Connection Manager for Automotive- Enabling a Shift in Connectivity to Support the Evolution of the Car

A Technical Paper prepared for SCTE by

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1. Introduction

The automotive industry has been on a transformational journey of digitization since the early 2000s. With the recent introduction of Advanced Driver Assistance Systems (ADAS) and the growth of electric vehicles (EVs), software defined architecture for vehicles is demonstrating expanding connectivity needs. This whitepaper explores the evolution of the automotive architecture towards a software-based model driven by vehicle electrification and the need for a digital chassis. It also discusses how an application like Connection Manager can solve the future automotive connectivity needs by enabling on-device-based switching, connecting to MSO networks to help accelerate software-defined vehicle architecture.

2. Digitization of the Automotive Industry: An Imperative for OEMs

The automotive industry has undergone a remarkable transformation since the early 2000s with the introduction of ADAS. “Connected Vehicles” are now ubiquitous among new cars. Historically, connected vehicles, although existing since the mid-1990s with providers like OnStar, were primarily focused on basic low data and voice connections for emergency and concierge services. However, the rapid growth of electric vehicles (EVs), along with the increasing prevalence of ADAS features requiring sophisticated software, has driven the industry towards digitization.

According to Juniper Research, the number of connected vehicles in service will reach 367 million globally in 2027, up from 192 million in 2023[1]. The rapid growth of almost 91% between 2023 and 2027 will be driven primarily by ADAS and infotainment.[2] By 2025 in the US, over 50% of cars sold are projected to have L1 driving automation, 35% will have L2 technology, 9% with L3 features and just 1% with L4/L5 technology[3]. Figure 1 below goes into further detail of ADAS and levels of driving automation.

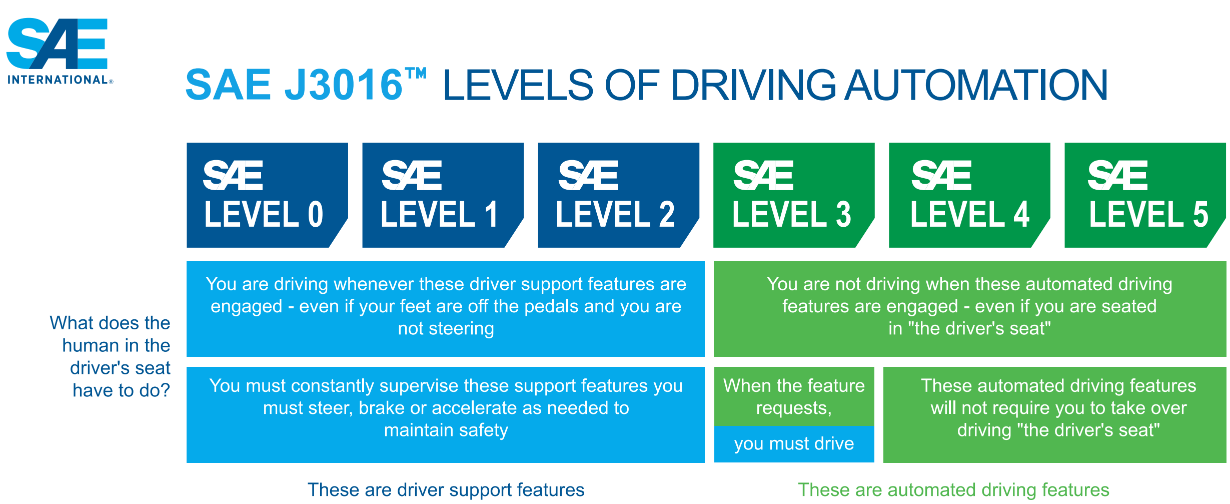

Figure 1: SAE Levels (Source: SAE, 2021, May 3)

3. Software Revolution of the Vehicle

So why is there an acceleration in digitization and driving automation now? For one, the electrification of the vehicle and its sudden and rapid rise in popularity.

The transportation industry is seeing several factors driving this electrification spike, but chief among them is the push from various regulatory jurisdictions to meet new ESG requirements. Most large regulatory bodies within the US and EU have put into place emissions restrictions on new vehicle sales. For reference, the US has a stated goal that half of all new passenger cars and light trucks sold will be zero-emission vehicles by 2030 while the EU will require all new cars sold in the EU to be zero-emission vehicles starting in 2035[4]. The industry is also seeing a major historical hurdle to EV adoption – cost – begin to erode. In 2023, the average internal combustion engine (ICE) vehicle in the US was $48k (up from $38k in 2020), allowing the cost gap to close compared to $53k for an EV[5] and resulting in EVs being price accessible. In conjunction with the price gap closing, regulatory bodies are continuing to subsidize EVs (Federal $7,500, e.g., Colorado $5,000), sometimes making the effective EV price lower than ICE vehicles, further accelerating demand of consumers' vehicle preferences towards EVs and accelerating Original Equipment Manufacturers (auto 'OEMs') shift toward EVs.

This electrification of automobiles and shift to autonomy threatens to halve the demand for vehicles worldwide over the next 20 years, due to increasing lifespan of EVs (more discussion follows on lifespan). This means OEMs must earn (higher margin) digital revenues if they are to maintain profitability. If they fail to drive usage of the infotainment unit, which assumes the ability to unlock digital revenue through application-based content and consumption, they will be unable to capitalize on the opportunity and it is anticipated that additional participants will come in over the top.[6]

To capture infotainment usage, OEMs need to abandon their legacy platforms and start again, providing an opportunity to redesign the relationship between hardware and software in the vehicle. The functionality of most vehicles today is defined by the hardware that is installed at the point of manufacturing. This means the specification of the vehicle is crystalized at the time of manufacture and there is limited opportunity for the OEM to make upgrades or changes once the vehicle has been manufactured. This new software-defined architecture will enable software to be updated remotely enabling new features and functionality as well as a full penetration of digital services into a model that generates digital revenue which OEMs need to survive.[6]

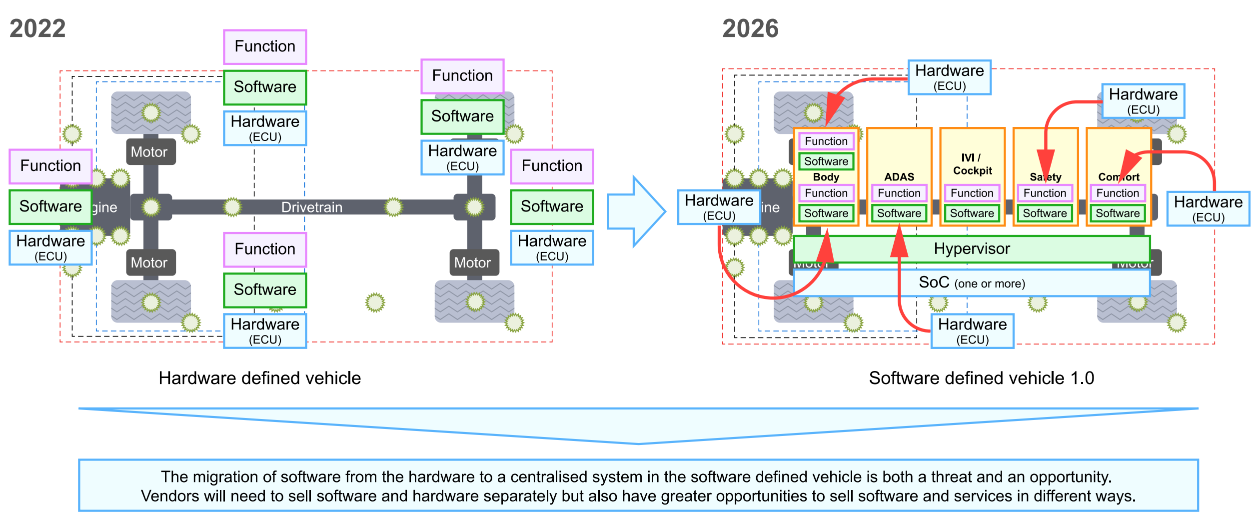

Figure 2: Hardware vs Software Defined Architecture[6]

With EVs, the R&D and component investment paradigm has flipped towards software vs. physical components.

With the increased investment in software integrated components, the average cost of vehicle-based technology for EVs has increased compared to ICE vehicles. Figure 3 shows a high-level breakdown of this component level cost change where investment capacity allows a shift to technology-based components, including software. OEMs are also shifting their approach to lifecycle management as this cost paradigm shifts. An industry that was originally based on planned obsolescence is transforming to one that places increased importance on the maintenance of software and with less components, will release resource capacity to reinvest in software[7]. Furthermore, the average lifespan of an ICE vehicle is ~14.8 years compared to the EV, which could be ~22.2 years[8]. Since there are no mass market EVs that are 22+ years old, the implied life of an EV is likely much longer. With this increase in the life of an EV as compared to that of an ICE vehicle, OEMs revenue model must change to capture service-based revenue through software services, further necessitating a shift towards software models.

<table>
<tr><th colspan="4">Average Price / Component - 2023</th></tr>
<tr><th></th><th colspan="2">ICE Price</th><th>EV Price</th></tr>
<tr><td>Avg Vehicle Components</td><td colspan="2">$48,000.00</td><td>$53,438.00</td></tr>
<tr><td>30,000 (ICE)</td><td colspan="2">$1.60</td><td>(For comparison) $1.78</td></tr>
<tr><td>20,000 (EV)</td><td colspan="2">(For comparison) $2.53</td><td>$3.56</td></tr>
<tr><th colspan="4">Applying ICE Component Cost to EV</th></tr>
<tr><td>Vehicle Components</td><td>Cost per Component</td><td>Price</td><td>SW Investment Capacity</td></tr>
<tr><td>20,000</td><td>$1.60</td><td>53,438.00</td><td>$10,562</td></tr>
<tr><td colspan="4">Software Investment (& Technology) Capacity represents current margin headroom to invest in software development, notwithstanding EV component cost increases</td></tr>
</table>

Figure 3: Comparing ICE and EV Average Component Price[5, 9]

As vehicles' lifespan increases and the focus shifts from hardware to software, automotive manufacturers are redefining their software strategies. Vehicle functionality is being digitized and, where possible, cost is being reduced. The maintenance of connected digital vehicles now requires continuous updates, similar to OS & application software patches and improvements on smartphones and PCs.

The advent of software-defined architecture has become crucial to the automotive industry and vehicles using this architecture will use large amounts of data, requiring significant connectivity capacity to be effective.[6]

4. Automotive Connectivity of the Future

The software revolution of the vehicle is something that OEMs must quickly master, but that is not the only race for competitive parity. The competitive advantage of the future will be moving up the curve on autonomous driving as the winners of the multi-hundred-billion-dollar ($700B+[10]) US automotive market will be the OEMs that demonstrate real autonomous L4/L5 driving. The pre-seeding of sensors with software upgradable vehicles is happening currently in Tesla and other auto manufacturers, and it is anticipated that capturing this data is needed to evolve autonomous driving algorithms and will result in exponentially growing data needs.

There will be two main pools of data that software-defined vehicles will generate. The first is digital data from digital experiences in the vehicle (digital cockpit and infotainment domain) and the other is the data generated by the driver assist and autonomous systems of the vehicle (ADAS domain). They are different in both size as well as time dependency and should therefore be assessed separately.[6]

The digital cockpit domain is where infotainment and the instrument cluster reside and is where all the data driving the digital experience in the vehicle will be generated. This could be smaller in total than generated by the ADAS domain (see below), but it will be time sensitive meaning that a good proportion of it will need to be delivered real-time via a cellular connection. Other aspects such as software updates (e.g., OS updates or app updates like Zoom in select 2024 Mercedes models) will be less time sensitive and could be delivered via WiFi when parked or charging without degrading the user experience or increasing reliance on cellular networks.[6]

The ADAS domain is where all driver assistance and autonomous features reside and where data from cameras, lidars and radars will be collected and processed. As L1 through L5 driving automation is developed and deployed in vehicles, the need for continuous and reliable processing, storage, and transport of data will become paramount. This will lead to very large volumes of data in its raw form, however the bulk will undergo processing in the vehicle in order to enable the ADAS functions to work. For example, raw video feeds will be processed into semantic scene descriptions (what the camera sees and where the objects are), which will be far smaller in size than the raw video feeds from which they were derived but still represent substantial amounts of data. How much of this data is uploaded will depend on how the machine vision algorithms in the cloud are trained, regardless, it is anticipated that every training scenario will improve the autonomous driving system and will result in significant amounts of data consumption if uploaded to the cloud. This training data will not be time dependent which, combined with its size and volume, makes it very likely that it will need to be uploaded over WiFi when the vehicle is parked and/or charging.[6]

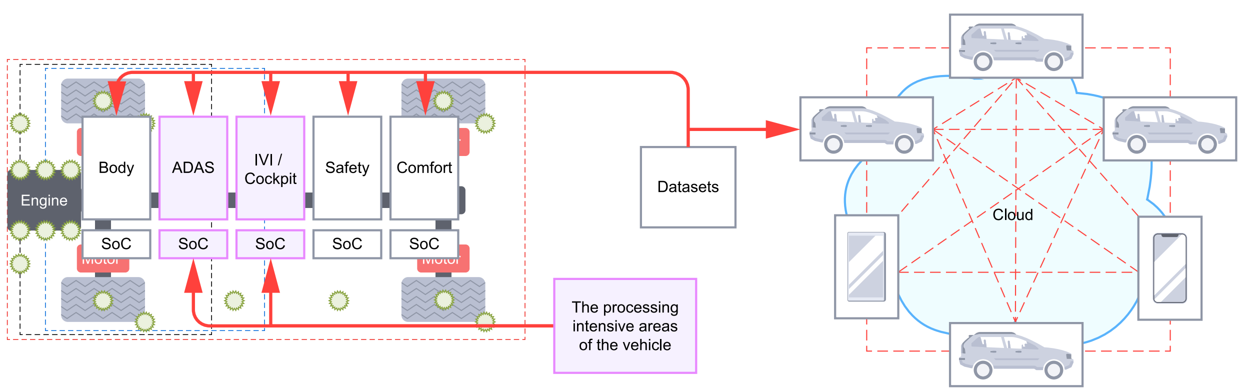

Figure 4: Data Transport Needs[6]

For reference on potential data payload sizes, Level 1 vehicles today can process up to three gigabytes per hour of data. As sensors and functionality increase in vehicles, they could process up to fifty gigabytes per hour[12]. Taking autonomous driving pioneer Waymo as a proxy for the L5 vehicle of tomorrow, a car will use up to eight cameras, three lidars and five radars. It is not unrealistic to think a fully autonomous vehicle could generate a continuous stream of data of up to 18TB per hour in complex driving conditions (e.g., snowy conditions)[12].

At some point after 2026, autonomous vehicles are likely to reach commercial grade and be deployed into the marketplace. It is at this point that data captured by vehicle sensors is likely to be uploaded far more frequently and in much greater volumes. Up until this point, ADAS system will be uploading and downloading data, but these will be mostly HD map and software system updates[6].

While it is unlikely that these payloads will be transferred back to the OEM or other cloud provider for processing due to cellular capacity and wireless wholesale costs, it is anticipated that corresponding data logs for this information will grow, and possibly be stranded on the vehicle[11]. 'Stranded data' translates to lost value from the digitization of the vehicle, not just for evolving active ADAS functionality, but for the future continuous improvement cycle inherent in good software development and next generation safety solutions.

Cellular connectivity alone has supported the connected vehicle to date; however, to support the connectivity needs of the future, such as software updates and ADAS training logs, OEMs will need to leverage high throughput, low-cost solutions. MSO broadband networks, including WiFi, are deployed across the majority of US households and can easily support automobiles of the future. And with wireline capacity being upgraded across all MSOs, connectivity can be offered at a price and throughput now and into the future that still allows OEMs to efficiently manage the ongoing costs with sufficient throughput for the needed software maintenance of the vehicle.

5. Rethinking Automotive Connectivity – A Complimentary MSO Broadband Solution

The increasing data needs of vehicles will require complimentary connectivity beyond just existing cellular networks. As ADAS features become more prevalent and vehicle autonomy increases, the data consumption will surge. With the high data rates and large volume of vehicle (250M+ vehicles in the US, similar in scale to smartphones of ~300M+), cellular networks require complimentary connectivity, like WiFi, which has been utilized by smartphones for years, and also CBRS. This use case will demonstrate the need for MSO solutions utilizing unlicensed spectrum such as WiFi and sharing scenarios like CBRS to offer a high throughput and cost-effective vehicle connectivity.

Looking to proven high throughput connectivity solutions in conjunction with mobile data might unlock the data growth needed to move the automotive industry forward. Broadband internet, WiFi and planned CBRS MSO networks are the missing element that automotive manufacturers should consider. In 2022 alone, the US and Canada had a total internet bandwidth of ~200 Tbps[13] with the average subscriber using ~587 GB per month[14] in their home. And WiFi has already demonstrated itself as a complimentary use case for smartphones as we have seen that MSO supported WiFi makes up a high majority of data traffic on smartphones today. Total data traffic on smartphones in 2022 was ~136 GB per month, of which, ~116 GB per month, or 85%, was over WiFi[15]. The smartphone of today and the automobile of tomorrow could end up looking very similar, and MSO Broadband supported through WiFi are poised to support the future growth of data consumption for cars as they do today for smartphones.

As autonomous vehicles are expected to generate a massive amount of data, car manufacturers will need to continuously increase bandwidths for both point-to-point data pipes and distributed network structures to meet these new data demands. Given the challenges in achieving Level 4 and 5 autonomy, complementary high-capacity networks such as broadband, WiFi and CBRS networks will play a pivotal role in enabling seamless data transfer of ADAS training logs, improving autonomous driving software models.

To meet customer expectations for a future software maintained vehicle full of applications, and digital experiences, automotive connectivity needs to be rethought. The seamless and error-proof maintenance of vehicles and continuously enhanced applications, including ADAS and L4/L5 autonomy, require additional capacity beyond current “mobile” connectivity solutions. Broadband and WiFi networks will play a complementary role, supporting high-throughput scenarios and satisfying data-intensive applications, while delivering the right customer experience.

Connectivity Solution	WiFi	Cellular
Avg. Speed	1 Gbps	40 Mbps
Transfer Time – 10GB Payload	1 min, 20 sec	33 min, 20 sec

Figure 5: WiFi vs Cellular Experience Comparison[16, 17]

A comprehensive approach, leveraging a combination of solutions, is necessary to address the evolving data needs of the automotive industry. However, auto OEMs will need to contend with a disparate set of mobile and broadband/WiFi networks, and Connection Manager emerges as a crucial bridge between these connectivity solutions, enabling smart on-device switching to optimize traffic flow. By managing multiple connectivity solutions with Connection Manager, automakers can drive a substantial portion of traffic to WiFi, ensuring an improved customer experience over a cellular connection.

6. Technical Overview – Connection Manager Switching Between Cellular, WiFi and Beyond (Satellite)

Connection Manager is a device-based connection application that can automatically and intelligently, authenticate broadband/WiFi and CBRS networks based on pre-configured thresholds and scenarios. Its primary function is to use logic to connect to the right connectivity solution based on the needs. Utilizing a Connection Manager on-device client and cloud-based solution will enable intelligent data offload with improved quality of service (QoS), ensuring least cost routing for high throughput, delay tolerant workloads (e.g., OTA updates, ADAS training log transfers).

Connection manager has been utilized successfully by MSOs in the US as an Android mobile software client that drives network connectivity decisions for WiFi and other cellular network (primarily MSO owned CBRS spectrum) connectivity. It helps to enable auto-authentication to configurable purpose-built WiFi and CBRS networks, supported by MSO broadband networks, while also capturing wireless connection usage data to improve QoS on a continuous basis.

Using MSO mobile offload as a use case, one can start to project how Connection Manager could drive an impact for the automotive industry, accelerating L4/L5 ADAS development by offloading stranded data logs through lower cost connections and higher throughput of broadband networks. Utilizing this mobile model, OEMs should consider on-device software connectivity solutions like Connection Manager and support it with hardware architecture to utilize complimentary MSOs networks.

The industry is already seeing the hardware architecture for the automotive industry evolve towards this multi-connectivity solution reality. Qualcomm’s Snapdragon Automotive Platform now supports a dual SIM dual active use case. This means two cellular (or other) connections can be utilized simultaneously and movement across subscriptions can happen without interruption. This platform also has WiFi 6 dual band support, which helps to demonstrate how chipset manufactures are viewing the future connectivity and bandwidth needs of the vehicle[18]. In this new hardware reality, one could envision the vehicle of the future connecting to a 5G MNO cellular network for emergency or mapping services, a MSO CBRS network for standard data streaming and offload while in motion, and, when stopped, a nearby WiFi access point for a low latency gaming or entertainment session. And as the vehicle begins to move again, these connections can be evaluated in real time by Connection Manager to connect to the most appropriate network option available for the use case and scenario, all while being seamless to the customer.

Connection Manager Server:
Hosted (e.g., AWS) server backend that stores and communicates connectivity policies and credentials to clients. Integrates to a separate mobile billing/activation (BSS) platform and a separate public WiFi authentication infrastructure (AAA).

Hosted PostgreSQL:
Hosted database server that stores all client device information, policies and manages CM application binaries for self-update process.

Connection Manager Clients:
Register with Connection Manager Server and receive connectivity policy information, network information, and credentials from server. Responsible for implementing policy and network auto-connections with host OS as well as collecting analytics and reporting information for product intelligence.

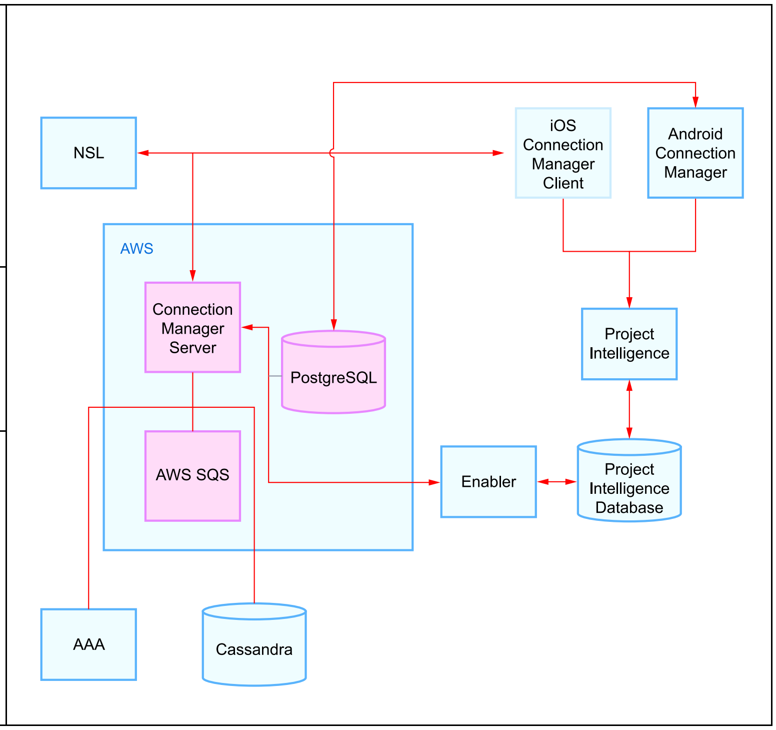

Figure 6: Connection Manager High Level Design

The Android mobile software client is currently embedded in Samsung, LG, and Motorola device firmware. It contains pre-granted and whitelisted Android permissions. Connection Manager also features an over-the-top (OTT) client Android SDK that is embedded within host applications, subject to permission limitations by user selection.

A connection manager application currently utilized by MSOs includes the following components:

- Built on open-source stack
- Elastic bean stalk instance with Auto-Scaling group to support on demand scaling
- Defined public private subnet, public private route table, NAT gateway, etc.
- Configured security group for Elastic load balancer, CM server and database, etc.
- Instance spread across multiple availability zones
- End-to-end TLS encryption (certificates managed by AWS certificate manager)
- Route 53 managed DNS to instance mapping
- VPS with AWS best practices
- Defined AWS WAF rules and Cloud Alerts
- Cloud formation script-based infrastructure creation and destruction

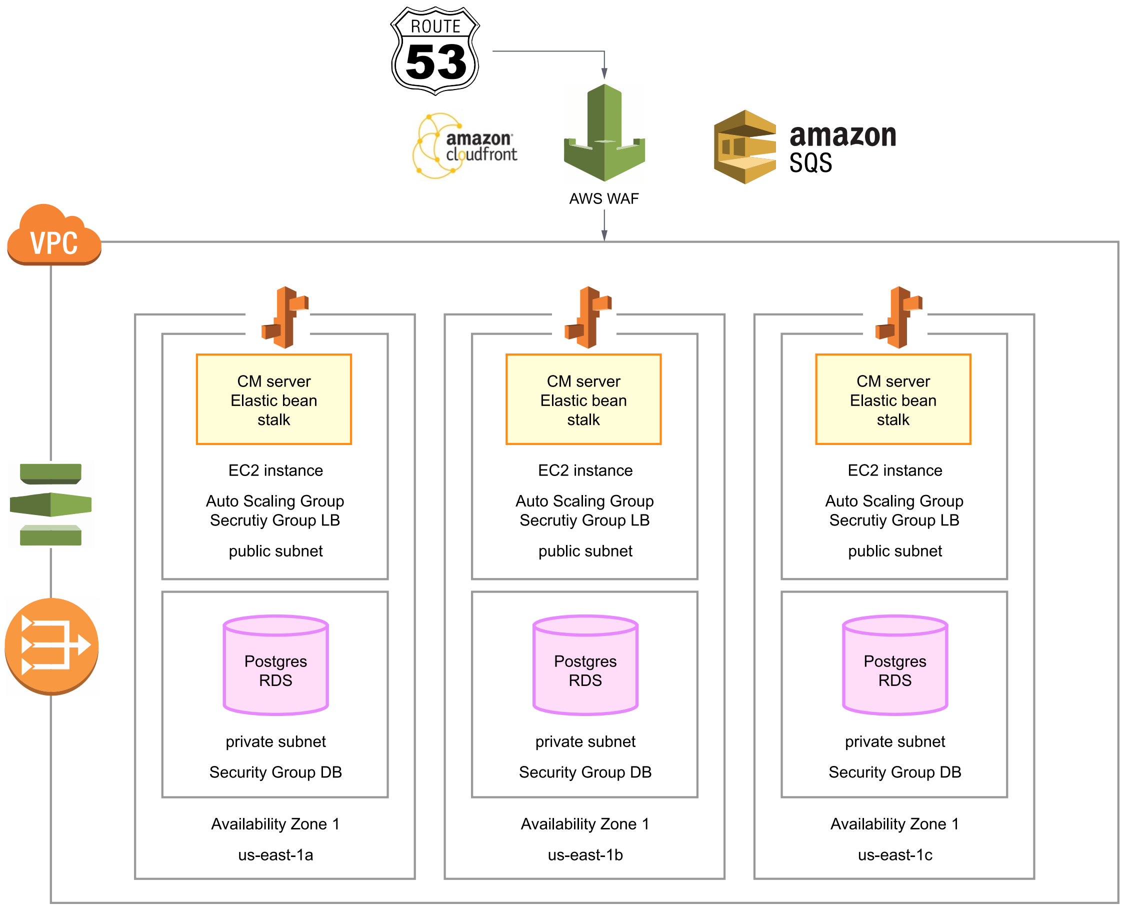

Figure 7: Connection Manager Components

7. Integration Points

Provisioning Platform (BSS) and CM Server: Account management operations (activate, deactivate, suspend) are sent in real-time to the CM server to update entitlements and policy per business rules. Upon next sync of policy to the device, the business rules are applied.

CM Server & Client: Clients register with CMS and receive all policy information assigned to the device per business rules.

Connection Manager Server & IDP Systems: CM Server must provision/deprovision unique per-device credentials into the IDP/AAA platforms to ensure the network parameters sent to the device are setup properly for the user.

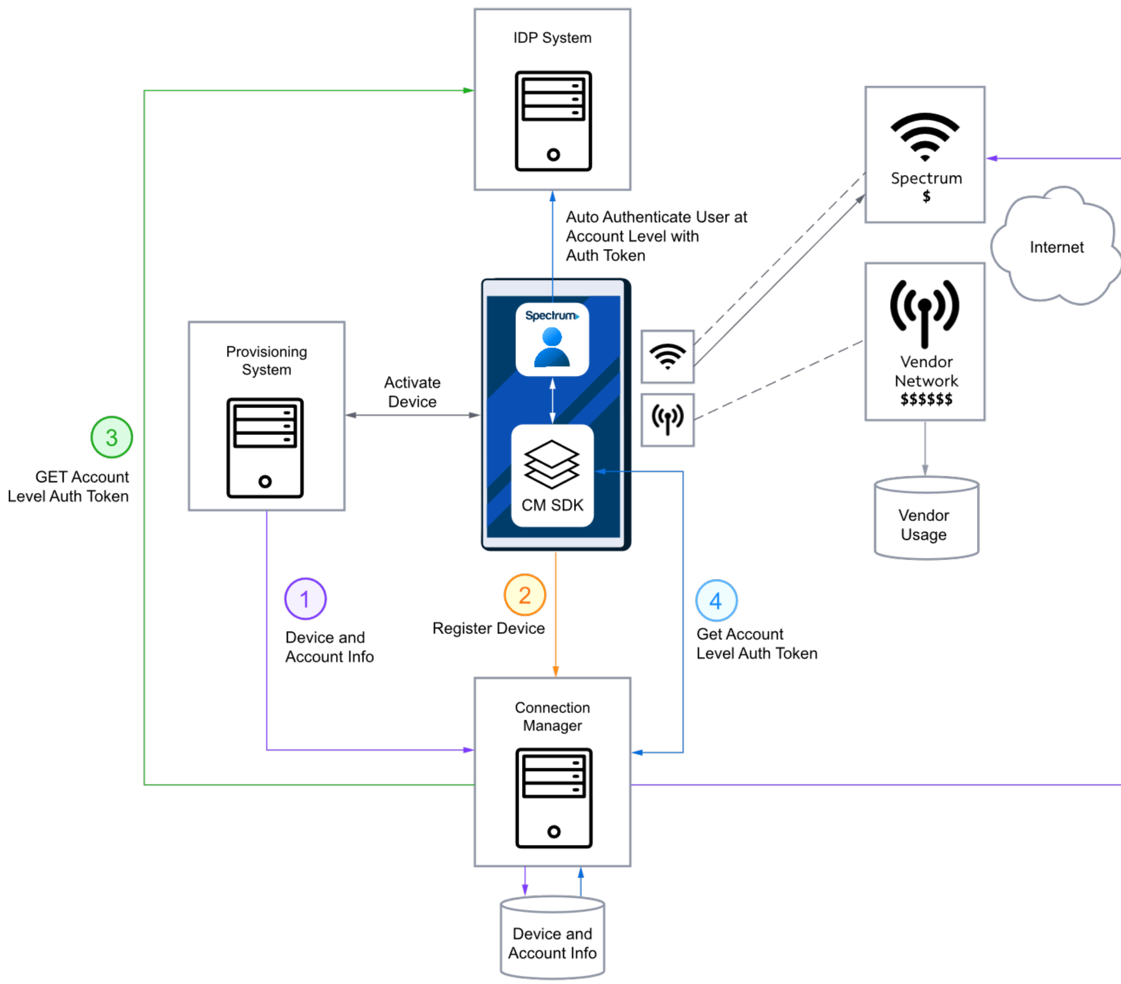

Figure 8: Connection Manager Integration Points

While Connection Manager was purpose built for a mobile offload use case, the current and future features can support the automotive use cases of the future. Current features include: network quality check, auto-connect, network management (including banned list), WiFi on/off control, user opt-out, network planning, and competitive analytics. As the application of Connection Manager broadens, the roadmap for logic will continue to evolve. Two key features on the roadmap are 1) support for satellite connectivity in conjunction with mobile and WiFi and 2) least cost routing intelligence to manage data traffic timing based on use case and cost considerations.

As OEMs contend with various connectivity options, the Connection Manager roadmap will support a real time, seamless management of all these connections and, based on traffic markings, enable more efficient cost management and higher throughput, resulting in improved outcomes (customer – faster updates, and OEM – vehicle maintenance and ADAS training log uploads). Utilizing a technical solution such as Differentiated Service Code Point (DSCP) markings, utilized by the MSO industry for years, combined with a QoS Competitive Index (QCI), will allow Connection Manager to ensure quality of service for connections and steer data as needed based on the speed and cost of the network, whether cellular (MNO or MSO), WiFi, or even satellite. Real-time payloads like telematics and entertainment can still be serviced in a meaningful way via cellular (MNO or MSO, based on availability), mobile connectivity. Emergency updates such as urgent vehicle maintenance updates (e.g., malware or known defect) can be transferred via the most appropriate network, such as higher cost, lower throughput cellular connection, if needed. Delay tolerant payloads such as training logs from ADAS systems can be queued at the right time and right priority on WiFi or MSO CBRS, based on speeds, and to ensure maximum compliance. The connectivity solution will be tuned to address the needs, always balancing cost and throughput.

8. Conclusion

The evolution of the automotive industry towards digitization, electrification, and software-defined architecture has highlighted the need for a transformative shift in automotive connectivity. As the reliance on high-bandwidth connectivity grows with the proliferation of software-defined vehicles, ADAS and the development of true autonomous driving, automotive manufacturers must rethink their approach to connectivity in order to stay competitive. The adoption of a Connection Manager, complementing existing cellular networks and new MSO CBRS networks with broadband and WiFi solutions, will be critical in addressing the increasing data needs, ensuring seamless maintenance and updates, and providing enhanced experiences for customers in the connected and autonomous vehicles of the future.

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