Large-scale Modeling of Future Automotive Data Traffic towards the Edge Cloud

Robert Protzmann
Fraunhofer FOKUS
Berlin, Germany
robert.protzmann@fokus.fraunhofer.de

Karl Hübner
DCAITI, TU Berlin
Berlin, Germany
karl.huebner@dcaiti.com

Norbert Ascheuer
atesio GmbH
Berlin, Germany
ascheuer@atesio.de

Uwe Bauknecht
Universität Stuttgart, IKR
Stuttgart, Germany
uwe.bauknecht@ikr.uni-stuttgart.de

Tobias Enderle
Universität Stuttgart, IKR
Stuttgart, Germany
tobias.enderle@ikr.uni-stuttgart.de

Ulrich Gebhard
Nokia Bell Labs
Stuttgart, Germany
ulrich.gebhard@nokia-bell-labs.com

Christian Raack
atesio GmbH
Berlin, Germany
raack@atesio.de

Arthur Witt
Universität Stuttgart, IKR
Stuttgart, Germany
arthur.witt@ikr.uni-stuttgart.de

***Abstract*—We elaborate traffic types and volumes generated by mobile automotive users and examine their impact on metropolitan transport networks. Utilizing a large-scale joint simulation environment, including vehicle traffic, future automotive applications, and novel network architectures, we generate data traffic demand estimations for the rather large area of Berlin-Brandenburg, Germany. Additionally, we include a comprehensive study about traffic estimations of fixed access traffic. In future works, this model can then be used for developing and testing future network and reconfiguration algorithms.**

***Index Terms*—5G, multi-domain simulation, edge cloud, distributed data centers, automotive communication, VSimRTI**

I. Introduction

Connected cars promise many applications to improve future mobility in various ways. First, mobile Internet applications will gain more usage and grow in bandwidth demands. Second, novel mobility services for traffic efficiency, safety and autonomous driving that leverage processing capabilities in distributed data centers (DCs) will be introduced. These services may exhibit a limited locational relevance, but strict latency and availability constraints. Moreover, the density of cars in a specific area can fluctuate significantly. As a result, very highly volatile data traffic with different communication links is expected as a new challenge for transport networks, demanding unprecedented flexibility for the mapping of services to network resources. The mapping must be instantaneous and efficiently use network resources while meeting the requirements for availability, latency and bandwidth.

Edge cloud computing is a capable solution to meet bounded latencies for certain services as data connections could originate and terminate in close proximity. Yet, synchronization traffic of neighboring DCs would be required to spread information across the network. Since transmitted information will be generally large, the DCs need to be connected by highspeed interconnects, which can only be realized using optical interfaces.

In this paper, we present a large-scale model of data traffic demands produced by future automotive applications in connection with distributed DCs. We choose the area of Berlin-Brandenburg (an area of 30 000 km^2, further referred to as *BB-area*). Various data required for this study is publicly available [1]–[3]. Fig. 1 gives an overview over the domains this model includes. Next to the vehicle traffic, which includes realistic moving patterns of vehicles within the BB-area, the mobile applications, the communication, the DC hierarchy, and the transport network is modeled.

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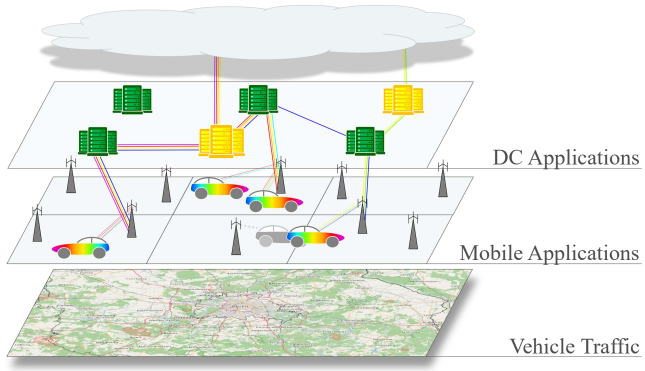

Fig. 1. The different domains to be modeled in this scenario: vehicle traffic, future automotive applications, transport network and DC applications.

Following this introduction, the second section of this paper presents the architecture of a large-scale reference network, which serves as a base for this study. Subsequently, Section III describes the generation of data traffic within this network using a joint simulation combining car traffic, future automotive applications, and the resulting network load. Finally, in Section IV, a conclusion is drawn.

II. Reference network

The physical network topology, representing the fiber cable layer, has been computed by combining the location of central offices (COs) [1] with street data (OSM) [2] in the BB-area. We followed the approaches developed in [4] to generate cable-topologies for nation-wide networks. Starting from a sparse street network connecting all given COs (a Steiner Tree), the network has been extended using OSM data until achieving bi-connectivity. Selecting 68 Metro and 4 Core among the 534 COs, we introduced a three-level hierarchy.

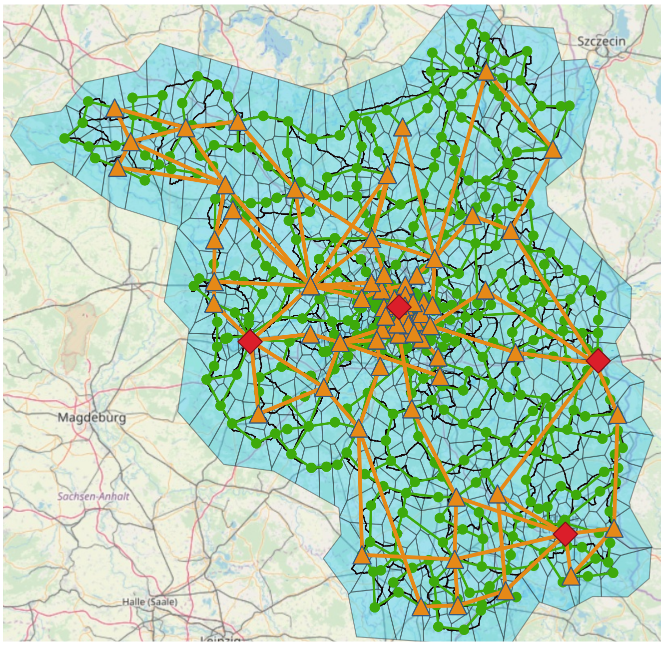

Fig. 2. BB-area fiber cable and *future* reference network: fiber cable paths in black, CO-rings in green, metro-rings in orange. Regional clustering for automotive traffic in blue, one region per node, background from [2].

The resulting reference network in Fig. 2 has 728 fiber cable links with realistic street-based distances.

The fiber cable layer has been used to realize a base network topology, see Fig. 2, using half-rings to connect COs to Metro nodes as well as Metro nodes to the Core. The corresponding fibers in the half-ring sides are routed disjointedly in the fiber cable layer towards two different nodes. We assume the network to be flexible enough to realize any desired IP topology, that is, all nodes are equipped with ROADMs capable of either terminating or forwarding (optical bypass) any wavelength channel carried over the connected fibers. For studies making explicit use of this topology see [5]. For the traffic modeling in this paper we mainly use the location and hierarchy of nodes.

III. Generation of Dynamic Traffic

The traffic model we present here consists of two aspects: future automotive traffic and estimations of fixed access traffic.

A. Future automotive traffic

The data traffic model of the automotive vertical includes seven service classes from the field of safety, traffic management and information as well as Internet applications [6]. Several application classes are well suited for edge computing approaches. Especially, safety applications could benefit as they usually address only a locally limited area for data exchange. In a DC hierarchy with COs, metro, and core nodes, it is possible to terminate the communication links and process the data already at metro DCs or even COs. However, such approaches introduce the need for an additional service to synchronize data between DCs.

Table I shows distinctive values regarding important communication parameters for the considered services. These values are in-line with related standardization and research efforts [6], [7]. The required bandwidths reflect the sum of up- and downlink data for boundaries between a conservative and aggressive estimation for one vehicle. When many vehicles are present at a certain location at the same time, the data amount for communication accumulates. The delay requirements for safety and traffic management applications represent end-to-end (E2E) values as these services follow a transmission pattern with periodic sending attempts for information updates of mobility data such as positions, speeds, sensor data and more. For Internet applications, round trip times (RTT) apply as requirement, due to the typical request/response pattern between clients and servers. The presented jitter sensitivity includes several aspects as the direct dependency towards jittering reception, the consequence for the application functionality, but also possible counteractions on application level (such as caching, buffering, or intelligent handling of redundant information). The data traffic model also includes other aspects for application usage, such as occurrence and duration of communication attempts, not displayed here in Table I.

TABLE I
Classification of future automotive services.

Category / Service Class	Bandwidth Assumption	Latency Requirement	Jitter Sensitivity
Safety			
Critical Short-Range	40 - 60 kbps	20 ms (E2E)	medium
Local Sensor Streaming	20 - 30 Mbps	20 ms (E2E)	medium
Traffic Management			
Tele-Operated Driving	25 - 40 Mbps	20 ms (E2E)	high
Traffic Information	100 - 200 kbps	1 s (E2E)	low
Internet			
Small Internet Data	200 - 500 kbps	5 s (RTT)	low
Internet Streaming	10 - 25 Mbps	50 ms (RTT)	high
Large File Download	50 - 100 Mbps	10 s (RTT)	low
Inter DC Sync Traffic	5 - 8 Mbps	20 ms (E2E)	medium

All the presented aspects are linked together in a joint simulation environment that reflects all combinations of the dimensions for the data generation from the automotive applications. Here, we use the co-simulation framework VSimRTI [8]. The vehicle traffic consists of realistic assumptions of commuter traffic in the BB-area, calibrated with real counting data from highways representing an average working day, and a busy day with lots of congestion [9]. The communication model in the simulation is based on the reference network described in Section II. In order to determine to which data center a vehicle is connected, the whole area has been divided into smaller regions, using a Voronoi diagram with one region per CO, see Fig. 2. Furthermore, the different service classes have been modeled as reference applications running on each single vehicle and generating traffic demand, while synchronization traffic is modeled between data centers depending on the service class.

As a result, a realistic model of data traffic amongst all 534 nodes in the network has been created. Here, the highly time-dependent nature of traffic demand can be observed, see Fig. 3 (top) for one example CO. With introducing edge computing, a slight overhead for synchronization traffic with neighboring DCs is recognized, yet reduces the traffic to be transmitted to higher hierarchical DCs, see Fig. 3 (bottom).

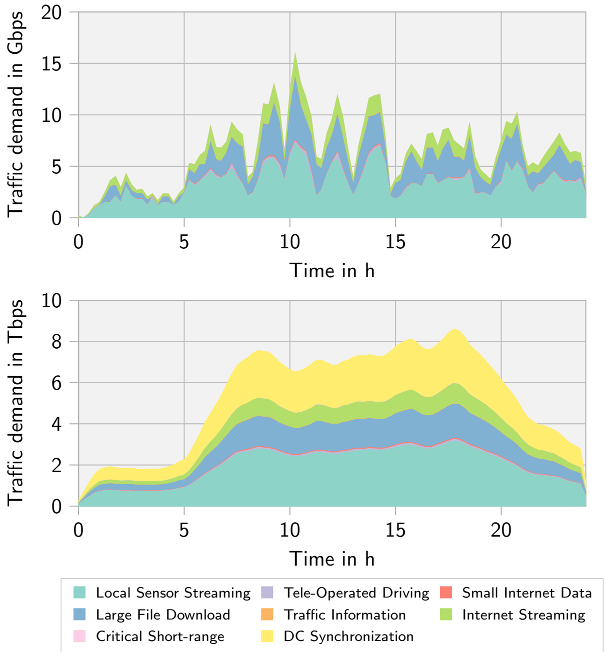

Fig. 3. Top: Highly volatile traffic demand of automotive mobile objects in one example region of the network (stacked).
Bottom: Total traffic demand over time of automotive mobile objects with the edge cloud approach within the whole BB-area (stacked).

Also, next to the highly dynamic changes in traffic demand over time, a high local volatility can be observed. While a CO close to a highway or within a city needs to handle a lot of data traffic, a neighboring CO covering only a few roads is underutilized (see Fig. 4).

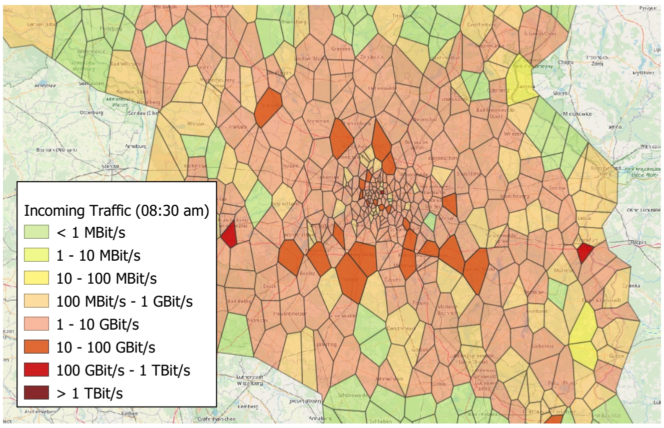

Fig. 4. Traffic occurrence in the BB-area indicating high local volatility in the centralized scenario (around 8:30 am). Map taken from [2].

B. Fixed Access Traffic

Apart from automotive data traffic, we are also interested in fixed access traffic of residential, business and data center customers that is transported in the same network. We therefore generated traffic matrices for those customers with the traffic model and generator presented in [10]. This traffic generator is based on diurnal traffic profiles and it distinguishes between different service classes. The population model of the traffic generator requires the number of inhabitants that are connected to a network node. We estimated the number of connected users based on fine-grained population figures given in [3].

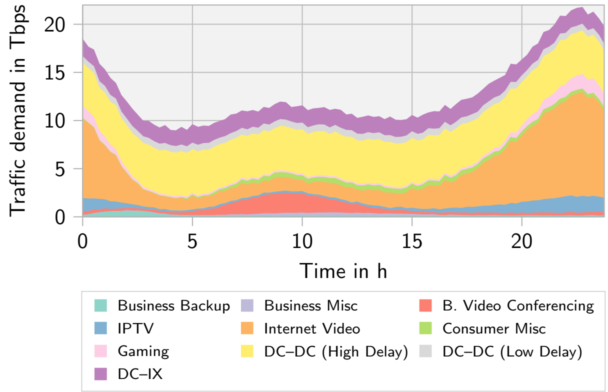

Fig. 5. Total fixed access traffic (stacked).

Cisco estimates the amount of IP traffic in Germany for the years 2016 up to 2021 [11], [12]. We extrapolated those values for the year 2025 and scaled them based on the number of inhabitants of Berlin and Brandenburg. The resulting fixed access traffic is shown in Fig. 5.

IV. Conclusions and Outlook

We presented a comprehensive data traffic model which provides traffic estimation for the large area of Berlin-Brandenburg in Germany. To achieve this, realistic assumptions for future automotive traffic and fixed access network traffic were made, utilizing estimations from statistical data and studies, as well as large-scaled simulations. As a result, a realistic model of highly dynamic data traffic with very volatile and time-dependent demand requirements has been created. In related work, this model is already in use by the authors for developing and testing network algorithms facing reconfiguration problems of photonic transport networks [5].

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