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Bluetooth Based In-Vehicle Infotainment for General Purpose and Multiuser Use Cases

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Abstract. Automakers envision and invest in a next generation of future cars enriched with concepts of connected car and smart automotive systems. These future cars employ in-vehicle networking as well as vehicle-to-anything communications technology for providing connected services to drivers, passengers and intelligent transport infrastructure in the vicinity. In this paper, we explore and focus on in-vehicle networking technology for realizing in-vehicle infotainment. Through a literature review on recent in-vehicle infotainment studies, we elicit and identify requirements, use cases and scenarios for in-vehicle infotainment systems. Then as a usable solution, we design and propose a Bluetooth-based in-vehicle infotainment for general purposes and multiuser use cases.

Keywords; Bluetooth; serial port profile; in-vehicle infotainment; in-vehicle networking; connected car

1. Introduction

Mobile vehicles are a ubiquitous platform around us that have potential use cases for personal and social connected car [1] and smart automotive systems [2]. Accordingly, automakers and service providers laboriously research and develop emerging and enabling technologies for realizing future cars. As a ubiquitous platform, mobile vehicles have two broad types of strategic applications [3]. First, it can be used as a self-contained

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system through an in-vehicle networking (IVN) [4]. Second, it can be designed as an opportunistic and interactive system interacting with various elements of intelligent transport systems (ITS) through appropriate vehicle-to-anything (V2X) communications technology. Fig. 1 depicts these two applications. Examples of the first application include in-vehicle infotainment (IVI), advanced driver assistance system (ADAS) [5] and automotive human-machine interface (HMI) [6]. Examples of the second application include various intelligent services that interact and communicate with other vehicles, pedestrian, Internet gateways, and traffic lights/signs [7]. In this paper, we focus on the first type of application, more specifically IVN for IVI.

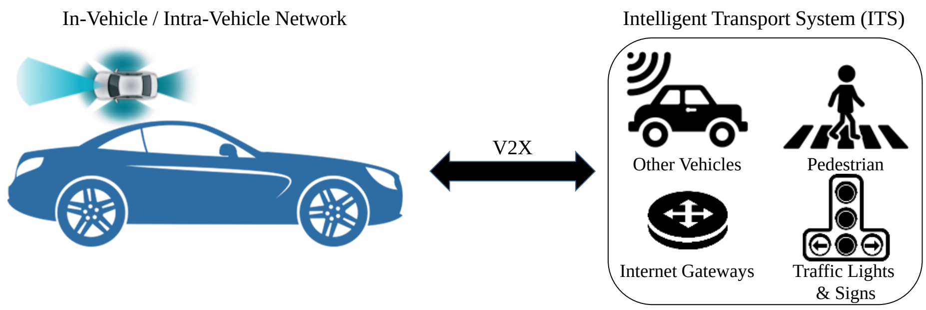

Fig 1. Mobile vehicles as a ubiquitous platform for two strategic applications.

A typical IVI system provides drivers and passengers with multimedia services locally through IVNs [8], once multimedia sources (i.e., radio, information, and video) are received. Mobile vehicles are shifting toward being more connected with intelligent infrastructure and smart devices while gaining autonomous self-control that frees the driver from the wheels. These changes provide previously unexplored opportunities for rich multimedia contents to be consumed for IVI while traveling. Consequently, automakers and service providers are considering several wired and wireless options including Bluetooth for implementing IVN and sub-systems of IVI [4].

Bluetooth is a wireless technology commonly found on commercial devices to exchange data over short distances. Along with Wi-Fi, Bluetooth prepares various use cases for convenient and casual interaction. There are already several Bluetooth profiles[1] such as Advanced Audio Distribution Profile (A2DP), A/V Remote Control Profile (AVRCP), Generic A/V Distribution Profile (GAVDP), and Human Interface Device Profile (HID) for serving different purposes. As more new use cases in connected automotive environment [9] are created, consumer needs and demands for multiuser scenarios are increasing. In this regard, we previously explored potential of Bluetooth

[1] Bluetooth profiles, https://www.bluetooth.com/specifications/profiles-overview

technology for IVI systems [10] and implemented a smart convergence platform for Software Defined Radio [11] and its mobile application companion [12]. Since typical users carry their smartphones wherever they go, a centralized Bluetooth connection management method will be useful for general purposed use cases as well multiuser scenarios where informative data are automatically shared between mobile devices and IVI systems [13].

The purpose of this paper is twofold. Firstly, we review recent IVI and IVN studies to elicit and identify requirements, use cases and scenarios for IVI systems. Secondly, we design and propose a Bluetooth device connection management method exploiting Bluetooth Serial Port Profile (SPP) for multiple connections as a usable solution for IVI systems. Specifically, we design and introduce an architecture for Connected Audio Application Platform (CAAP) referencing and extending our previous work [10][11][12], then show feasibility of our approach by demonstrating performance of SPP-based data transfer rates on selected mobile devices.

2. Related Work

A. Preliminaries

We first define and give references to concepts and terminologies used throughout this paper.

- Coppola and Morisio defined connected car as, “A connected car is a vehicle, capable of accessing the Internet at anytime, using either a built-in device or brought-in user devices; equipped with a set of modern applications and dynamic contextual functionalities, offering advanced infotainment features to the driver and passengers; capable of interacting with other smart devices on the road or in mechanical shops, leveraging vehicle-to-road infrastructure communication technologies; capable of interacting with other vehicles, leveraging vehicle-to-vehicle communication technologies. [1]”
- Vehicle-to-anything (V2X) communications refer to information exchange between a vehicle-of-interest and intelligent transportation system (ITS) elements [7]. Abboud et al. presented examples of V2X as dedicated short-range communications (DSRC), cellular networks and interworking solutions leveraging these two that are used for various connected vehicle systems and applications for road safety, passenger infotainment, car manufacturer service, and vehicle traffic optimization [7].

- In-vehicle infotainment (IVI) refers to any form of "the provision of information, entertainment, and communication functions within the vehicle. [14]" where examples include in-car radio, music/video player, and Internet access. Coppola and Morisio also identified main applications of IVI as music streaming, video streaming, games, Internet browsing, in-car Wi-Fi networks, and social networks [1].
- In-vehicle networking (IVN) refers to "an interface for facilitating the interaction between humans and the automobile's electronics [4]". Huang et al. described wired IVN approaches that include Controller Area Network (CAN), Local Interconnect Network (LIN), FlexRay, Media Oriented System Transport (MOST), Ethernet, and Power Line Communication (PLC) and wireless IVN approaches such as Wi-Fi, Bluetooth, UWB, and ZigBee [4]. When IVN is specifically used for IVI, it is sometimes referred as in-vehicle infotainment networks (IVINs) [8].
- Automotive human-machine interface (HMI) describes components and instrumentation of interfaces and interactions between the driver and the vehicle or between the passengers and the vehicle [6][14]. An academic conference on automotive HMI[2] covers various topics ranging from devices (head-up displays, sensors, cameras), interfaces (multi-modal, speech, audio, gestural, natural input/output, interfaces for navigation, text input and output while driving), and applications (in-vehicle communication, sensors and context for interactive experiences in the car, connected vehicles, information access, vehicle-based apps, entertainment, and autonomous driving).
- Intelligent transport system (ITS), ITS infrastructure and ITS applications are categorized into three main categories of safety, efficiency, and comfort based on their functionalities [3]. Dar et al. categorized that safety applications include collision avoidance, road sign notifications, and incident management, efficiency applications include management and monitoring applications, and comfort applications include entertainment and contextual applications [3].
- Software defined radio (SDR) provides "reconfiguration within a transceiver" [15] and employs a "reconfigurable architecture" [16] that are useful for multi-standard broadcasting and mobile devices [16]. SDR is one application area that we implemented in our previous work [11][12].

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[2] International ACM Conference on Automotive User Interfaces, https://www.auto-ui.org

B. Literature Review

In this section, we review related work on IVI (IVN and IVIN) in four aspects of wired IVN, wireless IVN, automotive HMI, and use cases, respectively.

1) Wired IVN: Wired IVN generally employs high bandwidth and more stable approaches. Alderisi et al. simulated and assessed use of IEEE Audio Video Bridging (AVB) standard and Time-Triggered Ethernet (TTE) for ADAS and in-car infotainment supporting audio and video streams [17]. Omerovic et al. proposed a communication protocol for sending commands between ADAS and IVI via Ethernet connection (TCP/IP sockets) [18]. Park et al. developed the Android-based IVI platform that used MOST for IVN and Wi-Fi or LTE for downloading applications [19]. There is an in-depth review of wired IVN approaches by Tuohy et al. who reviewed protocols and its bitrates for next generation wired intra-vehicle networks such as LIN (19.2 Kbps), CAN (1 Mbps), FlexRay (20 Mbps), MOST (150 Mbps), and LVDS (655 Mbps) [20].

2) Wireless IVN: A typical wireless IVN provides IVI to connect with other sub-systems and passengers' smart and mobile devices. Angelini et al. compared three modalities (i.e., gesture, speech, and touch interaction) for their IVI system where they used Bluetooth to send sensor data generated from a sensors-integrated steering wheel for gesture recognition [21]. Bi et al. examined WirelessHART mesh network that has the maximum data rate of 64 kbps for IVN and compared against controller area network (CAN) and local interconnect network (LIN) [22]. Chen et al. proposed the DRIVING framework to efficiently schedule the in-cabin Wi-Fi video streaming [23]. Kovacevic et al. developed prototypes where Bluetooth is used to for sending vehicle data to an embedded device (i.e., IVN) and Wi-Fi for internet connection [24]. Kurt and Gören proposed a mobile news reader application for IVI using the Ford SYNC technology[3] and SmartDeviceLink (SDL) [25]. Na et al. proposed and evaluated solutions to interference problems of Wi-Fi access in IVINs [8]. Noreikis et al. proposed in-vehicle application where an IVI system communicated with mobile applications via SmartDeviceLink to send vehicle data (consumption, odometer, GPS, etc.) [26]. Raja et al. presented 'WiBot!' to recognize in-car behavior and gestures with Wi-Fi by monitoring radio frequency fluctuation patterns [27]. Yoon et al. developed a multi-standard radio broadcasting platform (CAAP: Connected Audio Application Platform) where a mobile device can control the CAAP and received audio streams using Bluetooth Serial Port Profile (SPP) [11] and A2DP [12], respectively.

3) Automotive HMI: In our literature review, we encountered various automotive HMI that equipe people in the vehicle for expressive and natural interaction. Buchhop et al. investigated drivers' distraction of using in-vehicle touchscreen such as reacting to dangerous driving situations while using the touchscreen [33]. Coppola and Morisio

[3] Ford SYNC, https://www.ford.com/technology/sync/

stated that the main car interfaces should include button control, audio control, video display, UI rendering, car data access, and communication control, respectively [1]. Farooq et al. developed a novel haptic feedback environment using pneumatic and vibrotactile technologies for in-car communication [34]. Several studies proposed vision-based systems to classify hand gestures of drivers and passengers within the vehicle. Ohn-Bar et al. developed an HMI application in the car that recognizes hand gestures based on a combined RGB and depth descriptor [35]. Parada-Loira et al. developed a hand-gesture based automotive HMI that uses a visible-infrared camera mounted at the cabin ceiling [36]. Raja et al. developed an HMI to recognize gestures with Wi-Fi [27]. Sachara et al. presented a method for transforming time-of-flight (ToF) sensor data to be interpreted by Convolution Neural Networks (CNN) for gesture recognition [37]. Wang et al. repurposed capacitive sensors to distinguish who (i.e., driver or passenger) is interacting with in-vehicle touchscreens [38].

4) Use Cases and application scenarios: There are several common use cases and application scenarios in recent studies we reviewed. A non-exhaustive list is as follows. Contents for IVI can be personalized [28] and in-car software update scenario was also discussed [2]. IVI can be specifically used with wireless communication for SDR [12][29]. Also, several studies emphasized automatically sharing information between devices [13][25] and scenarios for supporting multiple users and social interaction [13]. Other uses include using IVI for browsing the Web [30], mobile news reader application for IVI [25], ADAS/IVI with multi-radio support [31], and for web services [32].

Table I summarizes results of our literature review in aforementioned four aspects.

TABLE I. A SUMMARY OF LITERATURE REVIEW (BLANCK CELLS WITH '-' ARE INTENTIONAL TO DENOTE 'NOT APPLICABLE')

Related Work	Wired/Wireless IVN	Automotive HMI	Use Cases
Alderisi et al. [17]	Ethernet	-	ADAS, IVI
Omerovic et al. [18]	Ethernet (TCP/IP)	-	ADAS, IVI
Park et al. [19]	MOST, Wi-Fi, LTE	-	IVI, Software Update
Tuohy et al. [20]	LIN, CAN, FlexRay, MOST, LVDS	-	Control traffic between ECUs, Multimedia, 'drive-by-wire' application, IVN
Angelini et al. [21]	BT	Gesture, Speech, Touch	IVI, HMI
Bi et al. [22]	WirelessHART	-	IVN
Chen et al. [23]	Ethernet, Wi-Fi	-	Video Streaming
Kovacevic et al. [24]	LAN, Wi-Fi, BT	Touchscreen, HUD buttons	IVI, Vehicle Monitoring

Related Work	**Wired/Wireless IVN**	**Automotive HMI**	**Use Cases**
Kurt & Gören [25]	Ford Sync, SDL	Touchscreen, Mobile Application	News Reader
Na et al. [8]	Wi-Fi	-	IVINs
Noreikis et al. [26]	SDL	HUD	IVI, Vehicle Monitoring
Raja et al. [27]	Wi-Fi	Simulator	HMI
Yoon et al. [11][12]	BT SPP, BT A2DP	Mobile Application	SDR Control, Audio Streaming
Garzon [28]	-	Driving Simulator, Central Command Unit	IVI Personalization
Greengard [2]	AppLink, MyLink	-	IVI, Software Update
Gu et al. [29]	Ethernet, HSDPA, BT, GPS, DSRC	Display, HMI Device, Speaker	SDR, IVI
Heikkinen et al. [13]	-	Mobile Devices	Multiple and Social Uses
Isenberg et al. [30]	-	-	Web Browsing
Racherla & Waight [31]	CAN, Ethernet	-	Multi-radio
Sonnenberg [32]	-	-	Web Service, IVI
Buchhop et al. [33]	-	Simulator, Touchscreen	Safety
Coppola & Morisio [1]	V2X, BT, DLNA, MirrorLink, USB, Wi-Fi	Car Dashboard	Traffic Safety, IVI, Traffic/Cost Efficiency
Farooq et al. [34]	-	Haptic Feedback, Touchscreen, HUD, Gesture Control	IVI
Ohn-Bar et al. [35]	-	Hand Gesture, Camera	HMI
Parada-Loira et al. [36]	-	Hand Gesture, IR Camera	HMI
Sachara et al. [37]	-	Gesture Recognition	IVI
Wang et al. [38]	-	Touchscreen, PicoScope, Capacitive Sensors	Multiusers Scenario
Son et al. [39]	USB, BT, Wi-Fi, LTE	Web Simulator	HTML5

3. Architecture of Multi-Bluetooth Device Manager for IVI

A. Requirements

Through our literature review in Section 2, we elicit following requirements and address them in our design of multi-Bluetooth device manager for IVI.

- Requirement 1: Support for unformatted raw data or customized protocol. Since there are already various protocols in wired IVN and wireless IVN, we should prepare an alternative protocol for novel applications and customized use cases. For example, we can support a generic method to send unformatted data that can be further tailored and customized by each developer. To do so, we can provide a generic workflow to establish, send, and close data transfer pathways and leave specific data protocol and handling to service and applications developers.

- Requirement 2: Separate high-bandwidth IVN and low-bandwidth IVN and designate applications accordingly. As we reviewed studies on IVN and IVI, there are approaches suitable for high-bandwidth usages. For these cases, we should employ high-bandwidth IVN and only use low-bandwidth IVN (in practice, wireless IVNs) for a short communication or with a medium that would not degrade on the low-bandwidth. For example, it is an overkill to use expensive high-bandwidth wired IVN to send a short message. Similarly, we should avoid sending a burst of large data streams via an incapable wireless IVN.

- Requirement 3: Support for multiple users (i.e., multiple smart devices) interacting with IVI who can control as well as consume multimedia contents provided by IVI. Even though there are several IVI use cases, multiuser scenarios involving multiple passengers with different smart devices are not common yet. As connected cars become more autonomous and connected, these types of scenarios should be encouraged and supported.

B. Target Use Cases and Application Scenarios

Following previous requirements, our target use cases and application scenarios involve multiple passengers (a driver included) using different smart devices to interact with IVI. For example, one passenger may switch a radio channel to different one using his mobile device. Then accordingly, the changed information is shared among other passengers in the vehicle through their own devices. Another example may involve one passenger receiving DRM (Digital Radio Mondiale) or DAB (Digital Audio Broadcasting) radio while another passenger receives FM/AM radio via her smart device. For both of these scenarios, each user should be able to access and control IVI with their own device and also should be notified when changes are made to the IVI by other passengers.

C. Proposed Architecture

Based on the elicited requirements and the elaborated target use cases, we design a usable solution satisfying the described criterion for IVI. Fig. 2 shows an architecture of multi Bluetooth device manager we designed for extending our previous Connected Audio Application Platform (CAAP) [12]. The main role of this manager is to track a record of new Bluetooth connection and open a SPP server with a corresponding SPP port for each unique Bluetooth MAC address as shown in BT SPP pathways of Fig. 2. These records are stored on a local Bluetooth device database where the manager can search and retrieve SPP port, handler and MAC address information, respectively. We chose to use Bluetooth, because it is supported in many smart devices by default and found results of other related work feasible. Lai and Leung used Bluetooth for providing a platform for multiplayer game [40]. Lapoehn et al. described concepts of linking nomadic devices via Bluetooth to the vehicle [41]. Sarker et al. used Bluetooth SPP for streaming sensor data where they achieved a data rate of 112 kb [42]. Inspired by these work, we chose to implement a BT SPP based multi-BT device manager for managing multiple smart device connections for IVI.

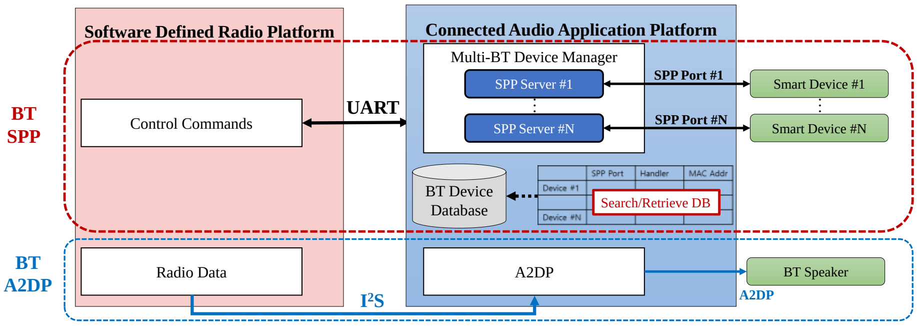

Fig 2. An architecture of multi Bluetooth device manager interacting with multiple smart devices via two pathways of BT SPP and BT A2DP.

4. Implementation and Evaluation

In this section, we show an implementation and evaluation of the proposed multi-BT device manager. To implement a prototype, we used a Bluetooth evaluation kit from Cypress (CYW920179Q40EVB-01 Evaluation Kit[4]) and several Android-based smart phones and tablets (LG G4, Lenovo Pad, Samsung Galaxy Note 9, and Samsung Galaxy Tab S4). The Cypress evaluation kit supports Bluetooth (BR + EDR + BLE) up to Bluetooth 5.0 and has several serial interfaces (2 UART, 2 SPI, I2C, PCM, and I2S). By exploiting SPP, we can send and receive raw or custom format data. SPP is a viable option when a specific use case is not covered by existing Bluetooth profiles. For multiuser scenarios, we consider a user controlling the centralized Bluetooth system (i.e.,

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[4] CYW920719Q40EVB-01 Evaluation Kit, http://www.cypress.com/documentation/development-kitsboards/cyw920719q40evb-01-evaluation-kit

CAAP) and the changed results are propagated to another user. To show feasibility of a procedural multiple connection, we measured SPP throughput on different mobile devices as shown in Table II and Fig. 3.

TABLE II. SPP THROUGHPUT PERFORMANCE ON VARIOUS BT DEVICES WITH THEIR MODEL NAME AND RUNNING ANDROID OS VERSION INFORMATION

Metric / Bluetooth Device	Transferred Data Size							
	100 KB				*1 MB*			
	Max. (KB/s)	*Avg. (KB/s)*	*Min. (KB/s)*	*Time (ms)*	*Max. (KB/s)*	*Avg. (KB/s)*	*Min. (KB/s)*	*Time (ms)*
LG G4 (LGE LG-F500S, Android 7.0)	42	35	17	2,991	38	37	33	26,935
Lenovo Pad (TB30X70F, Android 6.0)	43	41	38	2,407	41	40	37	24,999
Samsung Galaxy Note 9 (SM-N960N, Android 8.1.0)	43	39	33	2,543	38	38	37	26,417
Samsung Galaxy Tab S4 (SM-T835N, Android 8.1.0)	42	39	35	2,515	40	39	39	25,145

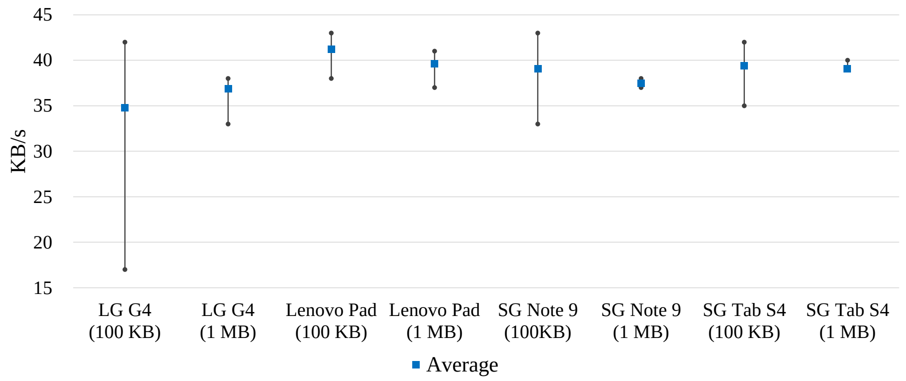

Fig 3. SPP throughput measured on different BT devices for sending data sizes of 100 KB and 1 MB.

We measured SPP throughput from the embedded system (i.e., Cypress Evaluation Kit) to the mobile device while multiple mobile devices are connected to the embedded system. For simplicity, the multi-BT device manager kept a track of two connected BT devices. We measured time to send unformatted data of 100 KB and 1 MB on each device, 10 times to record maximum, minimum, and average SPP throughput. As shown in Table II and Fig. 3, the proposed multi-BT device manager demonstrated a constant and stable performance in a range of 35 KB/s to 41 KB/s (equivalent to approximately 320 kbps) across different devices. To test different variations of mobile devices, we used smart phones and tablets from different makers released from 2015 to 2018 that run different versions of Android OSes (Android version 6.0 to 8.1.0).

The results presented in this section have several implications for the requirements identified in Section 3. For requirement 1, we have shown that BT SPP can be used to send raw or customized data format. We sent unformatted raw data of 100 KB and 1 MB via SPP where the recipient (i.e., mobile application and its service provider) will have to implement their own custom protocol and parser to handle them.

For requirement 2, we have shown that BT SPP is ideal for low-bandwidth usage and applications. Therefore, we recommend to use BT SPP for control commands and streaming media that requires low bandwidth. For example, bandwidth requirements for streaming TV shows and movies are higher (i.e., over 0.5 Mbps[5]) while requirements for streaming music are considerably modest (i.e., 320 kbps[6]). So our results of approximately 40 KB/s or 320 kbps are sufficient for streaming music, but impractical for streaming high quality videos.

For requirement 3, we have shown that BT SPP can operate while multiple BT devices are connected and several different devices (varying in makers, release dates, and Android versions) could be used in IVI context. Since individual passengers may use several kinds of devices, it is important to support a wide range of devices.

5. Conclusion

In this paper, we first reviewed recent IVI and IVN studies to elicit and identify requirements, use cases and scenarios for IVI systems. Then based on these findings, we designed and proposed a Bluetooth device connection management method exploiting Bluetooth SPP for multiple connections as a usable solution for IVI systems. Specifically, we proposed a multi Bluetooth device manager based on Bluetooth SPP for general purpose use cases and multiuser scenarios. We showed that SPP throughput performance

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[5] The Best Internet for Streaming, https://www.reviews.org/internet-service/best-internet-streaming/

[6] How much Speed Do I Need to Stream Music, https://www.highspeedinternet.com/resources/how-much-speed-do-i-need-for-pandora-and-spotify/

on commercial mobile devices, approximately 40 KB/s or 320 kbps, can be achieved for possible multiuser use cases, which is ideal and sufficient for control commands and streaming music. Our future work includes addressing security threats in the interfaces of wireless telematics systems [43] when multiple users access IVI and IVN, polishing content deliver protocols [44] and evaluating UI/UX of automotive HMI [45].

Acknowledgment

Icons used in Fig. 1 are Vehicle Tracking by Simon Child, Pedestrian Crossing by Adrien Coquet, Traffic Light by Arthur Shlain, Car by www.yugudesign.com, and play music by Gregor Cresnar, all from the Noun Project.

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