Impact of Fixed-Mobile Convergence

Stephan Pachnicke, Bogdan Andrus, Achim Autenrieth

***Abstract*—Fixed-Mobile Convergence (FMC) is a very trendy concept as it promises integration of the previously separated fixed access network and the mobile network. From this novel approach telecommunication operators expect significant cost savings and performance improvements. FMC can be separated into structural convergence (regarding the infrastructure) and functional convergence (regarding the necessary functionalities required in fixed and mobile networks). The latter one goes hand-in-hand with Network Function Virtualization (NFV), where important network functions are provided by a server inside of the next generation point-of-presence (NG-POP). In this article implications on the system architecture as well as structural and functional convergence topics will be discussed.**

***Index Terms*—Fixed-Mobile Convergence (FMC), Cloud-RAN (C-RAN), Network Function Virtualization (NFV), Optical Fiber Networks, Passive Optical Networks (PON).**

I. Introduction

In the next years further exponential growth of the data volume is expected. Especially in mobile networks a compound annual growth rate (CAGR) of more than 50% is expected [1] looking at the global mobile data traffic (Fig. 1). Also the number of connected devices will be growing significantly; especially the number of mobile and portable devices such as smartphones or tablets.

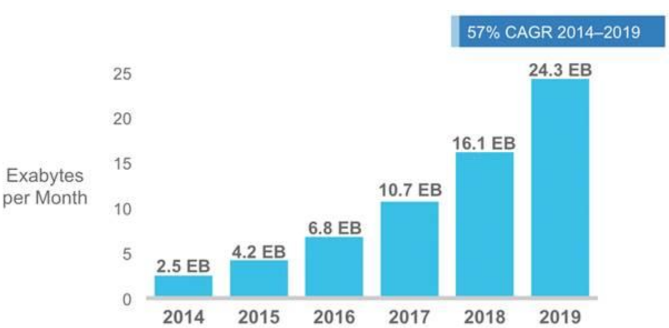

Fig. 1: Bandwidth growth in global mobile networks [1]

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The development of the novel 5G mobile standard has begun recently and it is expected to provide a 1000 times higher wireless area capacity compared to the level in 2010 and the possibility of facilitating very dense deployments of wireless communication links to connect 10-100 times the number of wireless devices [2]. These numbers already indicate that also a radically new approach must be taken to backhaul (and/or fronthaul) such enormous amounts of data.

In the fixed access network also significant bandwidth growth has been observed for almost two decades now (Fig. 2) and no change is expected in the near future. Major drivers are bandwidth-hungry multimedia and entertainment services such as video on-demand with HD-TV and 4K contents. Today most end-users are connected to the internet by digital subscriber line (DSL) technologies where VDSL2 and vectoring technologies enable transmission of some 200 Mb/s per subscriber over standard copper (2-wire) transmission lines, although with very limited reach of only a few hundred meters (fiber-to-the-curb, FTTC). Alternatively cable providers also offer a few hundred Mb/s bandwidth services (DOCSIS) with hybrid fiber-coaxial cable solutions. Both above mentioned technologies already require optical networks to be pushed closer and closer to the end customer.

Further increase of the transmission bandwidth will certainly rely on a different approach and the connection of the end customer directly by optical fiber (fiber-to-the-home, FTTH).

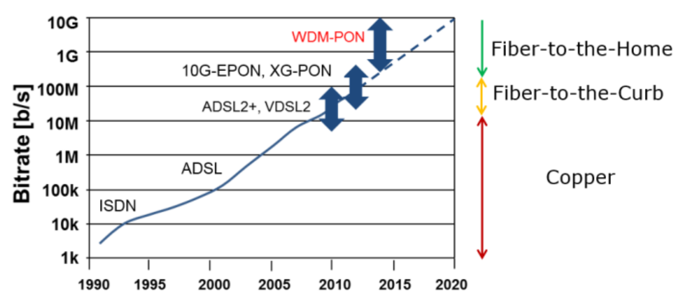

Fig. 2: Comparison of different access network technologies [3]

To deal with the above mentioned traffic growth challenges, Fixed-Mobile Convergence (FMC) may be a key-enabler. Up to now, fixed and mobile access networks have been optimized and evolved independently. Currently, there is almost complete functional and infrastructural separation of fixed-line access/aggregation networks and mobile networks. For example the availability of locations of mobile station sites and fixed network central offices are not re-considered by each other for new deployments. The vision for the future is one single network, which can provide all functions in a simple way. It is furthermore important to consider that investments in access infrastructure are long-term investments. Therefore, a sustainable mid- and long-term network evolution strategy is required.

The paper is organized as follows. In Section 2 the system architecture of an FMC network is outlined. In Section 3 the challenges for structural convergence are shown. In Section 4 the aspect of functional convergence is dealt with. Finally, a conclusion is drawn.

II. FMC System Architecture

A unified access and aggregation network architecture allowing fixed and mobile networks to converge is currently discussed intensively in research projects, at system vendors and network operators (e.g. [4]). FMC will be driven by an improved network infrastructure ensuring reduced cost, lower energy consumption and improved spectral efficiency. At the same time, the new FMC infrastructure will inherently improve performance and ease of use for the end user, e.g. due to reduced delay, increased throughput and seamless access to broadband networks.

Major requirements for the structural convergence are thus the ability to provide bit rates of ≥ 10 Gb/s (at least to dedicated business customers and remote radio heads, RRH) and to fulfill strict latency/jitter requirements, which are mandatory for mobile fronthaul connections. A good candidate for such a unified network infrastructure is a WDM-PON (wavelength-division multiplexed passive optical network) as currently being specified by the FSAN and ITU-T Study Group 15, Question 2 (ITU-T G.989.2) [5][6].

Another central element in the FMC concept is a next generation point-of-presence (NG-POP) which provides a Universal Access Gateway (UAG). A UAG will contain several building blocks especially an NFV-server, a Carrier Ethernet switch/aggregator, the WDM-PON optical line terminal (OLT) and a low-latency electrical cross-connect (compare Fig. 3).

The NFV-server can be built by a commercial-off-the-shelf (COTS) server, which can host a wide variety of network functions traditionally provided by dedicated (costly) hardware boxes. Major example of virtualized functions hosted in the NFV server are the mobile network evolved packed core (EPC) and universal authentication functions (uAUT) as well as advanced interface selection mechanisms to allow seamless handover between WiFi and mobile networks. More details will be given in Section 4.

Another important element of the UAG is a low-latency cross-connect. This device is necessary when utilizing the concept of base-band unit (BBU) hoteling (also termed cloud-radio access network, C-RAN). The concept of BBU hoteling involves pooling of mobile-traffic processing equipment in a single location, which may be several kilometers away from the actual antenna site for example at a main central office (Main CO). The RRHs are connected to such a BBU hotel by the (unified) optical access network (so-called fronthauling). Due to very strict constraints on latency and timing jitter of these fronthaul links only special low-latency cross-connects may be used, which will be explained in greater depth in the following section.

Finally, a Carrier Ethernet switch is used to aggregate the different users' channels to a higher bitrate pipe, which is

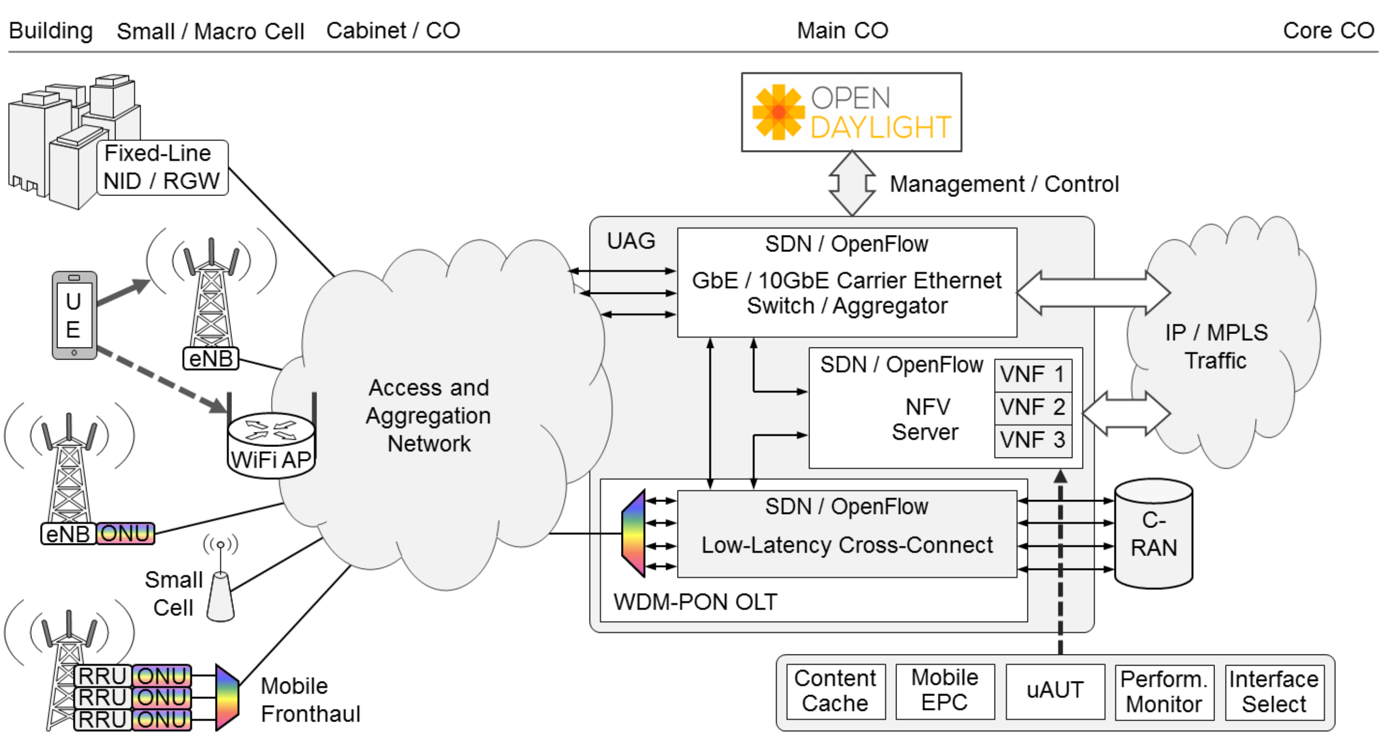

Fig. 3: FMC system architecture. (NID: network interface device; RGW: routing gateway; UE: user equipment; ONU: optical network unit; RRU: remote radio unit; UAG: universal access gateway; OLT: optical line terminal; VNF: virtual network function; EPC: evolved packet core; uAUT: universal authentication)

handed over to the IP/MPLS backhaul network. It is important to highlight that the different components of the UAG shall be centrally controlled by an SDN controller (e.g. Open Daylight, ODL) enabling dynamic reconfiguration of the different network elements on-demand.

III. STRUCTURAL CONVERGENCE

Structural convergence is defined as using the same access and aggregation infrastructure for fixed and mobile services. This enables sharing of the infrastructure resources between the different services (e.g. wireline backhaul, mobile front- and backhaul) and also pooling of certain resources.

The development of a converged access and aggregation network has to cope with the foreseeable network evolution of the fixed, Wi-Fi and mobile networks, including the evolution to 5G. For the fixed access network, this evolution includes node consolidation, concentration of access equipment in the Main CO, and the roll out of a passive fiber network towards the residential customers in an FTTC or FTTH approach.

The system solutions which are to be considered have to be selected with regard to the challenging FMC requirements namely capacity (including future scaling capability), reach (also considering site consolidation) and potential transparency (e.g. for transport of mobile fronthaul traffic). As result only fiber-optic solutions, which make use of wavelength division multiplexing and which support passive infrastructure can be considered. The respective solutions must be able to support legacy optical distribution networks (ODN) for residential access, i.e., they must support a power-split passive (PON) infrastructure. For green-field deployment and front-/backhaul, WDM-filtered or hybrid ODN is an option [7]. Finally, colorless operation of the end devices (Optical Network Units, ONUs) is required, to lower operational cost.

A (tunable) WDM-PON system can satisfy all the above mentioned requirements providing high data rates, long reach and low latency and jitter. A prototypical system has been demonstrated recently in a field trial showcasing novel tunable SFP+ modules and the concept of centralized wavelength control of the ONU wavelengths [8].

Another important aspect is the concept of BBU hoteling (or C-RAN), which involves pooling of mobile traffic processing equipment in a single location, potentially far away from the actual antenna site [9]. This requires transport of a digitized version of the analog (mobile) radio signal via the optical access network to the antenna location (also referred to as fronthauling), which is in turn reduced to only an RRH. For the transport of mobile fronthaul signals, the common public radio interface (CPRI) specification has been agreed on by major system vendors [10]. CPRI defines different line rate options, reaching up to 10 Gb/s transmission rate, required to carry a baseband I/Q signal of a TD-LTE format for 8 antennas with 20 MHz bandwidth. CPRI furthermore imposes strict requirements on transport latency and timing jitter. Currently commercial systems are only available for the 2.45 Gb/s line rate (CPRI option 3).

In recent measurements (compare Table 1) the compliance of a WDM-PON system with the CPRI standard has been evaluated at different line rates [11]. It has been shown that for CPRI options 3 (2.45 Gb/s) and 5 (4.91 Gb/s) the maximum jitter specification is fulfilled. In the measurements the maximum admissible jitter values have been exceed slightly only for a line rate of 9.83 Gb/s (CPRI option 7), however, that could easily be fixed by the use of a clock recovery at the ONU side. This proves the compatibility of a WDM-PON system with the mobile fronthaul requirements.

Apart from the mere transport capability additional cross-connection functionality may be desirable at the NG-POP. This can be used for example to switch over a link from one RRH to another RRH. In such a way the system could react on shifts in traffic patterns e.g. that a higher capacity (and an additional RRH) is required in a commercial area during daytime and in a residential area during night. As the maximum amount of latency that a network element may introduce in the case of mobile fronthauling should be negligible, only all-optical or very low-latency electrical switches may be used for that purpose.

Measurements of the latency of an electrical switch depending on the bit rate of the signal are depicted in Fig. 4.

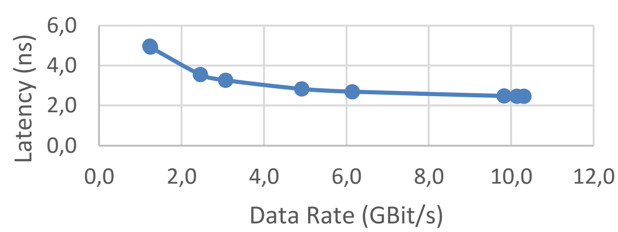

Fig. 4: Latency measurement at the low-latency cross-connect

The total latency consists of a small fixed amount (due to simple propagation delay) of approximately 2.1 ns and an additional factor of approximately 3.5 bit periods which can be associated to the clock and data recovery (CDR) and

Table 1: Jitter measurements of a WDM-PON system at different CPRI line rates [11]

	2.45 Gb/s	4.91 Gb/s	9.83 Gb/s	Maximum values according to CPRI specification
Deterministic jitter at transmitter	58.2 mUI	139.9 mUI	192.3 mUI	170 mUI
Total jitter at transmitter	71.7 mUI	139.9 mUI	192.3 mUI	350 mUI
Deterministic jitter at receiver	103.5 mUI	199.8 mUI	383.2 mUI	370 mUI
Combined deterministic and random jitter at receiver	135.9 mUI	271.7 mUI	536.8 mUI	550 mUI
Total jitter at receiver	136.mUI	271.5 mUI	537.8 mUI	650 mUI

retiming functions. The maximum measured latency always remained below 5.08 ns for all bit rates. This proves that also an electrical switch is feasible for cross-connecting CPRI streams.

IV. Functional Convergence

The convergence of fixed and mobile network functions, called functional convergence, is defined as the implementation of generic functions to realize similar goals in different network types (fixed, Wi-Fi, mobile). Functional convergence will impact the control plane of future networks through converged control mechanisms of both fixed and mobile networks, but will also impact the data plane through a better distribution of data flows in the converged network.

Two key aspects must be considered when talking about functional convergence namely network function virtualization (NFV) and software defined networking (SDN). The former one allows running various kinds of network applications on COTS hardware, which is independent from customized (and costly) network hardware. The latter one can change the forwarding behavior of the data plane in real time through vendor independent (and standardized) software interfaces.

An important (virtual) function to be realized at the UAG is the so-called converged subscriber and session management. This can be split into universal subscriber authentication (uAUT) and universal data path management (uDPM).

uAUT provides a single functional block with a single global user data repository [12]. At network level, uAUT provides access to a common subscriber authentication platform regardless of the access network (e.g. WiFi or mobile networks, bluetooth, etc.). This enable the user equipment (UE) to automatically authenticate in both a (public) WiFi network and the mobile network based on the credentials stored on the SIM card.

Furthermore, an additional advantage with an FMC network is that the traffic can be transported via several types of infrastructure to the UE (compare Fig. 5). For example it is possible to send packets either over the fixed access connection or via the mobile access connection and still having an entity in the network that is aware that it is the same user. In the FMC scenario the UE can be connected to more than one data path, advantages in terms of offloading and handover become available. In contrast to the connection control of today, when the UE connects to one data path determined by rules set locally, a more advanced scheme must take more into account. That means the connection control should be transferred to the uDPM and be used to maximize the utilization of the available infrastructure [12].

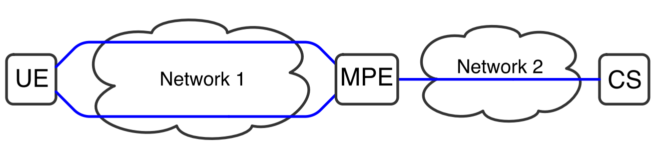

Fig. 5: Converged network with multiple data paths to the UE (MPE: multi path entity; CS: content server)

From Fig. 5 it can be seen that the content server (CS) is not involved in steering the traffic flow over the data paths, and network 2 is not affected by the dual connection. The management decision is realized exclusively by the uDPM module, which is hosted in the UAG (and which can configure the network by means of SDN).

As another example uDPM can offer joint scheduling of wireless and optical resources. This can be used to increase mobile capacity at a certain antenna site due to high demand. The process will involve reconfiguring a virtualized EPC residing in the NFV server and providing bandwidth in the optical layer (by the centralized network orchestrator) by configuring the low-latency cross-connects and the OLT of WDM-PON system accordingly.

One of the main challenges for NFV is to provide a similar reliability compared to purpose-built network equipment, while taking advantage of the virtualization benefits. A typical use case supporting resiliency, energy efficiency and client/management traffic load-balancing is the live migration of a virtual network function (VNF) between different NFV servers. An example of live-migration is depicted in Fig. 6, where two UAG entities are involved each comprising a low-latency cross connect and an NFV server. The red arrow indicates that VNF1 of the left UAG is transferred to the right UAG via the packet core network. This process is controlled automatically by the centralized network orchestrator (e.g. OpenDaylight) and can be initiated e.g. by a load-balancing function being executed also in the NFV server.

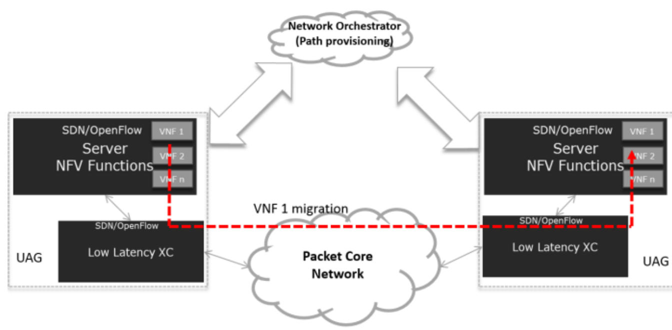

Fig. 6: VNF migration over temporary provisioned path by SDN network orchestrator

When migrating a VNF, a minimum downtime and negligible additional delay are desired with the purpose of preserving the service level agreement conditions. In recent experiments [13] conducted in a laboratory contained network, it has been shown that moving a VNF over a link with 80% utilization rate can be achieved with only a minimum downtime of 2.7 s. For time-critical and high reliability services zero-downtime can also be achieved. This is possible by using a dedicated link over the available infrastructure and temporary provisioning a fixed optical path for the migration cycle.

V. Conclusion

We have given an overview of fixed-mobile convergence challenges and solutions for future networks. For structural convergence next generation passive optical networks and especially (tunable) WDM-PONs are good candidates to serve fixed- and mobile network customers over a unified infrastructure. Regarding functional convergence the introduction of an NFV server at the next generation point-of-presence will be crucial. This server can host different kinds of virtual functions on COTS hardware and in combination with software-defined networking allows agile configuration of the network and provisioning of network functions on-demand. Both structural and functional convergence together will offer significant savings of networking costs and lead to energy consumption improvements due to sharing of infrastructure. FMC will have an impact on both control and data plane architectures. This will offer features beyond traditional network control by allowing deployment of applications on top of the infrastructure to automatically optimize across heterogeneous domains and quickly instantiate new end-to-end services.

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