# The Resources Placement Problem in a 5G Hierarchical SDN Control Plane

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**Abstract.** In this paper, we address the SDN Controllers and Virtual Network Functions (VNFs) placement problem in 5G networks. To this end, we propose an architecture for the 5G Control Plane and a method to determine the optimal placement of controllers and VNFs. The placement is determined according not only to latency and capacity requirements but also to type of Network Function (NF).

**Keywords:** SDN · NFV · CPP · VNFP · 5G

## 1 Introduction

SDN and Network Function Virtualization (NFV) have been defined as key drivers in the implementation of the 5G architecture. Their combination enables dynamic, flexible deployment and on-demand scaling of network functions, which are necessary for the development of the future Mobile Packet Core towards a 5G system [1]. However, to satisfy the 5G requirements while network costs are minimized, the SDN Controllers and VNFs placement should be carefully planned.

The Controller Placement Problem (CPP) was first defined in 2012 by Heller et al. [2]. Since then, this topic has been addressed in several ways. Despite the great variety of **related works**, just a few approaches this issue in 5G networks [3, 4]. The authors in [3] study the CPP considering the uncertainty in cellular users location without deepening in details about the control plane architecture. By contrast, Kentini et al. in [4] assume an SDN-based virtual mobile network architecture and define an algorithm for the SGW Controller (SGW-C) placement with the purpose of reducing SGW relocations and the load in the SGW-C.

The VNF Placement (VNFP) problem in mobile networks has also been addressed in some research works such as [5–7]. In [5] the authors propose an algorithm to place VNFs of PGWs and SGWs on a given topology of distributed DataCenters taking into account criteria of QoE for mobile users and SGW relocations. However, they do not consider either the variability of network traffic or VNF resource requirements. Similarly, Bagaa et al. [6] propose an algorithm to create virtual instances of PGW and determine their placement based on geographical location and applications/services type. Moreover, both [5] and [6] limit the scope of their work to specific NFs. In [7] the authors address the placement of all the core network functions. Although, they do not consider latency constraint on the VNF nodes and end-to-end network.

Despite the wide variety of research works in the field of the CPP and VNFP in mobile networks, until now, both **problems** have been solved separately. Thus, in this work, we attempt to propose a method to jointly resolve them.

The **hypothesis** of our research is that 5G services requirement of ultra-low latency can be achieved if the core networks functionalities and the SDN controllers are optimally placed.

## 2 Proposal of the 5G Control Plane Architecture

The architecture proposed for the mobile core network is based on the 5G 3GPP standardized architecture [8], SDN and NFV, as shown in Fig. 1. A two-level hierarchy of SDN controllers bridges between the control and user planes, specifically, between the Session Management Functions (SMFs) and the User Plane Functions (UPFs). Its bottom layer is composed of Area Controllers (ACs) which are mainly responsible for UPFs control and flows management. While, the upper layer is formed by Global Controllers (GCs), in charge of managing and controlling the ACs, doing load balancing and keeping a global network view. Moreover, both the control plane NFs and the SDN controllers are virtualized, deployed and executed on an NFV Infrastructure (NFVI).

### 2.1 Method for SDN Controllers and VNFs Placement

Assuming this architecture, our main objective is to find the optimal placement of the SDN Controllers and the VNFs, the Access and Mobility Management Functions (AMFs) and SMFs mainly, in order to minimize the network response time to users' requests. To this end, the controllers and core network functionalities are deployed by following one of the 5G key requirements: latency lower than 1 ms and 10 ms in the user and control planes, respectively.

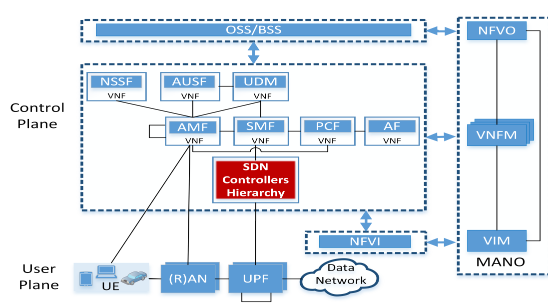


**Fig. 1.** Proposal of the 5G Control Plane architecture

**Algorithm 1** Assignment of UPFs to ACs

**Require:** $L_{req1}$, $C_{AC_{max}}$, $N_U$, $D_{N_u X N_u}$:Delay matrix, $T_{n_u}$: UPFs traffic matrix
**Ensure:** K: Number of ACs, $N_{AC}$: Set of ACs, $S_{u_k}$: Sets of UPFs $\in AC_k$
1: $K \leftarrow 1$, $N_{AC} \leftarrow \emptyset$, $S_{u_k} \leftarrow \emptyset$
2: $U \leftarrow$ Furthest UPF in average to others UPFs
3: $S_u \leftarrow U$ # $S_u$: Set of candidate positions ($n_{s_i}$) for $AC_k$
4: $C_{AC_u} \leftarrow T_U$ # $C_{AC_u}$: Capacity used in the AC to manage $S_u$
# Forming $S_u$ with neighboring UPFs ($n_{u_i}$) to U, $n_{u_i} \in N_u$
5: **for all** $n_{u_i} \in N_u$ **do**
6: **if** $d(n_{u_i}, U) \leq L_{req1}$ **and** $C_{AC_u} + T_{n_{u_i}} \leq C_{AC_{max}}$ **then**
7: $S_u \leftarrow S_u + n_{u_i}$, $C_{AC_u} \leftarrow C_{AC_u} + T_{n_{u_i}}$
8: **end if**
9: **end for**
10: **for all** $n_{s_i} \in S_u$ **do**
11: $S_{ns_i} \leftarrow n_{s_i}$ # $S_{ns_i}$: Set of UPFs $\in$ AC placed in $n_{s_i}$
12: $C_{AC_{ns_i}} \leftarrow$ Capacity used in the AC to manage $S_{ns_i}$
# Forming $S_{ns_i}$ with neighboring UPFs ($n_{nu_j}$) to $n_{s_i}$, $n_{nu_j} \in N_u$
13: **for** $n_{nu_j} \in N_u$ **do**
14: **if** $d(n_{nu_j}, n_{s_i}) \leq L_{req1}$ **and** $C_{AC_{ns_i}} + T_{n_{nu_j}} \leq C_{AC_{max}}$ **then**
15: $S_{ns_i} \leftarrow S_{ns_i} + n_{nu_j}$, $C_{AC_{ns_i}} \leftarrow C_{AC_{ns_i}} + T_{n_{nu_j}}$
16: **end if**
17: **end for**
18: **if** $U \in S_{ns_i}$ **then**
19: **Evaluate** $F_{sel_1}(S_{ns_i})$ # $F_{sel}$: Funct. to select AC best placement
20: **Update** $S_{ns_{i_{best}}}$ # $S_{ns_{i_{best}}}$: $S_{ns_i}$ with max. $F_{sel_1}$
21: **end if**
22: **end for**
23: $S_{u_k} \leftarrow S_{u_k} + S_{ns_{i_{best}}}$, $N_U \leftarrow N_U - S_{u_k}$
24: $N_{AC} \leftarrow N_{AC} + n_{s_i}$ # $n_{s_i}$: node with max. $F_{sel_1}$
25: **while** $N_U \neq \emptyset$ **do**
26: $U \leftarrow Z$, $K \leftarrow K + 1$ # Z: Nearest UPF to $AC_k$, $Z \in N_U$
27: **Go to** step 3
28: **end while**

The mobile network is modeled as a connected undirected graph G(N,E) where N is the set of nodes, E the links between them and $N_U \subset N$ and $N_R \subset N$ the sets of UPFs and (R)ANs, respectively.

Our method is composed of three phases. The aim of the first one is to find the optimal number of ACs and their placement, so that, the user plane latency will be minimized. The UPFs are assigned to the ACs following criteria of latency ($L_{req1}$) and available capacity in the ACs ($C_{AC_{max}}$). Algorithm 1 shows the procedure to determine the best SDN Controller position. The SMFs are placed in the same nodes that the ACs in order to reduce propagation delays.

In the second phase, the AMFs placement is determined according to constraints of latency and AMFs capacity. The main objective of this phase is to minimize the AMF relocations. To this end, the user equipments (UEs) are classified according to their grade of mobility and three levels of AMFs are deployed to manage UEs with low, medium and high mobility patterns. Others 5G core NFs like the Unified Data Management (UDM) and the Police Control Function (PCF) are also placed in the upper level of AMFs.

Finally, in the third phase, the ACs are assigned to the Global Controllers with the main aim of minimizing the latency between GCs. Minimum latency between GCs is a key factor in order to keep network consistency and reduce controllers' response time. This phase is quite similar to the first one, but in this case, ACs are assigned instead of UPFs.

## 3 Reflections

Ultra-low latency is a key requirement of 5G networks to support services like vehicular connectivity and M2M communication. But, offering low response time while reducing network resources consumption and costs is a big challenge. By an optimal planning of SDN controllers and VNF placement these objectives can be achieved. Dynamic optimization of elements assignment and deployment of NFVI resources will be an important task for future works.

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