The Traditional and New Generation in-vehicle Networks in Automotive Field

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***Abstract*—This paper provides an overview of the most commonly used traditional networks and new generation in-vehicle networks. Comparison and Usage and trends of in-vehicle networking protocols will be presented and categorized. The past few years have seen a large growth in the number and type of communication buses used in automobiles, trucks, construction equipment, and military, among others. Development continues even into boating and recreation vehicles. Areas for discussion will include SAE Class A, B, C, D. It is believed that the comparison presented in this paper would benefit application engineers in selecting an appropriate protocol.**

Keywords: In-vehicle networking, Communication protocol, Zigbee, UWB, Wi-Fi, Bluetooth, CAN, LIN, MOST, D2B, TTP/A/C, J1850, Byteflight, Flexray, PLC.

I. INTRODUCTION

Considering the automotive field over the few decades, In-vehicle communication system has been one of the most active areas of research. In fact, modern vehicles need to reach a very high level of excellence in terms of comfort, safety and energy consumption in order to meet the market needs. For example, several active and passive safety systems (e.g. Antilock Brake System – ABS, airbags, and seat belts…). Several other systems which will be mandatory in the near future (e.g., Electronic Stability Program – ESP, Forward Collision Warning – FCW, Lane Keeping Assistant – LKA…).In such a context, Information and Communication Technologies (ICTs) play a key role in the design and development of all automotive systems. In particular, most of them require using sensors, video cameras and others. On an average, these components can reach up to 35 to 40 percent in total production costs of a modern car ([1]) also Information technology is the driving force behind innovations in the automotive industry, with perhaps 90% of all innovations in cars based on electronics and software [2].

The current research trend is aimed at using in-vehicle communication networks characterized by better performance. In this way, the safety and reliability of existing systems can be improved. On the other hand, the use of different technologies will introduce new issues that have to be taken into account in the design phase. For example, the use of wireless communications will introduce significant security issues due to various types of cyber attacks from external entities, less present in traditional wired networks.

Furthermore, the emerging vehicular networks in the forms of intra-car, car-to-car, car-to-infrastructure communications [3] will enable a variety of applications for safety, traffic efficiency, driver assistance to be incorporated into future automotive designs. In such a context, this paper is aimed at summarizing the characteristics of the traditional and widely used new generation in-vehicle communication networks and at providing some innovative solutions and applications in the same field. The rest of this paper is organized as follows. Section II provides an overview of traditional in-vehicle networks and their comparison. Section III provides an overview of new generation in-vehicle networks and their comparison. Section IV provides issues related to in-vehicle network. Finally, future trends and paper conclusions are drawn in Section V and VI.

II. TRADITIONAL IN-VEHICLE NETWORKS AND THEIR COMPARIONS

Categories	Data Rate	Applications	Networks
Class A	Low (Less than 10kb/s)	Control of data related to body domain (Seat control, rain sensors, doors...)	LIN, TTP/A
Class B	Medium (10 to 125kb/s)	Transfer of general information (Vehicle speed, legislated emissions data...)	J1850, CAN-B
Class C	High (125kb/s to 1Mb/s)	Real time communication (Powertrain and chassis domain)	CAN-C
Class D	Very high (up to or more than 1Mb/s)	Telematics (Multimedia, internet, digital TV...)	MOST, D2B,Bluetooth, TTP/C, Flex Ray

Table1: Classification of Automotive communication protocol by SAE (Society of Automotive Engineers)

This section is aimed at describing the main in-vehicle communication networks that have been traditionally used in automobiles

More advanced and innovative communication systems will be described in the next section. In general, these protocols define both physical and data link layer in the ISO/OSI reference model and they are developed based on some alternative medium access control mechanisms [5]: CSMA/CD e.g. Ethernet, CSMA/CR e.g. CAN, CSMA/CA, TDMA e.g. TTP/C, FTDMA e.g. Byteflight and FlexRay.

LIN: It is a broadcast serial network comprising one master and typically up to 12 slaves. The LIN bus is an inexpensive serial communications protocol, which effectively supports remote application within a car's network. LIN was designed by the LIN consortium. It was particularly designed for low-cost communication between smart sensors and actuators in automotive applications [14].

TTP/A: Is a time-triggered real time field bus protocol used for the interconnection of low-cost smart transducer nodes. TTP/A aims at an easy and economically integration of sensors and actuators into a network. TTP/A can be implemented on low-cost micro-controllers, which suggests each transducer having a TTP/A interface.

J1850: The SAE J1850 is used for diagnostics and data sharing applications in vehicle. In many cases the J1850 interface bits will be found on an OBDII connector inside your car. OBDII [On-Board Diagnostics II] defines a communications protocol and a standard connector to acquire data from passenger cars.

Byteflight: Byteflight has been developed by BMW. It has mainly been used in highly safety related networks (i.e. passive safety) both in automotive and avionic domain that require high bandwidth and dependability. Byteflight is based on the flexible time division multiple access (FTDMA) mechanism, typically using the star network topology. Similar to time-triggered networks, Byteflight provides bandwidth reservation for nodes in the network while not using a static, predefined communication schedule.

CAN: Is one of the first automotive control networks. It is a vehicle bus standard designed to allow microcontrollers and devices to communicate with each other within a vehicle without a host computer. CAN is a message-based protocol, designed specifically for automotive applications but now also used in other areas such as industrial automation and medical equipment[11].

MOST: It is a high-speed multimedia network technology optimized by the automotive industry. It can be used for applications inside or outside the car. The serial MOST bus uses a ring topology and synchronous data communication to transport audio, video, voice and data signals via plastic optical fiber (POF). A MOST network is able to manage up to 64 MOST devices in a ring configuration. Plug-&-Play functionality allows MOST devices to be easily attached and removed [12].

D2B: is an optical data bus system connecting audio, video, computer peripheral and telephone components in a single ring structure within the vehicle. The D2B interface has a maximum fiber distance of 10 meters [13].

Bluetooth: It is a proprietary open wireless technology standard for exchanging data over short distances (using short wavelength radio transmissions in the ISM band from 2400-2480 MHz) from fixed and mobile devices, creating personal area networks (PANs) with high levels of security. Bluetooth is a worldwide recognized standard for low-cost, low-power, short-range wireless communication. The main in-car Bluetooth application is related to the possibility to use hands-free mobile phone systems in order to avoid driver distraction and increase its safety.

TTP/C: It focuses on the interconnection of components in order to form a highly dependable real-time system that is sufficient for critical applications such as X-by-wire in the automotive and avionics domains. It provides the services required for providing message transport for systems with predictable latency, membership service, clock synchronization, blackout handling, and error detection with low latency, redundancy management and implement these services without extra messages and with only a small overhead [4].

Flex Ray: is a high-speed serial [Synchronous and Asynchronous] communication system for in-vehicle networks using Point-to-Point [Star topology] links, at 10Mbps [Fault-Tolerant] over Un-shielded Twisted Pair [UTP] or Shielded Twisted Pair [STP] cable. Flex Ray is a fault tolerant bus and provides deterministic data transmission [15].

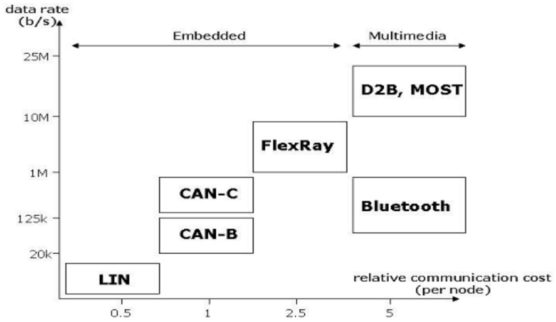

Fig 1: Comparison of several in-vehicle network protocols with respect to data rate and communication cost

Comparison: LIN and TTP/A are used for sensors and actuators both having NRZ for bit encoding and uses CRC for error detection both having data field length of 8 bytes and low financial cost. J1850 and CAN are used for control and diagnosis wherein J1850 has VPW; PWM for bit encoding whereas CAN have NRZ for bit encoding and both uses CRC for error detection both having data field length of 8 bytes and low financial cost. D2B and MOST are used for Audio/Video signal and Multimedia signal respectively and communication medium is optical fiber. Both have NRZ as bit encoding.

Protocol	General	Class	Data Rate	Network topology	Operating Voltage	Scheduling	Functional domain
LIN	**- low-speed , low-cost, time-triggered**	**A**	**20kb/s**	**Bus**	**12V**	**- master/slave, polling list based on schedule table**	**Body/comfort**
TTP/A	**- low-speed ,low-cost**	**A**	**25kb/s**	**Bus**	**12V**	**- master/slave , polling list based on schedule table**	**Sensors, Actuators**
J1850	**- non real time communication**	**B**	**41.6 kb/s**	**Bus**	**4.25V to 20V**	**- CSMA/CR**	**Body domain and diagnostic**
CAN	**- low-cost, simple, twisted pair , event-triggered, de-facto standard , most widely used**	**B, C**	**Up to 1Mb/s**	**Bus** **Star**	**1.5V to 3V**	**- CSMA/CR** **- Bitwise arbitration based on message identifiers**	**- Body/comfort** **- Powertrain** **- Chassis**
Byteflight	**- hybrid paradigm, POF**	**D**	**10 Mb/s**	**Star**	**2V**	**- FTDMA based on message identifiers , master/slave (for synchronization)**	**- Passive safety, Safety, critical , application**
MOST	**- cost-effective , data-efficient , hybrid paradigm , de-facto standard for multimedia, POF**	**D**	**Up to 24.8Mb/s**	**Ring** **Star**	**Up to 2V**	**- master/slave , support for (a)synchronous, point-to-point video and audio data transfer**	**- multimedia** **- infotainment**
D2B	**- Reliable, Weight saving, simple**	**D**	**Up to 11.2Mb/s**	**Bus**	**Up to 2.5V**	**-digital audio and video data transmission**	**-multimedia**
Bluetooth	**-low power, low cost, short range communication**	**D**	**Up to 3Mb/s**	**Bus** **Star**	**Up to 3V**	**- predefined and fixed communication schedule**	**-hands-free mobile phone systems, safety**
TTP/C	**- twisted pair or POF, time-triggered**	**D**	**Up to 25Mb/s**	**-Bus** **-Star**	**Up to 2V**	**- TDMA, predefined and fixed communication schedule (MEDL**	**- x-by-wire, Chassis (active safety)**
Flex Ray	**- hybrid paradigm, twisted pair (bus) or POF (star) , future de-facto standard , can be used in two modes (time or event triggered)**	**D**	**Up to 10 Mb/s**	**- bus** **- star** **- multi-star**	**3.3V to 5V**	**- TDMA in the static segment, FTDMA in the dynamic segment** **-predefined and fixed communication** **schedule (elementary cycle)** **- master/slave (for**	**- powertrain** **- chassis (active** **safety)** **- x-by-wire**

						synchronization	

Table 2: Summary of traditional in-vehicle communication network

III. NEW GENERATION IN-VEHICLE NETWORKS AND THEIR COMPARIONS

In future the connecting cables have a big impact on the vehicle in terms of mass (up to 50 kg) and installation cost because new generation in-vehicle networks demands dedicated buses for different applications, instead of having a single network [6]. The communication network of a modern vehicle is composed by several km of cables, with hundreds of connection points (usually more than 200). Therefore, that big complexity can easily lead also to diagnostic and maintenance issues.

Wi-Fi: Is the ultimate significance may be that it provides a glimpse of what will be possible with future wireless technologies. Wi-Fi was boosted by the growing popularity of high speed broadband internet connections in the home; it is the easiest way to enable several computers to share a broadband link. Using Wi-Fi, one can Quick/easy temp network access, Staff access to corporate network, Patron internet access (hotspot), Interconnecting two networks.

A wireless LAN (Wi-Fi) is a data transmission system designed to provide location-independent network access between computing devices by using radio waves rather than a cable infrastructure. Wi-Fi is meant to be used generically when referring to any type of 802.11 network, whether 802.11b, 802.11a, 802.11g etc. The first 802.11b networks could move data at up to 11 megabits per second (Mbps). Then came products using 802.11a, followed shortly thereafter by 802.11g, each with maximum speeds of 54Mbps and throughput of around 25Mbps. WLAN hardware built around 802.11g was quickly embraced by consumers and businesses seeking higher bandwidth. [7] The next Wi-Fi speed standard, 802.11n, will likely offer a bandwidth of around 108Mbps [8]. And because it will be an industry standard, n-compliant devices will be interoperable.

	802.11a	**802.11b**	**802.11g**	**802.11n**
Standard Approved	July 1999	July 1999	June 2003	Not yet ratified
Maximum Data Rate	54 Mbps	11Mbps	54 Mbps	600 Mbps
Modulation	OFDM	DSSS or CCK	DSSS or CCK or OFDM	DSSS or CCK or OFDM
RF Band	5 GHz	2.4 GHz	2.4 GHz	2.4 GHz or 5 GHz
Number of Spatial Streams	1	1	1	1,2,3, or 4
Channel Width	20 MHz	20 MHz	20 MHz	20 MHz or 40 MHz

Table 3: Comparison of the Primary IEEE 802.11 Specification

UWB (Ultra-wide band): is a technology for transmitting information spread over a large bandwidth. Ultra wideband broadcasts digital pulses that are timed very precisely on a carrier signal across a very wide number of frequency channels at the same time. This power-efficient solution will provide the high bandwidth required by the latest and future portable home and office devices for multiple digital video and audio streams.

UWB has recently attracted much attention as an indoor short-range high-speed wireless communication. [7]. One of the most exciting characteristics of UWB is that its bandwidth is over 110 Mbps (up to 480 Mbps) which can satisfy most of the multimedia applications such as audio and video delivery in home networking and it can also act as a wireless cable replacement of high speed serial bus such as USB 2.0 and IEEE 1394.

IEEE 802.15.3c: Is a high rate wireless personal area network developed by task group (TG3c) as a millimeter-wave-based alternative physical layer for existing WPAN's.

PLC (Power Line Communication): Power Line Communication (PLC) technology provides data transmission over direct current (DC) battery power-line. Doing that, it is possible to reduce the number of command and control cables, giving a clear advantage in terms of weight, space, and cost. Most PLC technologies limit themselves to one set of wires which are typically uses transformers to prevent propagating the signal, which requires multiple technologies to form very large networks.

This kind of transmission technology reached a satisfactory level of maturity during the last decade for the residential market, making it suitable also for in-vehicle applications. However, it is worth noting that indoor domestic PLC cannot be directly applied to cars without the due modifications and adaptations [16].

ZigBee: ZigBee is a widely used wireless sensor network in wireless communication technology, which is in the practical application not very ideal, especially in a large scale wireless zigbee sensor network, because the coordinator processing ability is very much limited at the earlier time. ZigBee provides self-organized, multi-hop, and reliable mesh networking with long battery lifetime [9-10]. ZigBee protocols are intended for use in embedded applications requiring low data rates and low power consumption. Though WPAN implies a reach of only a few meters, 30 feet in the case of ZigBee, the network will have several layers, so designed as to enable intrapersonal communication within the network, connection to a network of higher level and ultimately an uplink to the Web..Now days, in the large scale ZigBee wireless network the coordinator should deal with too much messages, which may be affects on information time delay, data packet loss, and sensor node out of control.

Standard	Wi-Fi	UWB	Zigbee	Bluetooth	PLC
IEEE Spec.	802.11a/b/g	802.15.3a*	802.15.4	802.15.1	P1901
Data rate	10 Mbps	400 Mbps	About 0.25 Mbps	Up to 3 Mbps	40 Mbps
Frequency band	2.4GHz, 5GHz	3.1-10.6GHz	868/915 MHz; 2.4 GHz	2.4 GHz	24-500 KHz
Max signal rate	54 Mb/s	110 Mb/s	250 Kb/s	1 Mb/s	Above 30 MHz
Nominal range	100 m	10m	10 – 100 m	10 m	< 100 m
Number of RF channel	14 (2.4 GHz)	1-15	1/10; 16	79	30-500 KHz
Channel bandwidth	22 MHz	500 MHz – 7.5 GHz	0.3/0.6 MHz; 2 MHz	1MHz	50-550 MHz
Modulation type	BPSK, QPSK COFDM, CCK, M-QAM	BPSK, QPSK	BPSK (+ ASK), O-QPSK	GFSK	OFDM
Basic cell	BSS	Piconet	Star	Piconet	--
Encryption	RC4 stream cipher (WEP), AES block cipher	AES block cipher (CTR, counter mode)	AES block cipher (CTR, counter mode)	E0 stream cipher	Rivest (128 Bit Key) DES (56 Bit Key)
Authentication	WPA2 (802.11i)	CBC-MAC (CCM)	CBC-MAC (ext. of CCM)	Shared secret	Shared secret
Data protection	32-bit CRC	32-bit CRC	16-bit CRC	16-bit CRC	8-bit CRC
Application	Wireless LAN, Internet	Non cooperative radar imaging, Target sensor data collection, Precision locating & tracking	Sensor Networks, Gaming, Network attach storage, Streaming music & video, Voice over IP	hands-free mobile phone systems, safety	Status monitoring & control, Automatic meta reading, Fire & security alarm

					system
Features	**Quick network access, Flexibility, Scalability, Lower cost**	**Very low energy level for short range high bandwidth communication**	**Cost effective, low battery & wireless connectivity, high throughput & low latency for low duty cycle application**	**Low power, low cost, short range communication**	**Low cost, simple to use, build in error checking**

Table 4: Summary of new generation in-vehicle networks

IV. ISSUES

More networks bring more cost. Obviously the number of ECUs per vehicle can't increase forever. An interesting way to cut down on the number of ECUs is to bundle functions into something called "domain controllers". This is a concept that has been talked about for awhile - sometimes called "regional computing" or generic "electric and electronic controllers (EECs). More progress needs to be made in vehicle electronic architectures. The industry has quite of experience in gateways, but not in routers, backplanes, or backbones. Another question is what networks will be needed to support hybrid and full electric vehicles? Many of the same protocols will suffice, but connecting dozens of battery packs or cells together is a new challenge [6].

V. FUTURE TRENDS

As vehicle industry has made great progress, new demands will be presented. For example, Different network systems may require for Electric vehicles, in-vehicle networking will develop rapidly. The following may be focussed on:

- High speed, real time, fault tolerant network control technique;
- Multimedia, broadband network;
- Luxuriant design and application of software;
- Standardization of network protocols.

VI. CONCLUSION

In this paper, we have compared the traditional in-vehicle networks and the new generation in-vehicle networks. In particular, LIN and TTP/A having low speed and cost and uses master/slave scheduling. D2B and MOST are meant for multimedia applications and they are having higher data rate. CAN is scalable and dependable due to its bus topology but CAN lack deterministic scheduling. LIN, FlexRay all provide deterministic scheduling. FlexRay bandwidth is variable with multiple channels available. LIN and FlexRay have a master node for handling scheduling of messages. CAN frames provide dependability and fault-tolerance via re-transmissions and error frames. CAN error frames and LIN diagnostic frames provide dependability and fault-tolerance, as well as security against network failures, attacks, or electromagnetic interference.

From an application point of view, Bluetooth is intended for a cordless mouse, keyboard, and hands-free headset and it comes in both traditional and new generation in-vehicle networks, UWB is oriented to high-bandwidth multimedia links, and ZigBee is designed for reliable wirelessly networked monitoring and control networks, while Wi-Fi is directed at computer-to-computer connections as an extension or substitution of cabled networks also PLC requires reduced number of command cables which results in reduced cost. The suitability of network protocols is greatly influenced by practical applications, of which many other factors such as the network reliability, roaming capability, recovery mechanism, chipset price, and installation cost need to be considered in the future.

VII. REFERENCES

[1] R. N. Charette, "This car runs on code," IEEE Spectrum, February, 2009

[2] Escar, Embedded security in cars 2006, Berlin, Germany, November 2006. http://escar.crypto.rub.de/06/general.html

[3] CAR 2 CAR Communication Consortiums. http://www.car-to-car.org/

[4] H. Kopetz, G. Grunsteidl, "TTP – A protocol for Fault-Tolerant Real- Time Systems". IEEE Computer, pages 14-23, January.

[5] T. Nolte. Share-driven scheduling of embedded networks. PhD Thesis. Malardalen University Press Dissertations, No. 26.

Department of Computer Science and Electronics, Malardalen University, Sweden, May 2006

[6] A. L. Lupini, "In-vehicle networking technology for 2010 and beyond," in Proc. of SAE 2010 World Congress & Exhibition , April 2010.

[7] Introduction to Wi-Fi technology, Retrieved on September 24, 2006 from www.wi-fitechnology.com

[8] Broadcom, 802.11n: Next-Generation Wireless LAN Technology, White Paper dated April 2006

[9] J. S. Lee, "Performance evaluation of IEEE 802.15.4 for low-rate Wireless personal area networks," IEEE Trans. Consumer Electron. , vol. 52, no. 3, pp. 742-749, Aug. 2006.

[10] J. S. Lee and Y. C. Huang, "ITRI ZBnode: A ZigBee/IEEE 802.15.4 Platform for wireless sensor networks," in Proc. IEEE Int. Conf. Systems, Man & Cybernetics , Taipei, Taiwan, Oct. 2006, pp. 1462-1467.

[11] CAN in automation. [Online]. Available: http://www.can-cia.org, June 2008.

[12] MOST cooperation. (Nov. 2008) MOST specification revision 3.0. [Online]. Available: http://www.mostnet.de

[13] D2B/SMARTwireX technology overview. (Dec. 2008). [Online]. Available: http://www.candc.co.uk

[14] LIN Consortium. (July 2008) LIN specification package, revision 2.0. [Online]. Available: http://www.lin-subbus.org

[15] FlexRay Consortium. (June 2008) FlexRay communication systems, Protocol specification. Available: http://www.flexray.com

[16] Khurram Hassain Zuberi, "Powerline carrier(PLC) Communication System" Master thesis, Department of Microelectronics and Information Technology, IMIT. Available: http://www.it.kth.ac