A Design of Low-Latency and Scalable Private 5G Core Network

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Abstract

In recent years, 5G network offers impressive capabilities that improve performance over previous-generation networks. Particularly, it provides many attractive factors for industrial communication such as unified wireless interface, guaranteed quality of service, mobility, etc. In industrial environments, it requires more capabilities of security and control management where a private 5G network comes as an attractive solution. It can also be deployed for a wide range of use cases across different industrial domains. However, in the private 5G network, the 5G Core network functions are placed in a single node. This leads to some advantages and disadvantages itself in industrial operations. In this study, we proposed an approach to accelerate the private 5G Core network using a combination of Cilium-eBPF and VPP-vSwitch to improve traffic routing in a design where 5G Core network functions can be separated into different nodes.

Ⅰ. INTRODUCTION

The private 5G Core network where all network functions are placed in one node makes it a central and easy-to-deploy architecture. Nevertheless, this architecture has an issue of a single point of failure (SPOF) [1] - specifically, in industry, the need to quickly recover a critical failed system is the most priority. In the case of all network functions designed in one only node, it is difficult to find the root cause of system failure. Therefore, an easy solution is to redeploy the system which makes delays in related operations. Separating the 5G Core network functions into different nodes helps to manage, scale up, and operate more efficiently. Besides, in a separate network-function architecture, the traffic routing also needs to be cared about to ensure the performance of the network. In this research, we proposed an approach where two network functions, AMF and SMF, are separated from other network functions of the 5G Core network. In addition to ensuring the traffic routing quality, we proposed to use Cilium-eBPF and VPP-vSwitch to improve north-south and east-south traffic routing respectively.

Ⅱ. RELATED WORKS AND BACKGROUND

A. A. PRIVATE 5G CORE NETWORK

A private 5G network [2] is a local area network built on 5G New Radio (NR) technology for devoted wireless access in a certain area, per definition. The fact that not all local 5G networks are private networks is stressed. One or more base stations that can scale based on capacity and coverage needs to make up the radio access network (RAN) portion of the private setup. In comparison to its public equivalent, a private 5G system's core network is relatively sparse. It might physically be housed in the same box as the base station or as a separate entity in the network. For a particular industrial application as well as for a number of different industrial activities with various needs, a private 5G network can be set up.

B. CILIUM-EBPF

Cilium-eBPF [3] is open-source software for transparently providing and securing the network and API connectivity between application services deployed using Linux container management platforms. The Cilium's kube-proxy replacement in eBPF consists at a high-level component: eBPF at the socket layer and eBPF at the driver layer. North-south traffic, that is, all inbound service traffic from an external source to a Cilium-managed node is handled as close as possible to the driver layer, operating on a single interface for both ingress and egress. This allows forwarding to be handled very fast, even dropping or reflecting traffic back out the inbound interface before any expensive operations occur higher up the stack. The latter component which is handling North-South traffic is then accelerated via XDP.

C. VPP-VSWITCH

The VPP-vSwitch platform [4] is an extensible framework that provides out-of-the-box production quality switch/router functionality. It is the open-source version of Cisco's Vector Packet Processing (VPP) technology: a high-performance, packet-processing stack that can run on commodity CPUs. The VPP platform grabs all available packets from RX

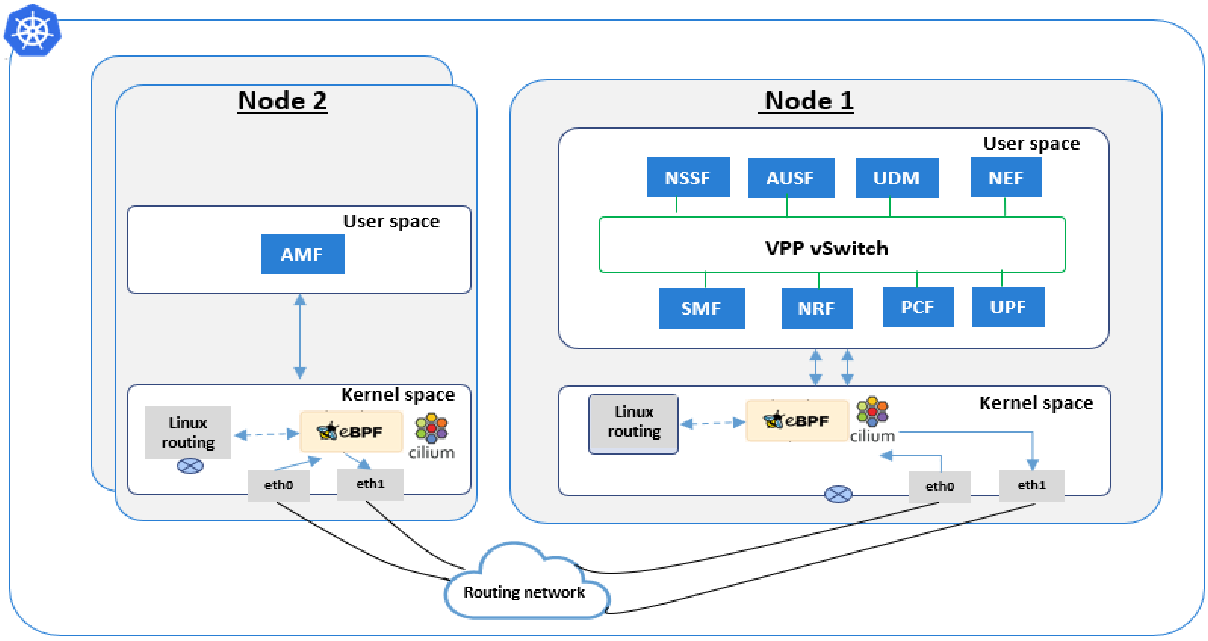

Figure 1. Architecture of AMF network function located in a separate node.

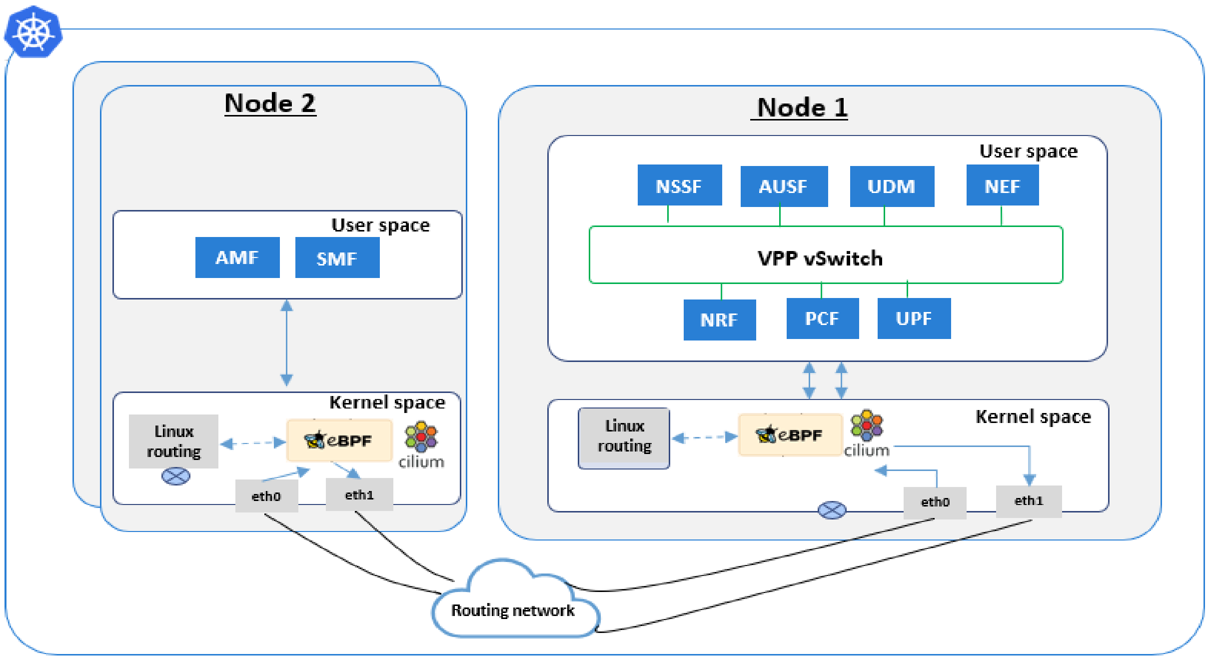

Figure 2. Architecture of AMF and SMF network functions located in a separate node.

rings to form a vector of packets. A packet processing graph is applied, node by node (including plugins) to the entire packet vector. Graph nodes are small and modular. Graph nodes are loosely coupled. This makes it easy to introduce new graph nodes. It also makes it relatively easy to rewire existing graph nodes.

D. NETWORK FUNCTION SEPARATION

In the 5G Core network, there are some network functions taking a critical responsibility – therefore, in some scenarios, a network function should be separated to effectively handle and scale up due to high requirements. For instance, satisfying the numerous number of requests from a large number of UEs requires the AMF network function to handle these incoming requests in a stable manner, and the resources for peak time are an important factor that needs to be considered as well. Subsequently, separate network functions (e.g., AMF) could be a considerable solution in order to manage, maintain, and avoid traffic bottleneck problems efficiently. In some cases, AMF and SMF network functions could be separated and placed in the same node because AMF communicates with SMF to handle the connection request. Consequently, this benefits scalability, resource utilization, and latency when satisfying a huge number of incoming requests.

Ⅲ. PROPOSED ARCHITECTURE

To achieve the goal of accelerating the private 5G Core network, we propose a design of two 5G Core network architectures: the first one separates the AMF network function from other network functions and the second one places AMF/SMF in the same node apart from other network functions. We choose AMF and SMF because they are critical components in 5G Core network architecture. The AMF plays the most critical role in 5G Core network. The major role of AMF is to handle NAS messages from UE. These NAS messages would mostly come from RAN (gNB) but theoretically, they can come from other non-3GPP components. While SMF collects all the information related to PDU session management from various network components and orchestrates those network components based on the request from AMF. This approach helps to scale up and avoid the risk of traffic overload/bottleneck pod effect on 5G Core network. In order to accelerate and make an efficient traffic routing in the proposed architectures, we use Multus to add one more interface to each network function which helps to separate the ingress and egress traffic then we proposed a traffic-routing design using a combination of Cilium-eBPF and VPP-vSwitch for north-south and east-west routing acceleration respectively (Figure 1, 2).

IV. ARCHITECTURE QUALITATIVE COMPARISONS

As expected in the designs, we consider five aspects that make our proposed architecture more outstanding than the original one (Table 1). The comparison aspects such as Fault tolerance, Scalability, and Resource utilization are strengths in our proposed architecture which are expected to improve the default architecture. Besides, we add Latency and Easy-to-deploy as comparison aspects because they are characters that may badly affect the proposed architecture in comparison with the default architecture.

In our proposed architectures, even the process of deployment requires some steps for environment installation for the first installation, but it gives more advantages for operations and maintenance. In particular, it would be easier to locate the root cause when an incident event happens in the system in comparison with non-separation architecture. This decreases the SPOF problem in the system. In terms of scalability and resource utilization, it would be more flexible to manage and monitor a node rather than a pod. Latency is ensured by using two different techniques (Cilium-eBPF and VPP-vSwitch) in order to improve both north-south and east-west traffic routing.

Cause AMF is responsible to get connections and choose SMF to handle the connection request. So, the resource to operate AMF is needed to control efficiently where node resource is easier to manage rather than pod resource. Because when all 5G Core network functions are deployed in the same node, the pod resource is limited due to the node resource. Moreover, this architecture is more flexible to scale up the exact network function which is required for a particular scenario. The AMF and SMF are placed next to each other which benefits reducing user handover latency and session establishment latency in comparison with the AMF separation design. This deployment type is suitable for scenarios that require low control plane delay.

Criteria	AMF Separation + eBPF, VPP-vSwitch	AMF/SMF Separation + eBPF, VPP-vSwitch	NF non-separation
Fault tolerance	Good	Good	Fair
Scalability	Flexible	More flexible	Not flexible
Latency	Good	Very good	Good
Resource utilization	Flexible	Flexible	Good
Easy-to-deploy	Normal	Normal	Easy

Table 1. Qualitative comparisons.

V. CONCLUSION

In this paper, we propose an approach to accelerate private 5G Core network by separating AMF and SMF network functions from other core network functions, which provides an efficient way to scale up and manage AMF/SMF network functions. Besides, a combination of Cilium-eBPF and VPP-vSwitch with a purpose of accelerating the traffic routing inbound and outbound 5G Core network is also used to highly accelerate the proposed architecture.

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[2] Aijaz, A. (2020). Private 5G: The future of industrial wireless. IEEE Industrial Electronics Magazine, 14(4), 136-145.

[3] Cilium-extended Berkeley Packet Filter, “Cilium-eBPF”, (https://cilium.io/)

[4] Vector Packet Processor-virtual Switch, “VPP vSwitch”, (https://wiki.fd.io/)