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An architectural vision for the future 5G cloudified packet core

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Abstract—A massive traffic increase is foreseen in the near future in mobile networks. Such data storm is expected to pose new challenging requirements to the existing mobile network architecture, since the traffic will be generated by a wide set of applications running on an increasingly high number of mobile devices and sensors. In this paper we propose a paradigm shift for the evolved Packet Core for the future 5G system. By leveraging on the economy of scale of software–based ICT technologies, namely Software Defined Networking and cloud computing, we propose a hierarchically cloudified mobile network. In particular, in this paper we focus on the mobility aspects within such new architecture, proposing low latency Layer 2 solutions for the Access Network, while exploiting aggregating Layer 3 mobility functionalities in the regional and national clouds.

I. INTRODUCTION

The Cisco forecast [1] of x10.000 increase of the data traffic in wireless networks by 2030 due to the combined success of smartphones and Machine–Type Communication (MTC) is regularly mentioned as a trigger for revisiting network architectures. A more careful analysis of the expected traffic increase revealed that more problems were to follow. In particular, new types of applications with extremely challenging requirements are appearing, such as vehicular communications specifically for remote control of autonomous systems, ranging from delivery drones to self–driving cars. Another non negligible aspect that does only marginally affect the amount of carried traffic but severely impacts the network management is the introduction of MTC traffic. As a matter of fact each of these connected devices is expected to contribute to the traffic amount with a reduced number of very small packets a day. Nevertheless the amount of devices simultaneously connected to the network will increase exponentially, creating potential difficulties to the existing systems. In particular, network management methods will need to be re–designed taking into account scalability as major design principle.

Latency and bandwidth become also very important players in the 5G game and through a revised deployment strategy based on Small Cells it could be possible to satisfy very tough requirements such as virtually zero latency (in the order of a few ms in the air interface) to high capacity systems, up to 10Gbps, while at the same time scale the network in order to accommodate the high number of expected devices [2].

These new tough challenges [3] can be synthetically summarized, as suggested in [4], in the following groups:

- High capacity, up to 1,000 times, mostly supporting streaming applications;
- Fast mobility, enabling vehicular type communications, both among vehicles and directed to the infrastructure;
- High reliability for critical applications, including public safety;
- Low "zero perceived" latency, especially for gaming and other applications requiring real time feedback;
- Low energy consumption, from both device and network side trimming down to 90% saving.

With the new tough requirements to be satisfied, the future 5G system is expected to be highly performing. Unfortunately just a new air interface and new Radio Access Network (RAN) only would not help keeping the promises, guaranteeing that 5G as a whole will completely satisfy the requirements. The current evolved Packet Core (ePC) architecture exploits a high degree of centralization - national–wise - due to its cost. While such cost can be reduced by the introduction of virtualised functionalities, it still does not solve the latency problems introduced by the long-distance connection between the terminal and the Packet Gateway. This is in counter–tendency compared to the trend of moving the services close to the users. Furthermore, relying on a central entity (or a few ones due to macro regional split) does not allow a flexible scaling of the network in terms of connected devices. For all these reasons we advocate that a radical paradigm shift in how the Core Network is implemented is strongly recommended for making 5G a truly effective and modern system.

In this paper we face such new paradigm shift, by proposing a high level architecture for 5G system that should maintain the promises in terms of satisfying the challenging requirements that the new traffic types impose. In particular, in this contribution, we focus on the mobility challenges, aiming at designing a pervasive, low latency mobility solution at Layer 2 (L2), thanks to Software Defined Networking (SDN), and at Layer 3 (L3), thanks to Distributed Mobility Management (DMM). Control plane mobility relies on SDN principles, with L2 switches and L3 routers to be regarded as Policy Enforcement Points (PEP) of decisions taken in logically centralised though distributed Policy Decision Points (PDP). In a nutshell, we claim to decentralise part of the Mobility Management Entity (MME) functionalities down into the

access network, either in the base stations operating as L2 switches, or at the L3 routers interconnecting several base stations. These decentralised features would be operated in nearby data centers.

The current paper is structured as follows: in Section II an overview of previous works on L2 and L3 mobility is presented in order to define the existing solutions and how they differ from our proposed architecture. Section III describes our solution, starting from a definition of the functional requirements and the design philosophy adopted for the proposed architecture. In particular, Section III-C deepens the aspects of the solution related to the mobility management in our proposed cloudified architecture. In Section III-D a critical analysis of the proposed solution is attempted, by identifying some of the open issues that can arise by such a proposal. Finally, conclusions are drawn in Section IV.

II. RELATED WORKS

The proposal for achieving terminal mobility through L2 switching is not novel. In the motivation to their own work in [5], the authors mention discussions at 3GPP as early as 2005. These authors themselves promote a pure L2 mobility solution, where the scalability issue of standard Ethernet is solved thanks to the Transparent Interconnection of Lots of Links (TRILL) protocol [6].

The difference between [5] and our approach is two–fold. On the one hand, the solution from [5] relies only on L2 mobility. We propose to achieve terminal mobility between base stations aggregated at the same router at L2, whereas terminal mobility across aggregated routers is supported at L3.

On the other hand, the control procedures described in [5] rely on Target Area Update (TAU) messages exchanged between base stations, Customer Edge switches and serving gateways. IP-MAC bindings are stored in a Distributed Hash Table (DHT), distributed over the nodes. In line with the split between the data plane and the control plane, and the logically centralised control plane promoted by SDN, we envision a set-up where mobility is handled through IPv6 Stateless Address Auto–Configuration (SLAAC) [7] supported by DMM.

A similar approach to the problem, only based on L2 mobility, is described in [8]. The authors promote a Hierarchical Ethernet Transport Network Architecture (HETNA) compliant with the IEEE 802.3 Ethernet standard, but operating differently, to solve the scalability issue of broadcast Ethernet. With location-based MAC addressing schemes and forwarding mechanisms within HETNA domains, the authors promote the adoption of Ethernet in the backhaul of cellular networks. The mapping between IP and MAC addresses is centrally stored in an Address Resolution System (ARS). The ARS can adopt a distributed implementation though, in a DNS-like fashion or with DHTs.

Again the specificity of the solution we promote lies in the interworking of L2 and L3 mobility, whereas [8] only focuses on L2 mobility.

Meanwhile, L3 mobility at large is discussed at the IETF, in particular in the Network Virtualisation over Layer 3 (nvo3)

and DMM working groups. Their ongoing work is relevant for the design of our solution, since gaps have been identified [9], [10]. Our solution is willing to address some of these gaps as described in Section III-C.

III. ENVISIONED ARCHITECTURE FOR THE 5G CORE

A. Motivation

Over the last years Ethernet has been augmenting the original set of Local Area Network (LAN) technologies with support for the new capabilities required to deliver Ethernet-based Metropolitan (MAN) or Wide Area Network (WAN) telecommunication services [11]. Providers are choosing to use L2 Ethernet in access and aggregation networks in general, and mobile backhaul ones in particular, to reduce complexity and costs [12]. For these reasons we envision an Ethernet based 5G architecture that smoothly integrates with access networks. While bearing this in mind in the re–design of the 5G ePC, the role played by the underlying transport network is not considered in this paper. Further analysis and investigation would though be needed before deploying the final product.

Simultaneously, the ICT industry is witnessing a radical paradigm shift, with the commoditisation of IT resources and its gathering in datacenters offering pay-per-use models in different flavours, the so called XaaS model (Anything as a Service). A similar trend is also perceivable in the mobile industry. By densifying so much the RAN due to the deployment of Small Cells, it is possible to exploit in many cases a cloudification of the system, putting together the computing units while deploying through a fiber fronthaul Remote Radio Heads (RRHs) only. This type of solution is definitely in line with the other increasing trend of virtualising the ePC functionalities into data centers, making the use of software entities instead of hardware ones.

By re-thinking the architecture in the light of ICT trending evolution, it is possible to make a design which is from the very beginning ready for cloudification and centralization, optimizing the data paths and the interfaces thus reducing the latency as promised by the 5G future system, exploiting, from the start, the potentialities offered by Network Functions Virtualisation (NFV) and SDN.

While the architecture can face a severe overhauling in how it is implemented and distributed in space (e.g. national versus regional) a certain set of functionalities and services are expected to be maintained, though in radically different shape, in order to ensure a proper functioning of the mobile network. Furthermore, certain elements that are not facing critical challenges in the future, have no reason to be replaced in other forms, and can be used in conjunction with existing legacy networks, in order to minimize the Capital Expenditure (CapEx) of the operator when deploying the new Core.

In particular the functionalities that are expected to be kept within the new architecture, and that form a base for the functional requirements of the system can be summarized as following:

- Subscription database containing all the relevant information about who is the user or the service provider and
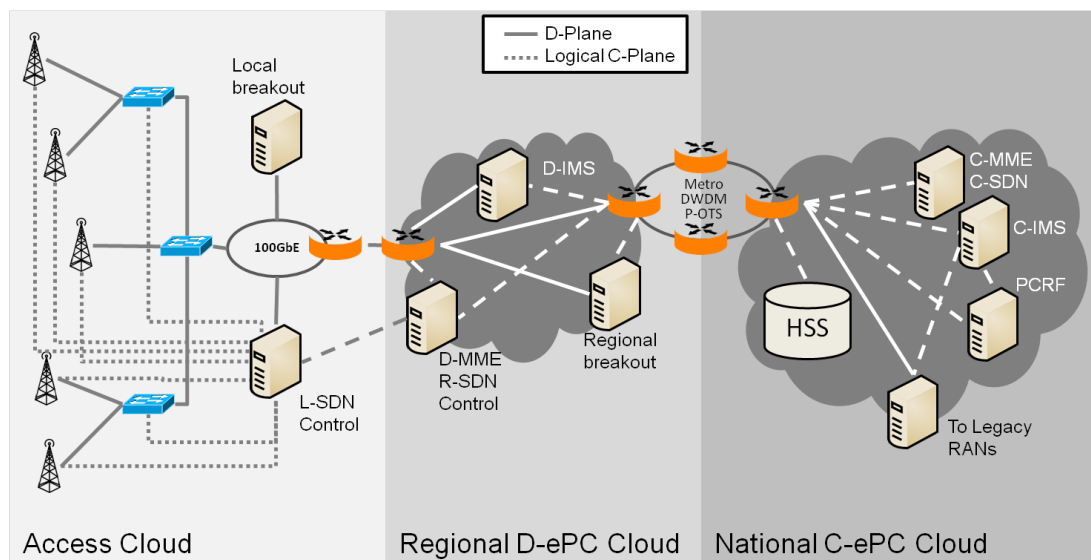
Figure 1. Proposed Architecture for the 5G ePC Network

which services are paid for; currently achieved through a Home Subscriber Server (HSS), this entity is expected to work in backward compatibility with existing legacy Cores.

- Policy and Charging Rule Function (PCRF): as for the previous item, this functionality is essential to run the mobile operator business, and there is no specific reason also in this case for changing how the PCRF works. In order to ensure cooperation with legacy systems and saving expenditure sharing of existing entities is foreseen.
- Multimedia services: currently they are implemented as IP Multimedia Subsystem (IMS), and it is essential for value–generation in the network. The current IMS is a complex system that is probably doomed to be re–designed to be leaner and easier to be distributed closer to the border of the network for latency reduction purposes.
- Mobility management: currently implemented in the MME, it collects a series of functionalities ranging from tracking areas – where to page the User Equipment (UE) – to UE context management. Thanks to SDN and NFV it is possible to re-design part of the system, and allowing a distribution of the functions for enhancing resilience and scalability of the network.

All those functionalities are present in the network architecture proposed in Section III-B, and they exploit SDN and cloudification in order to provide a lean, scalable, and up–to–date solution for the future 5G system. In particular, in this paper we focus on the mobility aspects of the architecture, trying to define how the role of the MME will change, by defining a L2 solution in conjunction with a L3 for regional mobility.

B. Architecture

We envision a clean slate, flattened "Ethernet-over-Radio" (EoR) architecture for 5G systems (see Figure 1), which

is Ethernet-based, IPv6 optimized, and where the Software Defined Networking (SDN) approach is a key tool for solving the foreseen challenges. With this vision, we aim at removing part of the traditional ePC complexity and therefore making 5G more scalable and efficient.

The proposed EoR architecture for 5G comprises an Access Cloud (AC), a Regional Distributed-ePC (D-ePC) Cloud, and a National Centralized-ePC (C-ePC) Cloud. The Access Cloud is composed of access points (APs) and commodity SDN– enabled switches that forward Ethernet frames to the mobile backhaul. Each device has a EUI64 (64 bits) MAC address which is a unique identifier of the network interface for communications with the 5G network. Although current Ethernet systems support only 48 bits, translation methods are foreseen given the IEEE policy of encouraging new system in adopting 64 bits address. This avoids MAC address space limitations.

APs act as wireless switches in which each radio link is a port. Each AP executes the bridging function [13], such that it forwards the Ethernet frames to the devices through its radio ports. Additionally, APs include support for broadcast and multicast frames between their ports. The objective is to enable a simple to deploy solution for extending the network. Similarly, terminals and MTC devices can support the bridging function. In this manner use cases such as self–backhauling (often called relaying) and device–to–device can be considered as extensions of the network making use of the same SDN functionalities.

Frames are then backhauled between the access and the Regional D-ePC through an Ethernet network for low cost and complexity. Evolutionary approaches to Spanning Tree Protocol (STP) such as TRILL [6] may be used in the Access Cloud to enhance performance. The size of an Access Cloud is mainly determined by the scalability limits of the L2 Ethernet technology. If this limit is reached, the Access Cloud can be subdivided in various clouds of smaller size. A Local Breakout
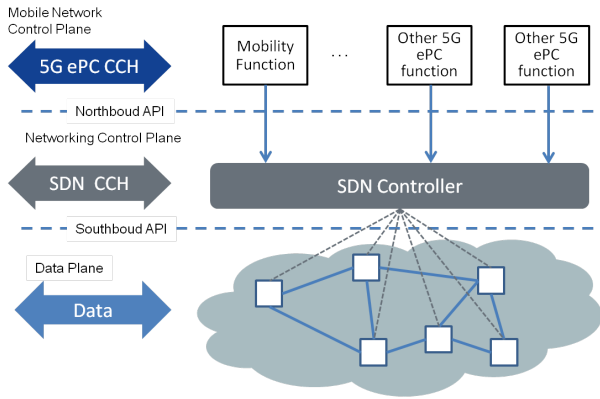
Figure 2. Envisioned integration of SDN in the 5G ePC. The SDN is in charge of the "networking control plane and configuration", while specific Mobile Network functionalities can be considered network applications connected through a Northbound API.

can be foreseen for offloading the Core network from bulky best effort internet traffic or accessing local services (such as content caching) with low delay.

The traffic from various Access Clouds in each regional area is aggregated at the Regional D-ePC Cloud. The Regional D-ePC Cloud is composed of one or more datacenters and it contains L3 routing devices that act as gateway towards a high speed core. These routers also execute L3 mobility functions (see Section III-C). Additionally, the Regional D-ePC can have a regional breakout to the Internet to provide a reduced latency Internet access. Moreover, delay-sensitive functionalities and services (e.g. vehicular remote control) are partly or completely distributed to the regional datacenters to benefit from a reduced and guaranteed delay (see e.g. D-IMS in Figure 1).

The high speed core interconnects the different Regional D-ePC Clouds between them, and these in turn to the National C-ePC Cloud. The National C-ePC Cloud keeps critical and control functionalities, such as PCRF, HSS, and interconnection to legacy RANs, on centralized datacenters.

The EoR architecture includes a SDN plane in charge of managing and orchestrating the networking control plane functions, by considering mobile network functionalities such as mobility, QoS and traffic steering, as network applications that run on top. A more detailed view of the envisioned integration of the SDN system is depicted in Figure 2.

The controller is physically composed of coordinated PDPs distributed through the architecture to locate them close to the devices they control. In the Access Cloud, APs and L2 switches are managed by PDPs which logically form a Local-SDN (L-SDN) controller. In the Regional D-ePC Cloud, L3 routers are managed by a Regional-SDN (R-SDN) controller, which also operates in coordination with the L-SDN controller. Similarly, a Centralized-SDN (C-SDN) controller is kept in the National C-ePC Cloud (see Figure 1). The objective is to partly or completely execute the control plane functions locally for improving delay and scalability performances. In particular, in the presented mobility solution, such controllers are a way

to distribute the functionalities previously centralised in the MME. Note that the local and regional SDN controller design is in line with the proposal from the FP7 project CROWD [14]. Accordingly, the Access, Regional and National division of the data plane of the proposed 5G ePC is aligned with the classic hierarchical architecture model [15] recommended when scalability is a major goal due to its modularity.

C. Mobility Management

Based on the architecture presented in Section III-B, we envision providing L2 mobility within an access cloud of a given region, and L3 mobility between different access clouds because in this case mobile devices will traverse different routing domains. A L2 mobility approach similar to the LTE radio handovers management with late path switch [16] can be implemented as shown in Figure 3.

A L2 tunnel between source and target APs is established for packet forwarding. This tunnel could be based e.g. on Ethernet MAC-on-MAC encapsulation. In the meanwhile, the target AP issues a more permanent path switch request to the L-SDN controller, that sends the reconfiguration command to the various switches along the path.

Regarding L3 mobility, several scenarios can be identified depending on the location of the source and target networks: between access clouds of the same operator, and between a 5G and a legacy network.

To preserve backwards compatibility and enable inter-domain operation, it is desirable to reuse and extend if necessary standard mobility protocols. For this reason we base our mobility solution on Mobile IPv6 (MIPv6) [17] and Proxy Mobile IPv6 (PMIPv6) [18]. This way, existing networks and hosts would not require any change, and mobility between 5G and legacy networks would be allowed.

DMM is another essential part of the proposed solution. This is because centralised management has severe drawbacks [19]. Firstly, the traffic is forwarded to non-optimal routes, introducing thus additional delay. Although it is possible to use the IPv6 Routing header to optimize the path in MIPv6,
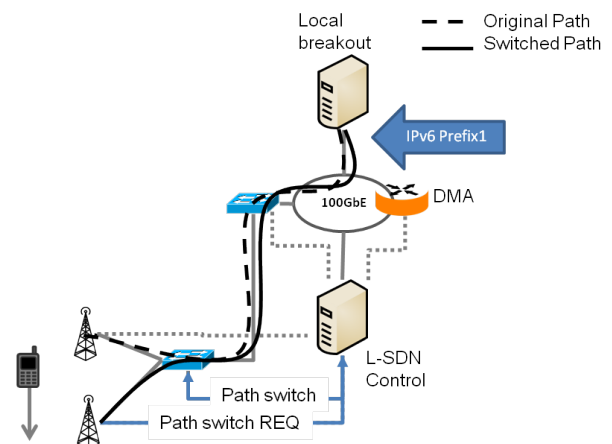

Figure 3. Mobility solution for intra–AC handover

this option is only available when the node to which the mobile is communicating supports MIPv6 [17]. Secondly, the centralized anchoring elements may constitute a single point of failure and imply a non scalable centralized tunnel management. Finally, the current mobility service is provided on a per bearer basis, meaning that most of user's communications are treated in an aggregated fashion. A finer granularity should be allowed, thus session continuity is granted only for those IP flows that really require it.

DMM basically assumes a flatter system, in which the mobility anchors are placed closer to the mobiles, splitting the control and data elements among the entities located at the edge of the access network. This approach nicely fits with our proposed SDN based 5G architecture, with SDN helping DMM in optimizing the path, and relying on pure DMM for resilience purposes.

Let us first consider mobiles moving between access clouds of the same 5G network. Host-based DMM schemes may be used. However they require the mobiles to support the MIPv6 stack. And additionally, the corresponding node need to also support the MIPv6 to use the IPv6 Routing headers (43 – Routing and 60 – Destination). To address a more general scenario, we envisage the use of mobility management schemes such as the ones described in [20], in which network-based DMM schemes based on PMIPv6 are defined. We can consider a partially distributed scheme where the data plane anchor is collocated at the local breakout and regional routers. With this approach, the traffic traverses only the Distributed Mobility Agents (DMA). The general procedure is illustrated in Figure 4. Initially, the mobile attaches to the AC whose mobility is managed by DMA1, which gives the IPv6 Prefix 1 to the node. By using SLAAC, the mobile node can configure a valid IPv6 address for this home network. The traffic of the sessions established while the mobile is attached to the first access cloud is routed by the DMA1. When the mobile moves from one AC to another, first a packet forwarding tunnel is established as previously mentioned. Even in this case the target AP issues a path switch request marked as (1) in Figure 4. Since the needed updates cannot be done locally, the L-SDN controller of the target AC, identified by the IPv6 Prefix2, sends a coordination request (2) to the hierarchically superior R-SDN controller. The latter reconfigures the edge router of the Regional Cloud, and sends a coordination command (3) to the L-SDN controller of the source AC. Finally reconfiguration commands are sent to all the switches and DMAs by all the interested L-SDN controllers (4). To be noted that while message (1) is part of the control plane of the mobile network, the other ones are part of the networking control plane that runs in the SDN layer, as shown in Figure 2.

The DMA2 provides the new IPv6 Prefix 2 for the new network. From now on, the new sessions established in the new access cloud are managed by DMA2. When the first session is closed, the corresponding DMA1 resources, allocated for resiliency purpose, are freed. Since the different DMAs are coordinated by a hierarchical system of controllers, a similar procedure could be designed also for inter-regional handovers. Finally, for the scenario in which mobiles move between 5G and a legacy network there can be several options. The more
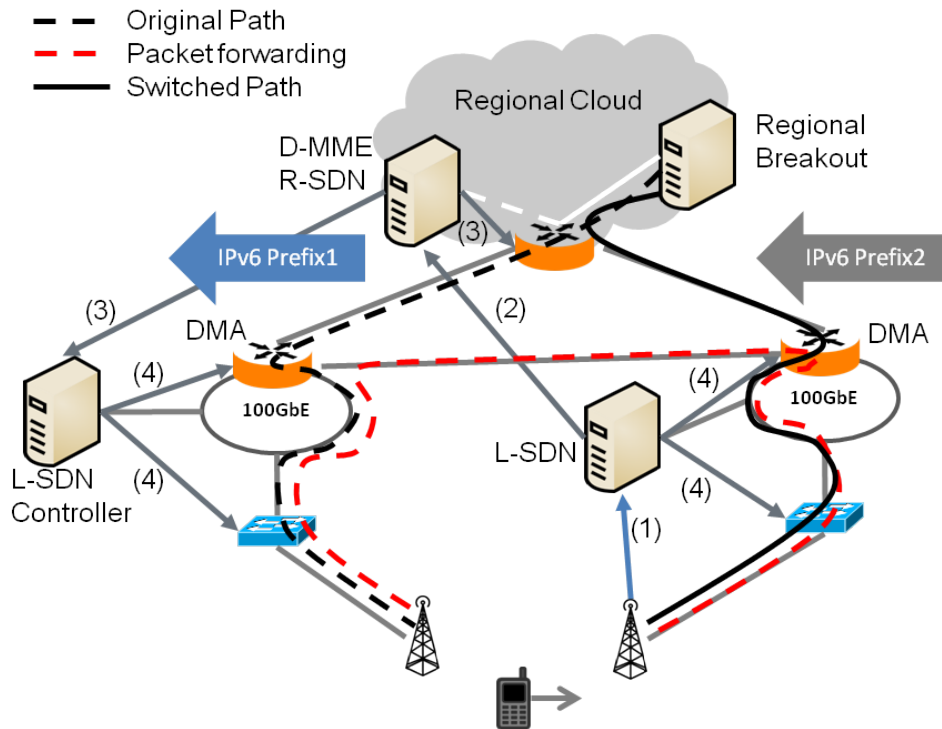

Figure 4.   Inter–AC mobility procedure assisted by R-SDN controller.

conservative one would be translating the traffic at the national C-ePC Cloud through a dedicated gateway, that takes care of both control plane and user plane translation to legacy protocols. A new, and more disruptive approach would be exploiting protocols such as Multi Path TCP (MPTCP) [21], that enables a transparent connection to multiple network interfaces, substantially de–coupling the 5G core from other legacy ones. This can have gains and drawbacks that are not here analysed and that can be considered open for further studies.

D. Open issues in the proposed architecture

The EoR architecture we are presenting in this paper raises many issues to be addressed in the near future. Some of them are listed hereafter.

The main issue is related to the coordination of controllers. SDN is often misleadingly described as offering a centralised control plane, whereas its centralisation is only logical. Obviously, a given domain operating according to SDN principles is not operated from a single central node, but from a set of nodes which need to cooperate somehow. The same issue appears in our proposed architecture, which requires distributed orchestration between L–SDN and R–SDN controllers. The means to perform this distributed orchestration in the most stable and robust way shall be investigated. Furthermore, a standardization of the SDN control channel should also be considered.

A second issue relates to the introduction of our proposed architecture. One can not expect cellular operators to schedule a flag–day for switching from one architecture to the other. Despite being disruptive, our approach will need to be progressively introduced in the network, step-by-step, in a way offering interfaces which enable legacy equipment to remain in production while our proposed architecture gains ground. These interfaces shall yet been designed.

In connection to this deployment issue, the position of Virtual Network Operators (VNOs) comes into picture. Our proposed architecture requires changes to the transport network. It then boils down to the (un)ability of VNOs to force their transport suppliers to perform those changes for the sake of their customers' operations.

Finally, from a more technical point of view, the L2 mobility we are promoting raises many technical questions. Traditional Ethernet, based on broadcasting and STP, does not scale efficiently. A more clever way to forward Ethernet frames should be adopted, be it based on MAC-in-MAC encapsulation, on IEEE 802.1ad VLAN stacking or MAC header rewriting in SDN switches. The pros and cons of those various methods to upgrade from STP–Ethernet shall be assessed.

IV. Conclusions

In the present paper we have presented a new Core Network architecture for future 5G systems. New challenging requirements are pushing towards re-design of the existing architectures, while at the same time ICT is shifting towards more and more software–based systems. By exploiting SDN and NFV from the very beginning of the design philosophy, the proposed architecture tackles the stringent requirements by putting particular stress in low latency solutions and network scalability. In the current paper we have also emphasized a potential solution for mobility within the RAN that exploits L2 as foundation for an SDN enabled mobility management, while relying on L3 for regional aggregated mobility. The proposed approach is expected to reduce mobility latency, while at the same time reducing the CapEx and OpEx by leveraging on current ICT trending technologies, thus exploiting its economy of scale.

Several open issues for future investigations have been also highlighted, that require careful analysis in order to make such a proposal a reality.

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