Implementing Edge Computing Architectures for Railway Applications: An example Using the Emu5GNet Platform

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***Abstract*—Data processing architectures are currently evolving to enable the deployment of critical real-time applications, particularly in the railway environment. Indeed, these new computing architectures could contribute to the definition of innovative services: platooning, remote driving, autonomous trains, etc. This is why many studies today aim at setting up optimal Edge Computing architectures that would allow critical services to be deployed as close as possible to the end user. It is therefore necessary to design a powerful simulation/emulation environment that could be used to validate the proposed solutions. In this paper we demonstrate how the platform we have implemented, Emu5GNet, could be used to enable the rapid design and evaluation of new Edge Computing solutions. We present the potential applications of Emu5GNet and a reusable use case comparing Edge and Cloud deployment as well as different strategies for Edge resources management.**

***Index Terms*—5G, Quality of Service, Edge Computing, Service Placement, Emulator, Evaluation**

I. Introduction

By positioning computing servers at the edge of the network, as close as possible to the end users, it would be possible to overcome the limitations of traditional Cloud Computing models [1]: variable latency, overuse of the communication network, etc. That is why Edge Computing architectures are now widely considered for services that require low latency, high data processing or adaptation to the current context [2]. This is particularly important in the railway environment to guarantee the efficient operation of critical applications related to rail users safety and involving data fusion/analysis or rapid decision-making.

Consequently, numerous studies are currently being carried out on Edge Computing architectures. These efforts are focused on three main issues: 1) the optimal positioning of Edge servers to ensure low deployment/operational costs (limiting the number of servers) and to guarantee an acceptable performance level [3], 2) the placement of end users services in the Edge infrastructure to maximize the architecture's utilization [4], and 3) the migration of services in the architecture (between Edge servers) to effectively take into account the mobility of the end users [5].

The evaluation of the proposed solutions for these Edge Computing architectures implies the implementation of complete emulation/simulation environments reproducing, in the railway context, both [6] 1) the mobility of the vehicles, 2) the variable performance level of the access networks (2G/5G), 3) the deployment of Edge servers and 4) the implementation of realistic railway applications. However, the existing solutions in the railway environment are only based on the implementation of experiments using the Matlab simulator [7]–[9]. The reliability of the experiments conducted is therefore limited.

That is why, in this paper, we demonstrate how the emulation environment we designed for railway networks, Emu5GNet [10], could be used for the definition, implementation and evaluation of Edge Computing approaches in this environment. The main contributions of this paper are:

- A review of existing solutions for Edge Computing deployment in a railway environment and, more broadly, mobile networks;
- The presentation of the Emu5GNet platform and the identification of its benefits for the implementation of Edge Computing services[1];
- The implementation and evaluation of a reusable Edge Computing use case using Emu5GNet [11].

In this paper, Section 2 compares existing solutions for Edge Computing implementation in a railway environment. Section

[1]Note that this platform can be accessed online: [11]

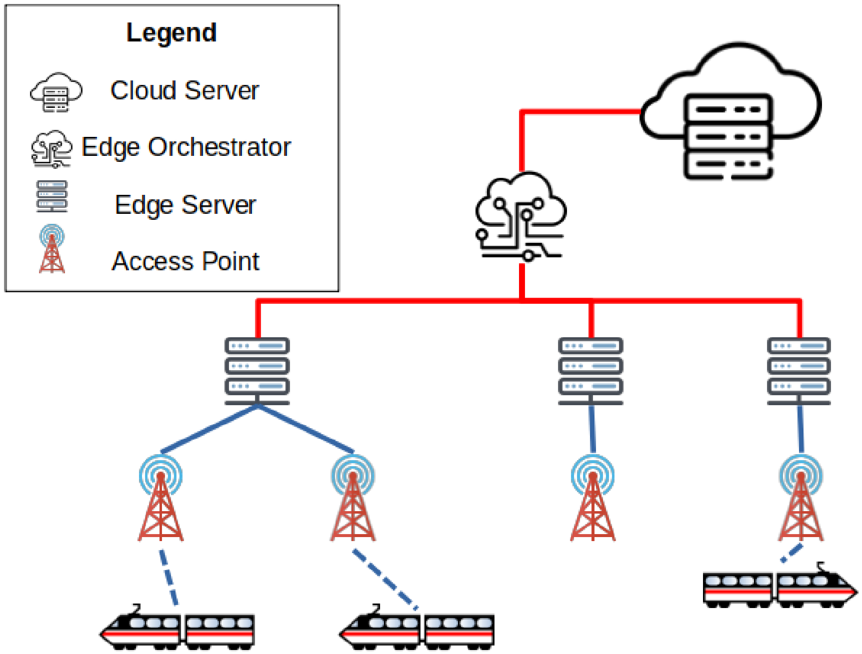

Fig. 1. Emu5GNet architecture

3 shows the potential benefits of the Emu5GNet platform for designing and evaluating Edge Computing applications. Finally, Section 4 proposes an example of the use of this platform, highlighting the outputs that it could produce.

II. Related works

The solutions considered so far for the implementation of Edge Computing services in the railway environment remain very limited. Existing works, like [7], [8] are based on the use of a Matlab environment that simulates both the network and the computing side. The results produced by this type of approach are therefore complex to evaluate and far from a real implementation. We can also add that they do not enable the deployment of practical railway applications.

Beyond the scope of the railway environment, the inter-car communication networks are also an environment mobility management and the deployment of critical applications (Co-operative and Intelligent Transportation Systems). Although there are more works related to Edge Computing in this environment [12], the simulation environments dedicated to vehicular communications do not include for the moment the idea of integrating complex computation servers [13], the computation tasks remaining purely simulated. Therefore, the direct application of existing solutions to railway communications seems impossible.

By considering environments with different constraints in terms of mobility and applications (Internet of Things, wired networks, etc.), we can note that many tools have already been designed for the simulation and realistic emulation of Edge Computing solutions [14]. The objectives of these simulators are multiple: to design optimal data processing architectures, to propose frameworks for the deployment of edge services, to propose algorithms for the optimal positioning of services, etc.

To enable the deployment of simulation/emulation platforms for critical railway services, potentially implemented in edge servers, it seems essential today to propose new solutions based on the proven tools existing in other environments. For this reason, Emu5GNet is presented in the following section.

III. Emu5GNet: Emulating Edge Computing Services in Railway Environment

This section aims to demonstrate how the Emu5GNet platform could be used for Edge Computing services deployment in the railway environment. To do so, we present: 1) the Emu5GNet architecture, 2) the features that could be configured with Emu5GNet, and 3) the research areas that could be covered with this platform.

A. Emu5GNet Architecture

Emu5GNet aims to allow the simulation/emulation of Edge servers in a railway environment. The main components integrated into this platform to enable that are (cf. Figure 1):

- Mobile End Users: Using Mininet-WiFi - Containernet [15], trains (and potentially any kind of mobile nodes: cars, pedestrians, devices) can be deployed as Docker containers in Emu5GNet. This enables the implementation of complex and realistic applications that can interact with the "outside world". Mobility of these nodes/end users is simulated using the SUMO simulator that can use real traffic data [16];

- Radio Access Network: To deploy communication networks, Emu5GNet integrates two different solutions: 1) Mininet-Wifi to deploy WiFi networks and UERANSIM (UE and gNB) [17] + Open5GS (Core) [18] to deploy complete cellular infrastructures (both 4G and 5G). Therefore, different radio access technologies with different levels of performance can be implemented and evaluated in this environment;
- Computing nodes: Integrating the VIM-EMU platform [19], Emu5GNet can be used to deploy realistic computing servers. These servers are implemented as Docker Containers that can integrate real railway services. These servers can be configured to act both as 1) Cloud Computing Servers and 2) Edge Computing Servers. To do so, latency parameters can be updated at any point in time;
- Computing nodes Orchestrator: Managing a set of servers necessarily implies the implementation of an orchestration solution. To do so, Emu5GNet includes scripts and APIs that allow jointly managing all the deployed servers: start, stop, move a service, etc. This allows users to quickly master the platform for the deployment of new solutions to define optimized edge solutions for railway networks.

B. Configurable Features in Emu5GNet

The Emu5GNet platform aims to enable the implementation and evaluation of a wide range of work related to Edge Computing. Therefore, this platform includes the possibility to configure a broad set of parameters:

- Edge nodes deployment: The idea of the platform is to allow the evaluation of an extensive panel of Edge Computing architectures. Therefore, different types of nodes (mobile/fixed) can be considered for the deployment of Edge servers. For example, edge nodes could be deployed at the base station level as well as at the train level. Note that Cloud servers can also be deployed;
- Edge nodes capabilities: The deployed platform is designed to allow dynamic management of all parameters related to the deployed edge servers: bandwidth allocated to a given server, computing power, available storage space, etc. This allows the implementation of heterogeneous processing architectures that can take into account the various possible deployments: at the base station level, at the terminal level, in the core network, etc.
- Edge nodes orchestration: Different orchestrators can be used concurrently to manage the edge servers deployed in Emu5GNet. This can allow not only the definition of different domains but also the implementation of concurrent strategies for the management of edge servers and the resources available within these servers;
- Network performance level: The network performance level, both wired and wireless, can have an impact on the capacity of edge servers. Indeed, high latency could lead to the inability of some edge servers to handle critical rail services. Emu5GNet allows setting the network performance level through different approaches: 1) by deploying different radio access networks (WiFi or Cellular) and core networks (SDN or 5G) and 2) by directly setting the performance level of the communication links: packet loss, latency, bandwidth, etc.

C. Potential Research Topics with Emu5GNet

The architecture implemented by Emu5GNet (cf. Section 3.1) and the elements that can be configured in the platform (cf. Section 3.2) seem to open the door to numerous research topics related to the railway environment and Edge Computing architectures:

- Edge Servers Placement: This is the first important issue [3]. Indeed, to simultaneously 1) optimize the deployment and management costs of the Edge Computing infrastructure and 2) guarantee a sufficient level of performance (computing capacity, latency, bandwidth) for critical railway applications, it is essential to find an optimal trade-off. The ability, with Emu5GNet, to parameterize both the capacity and positioning of Edge servers and the impact of the network could enable the design of new high-performance solutions;
- Edge Services Placement: Optimal use of the existing infrastructure is a second major objective in Edge environments. This involves optimizing the placement of the various railway applications, taking into account the capacity of the available Edge infrastructure and the requirements of these applications. The fact that 1) Emu5GNet integrates an Edge Orchestrator, 2) is based on Docker containers and 4) allows the deployment of real services enables the development of realistic solutions for Edge service placement in railway environment;
- Edge Services Migration: In a mobile environment, service migration is also a critical component. Indeed, this involves relocating services according to the mobility of the terminal devices (in particular trains). This aims to ensure that services are always placed as close as possible to the users so that low latencies can be guaranteed. The orchestrator implemented in Emu5GNet enables service migration from one Edge Server to another. Moreover, the integration of SUMO ensures the simulation of train mobility. Therefore, it is possible in this environment to work on the definition of Edge service migration policies;
- Future Architectures Definition: Edge Computing architectures are a new concept and the issues/questions/challenges are numerous. As identified in [20], the implementation of solutions that consider multiple network operators simultaneously has been scarcely considered so far in the road/rail environment. However, to guarantee continuity of service, this may be a necessary element. Solutions could need to be developed to this end and Emu5GNet, enabling the deployment of concurrent orchestrators, could be used to achieve that. Other subjects could also be imagined.

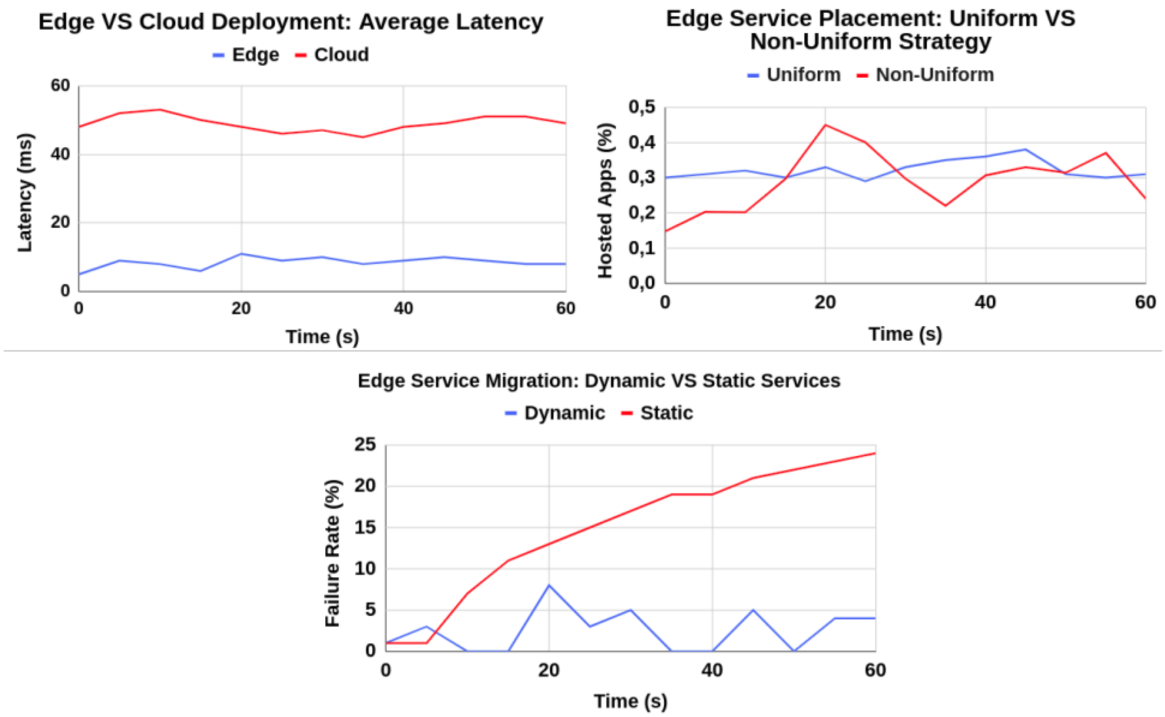

Fig. 2. Emu5GNet Use Case: Obtained Results

IV. Edge Computing and Emu5GNet: A First Use Case

This section aims to demonstrate how Emu5GNet could be used to simply evaluate different parameters/different for Edge Computing in railway environment. To do so, we designed a simple scenario: on a 3km2 a dozen of trains, using a 5G Radio Access network, are generating data (using the *iperf* command). Three edge data centers are deployed and distributed on the map. A remote Cloud server can also be accessed (cf. Figure 1). This scenario can be reproduced using the Emu5GNet Github Page [11].

More precisely, we considered the following scenario: each train simultaneously launches a variable number of services considered as critical applications (corresponding to iperf commands) and these services link to an Edge or Cloud server (acting as an iperf server and that could host, more broadly, any kind of server/application). The experiment lasts 60 seconds and a maximum of 135 simultaneous services were counted. The latency associated with the Cloud server is calculated based on the average latency data measured for Google Cloud servers in France. Different articles, such as [21], provide useful pieces of information regarding Cloud servers' latency measurement.

In this evaluation, we aimed to demonstrate that Emu5GNet can be used for 1) the definition of optimal architectures, 2) for service placement and 3) for service migration. We also wanted to highlight the fact that the platform can provide different types of results related to: 1) latency, 2) service placement failure rate or 3) percentage of services hosted on one of the deployed edge servers (3 in total as shown in Figure 1).

For this reason, Figure 2 shows three different curves:

- On the top left, based on the average latency times measured for Cloud servers, the idea is to highlight the potential benefits of deploying Edge servers in terms of latency. Over the duration of the experiment (60s), this curve compares the latency required to transmit data from a train to a) a Cloud server and b) an Edge server. Such measurements could also be used to define optimal, multi-tier Edge Computing architectures to optimize both the cost and performance level offered to rail services;
- On the top right, the idea was to demonstrate that the Emu5GNet platform can be relevant for the definition of placement strategies for Edge services. We have therefore basically compared two placement strategies, one uniform (services are distributed fairly by the orchestrator among the different servers) and the other non-uniform (non-equitable distribution). The curve displayed here allows us to see the percentage of services currently running on one of the Edge servers compared to the total number of services currently running in the infrastructure. Related to these placement strategies, many other curves could be obtained: energy overhead generated by a non-optimal placement strategy, estimation of the computational latency associated with each edge computing server, etc.
- On the bottom center, the idea was to demonstrate that the Emu5GNet platform can also be used for the evaluation of Edge service migration policies. To do so, we compared

two simple approaches: a) a first approach in which services are moved to the nearest edge server based on train mobility and b) a second approach in which deployed services are maintained end-to-end on the first server attached to the train. We have defined a maximum communication delay between the train and the edge server used (10s) and considered that the service placement is a failure when the latency exceeds this limit. Indeed, for a critical service, exceeding the defined maximum latency might not be acceptable. Thus, this curve allows us to see that not migrating edge services leads necessarily to an increased latency and a higher percentage of placement failures. Emu5GNet could therefore be used to define an optimal service migration strategy. In this context, many parameters could be evaluated such as the time needed for the migration of a service, the additional cost (computation, communication) caused by the migration strategy, etc.

Thus, this simple experiment shows that the Emu5GNet platform can be used for a wide range of implementations (see Section 3.3). Various server/service placement and migration strategies could be implemented and compared with this platform. The results obtained could allow to identify appropriate strategies for specific applications and optimization objectives: cost, performance, energy, etc. The potential applications of Emu5GNet are therefore numerous.

V. Conclusions

In this paper, we have described a new simulation/emulation environment that could be used for the implementation and evaluation of Edge Computing services/architecture in railway environments: Emu5GNet. To our knowledge, this platform is the first to allow realistic emulation of Edge servers and to integrate ideas of architectural evaluation (optimal server deployment) and node mobility (trains/cars/pedestrians). To demonstrate the potential benefits of Emu5GNet, we have highlighted in this paper the main applications that could be considered using this platform: Edge server/service deployment optimization, mobility management, etc. We have also proposed a reusable use case of the platform showing some of the results that could be obtained: latency computation, placement policy comparison, etc. In future work, we plan to further develop this platform and integrate new building blocks that will allow its use by a broad set of researchers.

VI. Acknowledgment

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