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Car Connectivity Consortium

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Abstract: Mobile devices such as smart phones have enabled consumers to gain access to a growing number of interactive and useful applications, anytime anywhere. However, once a user enters his/her vehicle the availability of such applications and their user experience degrades drastically – either because of being restricted to using the few applications available on the In- Vehicle Infotainment (IVI) system or due to the challenges of interacting with a tiny mobile device screen attached to a car dock. In this paper, we present Terminal Mode – a technology which transforms mobile devices into automotive application platforms and seamlessly integrates them into vehicle infotainment systems. This technology not only enables consumers to access their favorite mobile services and applications in a safe manner while traveling in a vehicle but also provides top quality user experience consistent with high end IVI systems.
Keywords Automotive User Interface Framework, Automotive Application Platform, Connected Car, In-Vehicle Infotainment Framework, Ubiquitous Mobile Interoperability.

INTRODUCTION

With smart phones and mobile internet devices rapidly becoming the application platform of choice, consumers expect to be able to use their favorite applications and services anytime anywhere. In parallel, another trend which has been observed is that as societies get more industrialized, people are spending a significant amount of their day in their vehicles, commuting from one place to another [13]. However, till date there has been very little innovation in designing systems through which consumers can access their mobile applications inside their vehicles in a seamless, intuitive yet safe manner. In this paper, we present Terminal Mode, a technology which enables smart phones and other mobile devices to seamlessly integrate into automotive infotainment environments and essentially become a dynamic and full-featured service and application platform and communications gateway for the automobile. Terminal Mode aims at enabling consumers to have services and applications at their fingertips on-the-move. Its goal is to serve as a catalyst for new services which interlink vehicle information with mobile device applications and fuel innovation in both mobile computing and automotive services domain. The rest of this paper is organized as follows. Section 2 covers related work and discusses existing mechanisms for accessing and using interactive applications inside an automotive environment and their respective advantages and disadvantages. Section 3 introduces the concept of Terminal Mode along with its basic architectural setup followed by the design considerations behind this technology. Section 4 covers the various components which comprise Terminal Mode and how they work together in a synergistic manner to provide quality user experience. Section 5 lists the benefits of Terminal Mode technology as compared to existing mechanisms, both from the perspective of the consumer and the automobile manufacturer. Finally, Section 6 concludes this paper and outlines future work.

RELATED WORK

Currently drivers and passengers can access services and applications in an automotive environment, through one of the following systems: (1) In-Vehicle Infotainment (IVI) systems; (2) Mobile device mounted on car docks, and; (3) Vertical integration of mobile devices with IVI systems.

2.1 In-Vehicle Infotainment Systems

In-Vehicle Infotainment (IVI) systems such as BMW's iDrive [6], Audi's MMI [2] and Alpine's after-market solutions [1] have been the primary application platform for interactive automotive applications till now. IVI systems are integrated into the car and provide an all-in-one solution which includes an application platform hooked up with driver-friendly displays and controls.

2.1.1 Advantages

The advantage of IVI systems is that they are designed specifically for in-car use. The physical UI components such as the displays and controls are optimized specifically for use by the driver and/or passengers in a vehicle. Furthermore, the design of IVI systems ensures that they comply with laws and regulations governing driver distraction and driver/passenger safety.

2.1.2 Disadvantages

IVI systems suffer from a number of disadvantages. Firstly, they can be quite expensive especially if they are factory fitted. Secondly, IVI system manufacturers have a much longer product development cycles as compared to consumer electronics manufacturers which implies that their systems are already outof- date in terms of hardware and software capabilities as compared to other consumer electronic devices, by the time they reach the market. On the other hand, consumers typically use their vehicles for an average of 8 to 12 years and this further increases the obsolescence of any integrated IVI unit over time. Thirdly, all IVI systems till now have proprietary architectures and closed application development environments. This not only leads to a paucity of applications due to fragmentation and a lack of mass-scale developer support (as compared to mobile device ecosystems) but also results in fewer updates to the applications. Furthermore, these applications are developed almost exclusively by vehicle manufacturers, OEMs and their partners and do not have a proper third party developer eco-system which can generate enough developer interest and momentum. Finally, most IVI systems still lack a proper app delivery portal despite some early efforts from manufacturers such as Ford [4] and users cannot easily browse, buy and install new applications.

2.2 Mobile Devices with Car Docks

With the advent of touch screen equipped mobile devices such as smart phones with finger-friendly UI, there has been a renewed surge in popularity of car docks which can be used for mounting one's mobile device on the windshield or the dashboard. The driver directly interacts with the mobile device, typically through its touch screen and uses the applications running on it.

2.2.1 Advantages

Unlike IVI systems integrated into vehicles, the car dock is an extremely cost effective and user-installable solution. Moreover, a typical user upgrades his/her smart phone every 2-3 years hence it always remains more updated in terms of hardware and software capabilities as compared to IVI systems. As a consequence of this, users have access to all the latest and popular applications without expending any extra effort. Furthermore, the user has access to all his/her mobile applications, preferences and data inside the vehicle.

2.2.2 Disadvantages

The main disadvantage of using smart phones mounted on car docks is that they are not optimized for use inside a vehicle. Mobile devices are extremely constrained in terms of display size and require the user's full attention in order to operate it. Moreover, the small size of the display and touch area make it difficult to operate from behind the wheel, when the device is attached to the windscreen or the dashboard at an arm's length.

This can prove to be unsafe for the driver and passengers of the vehicle due to increasing amounts of driver distraction and the poor quality of user experience. Also, by default smart phone applications have no way of being made aware of different driver distraction rules and regulations that have to be enforced and do not have any component which can for example, reliably prevent access to certain kinds of applications (such as a movie player) or block certain types of content (for example, SMS) while the vehicle is in motion.

2.3 Vertical Integration of Mobile Devices with IVI Systems

There have been several efforts towards vertical integration of mobile devices with IVI systems. The most commonly seen integration is the utilization of Bluetooth Hands Free Profile which enables drivers to make phone calls through the IVI system. Other more recent efforts involve sharing of data from the mobile device with the car's IVI system. In this way, the driver avoids interacting with the smart phone directly while driving but still has access to its data.

One example of this is the Google Maps integration with Ford SYNC [4]. In the Google Maps case, a smart phone user has the option to send map directions from their phone's navigation software to the navigation application hosted on the Ford SYNC IVI system located in the car. BMW has also collaborated with Research in Motion to integrate e-mail and media content from Blackberry devices into their iDrive IVI system [6]. However, this form of limited interoperability still suffers from all the disadvantages outlined in Section 2.1.2 since the applications are still hosted on and limited by, the constraints of the car's IVI system.

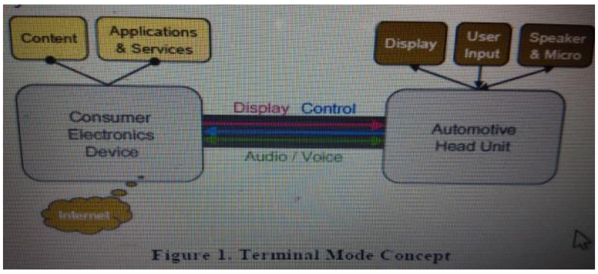

Figure 1. Terminal Mode Concept

Another example of such efforts is the development and release of the SYNC API by Ford which enables smart phone applications to interact with the user through the human-machine interface (HMI) of the SYNC IVI system [4]. However, these APIs are proprietary ones specific to SYNC and do not work with non-Ford vehicles. Hence, the same application will have to be re-written to work with different manufacturer-specific APIs in order to be widely usable. Furthermore, the APIs currently only support limited forms of interaction involving buttons, audio and low-quality matrix displays hence, more visually intensive applications such as the mobile device’s navigation software cannot be directly made available through the IVI system

THE TERMINAL MODE CONCEPT

The Terminal Mode concept combines the versatility and powerful application platform capabilities and development ecosystems of today’s mobile devices with the driver and passenger optimized UI hardware available in vehicle IVI systems. The result is a concept somewhere between using the applications natively on the mobile phone and using applications running in the vehicle IVI system.

Figure 1 depicts the Terminal Mode concept. In Terminal Mode, the mobile device (such as a smart phone) becomes the application platform for the automotive environment whereas the IVI system is responsible for user input and output. Figure 2 shows an example of what the Terminal Mode concept looks like when deployed in a vehicle. The mobile device hosts and executes all the applications and services accessible to the user and also acts as a communications gateway to the cloud. The vehicle IVI system on the other hand, provides the UI hardware and physical input/output capabilities through which the driver/passengers interact with applications running on the mobile device. These may include one or more displays, input mechanisms such as touch, buttons and multi-functional knobs, audio playback and voice input systems. The mobile device and the IVI system communicate with each other over one or more wireless or wired network interfaces.

From a user experience perspective, Terminal Mode offers "the best of the both worlds" where the large variety of mobile device applications is complemented and enhanced by the vehicle IVI system’s UI hardware thereby, providing a convenient and safe means for using these applications.

Figure 2. Terminal Mode inside a Vehicle

Figure 3. Smart Phone Music Player via Terminal Mode

From a technology perspective, it is much easier to add new consumer electronics capabilities into the vehicle environment via a mobile device than by directly integrating them into the car IVI system. In addition, an up-to-date mobile device typically provides the latest technologies, from radio connectivity, to multimedia codecs and at the same time, the openness of their software platforms coupled with the robustness of their developer ecosystems, allows for delivery of new applications and services at any time. For example, smart phone platforms such as Android and Symbian now come pre-loaded with free turn-by-turn navigation and voice guidance software. Utilization of Terminal Mode now enables users to access the same navigation software, maps, directions and location-aware services both inside the car and outside it in a seamless manner. The advantage of the Terminal Mode approach is that the user experience and interaction for the same application now becomes automatically tailored to the specific environment the user is residing in at any given time. When the user is outside the car, he/she directly interacts with the navigation software using the phone’s input/output mechanisms. Whereas when the user is driving, he/she interacts with the same navigation software using the IVI display and driver-friendly controls and is able to get the same quality of user experience as that of in-car navigation software running natively on the IVI system without the accompanying cost and other disadvantages. Figure 3 shows an example of a smart phone-based music player running on an IVI system using Terminal Mode.

3.1 Design Considerations

The following design considerations guided the research and development of Terminal Mode:

Standardization: Every aspect of the design (hardware and software) must be done with an eye towards industry standardization. Care must be taken to ensure that Terminal Mode is not tied to any specific automotive platform and must work and provide the same quality of user experience across vehicles from a wide range of manufacturers.

Do Not Re-invent the Wheel: Whenever possible use standard hardware and software interfaces and protocols that have withstood the test of time, instead of re-inventing proprietary ones. Unlike consumer electronic devices which have short lifecycles and undergo rapid updates, automotive electronics typically have a much longer lifecycle. Hence, as a rule of thumb, any technology implemented in them must be maintainable for at least 15 years. Moreover, using existing standardized technologies makes it easier for industry acceptance and standardization of the Terminal Mode technology as a whole.

Seamless Plug-n-Play Connectivity: The user must be able to use Terminal Mode with minimal disruption and steps. The transition from mobile device use to Terminal Mode must be a seamless one and typically should not require the user to do anything except possibly plug in his/her mobile device. In a nutshell, it should just work.

High Quality User Experience: Even though the applications will be executed on the smart phone, the user must at least get the same quality of user experience that is provided by apps running natively on the IVI system.

User Safety: Safety is of paramount importance. Terminal Mode must support all necessary mechanisms for ensuring driver/passenger safety and legal compliance. It must provide mechanisms where the vehicle IVI system can dynamically specify, set and activate rules related to applications, content and UI settings to ensure a safe user experience. These mechanisms must be platform agnostic and not tied to any specific automotive platform.

Application Agnostic: Terminal Mode must provide an application agnostic framework which makes it possible for existing mobile applications to benefit from it without any modifications.

Application Support: Apart from supporting existing mobile applications, Terminal Mode must also provide internal APIs for mobile phone applications which are designed from ground-up for in-car use. These APIs will be Terminal Mode specific but independent of any specific automotive or mobile device platform.

Support for Car Services: Terminal Mode must have provisions for enabling smart phone applications to get access to and utilize vehicle services such as in-car GPS and on-board diagnostics data.

Authentication and Attestation Support:

Terminal Mode must have mechanisms for ensuring that users can only connect and use certified genuine mobile devices and consume known types of content. There must be provisions for attestation of mobile devices, application and content before their use is allowed via Terminal Mode.

TERMINAL MODE COMPONENTS

In this section, we describe the various Terminal Mode components, their roles and how they work together to provide a high quality yet safe user experience. Figure 4 shows the Terminal Mode component stack.

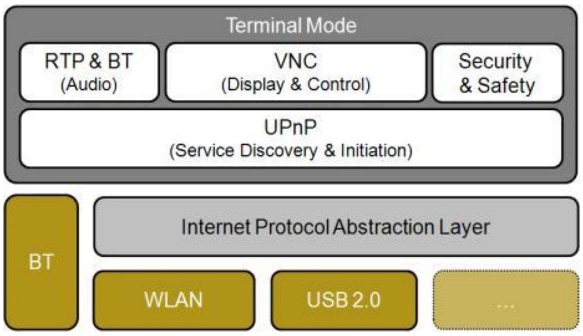

Figure 4. Terminal Mode Component Stack

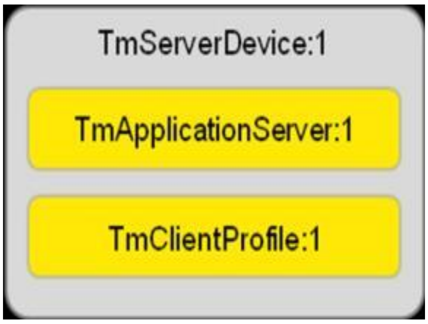

Figure 5. Terminal Mode UPnP Services

4.1 Connectivity

The primary requirement for connectivity in Terminal Mode was that it must be done using widely used standard interfaces and protocols which will remain both stable and relevant in the foreseeable future. This ensures that IVI systems, which have long development cycles, are not affected by rapidly changing hardware and software connectivity requirements.

4.1.1 Physical and Link Layer

For the physical layer a conscious decision was made to avoid using proprietary physical connectors in case of wired connectivity solutions. The following standard interfaces are used in Terminal Mode:

Universal Serial Bus (USB): For wired connectivity, the mobile device and the IVI system must support USB 2.0 or above. The IVI system will typically provide a USB connector into which the mobile device can be plugged in (as shown in Figure 2). Terminal Mode compliant devices must support USB Communications Device Class/Network Control Model (*CDC/NCM*) [12] which allows transfer of multiple Ethernet packages inside a single USB transfer. USB was chosen not only because of the high bandwidth it provides but also due to the fact that the same interface can also charge the mobile device while it is connected. In context of Terminal Mode, we see USB connectivity being used for longer journeys. Currently, USB support is mandatory for Terminal Mode compliant devices.

Wireless LAN (WLAN): For wireless connectivity, the mobile device and the IVI system should support 802.11b/g. Currently WLAN support is optional for Terminal Mode. Quite a few automotive manufacturers are looking at the option of providing a wireless access point inside the car and hence, can support this requirement. We see the WLAN option being used for short journeys where the user may not find it useful to physically take out his/her mobile device and plug it into a USB connector.

Bluetooth: Bluetooth is optionally used for audio output/input through the Hands Free Profile (HFP) and Advanced Audio Distribution Profile (A2DP).

4.1.2 Network and Transport Layer

Terminal Mode requires mandatory support for IP networking. IP was chosen as a suitable networking abstraction since it supports a large number of protocols for transporting multiple types of content streams (display, audio, user input etc.) over a single physical/link layer connection. On the other hand, if one were to choose different hardware connectivity solutions for each content type (for example, HDMI for video, native USB for control/data and audio-out for sound) we would be required to use a nonstandard proprietary physical connector to incorporate all the different types of connections. This is clearly undesirable since it requires IVI system manufacturers to make expensive hardware changes every time the physical connector specifications change.

For the transport layer, mandatory support is required for both TCP and UDP to ensure support for all well-known protocols for streaming data between the mobile device and IVI system.

4.1.3 Connection Set up

In order to facilitate automatic network setup and assignment of IP addresses, for peer-to-peer connectivity use cases (such as USB), the mobile device is required to have a DHCP server which will assign an IP address to the IVI system on establishment of network connection. This ensures that the user does not need to perform any manual network configuration

Figure 6.Application Menu generated by IVI System

Figure 7. IVI System using Multiple Client Profiles

4.2 Application Discovery and Configuration

Terminal Mode uses the UPnP 1.1 protocol [11] for automatic discovery, access and configuration of available applications on the mobile device. After a network connection is established between the mobile device and the IVI system, the UPnP server on the mobile device advertises the Terminal Mode services to the IVI system. The IVI system contains an UPnP Control Point which listens for the services being advertised and then utilizes them to access and configure the remote applications. The Terminal Mode services listed below run on top of the standard UPnP stack and are encapsulated within a TmServerDevice UPnP device (as shown in Figure 5):

TmApplicationServer: The TmApplicationServer service enables the IVI system to discover the applications available for access on the mobile device through Terminal Mode. It provides UPnP actions for getting the list of applications including information such as application identifiers, icons and other settings, launching and terminating applications on the mobile device and getting or subscribing to application status reports. The functionalities provided by this service enable the IVI system to generate a UI with its own branded look-and-feel which can be used to launch and terminate mobile applications without relying on the mobile device's application menu UI. This not only helps in preserving the look-and-feel of the IVI's interface but also provides the user with the same user experience as that of using applications running natively on the IVI system. Figure 6 shows an example of an IVI generated application menu for accessing mobile applications using the TmApplicationServer service. After an application is launched, the Remote UI components (Section 4.3) are responsible for transmission of display contents of the application's UI to the IVI system's display(s) and receiving user input events from the IVI system.

TmClientProfile: The TmClientProfile service allows the IVI system to specify and configure different client profiles on the mobile device. A client profile provides a standalone run-time session for running mobile applications after applying certain client-specified settings and rules. When the IVI system uses the TmApplicationServer service for launching applications, it can specify which client profile must be used for that application. Each client profile on the mobile device side also has its own independent display and control buffer hence, to the driver or passenger it feels as if they have exclusive access to the mobile device. For example, if the IVI system has 2 display/control units (Figure 7) – one for the driver and one for the passenger in the backseat, it can utilize 2 different client profiles, one for each display. For the client profile corresponding to the driver display, the IVI system can use TmClientProfile service actions to specify rules which prohibit the display of video content. However, for the second client profile corresponding to the passenger display, it can allow the display of video content. Hence, when the passenger launches a movie player, he/she can watch movies whereas the driver cannot see that content even though it resides and is running on the same mobile device.

4.3 Remote User Interface and Control

In Terminal Mode, the mobile device acts as the application platform and server whereas the IVI system is the remote UI client which is responsible for user I/O. Currently the following types of I/O are supported:

Input: Touch (Touch Screens/Track Pads), Non-touch (Buttons/Multi-functional Knobs) and Audio (voice).

Output: Video Display and Audio. However due to the modular architecture of Terminal Mode, new types of input and output can be accommodated in the future such as haptics and gesture-based control without breaking compatibility with existing applications and IVI systems.

4.3.1 Display and User Interaction

After the IVI system launches an application using the TmApplicationServer service, the application is brought to the foreground of the mobile device display and the display contents comprising the application GUI are transferred to the IVI system. Similarly, when the user provides some input to the IVI system, it is transmitted to the mobile device for taking necessary action (Figure 8). For this purpose, Terminal Mode uses the Virtual Network Computing (VNC) protocol [7] which has been widely used in remote desktop applications for many years. The VNC server resides on the mobile device and the VNC client resides on the IVI system. The VNC protocol transfers the contents of the server's frame buffer to the client side. Using the frame buffer as an abstraction allows the Remote UI to work withoutrequiring special application-level support. It also allows the mobile device to use different virtual frame buffers for multiple simultaneous user sessions, each corresponding to a different client profile in the TmClientProfile service.

Terminal Mode specifies certain extensions to the standard VNC protocol which provide a number of new features not inherently supported in the original VNC standard:

1. Mobile device display scaling, rotation and other modifications according to client preferences.
2. Mapping the IVI system's set of possible input events to the input events supported on the mobile device. This is especially important since the IVI system and the mobile device may have different input modalities (Figure 9). The actual mapping algorithms and their implementation are not specified by Terminal Mode and depend on the mobile device platform.
3. Enabling or disabling certain input events. For example, if the user is entering an address on the mobile device's navigation software using the IVI system's speller knob, the mobile device can use this feature to indicate which are the next possible sub-set of valid characters based on a dictionary of geographical names. Using this information the IVI system can suppress display of specific characters and block their

corresponding key events thereby cutting down on the number of choices and reducing driver distraction.

4. Cursor detection and keyboard trigger. When the mobile device detects that there is a text field in focus on its display and requires user input, it uses this feature to send a keyboard trigger message to the IVI system along with the location of the cursor. This enables the IVI system to automatically pop up its virtual keyboard and focus at/magnify a specific portion on the display so that the user can easily enter text with minimal distraction.
5. Application category and content information. The mobile device can provide information such as the application category and the types of content (possibly multiple) being displayed at any given time. This information can be used by the IVI unit to block undesirable content from being displayed and accessed. The IVI system can also notify the mobile device about applications and content which it must block during the Terminal Mode session.

4.3.2 Audio Input and Output

Terminal Mode supports audio input and output through both Bluetooth and Real-Time Protocol (RTP) [8]. The IVI system is responsible for audio playback and sensing the user's voice input and the mobile device is responsible for transmitting audio content and receiving and processing audio input.

In case of Bluetooth, the mobile device streams audio data to the IVI system using Hands Free Profile (HFP) or Advanced Audio Distribution Profile (A2DP). Having support for Bluetooth based audio streaming makes it possible for a large number of existing IVI systems to receive audio output from the mobile device with pre-existing hardware and software. Bluetooth HFP is also used by the mobile device for receiving voice input from the IVI system.

In case of RTP based streaming the mobile device streams audio data over the IP connection with the IVI system. It also receives audio input over the same connection. Terminal Mode compliant devices are required to mandatorily support 8-bit 8 KHz Mono and 16-bit 48 KHz Stereo PCM encoded audio formats.

In order to ensure a smooth interoperability between the Bluetooth and RTP components, the specifications also include rules for audio link selection and hand-off. This not only makes sure that there are no conflicts but also ensures that if the user is already using the mobile device (such as a phone call while entering the car), he/she is not interrupted while it transitions into Terminal Mode. Both the Bluetooth and RTP audio components are advertised as applications using the TmApplicationServer UPnP service. Hence, the IVI system can easily turn them on or off during the Terminal Mode session.

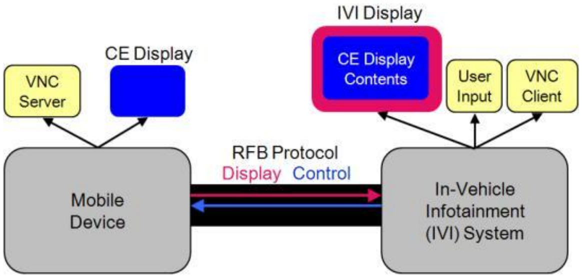

Figure 8. Remote UI and Control over VNC

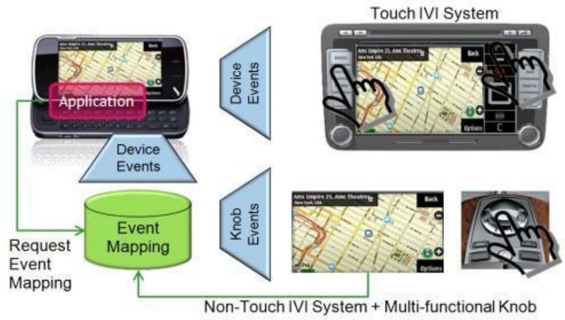

Figure 9. Input Event Mapping in Terminal Mode

4.4 Security & Safety

In an automotive environment, the security and safety of users are the primary concerns. The possible security and safety concerns in Terminal Mode are:

1 .Attacker can read and/or modify communication between the IVI system and the mobile device.
2 Mobile Device does not connect to the intended IVI system or vice versa.
3 IVI system connects to an uncertified mobile device which claims to be Terminal Mode compliant.
4 Non-compliant applications and content are used (for example, watching video while driving).

Hence, Terminal Mode contains a number of security mechanisms as part of its component stack.

4.4.1 Network Security

For wireless connectivity over WLAN, Terminal Mode requires the use of Link Layer authentication mechanisms such as WPA2. This prevents attackers from reading Terminal Mode traffic and also prevents unauthorized connections. For USB connectivity there is no similar requirement since the connection is a peer-topeer wired one.

4.4.2 Device Attestation

Device Attestation mechanisms ensure that the IVI system only connects to a mobile device which is from a Terminal Mode compliant manufacturer running approved software. A Device Attestation Protocol (DAP) based on standard X.509 certificates [3] and attestation mechanisms standardized by Trusted Computing Group [5] [10] is utilized. For details, please refer to the complete Terminal Mode specifications [9].

4.4.3 Application and Content Attestation

The IVI system can notify the mobile device using the TmClientProfile service, about specific application and/or content rules that need to be enforced. Terminal Mode defines a number of application and content categories which are used to determine what is being shown on the IVI system's display. Each application which is available through the TmApplicationServer service is accompanied by an application category and content category along with a trust level indicator. The trust level indicates whether a specific application has been certified by the mobile device manufacturer or by a trusted third party authority or by the application itself or by the user. Depending on the trust level of the application and content category information, the IVI system may or may not choose to provide access to certain applications as shown in Figure 10.

Figure 10. Preventing Driver Distraction

The content category information is also transmitted by the mobile device through one of the VNC extension messages, to indicate to the IVI system about the current contents of the display so that if required it can be blocked. The IVI system is also able to indicate which portion(s) of the mobile device display frame buffer it wants to be blocked. This is especially useful for interactive applications which might be allowed in general but may have some prohibited content on certain portions of their UI which need to be blocked, for example, a music player which might be displaying animated advertisement banners.

Terminal Mode allows the IVI system to challenge the mobile device at any time using the content attestation request/response message pair to securely verify that the content stream received from the mobile device is authentic. This message pair allows the IVI system to detect the following security risks originating from a man-in-the-middle attack: (1)

Modification of frame buffer display content, with unwanted content, and; (2) Modification of application and content category information, with fake settings. On being challenged, the mobile device provides a signed content attestation response containing the display frame buffer characteristics, allowing the IVI system to identify and minimize the risks of such attacks.

BENEFITS OF TERMINAL MODE

Terminal Mode provides a number of benefits to the consumers, automotive manufacturers and mobile device manufacturers.

5.1 Benefits for Consumers

The consumers benefit from Terminal Mode in the following ways:

- They get access to all their mobile applications and data both locally and in the cloud through their vehicle's IVI system.
- They can use mobile applications is a safe and legal manner without having to directly interact with the small screens and controls of their mobile devices.
- Terminal Mode will work on different vehicles from a wide range of manufacturers and will even work in rental vehicles. Consumers will have access to all of their personal services, applications and content coupled with a consistently familiar user experience regardless of the vehicle they are using at any given time.
- The IVI system in the vehicle automatically gets updated every time the mobile device is updated and upgraded.
- Users can easily download and use new or updated applications without having to wait for the IVI system manufacturer to provide updates. This also enables users to install approved applications on-demand unlike traditional IVI systems which mostly support only factory installed set of applications.
- Terminal Mode provides the same quality of user experience as that of native IVI applications without incurring any of the disadvantages of using native applications on an IVI system.

5.2 Benefits for Automotive Manufacturers

Automotive manufacturers and OEM suppliers benefit from Terminal Mode in the following ways:

- Terminal Mode provides added value to IVI systems by making them more upgradable and relevant in the long run. This provides a powerful incentive to potential customers to buy IVI units with their vehicle without worrying about them rapidly becoming out-of-date in terms of hardware and software capabilities.

- Terminal Mode components use hardware and software technologies which are accepted industry standards. This is important for automotive manufacturers, since they want to ensure that they do not have to perform frequent expensive redesigns of their IVI systems.
- Through Terminal Mode, IVI systems automatically get access to powerful mobile developer eco-systems with a large third-party developer pool. This enables IVI systems to always have access to the latest updated and popular applications without requiring the manufacturer to perform application development or upgrades.
- Application processing and UI capabilities get upgraded with the same frequency as mobile devices. This provides a consistently high quality in-vehicle user experience to customers without requiring much effort from the automotive manufacturers.
- IVI systems not only get access to all types of cloud services but more importantly get immediate access to the App Store eco-system. Now automotive manufacturers do not need to set up and maintain a separate App Store infrastructure and invest large amount of resources on something which is clearly not amongst their core competencies. Instead they can either use one of the existing App Stores for distribution of their own IVI apps or lease existing App Store infrastructure and white label it as their own custom store.
- Automotive manufacturers can utilize any Terminal Mode equipped mobile device as a vehicle telemetry platform for gathering vehicle usage and wear/tear data for statistical and preventive maintenance purposes, without requiring the installation of separate communications modules.

5.3 Benefits for Mobile Device Manufacturers

The mobile device manufacturers benefit from Terminal Mode in the following ways:

- Terminal Mode opens up an entirely new application space for mobile devices which has not yet been fully exploited. Mobile device manufacturers can provide automotive specific applications and services to the consumer thereby driving higher demand for both their devices and services.
- Mobile device manufacturers can provide App Store and other cloud resources as leased services to automotive manufacturers. They can also provide services which enable automotive manufacturers to gather/analyze vehicle data.

5.4 Benefits for Third-Party Developers

Third party application developers benefit from Terminal Mode in the following ways:

- Terminal Mode opens up the automotive application domain as a new source of revenue for third party developers and delivers it as an extension of the pre-existing mobile development and deployment ecosystem. Mobile application developers are now not only able to target the automotive application space but also do not have to learn new development platforms or technologies in order to do so.
- Automotive developers can now leverage both mobile and cloud computing capabilities to incorporate seamless and high quality user experiences into their applications.
- Terminal Mode enables a "*Write Once, Deploy Everywhere*" approach. It empowers developers to write automotive applications which will work across multiple vehicle models and manufacturers out-of-the-box.

CONCLUSIONS AND FUTURE WORK

In this paper, we presented Terminal Mode, a technology which transforms mobile devices into automotive application platforms and seamlessly integrates them into in-vehicle infotainment systems. This paper only provides a comprehensive overview of the technology and interested readers are highly encouraged to go through the complete Terminal Mode specifications that have been made public as a proposed industry standard [9].

As part of current and future work, the following aspects of Terminal Mode are being developed:

- Addition of video streaming mechanisms to the Remote UI components of Terminal Mode.
- Addition of discovery and delivery of vehicle based services to the Terminal Mode standard including access to on-board diagnostic data and other vehicle sensor data through the IVI system. Currently this is done out-of-band through the standard OBD-II interface available on most vehicles.

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