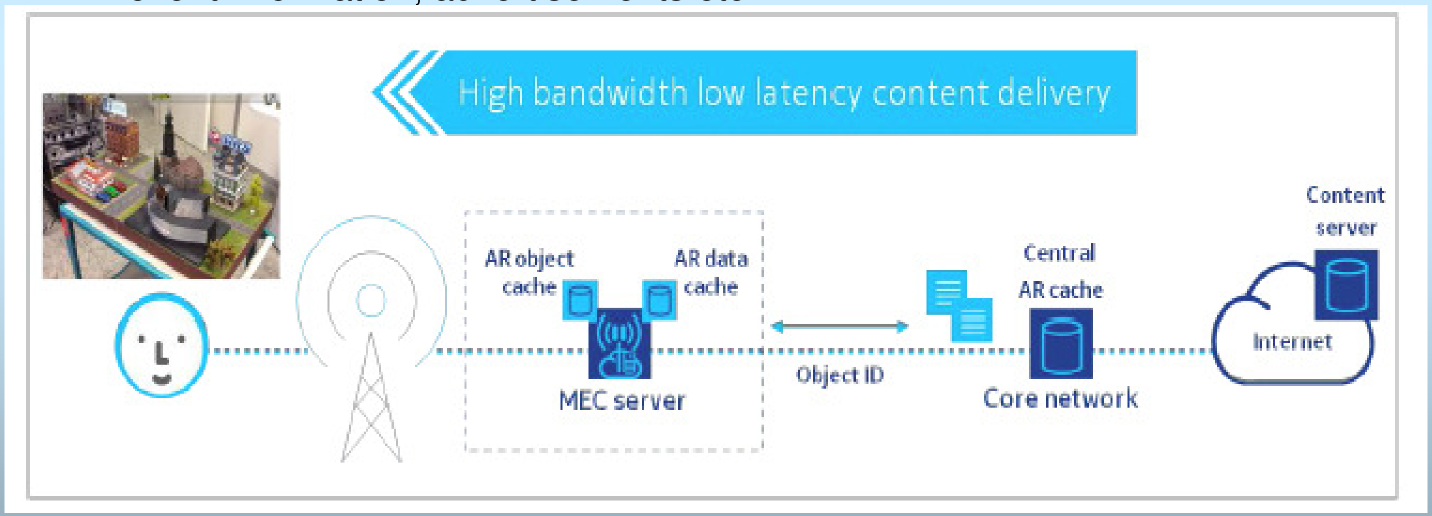
5. Mobile Edge Computing

- **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.

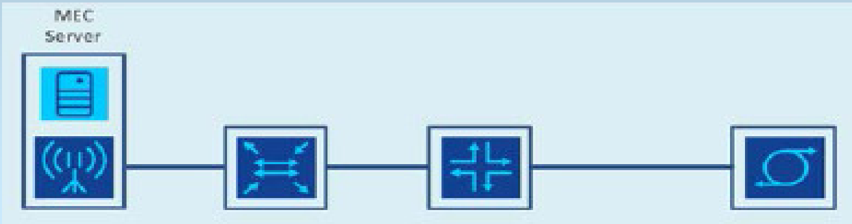


Source: https://portal.etsi.org/Portals/0/TBpages/MEC/Docs/Mobile-edge_Computing_-_Introductory_Technical_White_Paper_V1%2018-09-14.pdf
Mobile-Edge Computing – Introductory Technical White Paper

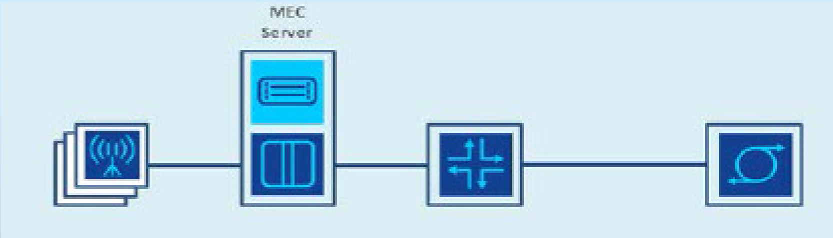
5. Mobile Edge Computing

- **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

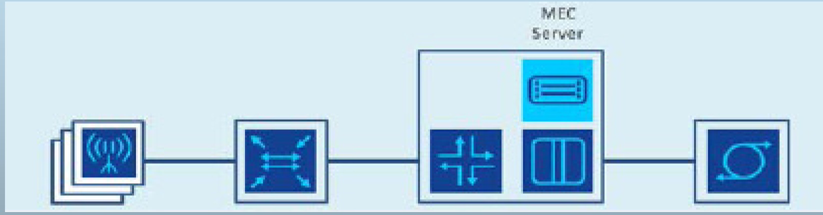
MEC at the LTE macro base station (eNB) site



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



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

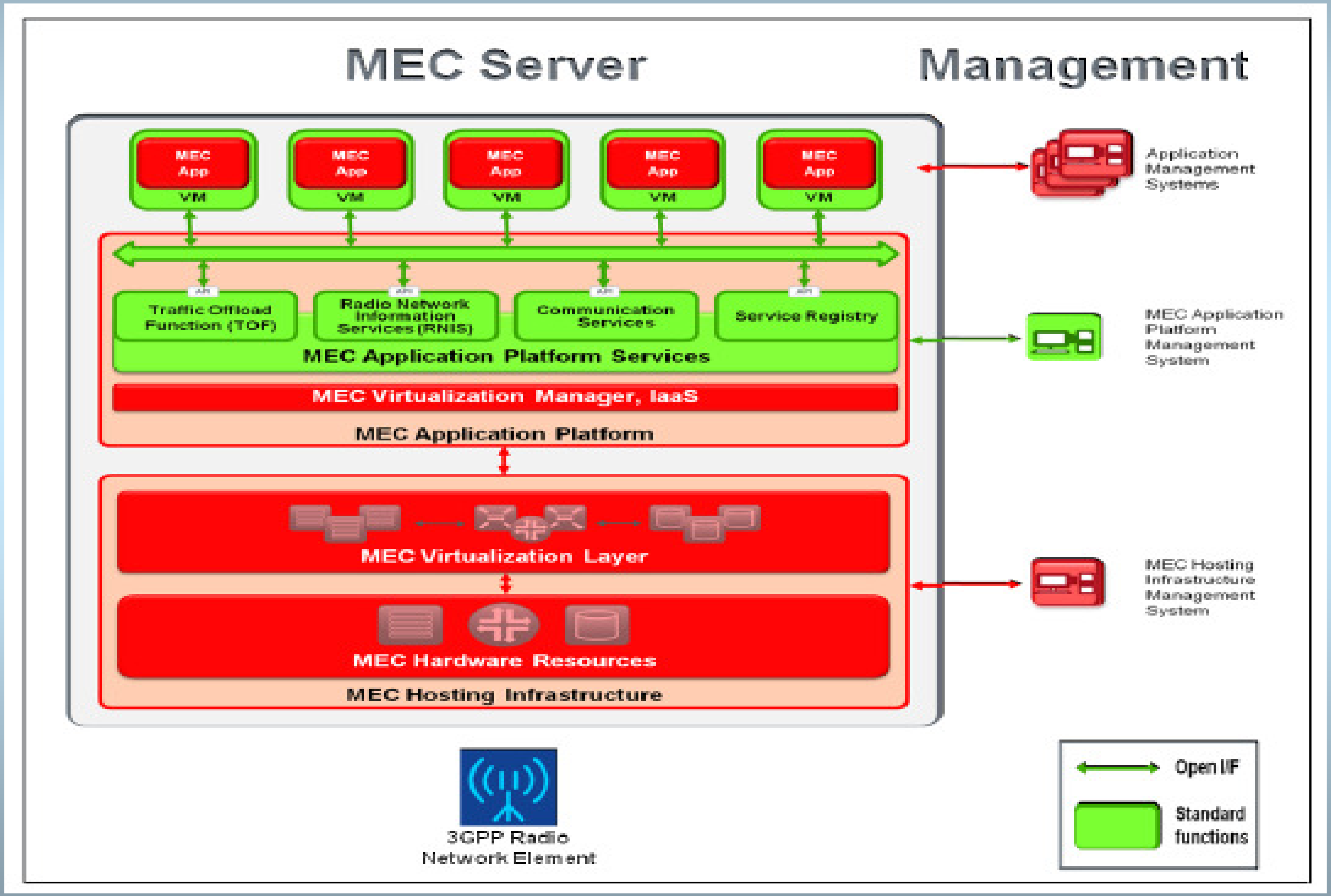


5. Mobile Edge Computing

- **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*



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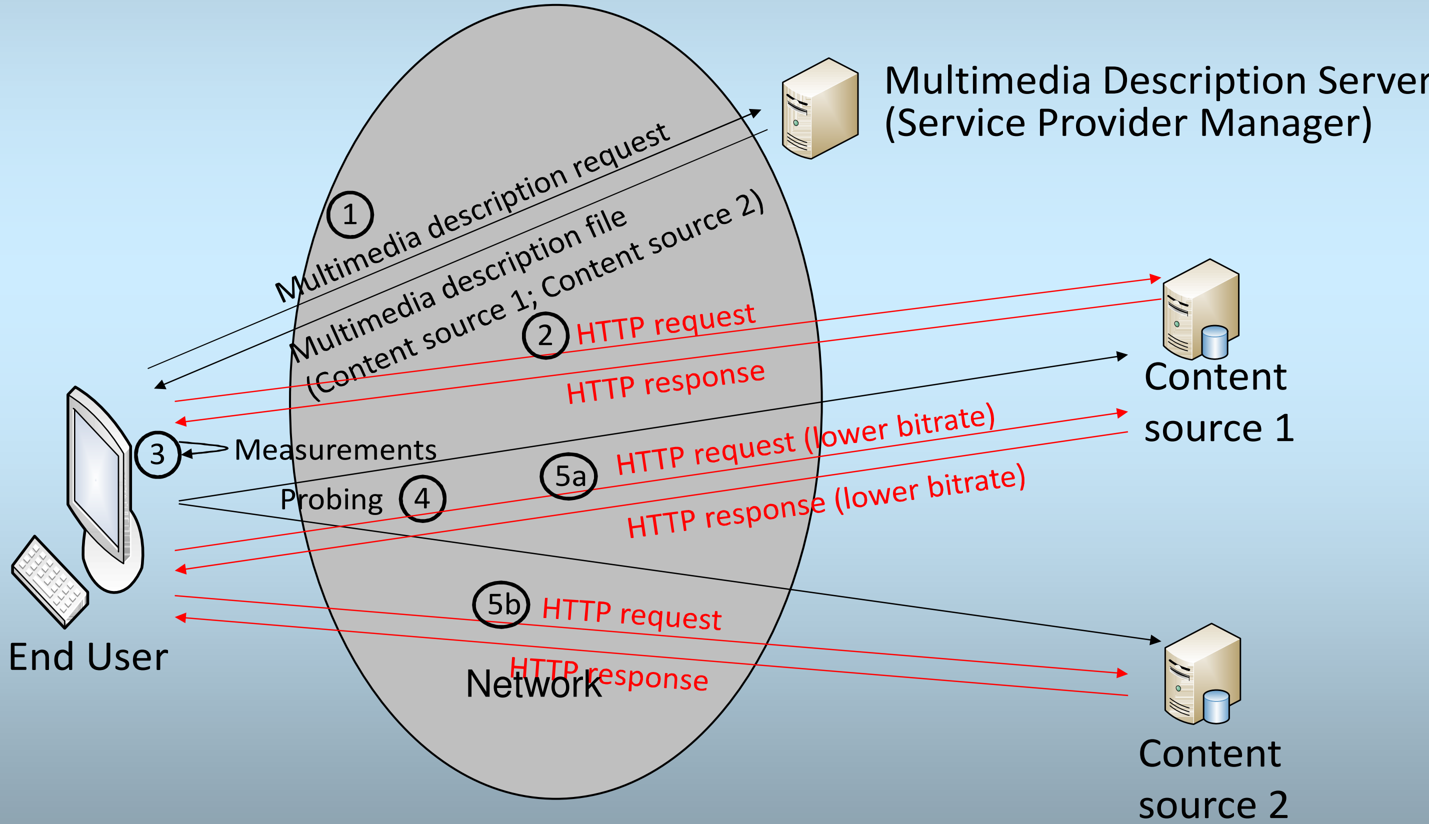
6. Example of a light OTT architecture

- **DISEDAN**
- **DI**stributed **SE**lection of content streaming source and **D**ual **A**daptatio**N** (2014-2015)- CHIST-ERA Int'l European Project
- **DISEDAN solution: *evolutionary and light architecture*** for content delivery via Internet
- **Novel concept :**
  - a. ***two-step server selection mechanism*** (at Service Provider (SP) and at End User) by using algorithms that consider context- and content-awareness;
  - b. ***dual adaptation mechanism during the sessions***
    - media flow adaptation
    - and/or content servers handover
- DISEDAN: **Over the Top (OTT) style of work**
  - **Simple management**
  - **Multi-domain, Network agnostic solution :**it can work over wireline or wireless network domains
  - Segmented video content delivery by using **Dynamic Adaptive Streaming over HTTP (DASH)**

6. Example of a light OTT architecture

- **Typical DISEDAN Use Case**
  - **Note : DISEDAN can be easily extended to H-CRAN context and benefit from eRRBU pool + caching**



6. Example of a light OTT architecture

- **Multi-objective optimization problems**
  To be applied to optimized server selection

  - **Minimize** $\{f_1(x), f_2(x), \ldots, f_m(x)\}$,
    - $x \in S$ (set of feasible solutions), $S \subset R^n$
  - ***Decision vectors*** $x = (x_1, x_2, \ldots, x_n)^T$
  - $(m \geq 2)$ possibly **conflicting** *objective functions* $f_i : R^n \rightarrow R$, i= 1, ..m
  - we want to minimize them simultaneously.

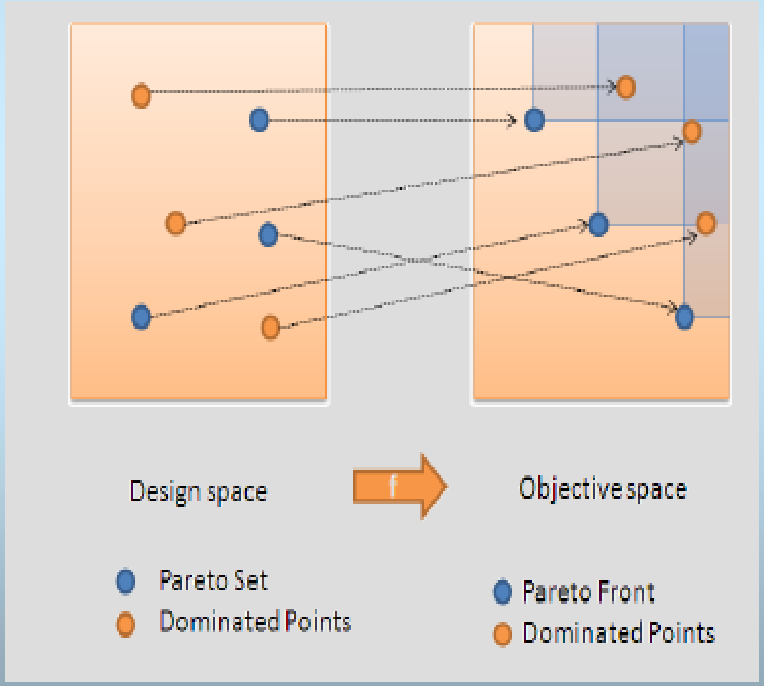
  - ***Objective vectors*** = images of decision vectors
    - *objective (function) values* $z = f(x) = (f_1(x), f_2(x), \ldots, f_m(x))^T$.
    - *feasible objective region* $W = f(S)$ = image of S in the objective space
    - Objective vectors are **optimal** if none of their components can be improved without deterioration to at least one of the other components.

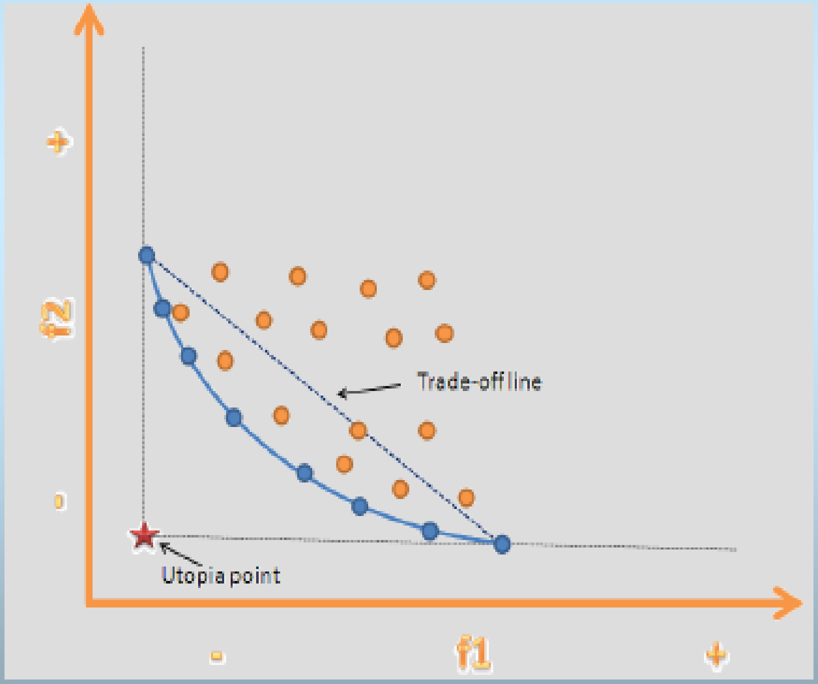
  - A decision vector $x\_ \in S$ is ***Pareto optimal*** if there does not exist another $x \in S$ such that $f_i(x) \leq f_i(x\_)$ for all $i = 1, \ldots, k$ and $f_j(x) < f_j(x\_)$ for at least one index j.

6. Example of a light OTT architecture

Multi-objective optimization problems

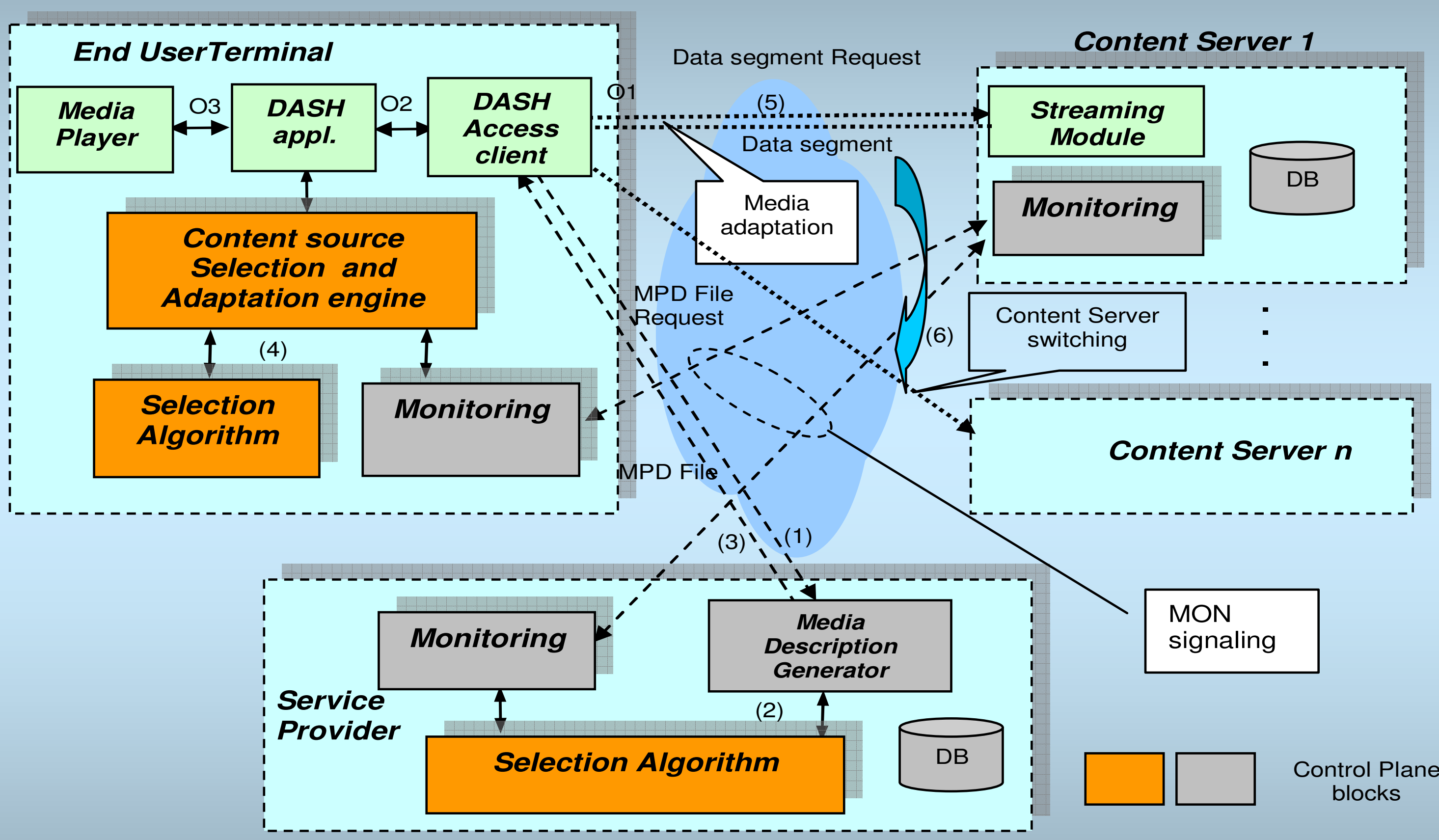
- Graphical illustration of the design space and Pareto front
- **Example:** x = (server, path); n= 2, $x \in Z^2$
- The paths and servers are identified through some positive integer indexes
- f(x) = (F1, F2) = (srv_load, avail_path bandwidth), m= 2
- "Tools" : MCDA, EMOA, etc.





6. Example of a light OTT architecture

DISEDAN Architecture



•DASH - Dynamic Adaptive Streaming over HTTP; MD – Media Description;
•DB – Data Base ; O1, O2, O3 – DASH Observation Points [ISO/IEC 23009-1]

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7. ⇨**Conclusions**

7. Conclusions

- **Content Delivery over wireless infrastructures**
  - Important area of services and applications for network and service providers including wireless support
  - 4G, 5G technologies – will have content delivery strong capabilities
  - “Tool” technologies: Cloud computing, SDN, NFV can cooperate to make content delivery more efficient and manageable
  - Managed and unmanaged solution coexistence
  - Candidate attractive solutions
    - 5G – CRAN, H-CRAN (Actual NSI – plays vital role for optimization)
    - Mobile Edge Computing
  - Caching may improve the performance
  - **Still open issues**
    - related to heterogeneity management
    - trade-off between computation and communication
    - advanced packet transmission strategies
    - cross-layer optimization
    - study of adaptive techniques performance in high mobility contexts

- 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 Neytworking
CDN	Content Delivery Network
CDNP	Content Delivery Network Provider
COTS	Commercial-off-the-Shelf
CoMP	Coordinated multi-point
CP	Content Provider
CRAN	Cloud RAN
CS-CIP	Content Services – Cloud Provider
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
FLUTE	File Delivery over Unidirectional Transport
HCRAN	Heterogeneous CRAN
HPHT	High Power High Tower, resemblance with today's
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
LPLT	Low Power Low Tower
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
- SMIL — Synchronized Multimedia Integration Language
- S/P-GW — Serving and Packet Data Networks Gateway
- SP — Service Provider
- STUN — Session Traversal Utilities for NAT
- TCP — Transmission Control Protocol
- TURN — Traversal Using Relays around NAT
- 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

- **1.1 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