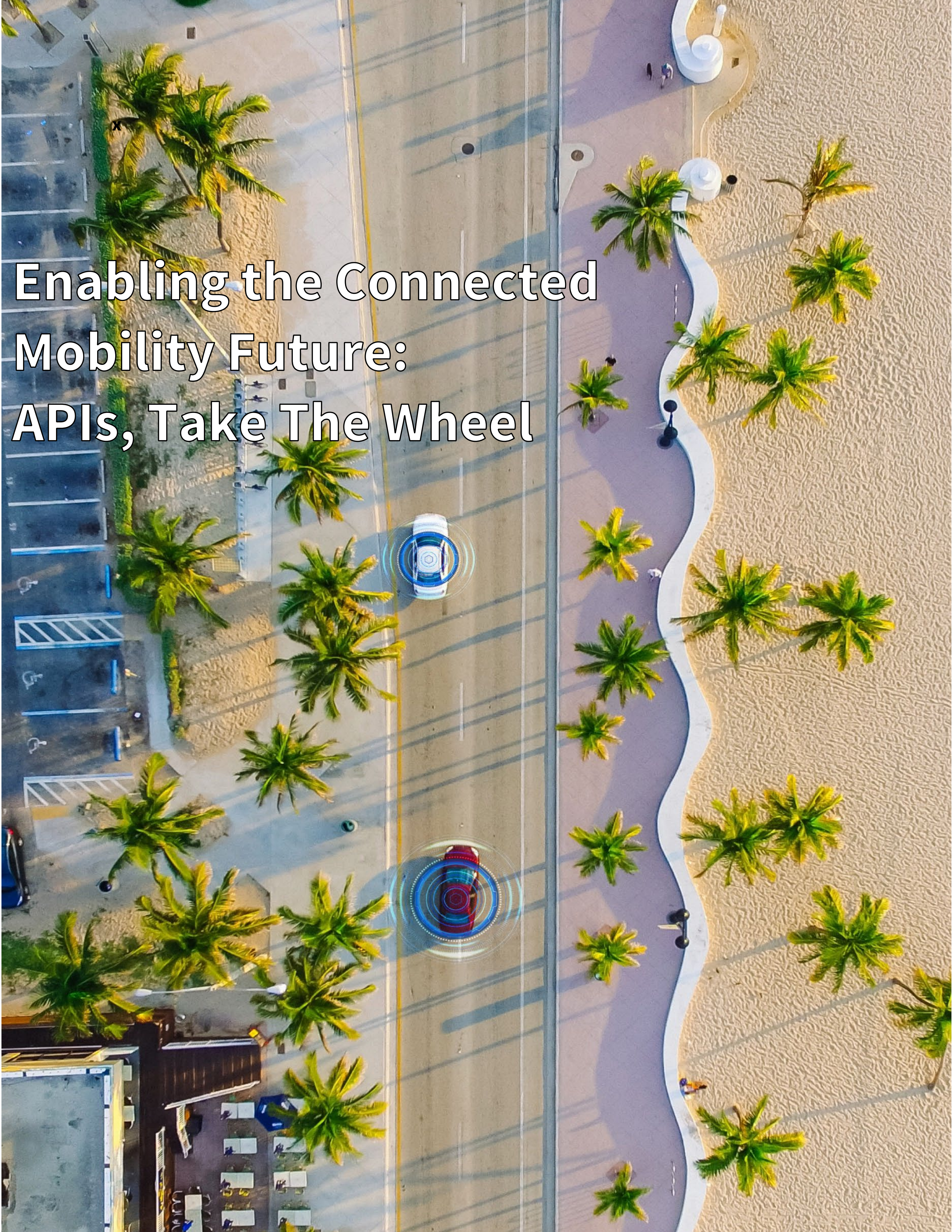
Enabling the Connected Mobility Future: APIs, Take The Wheel



Contents

Acronym Reference List

Acronym Used	Definition
MEC	Multi-Access Edge Compute
API	Application Programming Interface
5GFF	5G Future Forum
C-V2X	Cellular vehicle-to-anything
CSP	Cloud Service Provider
TSP	Telecommunications Service Provider
OEM	Original Equipment Manufacturer
EDS	Edge Discovery Service
QoS	Quality of Service
KPI	Key Performance Indicator
5GAA	5G Automotive Association
HV	Host Vehicle
IVE	In-Vehicle Entertainment
VR	Virtual Reality
AV	Autonomous Vehicle
OTA	Over-The-Air

Abstract

5G is bringing higher speeds, lower latencies, and other advanced capabilities to the masses. Those evolving 5G networks along with rising multi-access edge computing ("MEC") capabilities are powering major transformations and new value opportunities across industries. Application Programming Interfaces ("APIs") are critical tools stitching together the 5G network's connectivity fabric, bringing together connected products, and unlocking value for entire value chains from businesses to end customers.

The purpose of this paper is to highlight the 5G Future Forum's ("5GFF") efforts to overcome technical obstacles in today's connected world through driving interconnected and interoperable APIs within an international, partner-focused approach. Connected vehicle use cases are the context to which we highlight the desirability, viability, and feasibility of 5GFF partner-agnostic APIs that permit seamless communication between MEC infrastructures and connected vehicles. As 5G offerings become more ubiquitous, differentiated value for consumers and businesses driven by interoperable APIs will scale with the number of partners participating in this future.

Consider engaging with the 5GFF today to explore how these APIs and this initiative can help drive value for you and your customers during this evolution of connected mobility.

1. Introduction

1.1. Future of Mobility

Remember when 4G was first deployed? Widescale adoption of 4G led to the proliferation of digital applications that revolutionized the mobile landscape. Today, 5G expansion is primed to connect products in new ways, unlocking innovative and disruptive new use cases. In this paper, we look at how impactful innovations are made possible by faster, low-latency connectivity and network-based multi-access edge computing ("MEC") capabilities – specifically within the context of connected vehicles and the transformation of the mobility industry[1].

New vehicular user experiences and advanced use cases such as autonomous vehicles and cellular vehicle-to-anything ("C-V2X") can be taken a step further through the power of 5G; however, fast speeds & low-latency are only part of the story. Unfortunately, with disparate networks and connectivity protocols, application developers face multiple barriers to providing a seamless experience to their users. That full value and premier experience is unlocked through seamless communication and interoperability between vehicles, operators, and their MEC platforms.

We examine how the 5G Future Forum ("5GFF") is addressing and removing these barriers with application programming interfaces ("APIs"); the software technical interfaces enabling communication between all the connected equipment (e.g., vehicles, road sensors, networks, MEC, etc.). The role and importance of 5GFF APIs is demonstrated through the lens of select V2X sample use cases such as safer driving, in-vehicle entertainment, traffic flow efficiency, and more. These illustrative use cases have the potential to usher in safer mobility through accident reduction, better user experiences through new consumer services, and lowering the carbon footprint of traffic through improved efficiency, not to mention fostering new revenue creation and cost optimization opportunities for all stakeholders in the industry.

1.2. 5G Future Forum

Founded in 2020, the 5GFF aims to accelerate the delivery of 5G and MEC enabled solutions for developers and multinational customers around the world. Adopting a partnership-focused approach enables operators to create interoperable specifications, driving reach and scale, while empowering members to jointly innovate 5G cutting edge applications and use cases.

The 5GFF Experience and Exposure Management workstream is developing and testing APIs that will allow developer applications to seamlessly transition between MEC platforms across operators and regions. The technical teams work with leading technology companies and platform providers across the world, ensuring that the 5GFF APIs are applicable across a host of use cases and can be rapidly scaled, whenever and wherever needed.

In addition, the 5GFF technical teams are also collaborating with the API development teams at GSMA led initiatives such as Project Camara and Openverse, to contribute to the global effort of promoting global MEC interoperability. By complementing inter-operator connectivity development work across the ecosystem, the 5GFF is also working towards removing a siloed approach to solving a common problem.

The Commercial Ecosystems workstream engages with the global 5G community, validating and testing emerging 5G use cases where the 5GFF APIs can provide the most value. The workstream focuses on 5G use cases that are feasible today and in the near-term, while also evaluating the application of 5G beyond the current technological horizon. This allows the workstream members to determine the network and technology advancements required to make future use cases a reality. The Ecosystems workstream also engages with other leading technology organizations, ensuring the relevance and increased adoption of the 5GFF APIs.

All workstreams are comprised of leading technical and commercial teams from the 5GFF member base, including Verizon, Rogers, Telstra, Vodafone, America Movil, KT, and NOS. This enables the 5GFF to adopt a global and holistic view of where 5G is today and where it can be tomorrow.

Learn more about the 5GFF today and how we aim to revolutionize the deployment and adoption of 5G MEC in your home market: 5GFF website.

2. 5GFF APIs

2.1. Introduction

Tomorrow's automotive landscape will be defined by APIs, the software technical interfaces enabling communication and data sharing between equipment (e.g., vehicles, road sensors, networks, etc.). APIs are the key to realizing the future state discussed throughout this paper. The concerted effort to share APIs and technical requirements from Cloud Service Providers ("CSPs"), Telecommunications Service Providers ("TSPs"), and Automotive Original Equipment Manufacturers ("OEMs") results in an exciting ecosystem with significant opportunities for new products, services, and capabilities. The roadmap table below highlights the availability and timeline of these services, such as edge discovery services, and what is to come. The terms in the roadmap are described in section 2.2.

These 5GFF APIs are being deployed by operator members as they become available and are available to other 5G ecosystem members on the 5GFF website. For any questions regarding the availability and deployment of these APIs corresponding to your home market and/or application, please reach out using the Contact Us form on the 5GFF website.

The 5GFF API Roadmap:

API Category	This API Enables…	Availability
Edge Discovery Service (Location service)	...the ability to discover the most optimal MEC for deploying applications and enable application users to connect to the most optimal instance of the edge hosted application.	In Deployment
Workload orchestration (Location service)	…intent based workload placement and life cycle management of the applications on MEC	In Development
Quality of Service management (Quality service)	…developers to influence the network QoS in accordance with the application needs	
Network Intelligence exposure (Visibility service)	…visibility to the key network performance indicators to enable intelligent decision making and network aware application.	
Bidirectional API (Visibility service)	…standardized approach to exchange information between TSP and CSP considering the application needs in a holistic manner.	In Roadmap
Network Slicing (Quality service)	…the flexibility of mapping network slices to the application based on the type and requirements of the application and users.	

To address the use cases detailed in the following section (Section 3 below), the 5GFF has developed foundational APIs focused on MEC applications. These 5GFF APIs simplify traffic orchestration for MEC applications across networks. The power of MEC resides in part in its ability to provide local computing with low latency, by having mobile clients use the most optimal MEC node to handle application traffic. Existing traffic orchestration processes are complex and often rely on heavy lifting that is not specific to an application type, including identifying client geolocation through best-effort services or, even worse, manually mapping carrier IP addresses.

2.2. API Overview

Edge Discovery Service

The 5GFF Edge Discovery Service ("EDS") addresses the most fundamental challenge of the rapidly evolving edge-computing landscape: optimizing dynamic routing from mobile devices to an ever-changing set of MEC nodes by enabling seamless discovery and connectivity to the most optimal MEC location. The EDS can direct and connect application clients to optimal MEC endpoints for every application session. To determine the ideal 5G MEC platform for a device to be connected to, the EDS considers the device location, IP anchor location, current network traffic, and other factors. EDS is designed with developers in mind – to simultaneously launch and scale applications across operators and networks, globally. As adoption of these APIs broadens, developers will be able to use a common EDS API across all 5GFF members – minimizing the cost and time required to provide end-users with a seamless application experience[2].

These readily available APIs are fundamental for the use cases, enabling key base tasks such as finding the optimal 5G edge platform(s), registration of end points for carriers' services, and finding optimal service endpoints for clients (*Verizon 5G*). If you are a consumer, this means that as you drive from one coverage zone to the next, your service is not impacted even if the carriers are different.

Workload Orchestration

Building on top of MEC EDS, the focus of the Workload Orchestration API service is to define various sets of APIs for developers to orchestrate application workload through an intent-based API (i.e., an API that takes care of all the back-end operations pertaining to the work it does, like updating a database) that is TSP-agnostic. Workload placement, compute reservation, application lifecycle management, workload migration, and health monitoring are some of the categories of intents the API service plans to support.

Bi-directional APIs

MEC offers opportunities to empower new use cases that demand low latency, reduced jitter, and localized secure information processing. Bi-directional APIs are intended to exchange information that will enable TSPs and CSPs to offer best outcomes to developers and end customers.

5GFF is closely collaborating with CSPs on the development of bi-directional APIs for MEC that will outline specific information to be exchanged through APIs and event flows between TSPs and CSPs. The information shared through bi-directional APIs will play a foundational role in discovering, assigning, and managing optimal MEC resources and services effectively no matter how the workload has been provisioned. This allows either the TSP or CSP to have the insight needed to serve applications at the right location and compute power to take advantage of the capabilities that MEC has to offer.

Quality of Service ("QoS") Management

5GFF recognizes that for certain use cases, simply running the application on MEC is not enough. The network Key Performance Indicators ("KPIs") – such as latency, bandwidth, etc. - required to support these use cases warrant a need to support UE differentiation and application flow differentiation.

The QoS management API spec offers the capability for applications to request an enhanced quality of service based on the application and user requirements to be provisioned dynamically in real time. This translates to less lag for mobile gaming or faster reaction times that will enables autonomous vehicles to avoid a crash.

Network Intelligence Exposure
TSPs have had access to a wealth of data related to their network which has predominantly been used for internal initiatives. With MEC bringing compute to the edge of the network, network KPIs have gained external relevance as they provide valuable data points to MEC-hosted applications. 5GFF aims to expose important network KPIs like network utilization, throughput, latency, jitter, and packet loss in the form of APIs to enable applications to make real time decisions leading to improved end use experience.

Network Slicing
To meet the diverse needs of MEC-hosted applications, the network slicing and slice mapping API spec empowers applications to have more control over network configurations associated with the application end user. The API spec would abstract the intricate details of the underlying network elements so that developers have the freedom to continue to focus on new products and services.

3. Use Cases

The use cases referenced here are select examples and a subset of the repository located in 5G Automotive Association's ("5GAA") documentation as of September 2022; for up-to-date information please refer to the 5GAA website. For each use case, the APIs listed below are inclusive of technological enablers to build the stated example solutions and are not prescriptive in limiting possible API options; a use case's solutions design may offer flexibility to use varying degrees of some or all of APIs.

This sample set of use cases have been selected based on their relevance to 5GFF member objectives and relevance to their market(s) of operations. This is not an exhaustive list of C-V2X and represent a sample size of use cases where the 5GFF APIs have a key role to play in the enablement and delivery of the solution to the end user.

Metrics Definitions

For each use case, there are principal metrics to consider[3]:

Metric	Definition
Service Level Reliability	Based on an agreed QoS framework, the guaranteed and expected performance to start/initialize, perform and finalize (end-to-end) applications within Use Cases
Service Level Latency	Measurements of time from the occurrence of the event in a scenario application zone to the beginning of the resulting actuation.
Bandwidth	Speed at which data is being transferred, received and/or downloaded by application(s) based on the needs of the end user, i.e., driver, passenger, in-vehicle Electronics Control Unit.

Metric Range Classification

For each use case, there are principal metrics to consider:

Metric	Level	Range
Latency	High	100 ms or higher
	Medium	50-100 ms
	Low	5-50 ms
Bandwidth	High	50Mbps or higher
	Medium	10-50 Mbps
	Low	10 Mbps or lower
Reliability	High	99.99% or higher
	Medium	99% or higher
	Low	90% or higher

There are other metrics that have a role to play in C-V2X use cases, but the above have been selected and covered in this document, given their ability to demonstrate the application and utility of the 5GFF APIs. Below are the sample set of use cases:

- In-Vehicle Entertainment (IVE)
  - HD Content delivery via 4K streaming
  - HD Content delivery via 8K streaming
- Obstructed View Assist
  - Alternate view from CCTVs
  - Alternate view from Other Vehicles
- Create a High-Definition Map from Nearby Cars' Data
- Infrastructure Assisted Environment Perception
  - Road Infrastructure Data Enhances In-Vehicle Sensors to Improve Driving Experience

    - Road Infrastructure Alerts HVs of Nearby Vehicle Trajectories for Improved Safety
- Vehicles Collects Hazard and Road Event for AVs
- Continuous Traffic Flow through intersections

Each use case has a corresponding API dependency table, that highlights how the 5GFF teams envision each of the 5GFF APIs can enhance the delivery of that specific use case while utilizing operator MEC platforms.

3.1. In-Vehicle Entertainment (IVE) – HD content delivery via 4K or 8K streaming

(Reference[10]: Section: 5.2.6 in 5GAA_T-200116_TR_C-V2X_Use_Cases_and_Service_Level_Requirements_Vol_II)

The goal of this use case is to supply and deliver on-demand HD video content to HV passengers on mobile or in-vehicle entertainment systems, globally. As such, this use case is apt for the many screens we use on the go. Families on road trips, work colleagues traveling to a client site, or a high school football team heading to the championship game are just a handful of examples where each person may desire specific video entertainment content while in transit. These multi-display environments can accommodate 4K video today, paving the way for 8K in the near future to support gaming, virtual reality (VR), online education, interactive advertisements, and more.

Metrics Requirements for IVE

Use Case	Latency	Bandwidth	Reliability
4K Streaming	High	Medium	Low
8K Streaming	Low	High	High

API Dependencies

API Service	Function
Edge Discovery Service	*Required* – Needed to identify the optimal MEC to meet low latency requirements
Workload Orchestration	*Enhanced Functionality* – Ensure continuity of experience when a MEC Host change occurs due to latency optimization (i.e., when a vehicle moves out of range of a MEC Host and into the range of another)
Quality of Service Management	*Special Consideration* – Influences network when existing performance does not meet the application requirements. Additionally, needed to guarantee Bit Rate
Network Intelligence Exposure	*Required* – Optimizes video and audio based on network conditions
Bidirectional API	*Enhanced Functionality*
Network Slicing	*Special Consideration* – Influences the network in cases of capacity degradation due to various factors like high intensity usage. Additionally, it guarantees Bit Rate and Latency.

3.2. Obstructed View Assist – Alternate View from CCTVs & Other Vehicles

(Reference[10]: Section: 5.2.7 in 5GAA_T-200116_TR_C-V2X_Use_Cases_and_Service_Level_Requirements_Vol_II)

With Autonomous Vehicles ("AVs") on the horizon and recognizing the vast amounts of data collected by vehicle sensors on vehicle performance, state, and environment– an immediate, value-add opportunity for this data is safety enhancement. This vehicle data has the power to decrease the unpredictability of driving through increased knowledge based on hazard and dangerous road event data (i.e., accident information, hard braking, speed adjustments). V2X communication (i.e., vehicle-to-vehicle, vehicle-to-MEC) allows for that type of proactive and/or real-time decision making.

For this use case, the goal is to provide a HV with an alternate view when there are obstructed road segments, or possibly a notification to other cars on the road that a driver is pulling out with an obstructed view. When a HV faces an obstacle obstructing its view while on the road, at an intersection, sidewalk, parking lot, or driveway, it queries entities (e.g., CCTV or other vehicles) in its vicinity capable of providing a video stream that extends the HV's view, making it possible to see around or behind the obstacle[3].

Metrics Requirements for Obstructed View Assist

Latency	Bandwidth	Reliability
Medium	Low	High

API Dependencies

API Service	Function
Edge Discovery Service	*Required* – Needed to identify the optimal MEC to meet low latency requirements
Workload orchestration	*Enhanced Functionality*
Quality of Service Management	*Special Consideration* – Influences network when existing performance does not meet the application requirements
Network Intelligence Exposure	*Enhanced Functionality*
Bidirectional API	*Enhanced Functionality*
Network Slicing	*Special Consideration* – Influences the network in cases of capacity degradation due to various factors such as high intensity usage

3.3. Create a High-Definition Map from Nearby Cars' Data

(Reference[10]: Section: 5.4.6 in 5GAA_T-200116_TR_C-V2X_Use_Cases_and_Service_Level_Requirements_Vol_II)

Some advanced vehicles are equipped with LIDAR or other HD sensors that collect environmental information and share that information with a HD map provider (e.g., a cloud server). As an advanced vehicle travels through geographies, its LIDAR collects new environment information and shares with map providers for continuous dynamic updates. The HD map provider analyzes the collected information and merges it to build a regional HD map. This allows the construction of HD maps that are dynamically updated with increasingly accurate data. The vehicle would then receive (or build) a HD map in their on-board navigational system.

Metrics Requirements for HD Map Creation

Latency	Bandwidth	Reliability
High	Medium	High

API Dependencies

API Service	Function
Edge Discovery Service	*Required* – Needed to identify the optimal MEC to meet low latency requirements
Workload Orchestration	*Enhanced Functionality*
Quality of Service Management	*Special Consideration* – Influences network when existing performance does not meet the application requirements.
Network Intelligence Exposure	*Enhanced Functionality*
Bidirectional API	*Enhanced Functionality*
Network Slicing	*Special Consideration* – Influences the network in cases of capacity degradation due to various factors such as high intensity usage.

3.4. Infrastructure Assisted Environment Perception:

(Reference[10]: Section: 5.4.7 in 5GAA_T-200116_TR_C-V2X_Use_Cases_and_Service_Level_Requirements_Vol_II)

Advanced sensors such as radar, LIDAR and HD cameras can be widely used to provide real time environment reception to an AV to safely navigate hazardous roads. To do so, the AV must trust the data and be able to make real time decisions or inform the driver of impending hazards. The goal of this use case is to enable an AV to operate autonomously by perceiving the environment and increase trust in the AV's sensor perception data. This can be done by enhancing the viewing range, or taking responsive actions caused by other vehicles, road bends, dips, intersections, or limited sensor range. This use case is applicable for urban environments with established traffic infrastructure.

How this works: An AV is authenticated and enabled to receive authorized information from the local road environment (this data is frequently updated, e.g., every 100ms). Since AVs have unique IDs that detail their location, speed, direction, and size, they can identify themselves quickly in a dynamic map and then transform the data into a view from its own perspective. This data is then fused into the car's automated driving program to (1) increase the trust level of the car's own sensor by adding an independent source and (2) provide an enhanced road view to enable a smoother and more prepared driving experience.

Metrics Requirements for Environment Perception

Latency	Bandwidth	Reliability
High	Med-High	High

API Dependencies

API Service	Function
Edge Discovery Service	*Required* – Needed to identify the optimal MEC to meet low latency requirements
Workload Orchestration	*Enhanced Functionality*
Quality of Service Management	*Special Consideration* – Influences network when existing performance does not meet the application requirements
Network Intelligence Exposure	*Enhanced Functionality*
Bidirectional API	*Enhanced Functionality*
Network Slicing	*Special Consideration* – Influences the network in cases of capacity degradation due to various factors such as high intensity usage.

3.5. Vehicles Collect Hazard and Road Events for AVs

(Reference[10]: Section: 5.4.13 in 5GAA_T-200116_TR_C-V2X_Use_Cases_and_Service_Level_Requirements_Vol_II)

The goal of collecting hazard and road event data for AVs is to be able to share road, traffic, and weather information with other nearby AVs. This extends the information horizon of AVs, creating a safer driving environment. When a vehicle collects sensor data, the data becomes available for other AVs and V2X applications. In practice, when a vehicle detects a hazard or road event based on its own sensor data, the corresponding information is collected along with geographic location for the purpose of sharing with nearby vehicles, especially AVs and V2X AS.

Metrics Requirements for Hazard Detection

Latency	Bandwidth	Reliability
Low	Low	High

API Dependencies

API Service	Function
Edge Discovery Service	*Required* – Needed to identify the optimal MEC to meet low latency requirements
Workload Orchestration	*Enhanced Functionality*
Quality of Service Management	*Special Consideration* – Influences network when existing performance does not meet the application requirements
Network Intelligence Exposure	*Enhanced Functionality*
Bidirectional API	*Enhanced Functionality*
Network Slicing	*Special Consideration* – Influences the network in cases of capacity degradation due to various factors such as high intensity usage

3.6. Catch Every Green Light: Continuous Traffic Flow Through Intersections

(Reference[10]: Section: 5.6.3 in 5GAA_T-200116_TR_C-V2X_Use_Cases_and_Service_Level_Requirements_Vol_II)

This use case enables vehicles to communicate with roadside infrastructure to create a 'green wave', i.e., a progressive flow of green lights, minimizing the need to stop at intersections. A series of traffic lights (three or more) are dynamically coordinated to allow continuous traffic flow thru the intersections in a particular direction. The benefits of traffic flow optimization via dynamic traffic signal and phase changes are reduction of CO2 emissions, reduction of fuel consumption, reduction of cars' waiting time at side roads, pedestrians receive more time to cross (and help to cross streets with vehicles travelling in platoons), and increased traffic efficiency in urban areas. This helps drivers and/or autonomous vehicles to select optimal speed settings to avoid having to stop at a series of intersections.

Metrics Requirements for Traffic Flow

Latency	**Bandwidth**	**Reliability**
High	Low	Low

API Dependencies

API Service	Function
Edge Discovery Service	*Enhanced Functionality*
Workload Orchestration	*Enhanced Functionality*
Quality of Service Management	*Special Consideration* – Influences network when existing performance does not meet the application requirements
Network Intelligence Exposure	*Enhanced Functionality*
Bidirectional API	*Enhanced Functionality*
Network Slicing	*Special Consideration* – Influences the network in cases of capacity degradation due to various factors such as high intensity usage and delay

4. Commercial Relevance

Enhanced connected vehicles, use cases, and infrastructure, all united through interoperable 5GFF APIs, requires companies (i.e., CSPs, TSPs, OEMs, etc.) to direct their strategies and investments to build supporting infrastructure and connected vehicles capabilities. This investment will unlock and crystalize new revenue opportunities for those same companies.

4.1. Connectivity Investments and Efforts

OEMs and technology companies need to review and prioritize their strategies, efforts and investments related to connected vehicles. Below are recommended areas to ensure networks and capabilities can support the highlighted use cases and capture potential benefits (financial and non-financial). Prioritized items that need to be addressed within the technical ecosystems include but will not be limited to:

More robust end-to-end architectures

- End-to-end architectures integrating independent software elements into comprehensive platforms will improve functionality, reduce complexity and enable the implementation of features such as OTA (Over-The-Air) updates to be automatically, seamlessly and fast.

- The gap between complexity and productivity continues to grow. Automotive OEMs and other providers are already facing talent shortages and are seeing increments in costs associated with development. Focusing on a simplified and robust architecture will reduce this gap, while optimizing resource allocation and utilization.

Improved sensors and data acquisition systems

- Improved sensing capabilities such as HD video capture, light detection and environmental sensors with improved range that optimize data collection, processing, distribution at the right time (i.e., real-time, event based, batched) will be required to enhance each use case, empowering better user experiences and decision making.

Significantly increased computing power and interconnectivity

- With MECs and computing resources located closer to traffic and vehicles, important steps need to be taken towards increasing computing power and interconnectivity, leading to an improved overall connected vehicle user experience. OEMs need to build services to boost computing power to optimize end user experience. This is a key step to ensure end users truly experience the use cases as planned and designed. In summary, OEMs need to warrant low latency besides providing efficient management of IoT/IoV (Internet of Vehicles) services at the edge nodes.

- Containerization is a key solution OEMs are considering, given the latency, speed and other requirements for connected vehicle use cases. This is a virtualized solution that enables application and service orchestration, eventually playing a vital role in increasing computing power and enhancing the connected vehicle experience. Containers, with their small size and increased flexibility, offer benefits to ensure ultra-high-speed, ultra-low-latency and other technical advantages to facilitate the delivery of connected vehicle capabilities. In the IoV architecture, virtualized containers enable vehicles that require increased computation and large utilization of network resources to communicate with the edge node closest or a roadside unit (RSU). In addition, capabilities around network slicing, task off-loading, and load balancing will be applied to ensure delivery of different use cases.

Unified Communications Platforms for connected vehicles

- Currently vehicles' have specialized communication systems that can be combined these systems into a single unified communications ecosystem equipment, platform and service model. This could optimize one-time hardware and software costs as well as ongoing operating costs. For e.g., using a multi-purpose, on-board communications unit in lieu of a separate set of devices for audio, telematics, satellite radio, navigation, insurance data acquisition, Wi-Fi, smart traffic systems, parking, etc.

4.2. Potential Revenue Opportunities

The ecosystem of connected vehicles opens a plethora of new potential revenue streams across the automotive industry, including but not limited to manufacturers, dealers, service providers, technology companies. As several of these opportunities are driven by the collection and analysis of data, key stakeholders will have to take into factor in data privacy considerations prior to exploring any of these opportunities. Some of those opportunity areas include:

Connected Vehicle Care, Service and Monitoring

- Connected vehicles create a continuous link between owners and their vehicles, presenting potential opportunities for automakers in the field of remote vehicle monitoring, maintenance and customer assistance, and vehicle diagnostics – services that would otherwise be provided at an automotive facility.

- Connected service platforms provide access to increased customer data that can empower multiple services including CRM, payments, subscriptions – all offered through APIs – allowing for services and features based on subscription tiers and customer preferences, that can be activated digitally.

Enablement of innovative new business models

- Ability to transition from rigid, bundled packages to more customizable, consumption-based packages

- Online services for vehicle owners, drivers, passengers bring potential opportunities for industry players in the entertainment field by adding new subscription packages that can be accessed on-demand when users are in their vehicles.

- Loyalty programs could enable drivers, vehicle users and passengers to earn rewards for every mile driven or traveled and exchange such miles for different benefits from driving a connected vehicle with commercial partners who decide to enroll into these partnerships.

Data-driven Opportunities

- Access to real-time data captured from connected vehicles sensors, devices and the elements will pave the way to new business and revenue models, changing how consumers and businesses use and manage vehicle resources.

- The generation of all these data points will be one of many catalysts to implement the pay-for-use models or shared ownership of vehicle assets.

- Potential use cases that could become sources of significant revenue to Automakers, OEMs, lenders, fleet managers and other industry players include but are not limited to:

    - **Deep Analysis of vehicle wear and tear** making it possible to have detailed information of asset valuation and this will offer precise pricing models based on real usage of the vehicles.

    - **Vehicle rental and lease financing models.** These models are usually based on hours logged and miles; they do not capture risk accurately on how the asset is used, driven and handled by customers and owners. Real-time data can deliver thorough analytics of how the vehicles are driven allowing for dynamic pricing alternatives.

5. Key Conclusions and Findings

5G has opened the door for the next generation of experiences. The dramatic increase in speeds up to 100 times faster than 4G and reduction of latency allows us to consider use cases and applications such as autonomous vehicles, V2X communication, and more.

The 5G use cases discussed in this paper represent a sample of the broad opportunities for telcos to transform their role in an increasingly dynamic and connected automotive world. Crucially, MEC allows for the execution of computing closer to the end-user and when paired with improved bandwidth usage (due to 5G), provides near real-time performance of their services and applications. This capability is becoming more critical for networks that can be inundated by thousands of sensors and devices that are increasing in volume every day.

In this paper, we demonstrated how 5GFF advocates for APIs to broaden the horizon for commercial and technological opportunities through certain use cases. APIs are the connectivity fabric, the communication layer between connected vehicles and supporting infrastructure (i.e., MEC); they are the key to enabling value in the connected mobility future.

An interconnected approach is vital; a siloed approach to connected mobility will impair deployment speed and be detrimental to the value provided to customers and seen by stakeholders. It behooves all parties to prioritize interoperability from the beginning to best ensure the full potential of this connected mobility opportunity - starting with interoperable APIs.

With a concerted and collective effort, ecosystem players can define the next evolution of mobility to truly benefit customers and themselves; consider engaging with the 5GFF today and defining the API-driven future.

6. Appendix

6.1. 5G Edge Discovery Service APIs

Below tables display the deployed APIs organized by functional area that are current as of this paper's publishing. For the up-to-date repository of available APIs, please check the [5GFF website].

5G Edge Discovery

HTTP Request	Description
GET /mecplatforms	Find the optimal 5G Edge platforms based on a combination of service profile, region, or subscriber equipment.
GET /regions	Outputs a list of all regions in the Verizon 5G Edge service.

Service Discovery

HTTP Request	Description
GET /serviceendpoints	Find optimal edge application server endpoints for a client device to connect to.

Service Registry

HTTP Request	Description
POST /serviceendpoints	Register the routable service endpoints of a deployed application to a 5G Edge platform.
GET /serviceendpointsall	List all of the Service Endpoint IDs for a specific API key.
GET /serviceendpoints/{serviceEndpointsId}	Get the routable endpoints of a registered serviceEndpointsId.
PUT /serviceendpoints/{serviceEndpointsId}	Update routable endpoint information for a specified serviceEndpointsId.
DELETE /serviceendpoints/{serviceEndpointsId}	Deregister (delete) routable endpoints from a 5G Edge platform.

Service Profiles

HTTP Request	Description
POST /serviceprofiles	Create a service profile that describes the resource require ments of an application.
GET /serviceprofiles	Get all service profiles for an API key.
GET /serviceprofiles/{serviceProfileId}	Get an individual service profile.
PUT /serviceprofiles/{serviceProfileId}	Update a service profile.
DELETE /serviceprofiles/{serviceProfileId}	Deregister (delete) a service profile.

6.2. Latency and relatability figure conditions

This table displays the conditions under which the latency and relatability figures should be achieved:

Scenario	Vehicle density[10]	Relative velocity[10] (KM/H)	Communication range[10] (m)	Offered load[10] (Mbit/s/vehicle) (average/peak)
Urban	1,000 – 3,000	0 – 100	50 – 100	1.0/10
Suburban	500 – 1,000	0 – 200	100 – 200	0.5/10
Highway	100 – 500	0 – 300	200 – 1,000	1.0/10

The rationale behind these conditions is as follows:

Vehicle density: For urban environments, we assume that each vehicle occupies 6-12 meters of space (4 meters for the vehicle plus 2-8 meters gap). We assume three lanes per direction and 2-3 roads of this type, which leads to 1000-3000 vehicles/km^2. The value for suburban environments is derived similarly using 2 roads and 8-20 meters gap. For the highway scenario, one road is considered, and a 60-meter safe distance (12-meter for high density) between vehicles on the same lane is assumed, corresponding to a reaction time of 1.8 s and an average speed of 120 km/h (24 km/h for high density).

Relative velocity: To derive these values, we consider the maximum allowed speed (50 km/h, 100 km/h) and maximum possible speed in a car (250 km/h), respectively. The standard car from an OEM is limited in speed to 250 km/h (sports cars may not be limited).

Communication range: In urban environments, the cars within close vicinity are the major interaction partners, and hence a range of 50-100 meters is deemed appropriate. The ranges for the other speeds were chosen such that they scale like the stopping distance of a car (at the corresponding speed).

Offered load: The highest amount of data traffic, on average, is expected in urban and highway environments. Urban environments offer a high density of information and thus many objects to be signaled to the car. Highway scenarios can include fast traffic which requires more foresight and thus more information to be signaled to the car. The suburban environment is usually less dense, and traffic is comparably slow.

6.3. Considerations for Deployment of Intelligent Transportation Systems on Public Networks

As vehicles, 5G networks, and MEC infrastructures evolve and mature, an increasingly critical consideration to explore in future iterations and publications will be the impact of supporting an ITS on a Public Network. Special attention to the deployment and the required performance metrics necessary to implement the Use Cases associated with the 5GFF APIs is outlined below.

Overview

APIs are the main enabler for the realization of a V2X System, but there are other network requirements worth mentioning. A V2X system also requires that the physical assets comprising the Radio and Core Networks are in place and meet the coverage, capacity, latency, and security requirements associated with the above Use Cases.

Government entities (federal, state and cities) have typically deployed and operated their Traffic Management Systems ("TMS") via Private Networks to mitigate potential security risks. The introduction of a V2X system requires Public Networks to cover large portions of the roadway along with supporting signaling and payload requirements.

There will also be a need for Public Networks to implement robust security and privacy mechanisms to safeguard the network along with supporting novel strategies to incorporate data from myriad sources like weather and road conditions. The paragraphs that follow highlight the concerns in the five areas where the deployment of a V2X requires special attention for Public Networks: Security, Control, Flexibility, Quality of Service, and Coverage /Speed.

Security: Need to focus on efficient authentication methods and the potential added security risks associated with the use of Network Slicing as it will introduce another point of attack for hackers[6,7].

Control: Evaluate the impact of managing all of the many network elements and be able to assign highest priority controls within the V2X sphere along with facilitating scheduled and autonomous control modes associated with in- and out-of-coverage of the cellular network.

Flexibility: Ability to utilize variety of connections and manage the complex node-to-node relationships that is present in the V2X network along with monitoring and identifying any potential impacts to latency and reliability.

Quality of Service ("QoS"): Consideration of operational requirements for the different slices that will enable one to meet the QoS Targets for the Services along supporting other 5G traffic types (e.g., Massive Machine Type Communications (mMTC), Enhanced Mobile Broadband (eMBB), and Ultra-Reliable and Ultra-Low Latency Communications (URLLC)) and to address any impacts from intra/inter-MNO mobility.

Coverage / Speed: Modern day V2X will require a more extensive wireless system that provides ubiquitous coverage and sufficient resources (RAN and CN) to facilitate the communication between all of the participants or users of the transportation network along with providing key data notifications from government entities. Optimum Resource Utilization / Congestion Avoidance along with addressing the problem of communicating with vehicles that travel at high speeds will need to be considered and addressed[8].

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