The Role of Centralized Storage in the Emerging Interactive Cockpit

The automotive industry is going through one of the most significant transformations since the invention of the motorized vehicle. Beyond the trend of advanced driver-assistance systems (ADAS) and self-driving vehicles (Figure 1) or the move to electric vs. internal combustion engines, today's vehicle ownership is increasingly becoming optional rather than mandatory. Manufacturers have adjusted their offerings to appeal to an extension of a buyer's lifestyle to continue a personal relationship between owners and brand. Now and in the future, the digital cockpit experience is central in the quest for customer affinity to a brand.

Traditionally, brands have differentiated themselves based on powertrain features, styling, and most recently, the in-cabin experience. For the past decade, the in-cabin experience has been defined by the **in-vehicle infotainment (IVI) system**. These systems have evolved from multisource entertainment, navigation assist, and personal device integration devices to a fully connected experience. Buyers have been able to create some level of personalization based on menu-driven selections, speech recognition, text-to-speech, and other features. These selections traditionally have been captive to the vehicle and limited to a certain number of users.

The more recent goal of the in-vehicle system has been to create a seamless lifestyle experience extension to the user. As such, integration of Apple and Android devices has emerged, as well as full integration of the Android operating system and the Android ecosystem in the last two years.

Figure 1: CV2X Connectivity Will Enable the Safe Self-Driving Vehicle

Traditional IVI Systems

The architecture of the IVI system has traditionally been an isolated one, with the recent integration of the instrument cluster information bridge into the same assembly known as a domain controller. The domain controller was created to offer a cost reduction from a freestanding cluster and IVI system as well as to create information sharing between the two primary driver interfaces. Most of these devices are based on a single multicore system on chip (SoC) processor.

The architecture is divided into two domains, one being isolated for the safety-critical interface to the instrument cluster. This domain is typically certified under the Automotive Safety Integrity Level Class B (ASIL-B). Where connectivity is present in the vehicle, this function is separately enabled by a telematics control unit (TCU), which is often isolated by a secure gateway. The other domain is the IVI.

Despite all the efforts to offer a compelling user experience, these systems have not been able to keep pace with the level of innovation expected by buyers who assume their mobile experience outside the vehicle pertains here as well. The one key problem area has been the inability to reconfigure and update the system after the vehicle is in the field.

Figure 2: Typical Displays of an In-Cockpit Dashboard

Audi Launches Lightning Fast IVI With Downloadable Features for 2021

Audi recently announced a newly revised IVI system for 2021 models. In response to consumer concerns about sluggish performance compared to the latest generations of smartphones, Audi now uses a hardware platform that is 10 times faster than its previous generation.

The new system also features downloadable feature enhancements to be offered for purchase periodically during the life of the vehicle, an array of personalized streaming content, and unlimited Wi-Fi connectivity over a 1 GB/s LTE advanced modem. This is an obvious move to bring the in-car experience (such as that shown in Figure 2) closer to the personal device experience.

The Influence of Mobility

Demonstrating the changing culture of vehicle use and ownership, users will migrate between owned, shared, and mobility fleet vehicles.

The automotive industry has recognized the need for a mobile persona and is now developing the next-generation vehicle cockpit system to accommodate expectations. The fundamental needs of the cockpit are to:

- Identify users, often from a fleet population
- Onboard and protect user personal preferences, content access, and commercial/financial profiles
- Determine where users sit in the vehicle
- Deliver an interactive experience to a person individually in a seated location
- Deliver multiple experiences simultaneously
- Isolate each user from other passengers in the vehicle, where possible
- Delete or isolate a user's profile when not in the vehicle.

Mobility Identity Stored on the Vehicle

In addition, the vehicle is assumed to be part of a mobility fleet. More information about the vehicle itself must be stored, maintained and interacting with the centralized mobility service. Figure 3 shows the attributes.

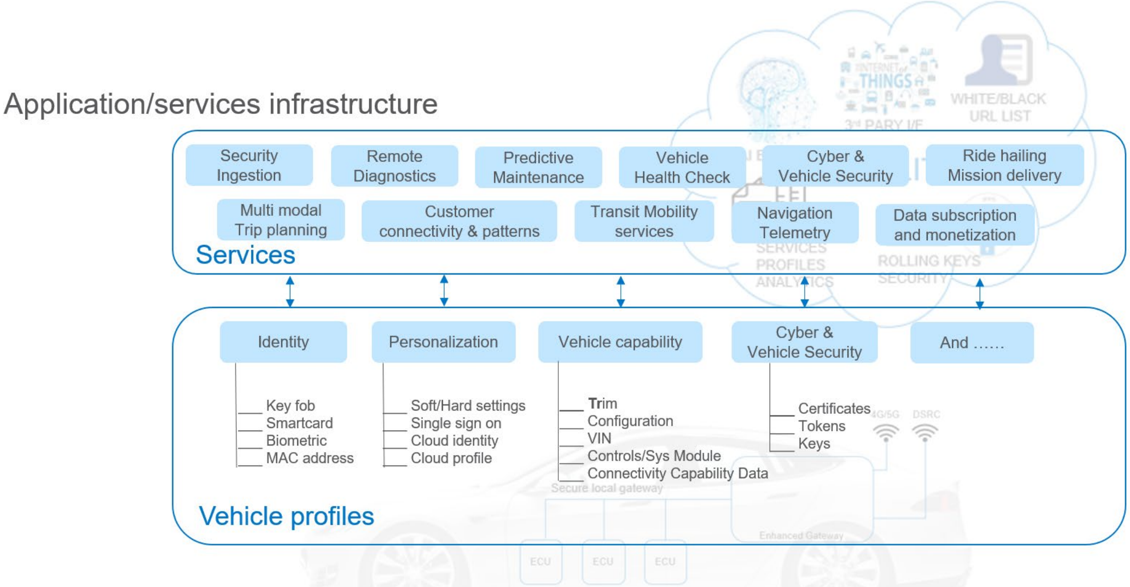

Figure 3: Application and Services Delivered According to User and Vehicle Profiles

Secure Over-the-Air Updates

To keep the vehicle updated and secure, several attributes regarding the individual vehicle likely will be stored on the vehicle and require secure over-the-air (OTA) update strategies (Figure 4):

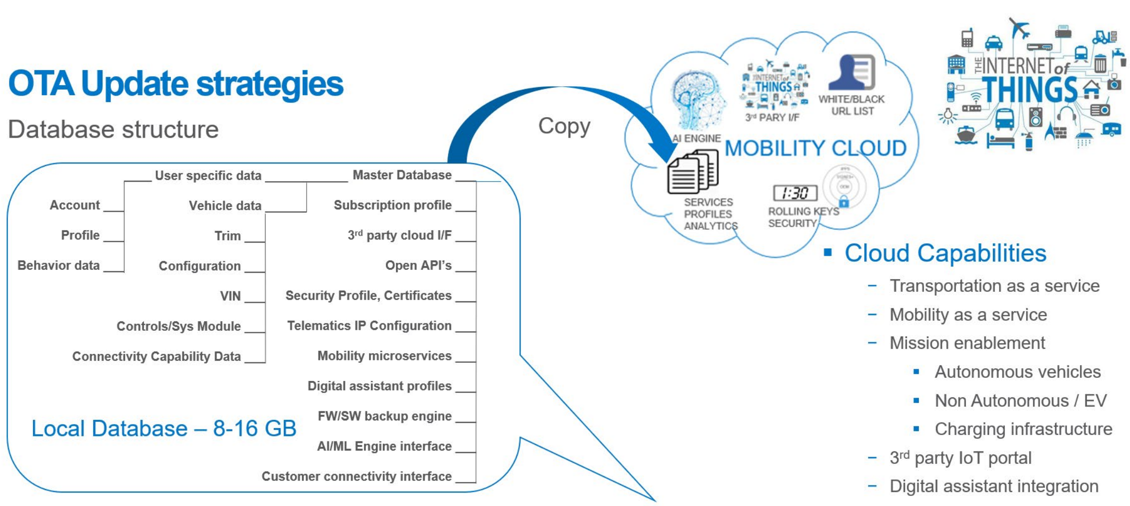

Figure 4: Over-the-Air Updates Link Databases, the Cloud and the Internet of Things (IoT)

The Interactive Cockpit Domain Controller

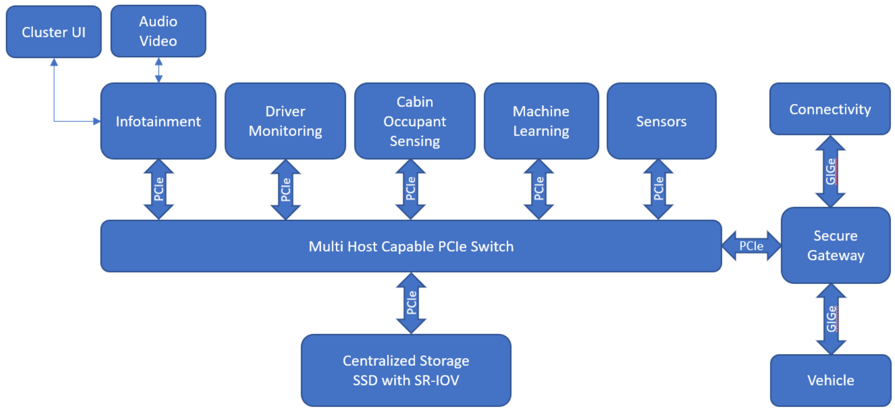

Figure 5: Functionalities of the In-Vehicle Cockpit Controller

Car manufacturers are currently developing cockpit domain platforms (Figure 5) to provide a level of functionality that maximizes the user experience for all passengers, creates secure personal mobile identity and profiling, enables mobility services within a fleet, and maintains fleet integrity and security while allowing ongoing refresh of features and functionality over the life of the vehicle.

These controllers will use multimodal user identification, including speech recognition; facial recognition; biometrics; spatial telemetry for occupant location; and multiple deployments of interactive services such as entertainment, IoT interaction and more. Profiles for users, vehicle identity/status, local content storage, and other factors are creating the need for overall storage approaching 1TB.

The cockpit domain controller will comprise these subsystems and others:

- Vision systems
- Multisource connected entertainments
- Audio capture systems
- Artificial intelligence (AI) accelerator
- Connectivity gateway
- Security infrastructure

Data ideally needs to be shared among these subsystems to create a well-integrated solution. Although there is a high volume of data exchange within the system, a user will expect the system to behave with minimal latency. And let's not forget system cost. It is paramount to maximize design efficiency since lower cost translates to higher fit rates.

From a data infrastructure standpoint, key system requirements include:

- Data transfer speed
- Ability to share data between multiple subsystems on one SoC or multiple dissimilar SoCs
- Ability to isolate processes to ensure design safety and security goals
- Ability to encrypt sensitive data where applicable
- Ability to securely update or remotely exchange vehicle profiles and stored data
- Ability to eliminate system redundancies to optimize cost

These attributes, at a minimum, point to a centralized NVMe™/PCIe storage solution as an advantageous design direction for this architecture.

The Benefits of a Centralized NVMe/PCIe Storage Solution

Data Transfer Speed

Figure 6 compares the performance of a UFS-based storage solution to a PCIe-based storage solution. Storage solutions based on the UFS interface have been popular for automotive IVI applications as the auto industry typically adopts SoCs originally designed for mobile phones in automobiles. In smartphones, UFS has established dominance as the successor to storage based on eMMC. However, as shown in Figure 6, PCIe-based solutions meaningfully outperform UFS-based storage solutions in both sequential and random read and write performance and, as such, are now seeing strong adoption in next-generation automotive platforms.

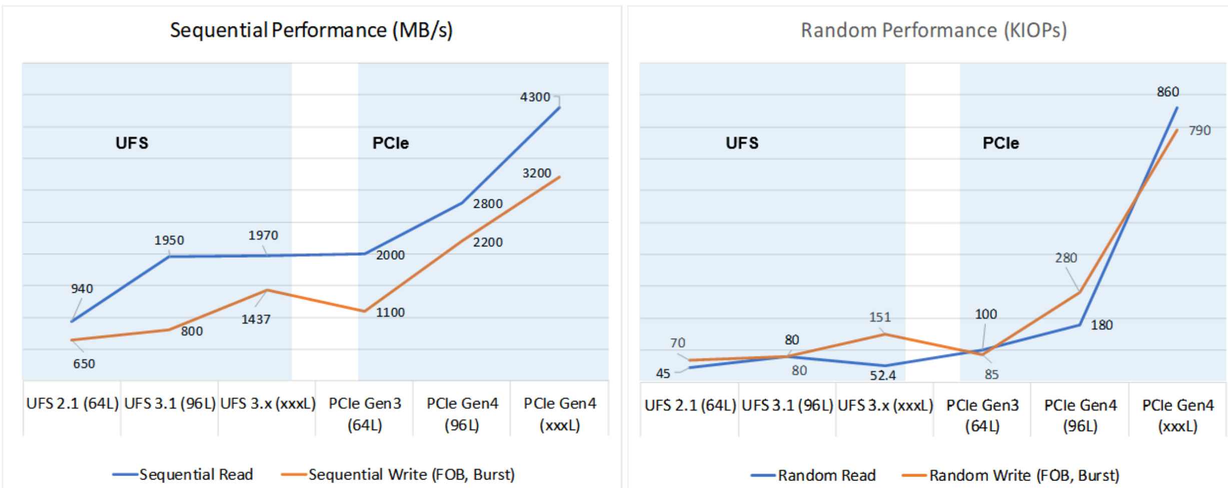

Figure 6: Comparing Performance of UFS Storage vs. PCIe-based Storage in Automotive Applications

With the introduction of PCIe-based storage solutions, it is likely these systems will utilize a PCIe backbone to integrate sensor fusion and action, much like an ADAS system but for the cockpit. System responsiveness is paramount, and a PCIe backbone offers data bandwidth of 2 GB/s per lane (8 GB/s for four lanes). For data storage and access, the PCIe interface offers the highest data transfer speed among storage solutions.

Automotive-grade solid-state drives (SSDs) based on NVMe architecture are well-suited to this need, offering data transfer speeds of 3 to 4 GB/s. The PCIe interface protocol is also far more efficient than other interfaces, offering additional low latency benefits when compared to UFS.

Ability to Share Data Between Multiple Subsystems

An automotive-grade SSD based on NVMe standards uses multiple namespace configurations. Namespaces are unique data storage areas that may be privately (namespaces A and C in Figure 7) or publicly (namespace B) accessible. Data that is intended to be shared between processes or subsystems can be defined as a public namespace for that purpose, whether on one SoC or multiple dissimilar SoCs.

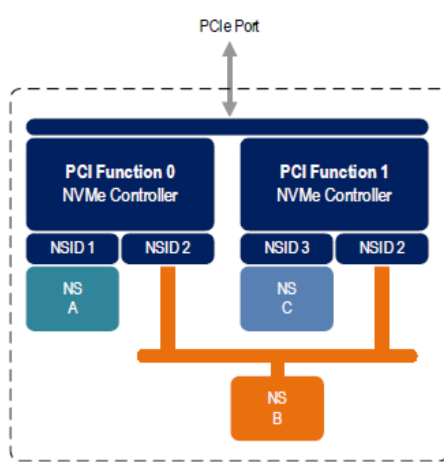

Figure 7: Example of Private and Public Namespaces

Ability to Isolate Processes to Ensure Design Safety and Security Goals

An automotive-grade SSD using NVMe standards can use industry-recognized, hardware-based isolation based on single root I/O virtualization (SR-IOV). This technology (Figure 8) allows the system's PCIe interface to be subdivided into multiple virtual machines running on the SoC environment that are isolated from one another, with each tied to unique virtual functions on the storage device. This technique is well recognized as a secure isolation method. SR-IOV offers an additional benefit of establishing direct connection between stored data and the active process in runtime. This eliminates the need for a system scheduler, such as a hypervisor, which leads to improved system speed and reduced latency. Again, this is a benefit to the user experience and system efficiency.

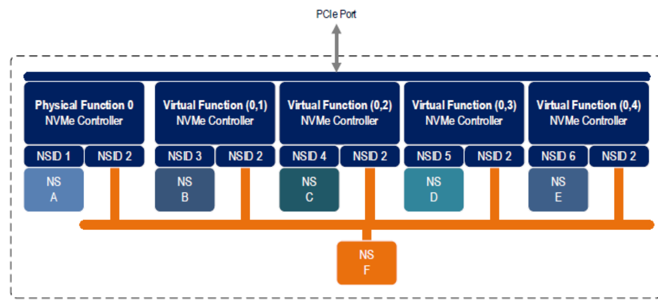

Figure 8: Example of Single Root I/O Virtualization

Ability to Encrypt Sensitive Data Where Applicable

An automotive-grade SSD based on NVMe standards also enables encryption of sensitive data stored on the drive. Such data may be vehicle firmware, personal identity information, whitelist/blacklist security profiles, and other information. Encryption is protected by symmetric private keys (Figure 9). Aside from encryption capabilities, these devices also offer cryptographically protected access control to data regions. These features provide strong benefit not just to the vehicle platform but also to the overall connected infrastructure interacting with the vehicle.

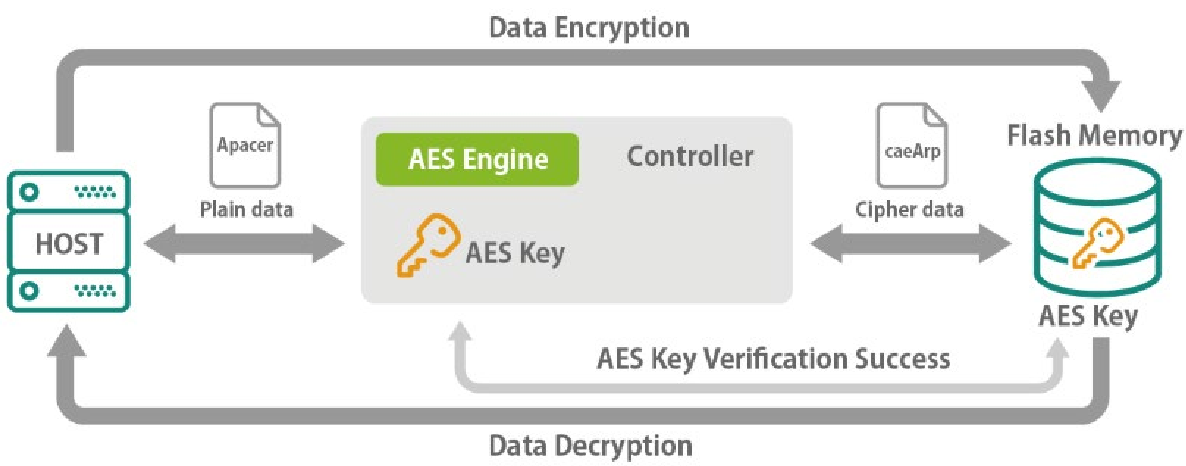

Figure 9: Using Key Management in an Advanced Encryption System (AES)

Ability to Securely Update or Remotely Exchange Vehicle Profiles and Stored Data

An automotive-grade SSD based on the NVMe standard uses cryptographic access control to the overall drive. This feature protects the drive from unauthorized access. Certain keys are used within the system to bind the physical drive to the system architecture and various components to minimize direct security threats. The standard also uses additional keys that are part of an overall remote security strategy that allows remote reprovisioning of the storage device by authorized sources while protecting stored data. In a catastrophic event, it is even possible to wipe all or a portion of the drive by remote authorization. This is one of the many features that help enable proactive and timely fleet management with requisite security.

Ability to Eliminate System Redundancies to Optimize Cost

Traditional architectures have in the past used a unique individual storage subsystem associated with each function. It should be clear from the benefits described here that none of the system-level benefits would be possible without:

- A centralized storage architecture
- A storage solution based on an automotive-grade SSD PCIe/NVMe device

Automotive SSDs with SR-IOV features are available in densities ranging from 128GB to over 1TB and are cost competitive with other storage devices, such as UFS, in similar densities. The array of beneficial features of NVMe-based SSDs are available with minimal additional cost.

By using a single storage device, storage cost and required printed circuit board area are minimized compared to multiple discrete storage entities.

Conclusion:

Centralized Storage Value Proposition

Centralized storage is necessary to enable data sharing between automotive functional systems and fundamental to creating the interactive and personalized IVI user experience desired in future vehicles. An automotive-grade SSD offers a rich set of features, including high speed, functional data isolation, cryptographic data protection, secure remote reprovisioning, and much more, at a price-per-density like more isolated storage devices such as UFS. Aside from eliminating design redundancy, SSDs require little printed circuit board real estate as they are available in small form factor ball grid array (BGA) packages.

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The Micron Advantage

Micron has been the No.1 supplier of memory devices to the automotive industry for 30 years, offering a full portfolio of volatile and nonvolatile solutions. Micron automotive architects routinely work with our customers as trusted design partners, enabling cost-effective and creative solutions to meet emerging industry needs.

The solution benefits of centralized storage and automotive-grade SSDs discussed here are being applied to next-generation architectures for 2023 and beyond in the areas of not only IVI, but also automated driving and central compute architectures at key OEMs and Tier-1 partners.

It is our goal to be not only the leading provider of memory devices but also a lead partner in solving system-level issues and offering high-benefit solutions for our customers.

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