Wireless Automotive Communications

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Abstract

This paper presents an overview of wireless automotive communication technologies, with the aim of identifying the strong candidates for future in-vehicle and inter-vehicle automotive applications. The paper first gives an overview of automotive applications relying on wireless communications, with particular focus on telematics. Then, the paper identifies the key networking technologies used for in-vehicle and inter-vehicle applications, comparing their properties and indicating future challenges in the area of wireless automotive communications, with a focus on real-time aspects.

1 Introduction

Nowadays the two areas that are getting most attention in automotive communications are protocols and technologies supporting x-by-wire applications, e.g., Flexray [3], and protocols and technologies for telematics and wireless applications. Automotive telematics refers to any kind of vehicle information or communication service that relies on a wireless communication link.

There are several applications pushing for the adoption of wireless communications in automotive systems, both within the vehicle (in-vehicle communications) and between the vehicle and its surroundings (inter-vehicle communications). Looking at in-vehicle communications, more and more portable devices, e.g., mobile phones, portable GSM devices and laptop computers could exploit the possibility of interconnection with the vehicle. Also, several new applications will exploit the possibility of inter-vehicle communications, e.g., vehicle-to-vehicle [2] and vehicle-to-roadside communications.

This paper presents the most common wireless protocols used for in-vehicle and inter-vehicle communications in the automotive industry, and the ones that might be used in the near future. After an overview of typical telematics services and applications in Section 2, relevant wireless automotive networking technologies for in-vehicle and inter-vehicle communications are presented and compared, pointing out real-time related aspects, in Section 3. Finally, the paper is summarised in Section 4.

2 Telematics

Automotive telematics enables the deployment of a number of new services and applications integrating wireless communication technology into a vehicle. As a result, the vehicle acquires new capabilities and offers more services to its users. Examples of telematics services and applications are:

- *Navigation and traffic information systems* - A vehicle equipped with a telematics unit can direct a driver to a desired location, while providing real-time traffic information for a given route.
- *Voice recognition and wireless Internet connection* - Drivers and their passengers can receive and send voice-activated e-mails while on the road.
- *Safety systems* - Collision avoidance systems, unsafe driving profiling, intelligent airbag deployment systems. Communications between the vehicle and its surroundings, e.g., other vehicles and roadside objects. Automatic airbag deployment notification. Accident and roadside assistance. An example is given by the General Motors Advanced Automatic Crash Notification (AACN) system available on many GM OnStar™-equipped vehicles.
- *Security systems* - Vehicle antitheft and stolen vehicle tracking services. Tracking and remote door unlocking is provided by OnStar™-equipped vehicles.
- *Diagnostics and maintenance services* - Remote diagnostics and/or maintenance systems, vehicle and driver monitoring.

3 Wireless automotive communications

In this section three Personal Area Network (PAN) standards for in-vehicle communications are presented: Bluetooth (IEEE 802.15.1) [1, 5], ZigBee (IEEE 802.15.4) [8, 5], and Ultra Wide Band (UWB/IEEE 802.15.3a) [7, 5]. Also, one Wireless Local Area Network (WLAN) for inter-vehicle communications is presented: Wi-Fi (IEEE 802.11a/b/g) [4]. All these technologies are possible candidates for wireless real-time control systems found in automotive systems. Important issues not discussed in this paper are safety and security. In general, concerning safety, a wireless link is more sensitive to interference compared with a wired one. Also, from a security perspective, the wireless medium makes the system reachable from outside, possibly subject to intrusion. Moreover, it is still an open issue whether wireless networks introduce health risks for the driver of the vehicle.

3.1 Bluetooth

Bluetooth (IEEE 802.15.1) [1, 5] currently provides network speeds of up to 3 Mbps. Originally devised for PAN deployment for low-cost, low-power, short-range wireless ad hoc interconnection, Bluetooth technology has fast become very appealing also for the automotive environment, as a potential automotive wireless networking technology.

In response to interest by the automotive industry, in December 1999 the Bluetooth Special Interest Group (SIG) formed the Car Working Group. The Hands-Free profile was the first of several application level specifications from the Car Working Group. Using the new Hands-Free profile, products that implement the Bluetooth specification can facilitate automatic establishment of a connection between the car's hands-free system (typically part of its audio system) and a mobile phone. Bluetooth wireless products incorporating these new enhancements enable a seamless, virtually automatic interface between the car and wireless products. Today, Bluetooth allows hands-free use of a mobile phone either through the car's audio system or wireless headsets, resulting in better sound and control, and a safe solution to legislation banning mobile phone use while driving.

The Bluetooth SIG, in November 2004, laid out a three-year roadmap for future improvements to Bluetooth. Prioritised targets include Quality of Service (QoS), security, power consumption, multicast capabilities, privacy enhancements. Long-range performance improvements are expected to increase the range of very low power Bluetooth-enabled sensors to approximately 100 meters.

3.2 ZigBee

ZigBee (IEEE 802.15.4) [8, 5] is a new low-cost and low-power wireless PAN standard, intended to meet the needs of sensors and control devices. Typical ZigBee applications do not require high bandwidth, but do impose severe requirements on latency and energy consumption. Despite the number of low data rates proprietary systems designed to fulfil the above mentioned requirements, there were no standards that met them. Moreover, the usage of such legacy systems raised significant interoperability problems which ZigBee technology solves, providing a standardized base set of solutions for sensor and control systems. The ZigBee Alliance (with over 120 company members) ratified the first ZigBee specification for wireless data communications in December 2004.

ZigBee provides network speed of up to 250 Kbps, and is expected to be largely used in home and building automation (e.g., for fire detection, security and access monitoring, heating, lighting and environment control), and in industrial process monitoring and control systems (e.g., for use in monitoring and control of industrial processes and equipments, especially in hazardous environments inaccessible to normal wired systems).

3.3 UWB

UWB (IEEE 802.15.3a), or Ultra Wide Band [7, 5], is a potential competitor to the IEEE 802.11 standards. However, UWB is more intended for home multimedia networking, whereas 802.11 networks targets data networking, not only in home environments, but also in public and enterprise environments. Looking at the wireless PAN market, currently dominated by Bluetooth, UWB offers a solution with much higher bandwidth. Network speeds offered by UWB are in theory several hundreds of Mbps, although initially speeds of up to 100 Mbps are more likely.

UWB uses very low-powered, short-pulse radio signals to transfer data over a wide spectrum of frequencies. This broad spectrum of frequencies makes it tolerant to disturbances, making it attractive for a noisy automotive environment.

3.4 Wi-Fi

Wi-Fi (*wireless fidelity*) is the general term for any type of IEEE 802.11 network [4]. Examples of 802.11 networks are the 802.11a (up to 54 Mbps), 802.11b (up to 11 Mbps), and 802.11g (up to 54 Mbps). These networks are used as WLANs.

The three 802.11 standards differ for the offered bandwidth, coverage, security support and, therefore, the kind of applications supported. 802.11a is better suited for multimedia voice, video and large-image applications in densely populated user environments. However, it provides relatively shorter range than 802.11b, which consequently requires fewer access points for coverage of large areas. The 802.11g standard is compatible with and may replace 802.11b, partly due to its higher bandwidth and improved security.

3.5 Discussion

A summarising comparison of the wireless technologies discussed in this paper is presented in Table 1.

. Standard	Bluetooth IEEE 802.15.1	ZigBee IEEE 802.15.4	UWB IEEE 802.15.3a	Wi-Fi IEEE 802.11a/b/g
Freq. band	• 2.4 Ghz & 2.5 Ghz (ver 1.2)	• 2.4 Ghz	• 3.1-10.6 Ghz	• 2.4 Ghz (b/g) & 5 Ghz (a)
Network	• P2P	• Mesh	• P2P	• P2P
Modulation technique	• Frequency Hopping Spread Spectrum (FHSS)	• Direct Sequence Spread Spectrum (DSSS)	• Orthogonal Frequency Division Multiplexing (OFDM) or Direct-Sequence UWB (DS-UWB)	• OFDM or DSSS with Complementary Code Keying (CCK)
Maximum network speed	• 1 Mbps (ver 1.0) • 3 Mbps (ver 1.2) • 12 Mbps (ver 2.0)	• 250 Kbps	• 50-100 Mbps (480 Mbps within short ranges expected).	• 54 Mbps (802.11a) • 11 Mbps (802.11b) • 54 Mbps (802.11g)
Network range	• Up to 100 meters, depending on radio class (effective 10 meters).	• Up to 70 meters (effective 20 meters).	• Up to 20 meters (effective 10 meters).	• Up to 100 meters (effective 50 meters).
Main usage	• Voice applications. • Eliminating short-distance cabling.	• Sensors/control applications. • Grand-scale automation. • Remote control.	• Multimedia applications. • Healthcare applications.	• Office and home networks. • WLAN. • Replace Ethernet cables.
Strong points	• Dominating PAN tech. • In vehicles today. • Easy synchronization of mobile devices. • Frequency hopping tolerant to harsh environments.	• Static network. • Control/sensor. • Many devices/nodes. • Small data packets. • Low duty cycle. • Low power.	• Easy and cheap to build. • Consume very little power. • Provides high bandwidth. • Broad spectrum of frequencies (robustness).	• Dominating WLAN tech. • Know-how.
Weak points	• Interference with WiFi. • Consume medium power.	• Low bandwidth.	• Short range. • Interference.	• Traditionally consume high power.
Automotive usage (potential)	• Portable devices. • Diagnostics tools. • Real-time communications. • Device connectivity.	• In-vehicle communications. • Mobile/static sensor networks.	• Robust vehicle communications. • High bandwidth communications.	• Inter-vehicle communications. • Vehicle-to-vehicle. • Vehicle-to-roadside.

Table 1. Wireless technologies for automotive systems.

3.5.1 Technology comparison

¿From a general perspective, the main differences between the wireless technologies considered originates from the different target applications they were optimized for. Bluetooth addresses voice applications, eliminating short distance cabling, is suitable for hands-free audio but also for synchronization of cell phones to PDAs, file transfer, ad-hoc networking between capable devices. For these applications a network range of a few tens of meters is sufficient together with network speeds of a few (1-2) Mbps. This is what Bluetooth provides.

ZigBee, on the other hand, addresses sensors and control, and other short message applications. ZigBee applications are consisting of lots of devices typically requiring small data packets with a lightweight protocol and a small protocol stack. Network speed here is not as important as for the other technologies presented in this paper, and currently only 250 Kbps is provided. Nodes can be scattered around in a slightly larger area compared with Bluetooth.

UWB is the upcomer (although historically it has its roots in the sixties), providing interestingly high network speeds together with a robust communications using a broad spectrum of frequencies. This technology is best suited at very short range (a few meters), compared with the others, but the bandwidth it provides (up to 480 MBps) is magnitudes higher compared to the other technologies.

WiFi is developed as a replacing technology for wired Ethernet used mainly in home and office environments. To provide mobility, network speeds and range should be as high as possible. 54 Mbps is provided and the network is still effective around 50 meters.

Considering power usage, both ZigBee and UWB require very low power for operation. On the other hand, although much better than WiFi, which is not built with low power as the prime target, Bluetooth requires about 50 times more energy to transfer a single bit compared to UWB.

3.5.2 Automotive applications

Looking at the automotive context, Bluetooth is built into many vehicles today. Hence, it is currently the most widely-used automotive wireless technology. The frequency hopping modulation technique is also suitable in harsh environments often found in automotive applications. The availability of Bluetooth in vehicles and cell phones, means that it already today provides a technology for telematics applications. In a Bluetooth-enabled vehicle, the car audio system takes over the phone function. In addition, other Bluetooth devices can easily interconnect within a Bluetooth-enabled car: for example, portable devices, such as DVD, CD, MP3 players, can be connected to speakers. Moreover, hand-held computers and diagnostic equipments can interface to the car and access services provided by the on-board diagnostic and control systems through Bluetooth interfaces. Beyond entertainment and phone calls there are other emerging possibilities, including remote starting to warm-up the car in the winter or start the air conditioning in summer, iPod or MP3 players streaming to the audio system, a remote parking garage or home garage door controller, and payment for gas at the pump and toll road payments.

ZigBee on the other hand, fills a gap not provided by the other technologies, namely the interconnection of wireless sensors for control. ZigBee is expected to be used in monitoring and control applications, related to temperature and humidity measurement as well as heating, ventilation, air-conditioning and lighting control. There are also quite novel and original ways of using ZigBee for the driver's benefit. One of them is rental car monitoring. A ZigBee-enabled monitoring system could allow customers to quickly drop off a rental car without waiting for the attendant to check gas or mileage. Other interesting automotive applications are tire-pressure monitoring and remote keyless entry. Further proposals involve attaching a ZigBee device to anything which should not be lost (e.g., car keys), so that, whenever the device goes out of range, an alert signal is generated from a ZigBee-equipped phone.

UWB is the newcomer in this area, possibly providing robust communications thanks to its usage of a broad spectrum of frequencies. We are likely to see UWB in applications requiring high bandwidth, such as interconnection of multimedia devices. Other automotive applications are collision-detection systems and suspension systems that respond to road conditions [7]. However, UWB being a young technology, no such applications are available to date.

For inter-vehicle communications, WiFi is the most interesting technology today, partly due to its extensive usage in office and home networks, but also due to its availability. Hence, it is often used in pilot research projects. Wi-Fi is used for inter-vehicle communications by, e.g., the Car2Car Consortium [2], a non-profit organisation initiated by European vehicle manufacturers. Applications here are advanced drive assistance reducing the number of accidents, decentralized floating car data improving local traffic flow and efficiency, and user communications and information services for comfort and business applications to driver and passengers. Research projects working in this area are, e.g., the European Network-on-Wheels (NoW) project [6].

3.5.3 Real-time issues

From a real-time point of view, most telematics applications do not feature real-time requirements in the strict sense. Navigation and traffic information systems require position and Internet-like communications, providing traffic information and directions. Voice applications have slightly higher requirements on QoS, e.g., real-time voice processing and recognition. However, some safety-systems do have real-time requirements, e.g., communications between the vehicle and other vehicles or roadside objects, implementing collision detection/avoidance systems or active suspension systems that respond to road conditions. Moreover, diagnostics and service tools could make real-time data available during operation of the vehicle. Also, real-time requirements are put by the usage of wireless technologies as a redundant link between nodes linked with wired type of networks.

None of the wireless technologies presented in this paper provide *hard* real-time guarantees, since they are not as deterministic as wired technologies and messages are more likely to be corrupted. However, they can make use of real-time dependability concepts to provide as good service as possible in the area of wireless automotive real-time communications.

4 Summary and way forward

This paper has presented existing and upcoming automotive wireless networking technologies, and identified basic wireless applications relying on these technologies. There are several open issues to be addressed. First, which wireless automotive applications rely on real-time systems and how existing research on wireless real-time communications can provide support for these applications. Other important points are related with the integration of wireless networking technologies and with the interoperability problems which could be expected in the automotive domain. Finally, it should be discussed how these wireless technologies should be integrated in the existing communications architecture comprising several network protocols, e.g., CAN, LIN and MOST, and if such an architecture *should* be extended with a wireless infrastructure.

References

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