Integrated Service Discovery and Placement in Information-Centric Vehicular Network Slices

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***Abstract*—Connected and autonomous driving is one of the prominent vertical applications to showcase the capabilities of the 5G mobile network to transform and disrupt numerous industrial sectors and service chains. Cooperative autonomous mobility applications require ultra low latency communication, utilize massive broadband connections for vast numbers of connected devices, all of this under high mobility settings. Cloud and Edge Computing, artificial intelligence (AI), and the Internet of things (IoT) pave the path for the most important role of 5G: to attain an integration platform for the challenges of vertical applications. In this work, we first review these enabling features of 5G for autonomous driving and their integration in our autonomous driving testbed on urban public roads. We then propose an enhancement to the 5G vehicle to everything (V2X) architecture by incorporating the information-centric communication paradigm. Our simulations of a proposed approach for integrated service discovery and placement in the high mobility settings of autonomous driving applications show improved service continuity and latency measured by hop counts to service endpoints and number of cache nodes. The results serve as a base line performance indicator for the practical implementation of the proposed approach.**

***Index Terms*—ICN, 5G, Network Slicing, Edge Computing, Autonomous Driving**

I. Introduction

Connected and cooperative autonomous mobility (CCAM) is aiming at disrupting the transportation sectors. Emerging use cases for increasing levels of autonomous vehicles (AV), such as platooning, remote driving, cooperative sensing, surround view, emergency maneuvering, digital maps [1], are being realized for improved driving experience and safety.

Addressing the challenges from future vertical applications such as CCAM is one of the main design objectives for the 5th generation mobile network (5G). 5G features manifold improved network performance in terms of latency, bandwidth, number of connected devices, mobility, among others. The most important features for CCAM support are Cellular Vehicle-to-Everything (C-V2X), new radio, and Network Slicing (NS). C-V2X enables vehicles to communicate with other components of the driving infrastructure. NS enables multi-tenant access to the 5G network infrastructure by configuring and composing virtualized core and access network (CN, AN) functions (VNF), fitting each application service's QoS requirements.

Besides the 5G network, CCAM applications also rely on other technologies, such as big data analytics, IoT, and machine learning to process the massive amount of data generated by the roadside infrastructure and create situational perceptions for the AVs. One important but less mentioned feature of 5G is its role as an integration platform for those technologies. A core part to attain this vision is the integration with multi-access edge computing (MEC), bringing compute nodes close to the roadside and AVs, and using it for the deployment of low latency CCAM applications, e.g for object detection, traffic analysis, and 5G VNFs themselves. Given these aspects, 5G allows for novel solution approaches implemented as special NSs to be integrated into and enhance 5G core functionalities, e.g. a NS with network functions for information-centric networking (ICN) communication, which can be combined with and take advantage of the 5G core VNFs. Such a novel approach is motivated by the future CCAM scenarios with high mobility, which expose the limitations and inefficiencies of the predominantly host-centric IP-based communication in current mobile vehicular networks, i.e., limited support for one-to-many communications, requiring identities of the communication endpoints to be known in advance [2] or relying on the host resolution service (DNS) with high delays. In addition, the client-server based data exchange among CCAM components relies on the standard IP protocol e.g. for geo-location based messaging services or topic-based message queues. This leads to increased request processing on middle nodes or centralized message brokers, as the network control aims to guarantee session continuity.

To eliminate such inefficiency in the current C-V2X architectures, approaches for incorporating ICN paradigm in 3GPP architecture for C-V2X communication has been proposed by recent works, which allows devices and applications to request data from the network without the need to resolve the data source IP addresses and enables resilient vehicular networks. In [2], [3], the authors propose the integration of ICN protocol stack in the radio access network (RAN) entities such as UEs, eNodeB. In [4], the extensions to 5G core network (CN) control plane and user plane to support ICN are proposed.

The aforementioned approaches aim at a native support for ICN in future C-V2X architecture. In this work, we propose a more practical approach leveraging 5G network slicing and software defined networking (SDN) capabilities. The proposed information-centric V2X slice architecture for vehicular communication consists of a software-defined (*SDNized*) ICN vehicular network slice formed by AV and roadside units (RSU) and a 5G V2X network slice. Instead of enabling ICN capability in 5G RAN and core network, the 5G V2X slice serves as an overlay network for the software-defined control plane of the vehicular network slice. As such, native ICN support by 5G network is not required and the ICN vehicular network can be realized as a specialized network slice. While the main focus is on service continuity in the proposed information-centric V2X network, we highlight the need for an application aware unified NS management and orchestration component.

Our contributions can be summarized as follows:

- We report on the development of our autonomous driving testbed in real urban roads, which comprises 5G, edge computing, and IoT middleware infrastructure for CCAM (Section III) and propose an architecture for a testbed component, an SDNized ICN (S-ICN) C-V2X network slice, which enhances the 5G C-V2X technologies with flow-based and information-centric network capability for CCAM applications (Section IV).
- We elaborate on an integrated service discovery and placement approach based on the proposed S-ICN V2X architecture to achieve low latency and service continuity for CCAM.
- The proposed service approach is simulated and evaluated with the configuration parameters of our autonomous driving testbed. The results show an improved service response time and MEC resource utility (Section V).

II. Enablers for Information Centric 5G V2X

In this section we provide the essential background for the main enablers of CCAM applications.

A. 3GPP C-V2X Standard

5G network enables V2X communication through radio interface for vehicles (data plane Uu) with unicast and sidelink interface (PC5) for direct V2V with multicast, broadcast and unicast modes. Certain 5G core functions involve in the provisioning and control of V2X connectivity, e.g., access and mobility function (AMF), policy control function (PCF), Unified data management (UDM), etc. These functions authenticate and manage users' V2X connectivity based on subscription data, e.g., location, frequencies, etc, stored both in core network and user devices. In addition, V2X Application and V2X Application Server (AS) are the respective components of the client-server based V2X applications services. CCAM services are deployed as ASs, which provide traffic information for AVs. V2X applications are deployed in AVs, which receive information from the ASs. Endpoints of the ASs are solicited by the 5G core or preconfigured in the AVs. More details of the related 5G V2X architecture are provided in [5], [6].

B. Information Centric Networking

ICN [7] is a future network paradigm that shifts from the current host-centric communication to a request-driven content retrieval model. With ICN, consumers use content name instead of the host address to retrieve content from any host holding a copy of the content. The content requests are sent to all network interfaces and forwarded by other ICN nodes (router) in the network. The content sources sent requested data to the consumers through the interfaces from which the requests arrive. The content data reaches the consumers through the reverse path of the requests and can be cached by the intermediary nodes to serve future requests for the same data. In-network caching and routing are the subjects of various ICN researches [8], [9].

C. Network Slicing Management

Network slicing is a concept for multiple vertical services to share the same network infrastructure with guaranteed QoS requirements, proper isolation, and security. NS is studied by several standard organizations, e.g., NGMN, 3GPP and ONF, and is an important feature of 5G. 3GPP broadly defines four type of network slices, i.e., eMBB, URLLC, MIoT, V2X, and core network functions for NS selection and management [6]. Network slice template is an abstraction of a network slice, which is instantiated with concrete network resources and functions and associated with each vertical service. NS technology covers broad techniques for network functions virtualization (NFV), resource management, multi-domain federation, etc, which are the subjects of active academic and industrial researches [10], [11].

III. Architecture of the Autonomous Driving Infrastructure

In this section, we detail the Diginet-PS autonomous driving testbed [12] infrastructure in a complex urban environment. Advanced 5G, MEC, SDN, and ICN technologies are integrated as enablers for demanding CCAM applications. The architecture components and protocols description provide the system settings for the main focus of this work discussed in the next Section, which is a model and an algorithm for integrated service discovery and placement for optimized CCAM services deployment in the testbed.

The Diginet-PS testbed allows trials of various CCAM use cases for autonomous vehicles in mixed and real traffic with traditional vehicles. As a result, the infrastructure is designed to enable vehicle intelligence, i.e., situational awareness and environment perception. The AVs enhance their perception by relying on relevant digital maps for the driving situation from CCAM services deployed at various infrastructure layers. In order to produce the maps, CCAM services, e.g., traffic control, local dynamic map (LDM) [13], and edge dynamic map (EDM), require context data related to the AVs' position, driving patterns, and other road sensor data, to be processed and communicated the AVs in real-time. The first perception layer consists of the AVs equipped with onboard sensors, e.g, Lidar, radar, and camera sensors, which provide data for its local environment perception. An AV's on-board unit (OBU) consists of a computing platform for various object detection, data fusion, and processing services, etc, which produce an LDM to support their driving decisions. The OBUs are also

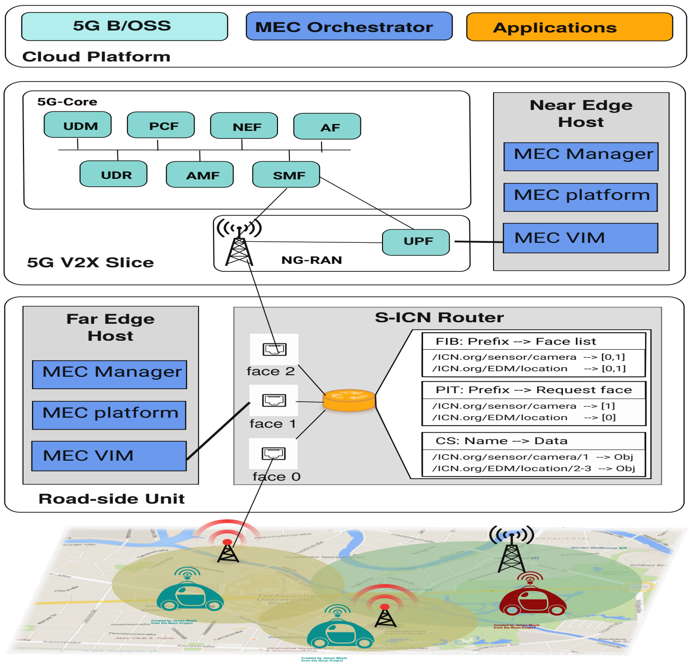

Fig. 1. Integrated MEC and 5G Deployment for Autonomous Driving

equipped with 5G modem for C-V2X communication. The second perception layer consists of the RSUs infrastructure. Various types of sensors are connected with the RSUs, e.g., traffic analysis, road condition, weather, environment, etc, which are additional data sources providing external situational information to the AVs. With large computing resources, the RSUs serve as a far edge infrastructure for the ITS, data fusion, data analytic services. These services are used by the EDM service to aggregate traffic situation information for the AVs.

The last perception layer consists of a central cloud and a distributed near edge infrastructure. This layer typically hosts global management and orchestration services for the distributed network (e.g., 5G slice management), distributed MEC (e.g., MEC orchestrator), ITS, and CCAM services deployed in the RSUs and cloud infrastructure.

In such a highly mobile and distributed system, client-server communication between the CCAM services and the AVs poses much overhead for mobility management, context-based applications, among others. ICN based communication eliminates the complexity of managing the end-to-end and host-based connectivity for CCAM services. The autonomous driving infrastructure components are depicted in Figure 1 and described next.

A. Road-side Infrastructure

The road-side infrastructure includes various road sensors providing relevant autonomous driving data and RSUs deployed along the road. The RSUs serve two purposes: extending the cellular coverage with smaller heterogeneous wireless coverage and extending the centralized computing platform with distributed MEC (edge hosts). As the result, the road-side infrastructure provides a far-edge platform for CCAM applications and VNFs to be deployed close the AVs and UEs for low-latency services and offloading data traffic from the cellular network. The RSU is depicted in Figure 1 with a network and computing components. The far-edge host is a computing platform providing virtualization resources and managed by a distributed VIM manager, e.g., OpenStack or Kubernetes platform. The challenges for the VIM management are to maintain distributed resource utilization, applications and NFVs scheduling/allocation, among others. The software-defined ICN (S-ICN) router controls the service and application contents from cloud and MEC services downwards to the AVs and road sensors and road-side data upwards in the reverse direction. The S-ICN router extends the basic ICN routing with a centralized content flow control. Detailed functionality of the S-ICN router and its integration in a C-V2X slice are provided in the next Section.

B. Multi-access Edge Infrastructure

Future mobile applications such as IoT and CCAM require low latency and high bandwidth communication for large amount of data at the network edge. Such requirements call for new distributed application service architectures with multiple service instances deployed at different MEC locations. The MEC infrastructure enables operators' VNFs and CCAM services to be hosted close to the UE's point of attachment, which results in efficient services provisioning through reduced latency and data network load. Beside the far-edge hosts deployed in the RSUs, MEC hosts with larger capacity are typically provided by the network operator, i.e., a central office rearchitected as a data center (CORD). The ETSI MEC workgroup defines a MEC reference architecture in [14], which consists of the MEC hosts and MEC management components to host MEC applications within an operator network. They are depicted in Figure 1 as the Edge Hosts and MEC Orchestrator. In the MEC host, a virtualization infrastructure with network, storage and computing resources is managed by a MEC platform. The MEC platform carries out local management functionalities to enable MEC applications and services. These functions include MEC services, service registry, traffic control, DNS handling. The MEC management consists of MEC system-level management (MEC Orchestration) and MEC host level management. The former orchestrates the complete MEC system with global information from the lattger,which comprises a MEC platform manager and a VIM manager. It manages the distributed MEC host resources and applications. The MEC platform manager provides functionalities, e.g., platform element management, application rules and request management, and application lifecycle management.

C. Virtualized 5G Mobile Network

5G system is designed for easy integration with MEC as a key technology to support low latency and increased quality of experience. MEC can be mapped to 5G application functions (AF), which have access to other services and information provided by the 5G network functions based on some policies.

There are different deployment options for MEC to support various vertical use cases. A virtual 5G network slice is shown in Figure 1. A user plane function (UPF) can be deployed close to the RSUs and AVs. The 5G core steers traffic from the UPF to the access network based on the RSU subscription data and location, the information provided by the AF, policy, or other related traffic rules. Due to the vehicle mobility and the transfer of CCAM service instances between the RSUs, service or session continuity is required. The 5G Core Network may expose network information and capabilities to edge computing. The AF can be allowed to interact directly with the Control Plane Network Functions or is required to use the external exposure framework (NEF). Details of the 5G architecture with MEC support are provided in [6].

D. Cloud Infrastructure

The cloud infrastructure provides on-demand and large-scale resources for CCAM applications, 5G network functions, and other management and orchestration (MANO) components. These applications and network functions require intensive computing resources to analyse global system data and execute management algorithms. The less computing-intensive and highly responsive tasks are offloaded to the MEC hosts. Therefore the management of application state and lifecycle is crucial for consistent system operations. While many of the requirements related to resource demands are addressed by the selected cloud management platform, the top-level orchestration must be incorporated with the distributed MEC, network, and application management components and configure them to meet the applications' end-to-end QoS requirements.

IV. System Model of the SDNized Information Centric C-V2X Network Slice

A typical requirement of the wireless edge networks for CCAM is the co-existence of heterogeneous radio technologies and routing protocols required by different applications and devices, which are not integrated and managed by mobile broadband systems (5G). This poses significant challenges for the end-to-end management of application data flows, e.g., sensor data streams and control signals, across the cloud, edge, 5G, and sensor network domain. Needless to say, the IP based connectivity requires protocol translation to be carried out at each network domain border, i.e., from the sensor network to IP broadband, 5G core to data center virtualized network. As the result, the added transmission delays and mobility management complexity make it challenging to provision CCAM applications with the required latency and other QoE parameters. Given the aforementioned advantages of ICN paradigm, we propose a S-ICN overlay on top of a C-V2X network slice, which connects and manages the content exchange among the MEC infrastructure, AVs and road sensors.

Figure 2 shows a hybrid network architecture to support V2X and D2D communication, which extends the 3GPP's 5G architecture for V2X [5] with a Software Defined ICN (S-ICN) segment. The S-INC V2X is a effective access network (AN) consisting of point of attachments (PoA) with multiple interfaces of different wired and wireless technologies, i.e., the RSUs with Wi-Fi, mmWave, 5G, and BLE to connect with road sensors and vehicles. On each PoA, the interfaces are managed by an S-ICN router, which controls data flows based on the information being transferred, e.g., sensor data, control information, application data, etc. The PoA may also contain a mobile far-edge host providing storage and computing capability for local data processing or local SDN control applications. This infrastructure allows most generated data to be processed and communicated in the AN resulting in very high throughput, low latency, and reduced load on the cellular network. In order to fully support mobile applications, a mobile PoA (installed on vehicle or user equipment) must be fully integrated with guaranteed QoS requirements for on-board sensors and applications. The resulting challenges for mobility management, session continuity, and end-to-end flow control are addressed within the C-V2X slice.

In the proposed system, the 5G slice in effect provides a reliable and low latency back-haul for the S-ICN control plane. The V2X servers components specified in the 5G V2X architecture are implemented with a global S-ICN controller, an ICN service broker (service directory), and other CCAM applications, which are hosted in the near-edge close to the network core or in data center infrastructure as shown in Figure 2. The S-ICN controller is connected with the S-ICN routers through the 5G core UPF over N6 interface and the NG-RAN (gNB) over Uu interface. In the NG-RAN, this control plane is extended to the mobile S-ICN routers (on AVs) through the V5 (SDN-C) interfaces. The V2X based control plane can also be used for the exchange of control information among the centralized and mobile SDN controllers.

A. SDNized ICN routing protocol

The S-ICN AN is realized by an ICN routing architecture with an SDN overlay network [15], in which the content request routing decision is made by a centralized entity. The ICN requests are not flooded through all S-ICN routers as in the original ICN protocol. Upon receiving a request, a packetIn containing the data name is sent to the logically centralized SDN-Controller. The controller then requests the Service Directory to provide the end point of the requested data sources (application services) to serve the request. With a global view of the network and optionally information from related application servers, the controller can identify the optimal path between a data requester and data sources and install the corresponding flow rules in the S-ICN routers. Additionally, by extending the naming scheme to contain additional application context, e.g., location, QoS, and other attributes, a dynamic and context based selection of suitable applications can be realized. In case no data source with the required QoS constraints is available, the MEC Orchestrator can be requested to reallocate or provision the data sources or applications at different edge locations.

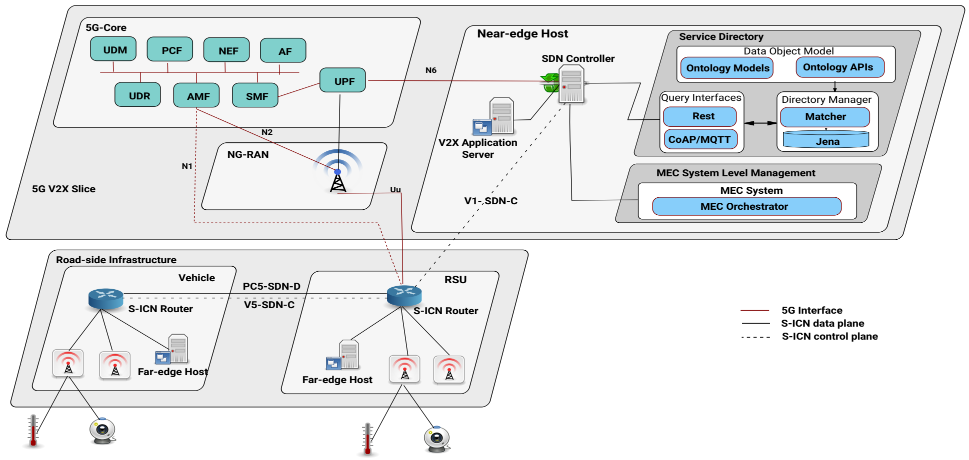

Fig. 2. SDNized Information Centric C-V2X network slice architecture based on the 5G system architecture for V2X communication over PC5 and Uu intefaces.

While such infrastructure can eliminate discovery overhead of ICN protocol, an additional registration protocol is required for data sources to provide their description to the service directory. Such protocol can also make use of the PacketIn payload or other application-specific protocol for the communication of registration messages to the service directory. Details of the service discovery and intent matching approach are discussed in our previous work [16].

B. 5G V2X Slice for S-ICN Control Plane

In the proposed S-ICN architecture, the centralized network control components are placed in a near-edge host, while the distributed SDN controller and S-ICN routers are located in the mobile access network. As the result, the S-ICN control plane must rely on the 5G user plane, i.e., a 5G V2X slice, to manage the S-ICN routers.

There are two V2X communication modes utilizing Uu and PC5 interfaces. For authorization and provisioning, the parameters for V2X communications are preconfigured in the UEs or sim module, or provided by the V2X application server (AS) or the PCF to the UEs. For PC5 based communication, the policy parameters include the radio parameters for (non)-operator managed radio access technologies (RAT) with geographical areas and other parameters, e.g., policy for RAT selection, privacy policy, mapping of V2X service type to communication modes, QoS profiles, etc. Over the PC5 interface, V2X services and messages are exchanged between UEs in all mentioned modes over both IP and non-IP based protocols. Over the Uu interface, the V2X messages are routed towards the AS or UEs using the existing unicast routing. In the proposed S-ICN slice, the RSUs and AVs (UE) discover the centralized SDN controller over Uu interface with preconfigured AS address. The address information can also be provided by the AMF over N1 interface.

C. V2X Service Discovery and Placement

As the C-V2X slice serves as a control plane for the S-ICN slice, the 5G core functions of the C-V2X slice must be properly configured for low latency, mobility, and efficiency. Latency reduction for C-V2X communication may be achieved by various mechanisms, e.g., edge computing, where the S-ICN central controller is implemented as a V2X Application Server. In this section we describe the model for CCAM service discovery and placement in the V2X S-ICN slice.

In the aforementioned urban testbed, at a certain time, there are a set of $v \in \mathbb{N}$ AVs $\mathcal{V} = \{j : 0 \leq j \leq v\}$ that consume data from a set $\mathcal{S} \in \mathbb{N}$ of services and data source, i.e., sensors, EDM, multi-media. The services can be flexibly deployed on a set of $h \in \mathbb{N}$ edge hosts $\mathcal{H} = \{i : 0 \leq i \leq h\}$, each of which has capacity of $s_h \in \mathbb{N}$ compute units. An AV sends a service request $(v, s, \mathcal{P})$ (i.e., ICN interest packet) containing the ID of service consumer v, the service type s and a set $\mathcal{P}$ of required service parameters, i.e., funtional and non-functional descriptions. The service requests arrive according to independent Poisson processes with rate $\lambda_(v, s) > 0$. For each service there is a subset of cloud hosts $\mathcal{H}_s \subseteq \mathcal{H}$, where the services are deployed and can always serve the requests. The service requests first reach the ingres S-ICN routers, which return the requested service data if available in the content store or route the request to a known (edge) host based on the information in the FIB and the flow tables. If a service deployment is unknown, the S-ICN routers forward the request to a centralized S-ICN controller, which starts the service discovery as described next.

1) Service Description and Discovery: When a service request is received from the routers, the S-ICN controller looks up suitable services in the *Service Directory (SD)* based on the service description $\mathcal{P}$. The *Service Discovery* function, which is deployed in the far edge part of the S-ICWEN slice, is responsible for matching data and service requests from AVs with CCAM services. A generic data model for the description of CCAM services, sensors, and smart objects is developed based on the semantic description framework OWL-S [17]. OWL-S is a first-order logic framework for describing web services attributes, APIs, and communication protocols as a knowledge graph of concepts and their relationships. We extend OWL-S ontologies for smart cities with ITS domain concepts in [18], in which the input-output-precondition-effect (IOPE) model is applied for functional description of the services and smart objects together with other non-functional attributes and complex behaviors. When deployed, the services and sensors are registered with descriptions of their attributes, constraints and access methods (service endpoint or API) in the SD's semantic database (Jena). Examples of the service parameters are QoS (bandwidth, delay, throughput), functional, non-functional (cost, reliability, etc). An approach for semantic matching of service requests and descriptions with energy-based model is described in our previous work [16].

When matching services are found, the controller select an optimal service according to certain objectives, e.g., QoS, cost, reliability, etc. Based on the service endpoint description, the controller calculates an optimal path towards the service requester v and installs flow rules on the S-ICN routers on the path. Optimization approaches for service selection and route calculation by the controller are the focus of our future works. As the focus of this work is to achieve low latency response to CCAM service requests through optimal placement of services in MEC infrastructure, we assume the discovery, deployment and flows setup to each edge location incur a fix delay budget $f_h \in \mathbb{R}_+$. The delay caused by sending service data from edge host h to the requester v (service cost) is $d_{vh} \in \mathbb{R}_+$.

2) Service Placement: The distributed MEC deployed in the RSUs allows services to be deploy on the roadside closed to the vehicles or in the transport and core network depending on the edge hosts' resource capability and the AVs'delay requirements. The formulation allows us to define the problem an an instance of the uncapacitated facility location problem [19], which is NP-hard. We look for a subset $\mathcal{M} \subseteq \mathcal{H}$ of the edge hosts where the services are deployed, a mapping $\sigma : \mathcal{V} \rightarrow \mathcal{S}$ of the service requests to the hosted services with minimum delay cost:

$$\sum_{h \in \mathcal{M}} f_h + \sum_{v \in \mathcal{V}} d_{\sigma(v)v} \quad (1)$$

The problem can be formulated as an integer linear program, which can be solved in polynomial time, as follows:

$$\begin{aligned} \text{maximize} \quad & \sum_{h \in \mathcal{H}} f_h y_h + \sum_{h \in \mathcal{H}} \sum_{v \in \mathcal{V}} d_{hv} x_{hv} \\ \text{subject to} \quad & x_{hv} \leq y_h \quad (h \in \mathcal{H}, v \in \mathcal{V}) \\ & \textstyle\sum_{h \in \mathcal{H}} x_{hv} = 1 \quad (v \in \mathcal{V}) \\ & x_{hv} \in \{0,1\} \quad (h \in \mathcal{H}, v \in \mathcal{V}) \\ & y_h \in \{0,1\} \quad (h \in \mathcal{H}) \end{aligned} \quad (2)$$

In order to trade off the optimal resource efficiency for low service placement calculation delay, we solve the problem with an approximation algorithm proposed by Jain et al. [20]. The algorithm has the complexity class $\mathcal{O}(|\mathcal{H}|^2|\mathcal{V}|)$ and the approximation factor 1.6 of the total service cost $\sum_{v \in \mathcal{V}} c_v$. In the simplified model, the service cost represents response time or number of hops from data consumers to data sources or service. It can be extended to encompass package delay, cache misses, etc.

V. Evaluation Results

In this work, we focus on the evaluation of the proposed CCAM service placement in the S-ICN V2X network slice. The approach and analysis for service discovery and matching are reported in [16].

A. Experiment Settings

While the CCAM components of the testbed are tested on the real roads, we can only use the simulation for the evaluation of the large scale vehicular networks. However, parameters of the real driving environment are used for the simulation settings. We implement the vehicular network with scale-free topology in NS3 simulator, Figure 3a), because in both scale-free and V2X vehicular networks the nodes are more clustered with its neighbors (AV, RSU) than with remote nodes (cloud). We run the experiments on Ubuntu 18.04 with 8 CPUs core and 16 GB RAM.

B. Evaluation of the ICN Service Placement Approach

In the approximation algorithm, we increase one unit t of the service cost for each AVs, which is one hop toward a data source (edge host). We first carried out 10 experiments with 100 nodes (AV and edge host) and compare the optimized placement with a random placement strategy. The result depicted in Figure 3b) shows an average optimized distance of 2 hops to the services compared to 2.5 to 3.5 hops in random placement. We then scale out the network up to 100 nodes. The result in 3c) shows slightly shorter paths for networks with less than 300 nodes. Larger networks still have average paths with less than 2 hops. Finally, we investigate the resource utilization in the edge network by observing the number of edge hosts used for service placement, which accounts for 10% of the number of nodes in the network. The result depicted in Figure 3d) shows that only a third of the available edge hosts are required for the optimal placement.

VI. Conclusion

In this work, we first detailed the architecture of our autonomous driving testbed in real urban roads. Taking advantage of 5G with its flexible architecture as an integration platform, we proposed architecture of an SDNized ICN (S-ICN) C-V2X network slice, which enhances the 5G C-V2X technologies with flow-based and information-centric network capability for vehicular networks. We elaborated on an integrated service discovery and placement approach and algorithm for the proposed S-ICN V2X architecture to achieve low latency and service continuity. The proposed service management algorithm was evaluated with the configuration parameters of the urban autonomous driving testbed. The simulated results showed an average distance of 2 hops to service endpoints and requires 1 MEC host for each 10 service users in the vehicular network topology.

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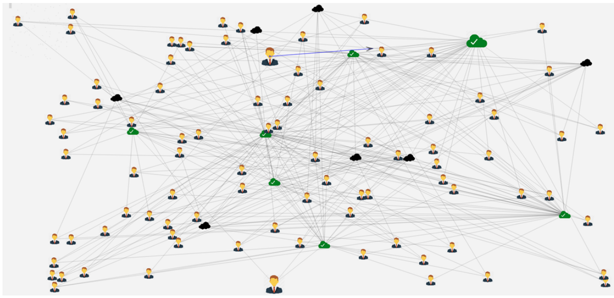
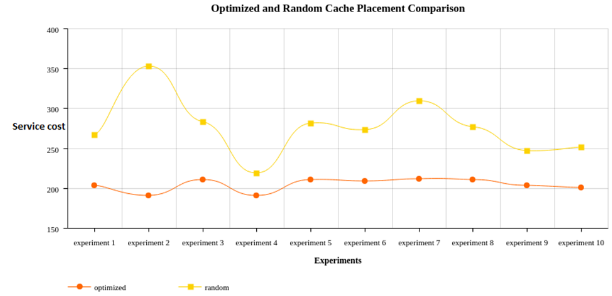
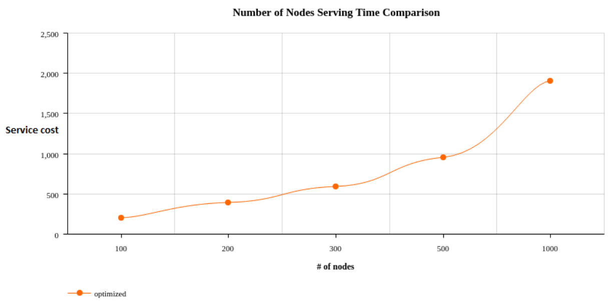


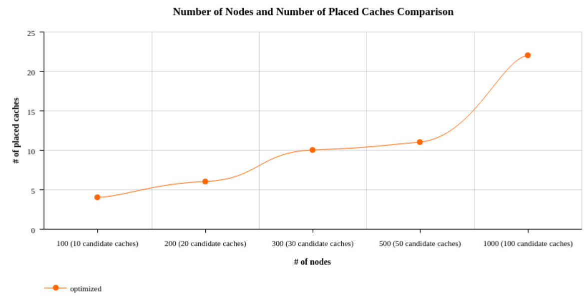
(a) V2X vehicular network simulated with scale-free topology.



(b) Comparison of optimized and random placement strategies.



(c) Total serving time for number of nodes.



(d) Number of edge hosts required for number of nodes.

Fig. 3. V2X vehicular network experiment.

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