Computing Paradigms in Emerging Vehicular Environments

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1 Motivation

Human life is the central element of any technological evolution and revolution. New smart and connected devices pop up every year.

However, vehicles still have not fully received all the connection that, in the last 30 years, has been established globally by the use of computers, and by Wi-Fi, 3G, 4G, 5G networks. Connected vehicles have the potential to increase road safety, driver well-being, plus fewer congestion and less pollution problems.

Vehicular computing paradigms are an essential evolution of cloud and edge computing in vehicular environments towards novel and safer transportation and traffic networks.

2 Vehicular Computing Paradigms

In Vehicular Cloud Computing (VCC), vehicles as a form of a cluster with the processing power equivalent to high-demanding services, as Machine Learning or Big Data ones. The common example is to imagine vehicles parked in a parking lot, where their computational resources are lending to nearby businesses in exchange for benefits for vehicle users.

In **Vehicular Fog Computing (VFC)**, services, processes, and data are handled between the Cloud and the Edge of the network, increasing the availability of both sides (Edge and Cloud) to interested parties. Vehicles are dynamic allocated to the VFC network as long as enabled.

In **Vehicular Edge Computing (VEC)**, services, processes, and data whose availability and execution time needs to be measured in real-time are dynamically distributed and computed by nearby vehicles (known then as fog nodes) without the need to offload to the Cloud. External networks are relieved from congestion and local services are served immediately to local interested parties. It can work locally without a connection to the Internet.

Feature	VCC	VEC(VFC)
Geographic Location	Remote	Near users
Latency Quality	Low	High
Communication	Limited by Network infrastructure when using Cloud	High enough to real-time
Computing Power	Between medium to high	High if achieving fully expected integration
Cost	High (big when using the cloud, also can be bigger than VEC if memory in vehicle for "big tasks" is a must)	Low (granular, vehicle by vehicle built in)
Dynamics	Expected to be somewhat stationary	Ephemerous, and rapidly changing

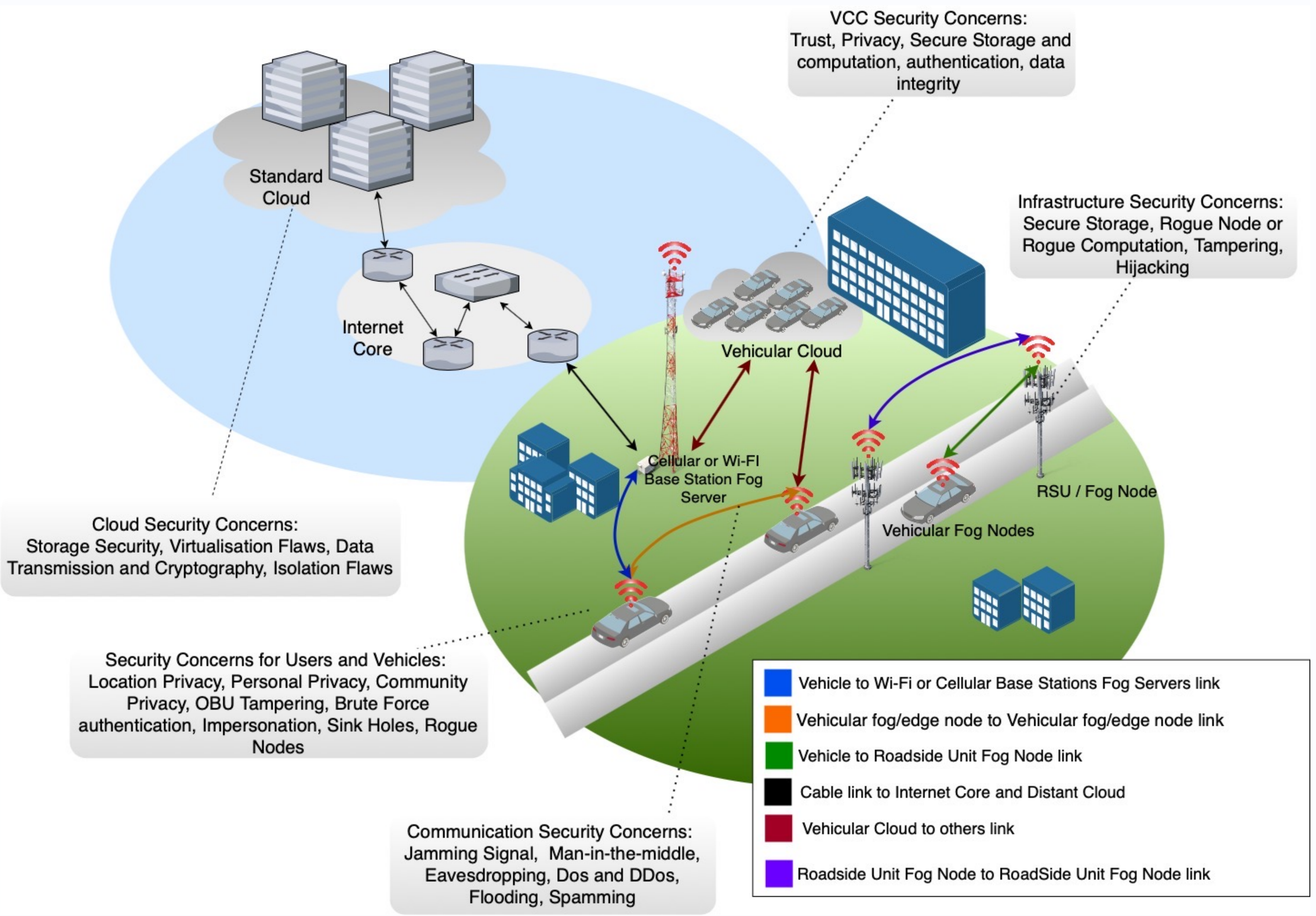
4 Vehicular Architectures and Security Concerns

Vehicular networks comprise numerous nodes, devices, and services.

The two basic architectures are Vehicular Ad-hoc NETworks (Subset of Mobile Ad-hoc NETworks) and Internet of Vehicles (a subset of the Internet of Things).

Security attacks such as spamming, phishing, masquerading, sybil, sniffing, eavesdropping, and man-in-the-middle affect these networks with consequences in privacy. However, attacks such as Onboard Unit tampering, signal jamming, (Distributed) Denial of Service, and the existence of Malicious Rogue Nodes can lead to catastrophic consequences to occupants' and vehicles' overall safety.

Vehicular Environments' Privacy can be considered in three scopes: location-based privacy (not disclose location without request), personal and common interest privacy (not disclose specific places certain vehicles commonly go), and community privacy (not disclose places groups of individuals have in common).



3 Wireless Technologies For Vehicular Networks

Wireless Access in Vehicular Environments (WAVE) is a standard for radio technologies and its set of services. Speeds can go up to 27 MB/s within the 1000 m range. Onboard units, Roadside units, and wave interface are defined by it.

WAVE is widely adopted and has a solid development background. It does not have obligations with mobile carriers and was made specifically for transportation systems and vehicles in general.

Industries proponents that adopt **WAVE**: General Motors, NXP, Toyota, Volkswagen, and others.

5th Generation of Cellular Networks is the current Cellular Radio Technology being adopted worldwide. Its speeds are up to 1 Gbps, and latencies in 1 ms. Due to its promised specifications and involved technologies (millimeter-Wave, Non-Ortoghonal Multiple Access, Multiple Radio Access Technology, among others), it is believed to help vehicular networks, mainly Internet of Vehicles.

The burden of cellular networks is the necessity of a carrier, having the same issues as usual in mobile phone service offerings, for example. Also, the 5G-ready devices will share the regional network with other thousand to millions of devices.

Industries proponents that adopt 5th Gen: Ford, Intel, Qualcomm

5 Future Directions

The three technologies below will help future vehicular environments by introducing 1) flexibility into the network, 2) more powerful wireless connections, and 3) programmability abstraction, respectively.

1) Software–Defined Networks decouples data and control-planes in a network, allowing several data traffic patterns to be easily managed by the network core. This flexibility allows novel vehicular environment protocols to shape data exchange optimistically.

2) 6th Generation Mobile Networks expects to deliver data rates about 1 to 10 Gbps for average users, latencies below 1 ms, and 100 times higher energy efficiency. 6G benefits promise to surpass WAVE ones, enabling its adoption with fair low energy cost for devices.

3) Serverless Computing highly virtualize resources (computation) in an event-driven way. As a cloud-native technology, Vehicular Cloud Networks inherit its benefits.

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Collaborators from the following countries were involved in this research: