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Multiplex Bus Progression 2003

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ABSTRACT

A previous SAE 2001 Congress paper, "Multiplex Bus Progression" [1] introduced the idea of categorizing vehicle serial data protocols into additional areas beyond the traditional SAE Class A, B, and C. This paper will expand on that idea, and provide a 2003 update to the Diagnostics, SafetyBus, Mobile Media, and X-by-Wire categories. All existing mainstream vehicular multiplex protocols (approximately 40) are categorized using the SAE convention plus the new groupings. Top contenders will be pointed out along with a discussion of the protocol in the best position to become the industry standard in each category at this time.

INTRODUCTION

CURRENT MULTIPLEX CATEGORIES –The multiplexing of automotive electrical data onto communication buses dates back to the late 1970s. It was originally hoped that a single bus protocol could handle the needs of any vehicle. Gradually that expanded to the SAE categorization of Class A, B, and C and the realization that up to three protocols and/or networks may be necessary.

By 1995 the need for multiple buses per vehicle was becoming apparent [2]. The cost tradeoff, especially, was studied – do you put everything on one bus or split it up into several buses? Which is more economical? Which is more efficient?

This paper proposes the idea that at least eight in-vehicle networks may be necessary – mainly on high-end vehicles in the next ten years. These categories include (besides the existing SAE classes) diagnostics, airbag, mobile media, X-by-Wire, and wireless. Each area needs its own protocol and one or more networks running that protocol. Sometimes this is for safety reasons, such as with airbags or X-by-Wire. But regardless of vehicle function partitioning, we now have distinct classes of signals that will communicate over their own network, or networks (i.e. multiple sub-buses for smart connector) [3].

This paper may have a similar look to the previous one, but many of the protocol contenders have been updated. The comparison tables remain so as to retain a single source of reference.

Although not discussed at length in this paper, there is a distinction between protocol and network. Conceivably one might have the same protocol running on several networks – say CAN for both a body bus and a powertrain bus. So even though there could be eight or more networks, there may actually be fewer protocols used. Also, not all protocols are complete – meaning they specify attributes of all seven layers of the OSI model [4]. Some are only physical layers (i.e. GM UART, J1708). Some are only higher layers (i.e. TTP).

CURRENT STATUS OF THE OLD CATEGORIES

CLASS A – Usage is for low-end, non-emission diagnostic, general-purpose communication. Bit rate is generally less than 10 Kb/s and must support event-driven message transmission. Cost is generally about "x" adder per node. This cost includes any silicon involved (i.e. microprocessor module or transceiver, etc.), software, connector pin(s), service, etc. The "cost" data discussed in this paper is very crude and is only to be used to compare with other categories.

Not much has changed in the last couple of years in this area. LIN continues to make strides as a common subbus protocol. Proprietary protocols continue to disappear.

Some examples of Class A protocols are listed in Table 1a.

NAME:	USER:	USAGE:	MODEL YEARS:	COMMENTS:
UART	GM	Many	1985 - 2005+	Being phased out
Sinebus	GM	Audio	2000+	Radio steering wheel controls
E&C	GM	Audio/HVAC	1987 - 2002+	Being phased out
I^2C	Renault	HVAC	2000+	Used little
J1708/J1587/J1922	T&B	General	1985 - 2002+	Being phased out
CCD	Chrysler	HVAC, audio, etc.	1985 - 2002+	Being phased out
ACP	Ford	Audio	1985 - 2002+	
BEAN	Toyota	Body	1995+	
UBP	Ford	Rear backup	2000+	
LIN	many OEMs	Smart Connector	2003+	LIN Consortium developing

Table 1a: Some Class A Protocols

Most of these Class A protocols are UARTs. UART is very simple and economical to implement. Most microcontrollers have the necessary SCI module built-in, or it can be implemented without a microprocessor. The transceiver is smaller and cheaper than those of other protocols. The transceiver IC may be a custom chip combining multi-protocol capability with regulators, drivers, etc. Right now the leading candidate for a Class A world standard is LIN.

Table 1b compares some of the major attributes of some of the Class A protocols from Table 1a.

	BUS NAME							
FEATURE	UART(ALDL)	SINEBUS	E & C	I^2C	SAE J1708	ACP	BEAN	LIN
AFFILIATION	GM	DELCO	GM	PHILIPS	TMC - ATA	FORD	TOYOTA	Motorola
APPLICATION	GENERAL & DIAGNOSTICS	AUDIO	GENERAL		CONTROL & DIAGNOSTICS	AUDIO CONTROL	BODY CONTROL & DIAGNOSTICS	SMART SENSORS
MEDIA	SINGLE WIRE	SINGLE WIRE	SINGLE WIRE	TWISTED PAIR	TWISTED PAIR	TWISTED PAIR	SINGLE WIRE	SINGLE WIRE
BIT ENCODING	NRZ	SAM	PWM	AM	NRZ	NRZ	NRZ	NRZ
MEDIA ACCESS	MASTER/ SLAVE	MASTER/ SLAVE	CONTENTION		MASTER/ SLAVE	MASTER/ SLAVE	CONTENTION	MASTER/ SLAVE
ERROR DETECTION	8-bit CS	NONE	PARITY	ACK bit	8-bit CS	8-bit CS	8-bit CRC	8-bit CS
HEADER LENGTH	16 BITS	2 BITS	11 - 12 BITS		16 BITS	12 - 24 BITS	25 BITS	2 BITS/BYTE
DATA LENGTH	0 - 85 BYTES	10 - 18 bits	1 - 8 BITS			6 - 12 BYTES	1 - 11 BYTES	8 BYTES
OVERHEAD	Variable	75 %	Variable	45 %	Variable	25 %	28 %	2 BYTES
IN-MESSAGE RESPONSE	NO	NO	NO		NO	NO	NO	NO
BIT RATE	8192 b/s	66.6 KHz – 200 KHz	1000 b/s	1 - 100 Kb/s	9600 b/s	9600 b/s	10 Kb/s	1 - 20 Kb/s
MAXIMUM BUS LENGTH	Not Specified	10 METERS	20 METERS	Not Specified	Not Specified	40 METERS	Not Specified	40 METERS
MAXIMUM NODES	10		10			20	20	16
µ NEEDED?	YES	NO	YES		YES	YES	YES	NO
SLEEP/WAKEUP	NO	NO	NO		NO	NO	NO	YES
H/W AVAIL?	YES	NO	YES		YES	YES	YES (?)	NO
COST	LOW	LOW	LOW		MEDIUM	LOW	LOW	LOW

Table 1b: Comparison of Class A Protocols

CLASS B – Usage is for the vast majority of non-diagnostic, non-critical communication. Speed is between 10 Kb/s and approximately 125 Kb/s. Must support event-driven and some periodic message transmission plus sleep/wakeup. Cost is around 2x per node. Protocols used for Class B networks are listed in Table 2a.

NAME:	USER:	USAGE:	MODEL YEARS:	COMMENTS:
GMLAN (low)	GM	Many	2002+	GM only user; J2411 single wire CAN
GMLAN (mid)	GM	Infotainment	2002+	95.2 Kb/s– might be IDB-C
Ford MSCAN	Ford	Various	2004+	125 Kb/s; J2284
DCX LSCAN	Chrysler	Various	2004+	125 Kb/s; ISO 11519
ISO 11898	Europe	Many	1992+	Various speeds – 47.6 Kb/s to 500 Kb/s in use
J2284	GM,Ford, DC	Many	2001+	500 Kb/s; based on ISO 11898
Fault-tol CAN	Europe	Many	2000+	ISO 11519 CAN
Class 2	GM	Many	Until 2002+	J1850; being phased out
PCI	Chrysler	Many	Until 2002+	J1850
SCP	Ford	Many	Until 2002+	J1850
J1939	T&B	Many	1994+	Replacing J1708/1587/1922
Intellibustbd	tbd	tbd		In use for aircraft industry

Table 2a: Some Class B Protocols

The world standard in this area is still CAN. In particular, ISO 11898 at around 100 Kb/s for car applications and J1939 at 250 Kb/s for Truck & Bus applications. Both of these use the same digital circuitry and transceiver in many cases. J1850 continues its usage, and in fact may not have peaked yet in annual volume.

The ISO 11519-2 "fault-tolerant" low speed 2-wire CAN interface is becoming popular in some car applications, but is still a small percentage of implementations. This CAN physical layer is slower and costs more than an ISO 11898 interface, but the bus fault detection capability is enticing.

Intellibus is shown for the first time in this survey. It has not been picked up by any automotive applications yet, but holds promise due its low cost and flexibility.

Table 2b compares some of the major attributes of the Class B protocols from Table 2a.

	BUS NAME					
FEATURE	CAN 2.0 ISO 11898 ISO 11519-2 ISO 11992 J2284	J1850 ISO 11519-4			SAE J 1939	Intellibus
AFFILIATION	BOSCH/SAE/ISO	GM	FORD	CHRYSLER	TMC - ATA	Boeing/SAE
APPLICATION	CONTROL & DIAGNOSTICS	GENERAL & DIAGNOSTICS	GENERAL & DIAGNOSTICS	GENERAL & DIAGNOSTICS	CONTROL & DIAGNOSTICS	CONTROL & DIAGNOSTICS
TRANSMISSION MEDIA	TWISTED PAIR	SINGLE WIRE	TWISTED PAIR	SINGLE WIRE	TWISTED PAIR	TWISTED PAIR
BIT ENCODING	NRZ-5 MSb first	VPW MSb first	PWM MSb first	VPW MSb first	NRZ-5 MSb first	Manchester Bi-phase
MEDIA ACCESS	CONTENTION	CONTENTION	CONTENTION	CONTENTION	CONTENTION	Master/Slave
ERROR DETECTION	CRC	CRC	CRC	CRC	CRC	CRC, Parity
HEADER LENGTH	11 or 29 BITS	32 BITS	32 BITS	8 BITS	29 BITS	16 - 48 Bits
DATA FIELD LENGTH	0-8 BYTES	0-8 BYTES	0-8 BYTES	0-10 BYTE	8 BYTES	0 - 32 Bytes
MESSAGE OVERHEAD	9.9 % - 22 %	33.3 %	33.3 %	8.3 %	9.9 % - 22 %	28% - 75%
IN-MESSAGE RESPONSE	NO	Optional Normally NO	Optional Normally YES	Optional Normally YES	NO	Optional
BIT RATE	10 Kb/s to 1 Mb/s	10.4 K b/s	41.6 K b/s	10.4 K b/s	250 Kb/s	12.5 Mb/s
MAXIMUM BUS LENGTH	Not Specified 40 (Typical)	35 METERS (5 Meters for scan tool)	35 METERS (5 Meters for scan tool)	35 METERS (5 Meters for scan tool)	40 METERS	30 METERS
MAXIMUM NODES	Not Specified 32 (Typical)	32	32	32	30 FOR STP 10 FOR UTP	64
µ NEEDED?	YES	YES	YES	YES	YES	NO
SLEEP/WAKEUP	NO	YES	NO	NO	NO	YES
H/W AVAIL?	YES	YES	YES	YES	YES	FPGA
COST	MEDIUM	LOW	LOW	LOW	MEDIUM	MEDIUM

Table 2b: Comparison of Class B Protocols

CLASS C –Usage is for somewhat fast, higher bandwidth systems such as engine timing, fuel delivery, etc. Bit rate is between 125 Kb/s and 1 Mb/s. Must support real-time periodic parameter transmission (perhaps in the few milliseconds range). Unshielded twisted pair is the medium of choice instead of shielded twisted pair or fiber optics. Cost is about 3x to 4x per node, unless STP or fiber optics is involved – which is typically necessary above 500 Kb/s. Typical protocols used are listed in Table 3a.

NAME:	USER:	USAGE:	MODEL YEARS:	COMMENTS:
GMLAN (high)	GM	All	2002+	500 Kb/s; J2284
HSCAN	Ford	Various	2004+	500 Kb/s; J2284
HSCAN	Chrysler	Various	2004+	500 Kb/s; J2284
ISO 11898	Europe	Most	1992+	Various speeds of CAN
J1939	T&B	Most	1994+	250 Kb/s CAN

Table 3a: Some Class C Protocols

J1939 is commonly used for Class B and Class C applications for truck & bus, construction, agriculture, marine, and other industries. Most passenger car applications run ISO 11898 at 500 Kb/s for their Class C network. The big difference from CAN in Class B applications is the type of nodes that are connected. Total CAN usage, according to CAN in Automation (CiA) is in the hundreds of millions of nodes worldwide.

Table 3b compares some of the major attributes of the Class C protocols from Table 3a. GMLAN is not shown due to its confidentiality to GM.

	BUS NAME		
FEATURE	CAN 2.0 ISO 11898 ISO 11519-2 ISO 11992 J2284	SAE J1939	Intellibus
AFFILIATION	BOSCH/SAE/ISO	TMC - ATA	Boeing/SAE
APPLICATION	CONTROL & DIAGNOSTICS	CONTROL & DIAGNOSTICS	CONTROL & DIAGNOSTICS
TRANSMISSION MEDIA	TWISTED PAIR	TWISTED PAIR	TWISTED PAIR
BIT ENCODING	NRZ-5 MSb first	NRZ-5 MSb first	Manchester Bi-phase
MEDIA ACCESS	CONTENTION	CONTENTION	Master/Slave
ERROR DETECTION	CRC	CRC	CRC, Parity
HEADER LENGTH	11 or 29 BITS	29 BITS	16 - 48 Bits
DATA FIELD LENGTH	0-8 BYTES 11 or 29-bit ID	MOST ARE 8 BYTES 29-bit ID	0 - 32 Bytes
MESSAGE OVERHEAD	9.9 % - 22 %	9.9 % - 22 %	28% - 75%
IN-MESSAGE RESPONSE	NO	NO	Optional
BIT RATE	10 Kb/s to 1 Mb/s	250 Kb/s	12.5 Mb/s
MAXIMUM BUS LENGTH	Not Specified 40 (Typical)	40 METERS	30 METERS
MAXIMUM NODES	Not Specified 32 (Typical)	30 W/ SHIELDED TWISTED PAIR 10 W/ UNSHIELDED TP	64
μ NEEDED?	YES	YES	NO
SLEEP/WAKEUP	NO	NO	YES
H/W AVAIL?	YES	YES	FPGA
COST	MEDIUM	MEDIUM	MEDIUM

Table 3b: Comparison of Class C Protocols

NEWER CATEGORIES

EMISSIONS DIAGNOSTICS – Usage is to satisfy OBD-II, OBD-III, or E-OBD. Must be a legally acceptable protocol. Protocols used today (or soon) are listed in Table 4a. There is overlap with some of the other categories.

NAME:	USER:	USAGE	MODEL YEARS:	COMMENTS:
ISO 15765-4	Europe	E-OBD	2000+	E-OBD CAN
ISO 15765-4	All	OBD-III	2007+	OBD harmonized
J 1850	GM, Ford, DC	OBD-II	1994+	Not accepted in Europe
ISO 9141-2	Europe, Asia, some U.S.	OBD-II, general	1994+	Old OBD-II UART
ISO 14230-4	Many	OBD-II, OBD-III	2000+	Keyword 2000

Table 4a: Some Emission Diagnostics Protocols

Since this data link is only needed between the engine controller and the off-board connector, a simple approach is sufficient. Most automakers and truck makers are using KW2000 (ISO 14230) already so this is rapidly becoming the emissions diagnostic standard. In the U.S., high-speed CAN will be phased-in as the "OBD-III" emissions test interface beginning in MY04. This will be the only legally acceptable protocol by MY07. SAE J2480 was an initiative to develop a CAN emissions diagnostic interface, but it was found to overlap with ISO 15765 so it has been abandoned. General information on these protocols is shown in Table 4b.

	BUS NAME					
FEATURE	**ISO 15765**	**J1850 ISO 11519-4**			**ISO/DIS 9141 ISO/DIS 9141-2**	**KEYWORD xx (71, 72, etc.)**
AFFILIATION	ISO	GM	FORD	CHRYSLER	WORLD	Various
APPLICATION	EMISSIONS DIAGNOSTICS	GENERAL & DIAGNOSTICS	GENERAL & DIAGNOSTICS	GENERAL & DIAGNOSTICS	DIAGNOSTICS ONLY	DIAGNOSTICS
TRANSMISSION MEDIA	TWISTED PAIR	SINGLE WIRE	TWISTED PAIR	SINGLE WIRE	SINGLE WIRE	1-WIRE
BIT ENCODING	NRZ	VPW MSb first	PWM MSb first	VPW MSb first	NRZ (strt, 7D, P, stop) LSb first	NRZ
MEDIA ACCESS	TESTER/ SLAVE	CONTENTION	CONTENTION	CONTENTION	TESTER/SLAVE	MASTER/ SLAVE
ERROR DETECTION	CRC	CRC	CRC	CRC	PARITY (odd)	x-bit CS
HEADER LENGTH		32 BITS	32 BITS	8 BITS	Not Specified	16 BITS
DATA FIELD LENGTH		0-8 BYTES	0-8 BYTES	0-10 BYTE	Not Specified	0 - 85 BYTES
MESSAGE OVERHEAD		33.3 %	33.3 %	8.3 %	Variable	Variable
IN-MESSAGE RESPONSE		Optional Normally NO	Optional Normally YES	Optional Normally YES	NO	NO
BIT RATE		10.4 K b/s	41.6 K b/s	10.4 K b/s	<10.4 Kb/s	5 b/s - 10.4 Kb/s
MAXIMUM BUS LENGTH		35 METERS (5 Meters for scan tool)	35 METERS (5 Meters for scan tool)	35 METERS (5 Meters for scan tool)	Limited by total impedance to ground	Not Specified
MAXIMUM NODES		32	32	32	Limited by total impedance to ground	10
μ NEEDED?		YES	YES	YES	YES	YES
SLEEP/ WAKEUP		YES	NO	NO	NO	NO
H/W AVAIL?		YES	YES	YES	YES	YES
COST		LOW	LOW	LOW	LOW	LOW

Table 4b: Comparison of Emission Diagnostics Protocols

MOBILE MEDIA – Usage is for "PC-on-wheels" applications. At least two different networks and protocols may be necessary. These sub-categories will be referred to as low speed and high speed. Beginning with this paper wireless is now in its own category. The necessary bit rate for mobile media applications is between 250 Kb/s and 100 Mb/s+.

Low Speed - Usage is for telematics, diagnostics, and general information passing. Cost is around 3x per node. IDB-C, a token-passing form of CAN at 250 Kb/s, has fallen out of favor. Most OEMs already have a mid-speed bus based on CAN to handle low-end telematics communication functions. There has been recent interest in a lower cost "high-end" network that can handle digital audio streams, but not necessarily video. Toward that end, the D2B and MOST developers are working on copper-based solutions. Depending on the EMC performance, 10 Mb/s, 25 Mb/s, or even 50 Mb/s bit rates are being proposed. Table 5a lists some possible low-speed mobile media protocols.

NAME:	USER:	MODEL YEARS:	COMMENTS:
IDB-C	none long term	2002+	250 Kb/s CAN; **www.idbforum.org**
D2B SmartwireX	tbd	2005+	**www.candc.co.uk/candc_company**
MOST over copper	tbd	2005+	**www.mostcooperation.com**

Table 5a: Some Low-Speed Mobile Media Bus Protocols

High Speed - Usage is for real-time audio and video streaming. Cost is around 15x to 25x, mainly due to fiber optics. Fiber optics will be necessary due to the high speed required to pass real-time video streams from multiple sources to multiple outputs. Will probably have to be compatible with industry-standard systems such as Connected Car PC, or AutoPC. D2B has seen the first usage (Mercedes 1999 S-class) but MOST appears to be the top contender at this time. The IDB Forum is leaning toward Firewire via an effort called "IDB-1394". The Automotive Multimedia Interface Collaboration (AMI-C) has set their sights on MOST and Firewire. Table 5b lists some possible high-speed mobile media protocols. Table 5c is a summary of details on some of the low-speed and high-speed protocols.

NAME:	USER:	YEAR:	COMMENTS:
D2B	Mercedes, Jaguar	1999+	**www.candc.co.uk/candc_company**
MOST	BMW, GM, DC, Ford, VW, Toyota	2000+	**www.mostcooperation.com**
Firewire	DC	2000+	**www.1394ta.org**
USB	Clarion	1998+	**www.autopc.com**
IntelliBus	Boeing	2004+	**www.intellibusnetworks.com**

Table 5b: Current High-Speed Mobile Media Bus Protocols

	BUS NAME						
FEATURE	**IDB-C**	**Intellibus**	**MOST**	**SmartWireX**	**MML**	**USB**	**IEEE 1394**
AFFILIATION	SAE	Boeing/SAE	Oasis	C&C	DELCO	Commercial	IEEE
APPLICATION	Aftermarket Entertainment	CONTROL & DIAGNOSTICS	Stream Data & Control	STREAM DATA & CONTROL	STREAM DATA & CONTROL	PC DEVICES	PC DEVICES
TRANSMISSION MEDIA	2-Wire	TWISTED PAIR	Optical	TWISTED PAIR	OPTICAL FIBER	SHIELDED TWISTED PAIR	SHIELDED TWISTED PAIR
BIT ENCODING	NRZ	Manchester Bi-phase	BiPhase	PWM	NRZ	NRZ	NRZ
MEDIA ACCESS	Token-slot	Master/Slave	Master/Slave	Master/Slave	Master/Slave	Contention	Contention
ERROR DETECTION	15-bit CRC	CRC, Parity	CRC	Parity	CORRECTING (optional)	CRC	CRC
HEADER LENGTH	11 BITS	16 - 48 Bits			1 BYTE		
DATA LENGTH	8 BYTES	0 - 32 Bytes			1 - 200+ BYTES		
MESSAGE OVERHEAD	~ 32 BITS	28% - 75%			5 - 10 %	25 %	25 - 30 %
IN-MESSAGE ACK.	1 ACK BIT	Optional	No	No	No		
BIT RATE	250 Kb/s	30 Mb/s	25 Mb/s	tbd kb/s	110 Mb/s	12 Mb/s	98 - 393 Mb/s
MAXIMUM BUS LENGTH	TBD	30 METERS	TBD	150 METERS	10 METERS		72 METERS
MAXIMUM NODES	16	64	24	50	16	127	16
μ NEEDED?	YES	NO	YES	YES	YES	YES	YES
SLEEP/WAKEUP	YES	YES	YES	YES	YES	NO	NO
H/W AVAIL?	NO	FPGA	YES	YES	NO	YES	YES
COST	LOW	LOW	HIGH	HIGH	HIGH	MEDIUM	MEDIUM

Table 5c: Comparison of Mobile Media Protocol

Wireless – Usage somewhat undetermined at this time. Will be necessary (initially) for cell phones and palm PCs (PDAs). Eventual use may include cameras, pagers, etc. Cost target is around 5x per node.

Much of the advertisement attention has been with Bluetooth. However, 802.11 also has its proponents, so many groups and suppliers are studying co-location so that products containing either standard can exist near each other. Ultrawideband (UWB) is the wild card that some think will "blow Bluetooth and 802.11 away". Approved by the U. S. Federal Communications Commission (FCC) in February 2002, it is essentially "white noise" communication. Using precise clocking, tiny amounts of information are transported across a very wide range of frequencies at very low power (perhaps 1/10000 that of a cell phone). Compared with spread spectrum which uses a small range of frequencies one at a time, UWB uses a wide range of frequencies all at once. UWB can be used for global position sensing, works indoors, and easily penetrates obstructions.
Leading wireless protocols are listed in Table 6.

NAME:	USER:	MODEL YEARS:	COMMENTS:
Bluetooth	tbd	2005+	**www.bluetooth.com**
IEEE 802.1	tbd	tbd	**www.ieee802.org/11**
UWB	tbd	tbd	**www.uwb.org**

Table 6: Current Wireless Mobile Media Bus Protocols

SAFETYBUS – Usage is for airbag systems. There may be two, or more, buses such as one for firing and one for sensing. Must support at least 64 nodes consisting of squibs, accelerometers, occupant sensors, seatbelt pretensioners, etc. Cost is (hoped to be) 1x to 2x per node. The USCAR "SafetyBus" committee was attempting to standardize on a suitable protocol, but degraded into separate, independent, camps. The two main ones are Safe-by-Wire and BST. Byteflight is in production in at least one BMW vehicle. Table 7a is the list of current airbag network protocols.

NAME:	USER:	YEARS:	COMMENTS:
Safe-by-Wire	tbd	2002+	Delphi-TRW-Philips-Autoliv-SDI
BST	tbd	2002+	Bosch-Siemens-Temic
DSI	tbd	2002+	Motorola/AMP
Byteflight	BMW	2002+	"ISIS", SI

Table 7a: Current SafetyBus Protocols

Many issues here involving packaging constraints, existing mechanical envelop, legalities, etc. The winning protocol may well be a hybrid of several existing proposals. In fact, BST and Safe-by-Wire are actually hybrids of earlier protocols. For now there is no clear industry direction. Table 7b compares these protocols.

	BUS NAME			
FEATURE	**BST**	**SafeByWire**	**DSI**	**Byteflight**
AFFILIATION	Bosch-Siemens-Temic	Delphi-Philips-TRW-Autoliv-SDI	Motorola	BMW
APPLICATION	Airbag	Airbag	Airbag	Airbag
TRANSMISSION MEDIA	2-WIRE	2-WIRE	2-WIRE	2-WIRE or 3-WIRE or optical
BIT ENCODING	Manchester Biphase	3-level voltage	3-level voltage	
MEDIA ACCESS	MASTER/ SLAVE	MASTER/ SLAVE	MASTER/ SLAVE	MASTER/ SLAVE
ERROR DETECTION	Odd Parity and/or CRC	8-bit CRC	4-bit CRC	16-bit CRC
HEADER LENGTH	Various	Various	Various	Various
DATA FIELD LENGTH	1 byte	1 byte	1 - 2 bytes	1 byte
MESSAGE OVERHEAD				
IN-MESSAGE ACK.	NO	NO	NO	NO
BIT RATE	31.25 Kb/s, 125 Kb/s, 250 Kb/s	150 Kb/s	5 Kb/s - 150 Kb/s	10 Mb/s
MAXIMUM BUS LENGTH	TBD	25 - 40 m	TBD	TBD
MAXIMUM NODES	12 squibs, 62 slaves	64	16	
μ NEEDED?	NO	NO	NO	NO
SLEEP/WAKEUP	NO	NO	NO	NO
H/W AVAIL?	YES	YES	YES	YES
COST	LOW	LOW	LOW	LOW

Table 7b: Comparison of SafetyBus Protocols

DRIVE-BY-WIRE – Usage is for brake-by-wire, throttle-by-wire, steer-by-wire, etc. applications. Bit rate is between 1 Mb/s and 10 Mb/s. Fiber optics will be necessary due to the increased speed. The utmost in reliability, performance, and real-time capability is required. Cost is around 15x+ per node. Some possible candidate protocols are given in Table 8a.

NAME:	USER:	YEARS:	COMMENTS:
TTP/C	BMW, Audi	2004+	**www.tttech.com**
TTCAN	tbd	tbd	**www.can-cia.de**
FlexRay	BMW, DC, GM, Audi	2004+	**www.flexray-group.com**

Table 8a: Current Drive-by-Wire Protocols

TTP has the momentum, but work is underway to see if CAN is capable of doing the job (i.e. TTCAN). Meanwhile, FlexRay continues to win support. At this time, none of these protocols are in an automotive application. A major issue is how much fault tolerance is really required. Any scheme will require dual bus interfaces, dual microprocessors, bus watchdogs, timers, etc. Cost is a big problem. The level of fault-tolerance needed requires a lot of silicon and software which, of course, is expensive. The consortium TTAgroup (www.ttagroup.org) is trying to standardize on a protocol, but (like other consortiums) will apparently allow a choice of protocols - either TTP/C or FlexRay. Who knows, in a couple more years TTCAN may be chosen too! Table 8b is a comparison of these protocols' details.

	BUS NAME			
FEATURE	**TTP**	**Intellibus**	**FlexRay**	**TTCAN**
AFFILIATION	U-VIENNA	Boeing/SAE	Motorola	CiA
APPLICATION	Safety Control	Safety Control	Safety Control	Safety Control
TRANSMISSION MEDIA	Not Specified	Twisted pair	Twisted pair or fiber	Twisted pair
BIT ENCODING	Not Specified	Manchester Bi-phase	NRZ	NRZ-5
MEDIA ACCESS	Isochronous	Master/Slave	Time or Priority	Time or Contention
ERROR DETECTION	16-bit CRC	CRC, Parity	24-bit CRC	15-bit CRC
HEADER LENGTH	1 Byte	16 - 48 Bits	40 Bits	11 - 29 Bits
DATA FIELD LENGTH	16 Bytes	0 - 32 Bytes	0 – 246 Bytes	0 - 8 Bytes
MESSAGE OVERHEAD	18.75 %	28% - 75%	3% - 100%	9.9 - 22%
IN-MESSAGE ACK.	YES	Optional	NO	YES
BIT RATE	Not Specified	12.5 Mb/s	10 Mb/s	1 - 2 Mb/s
MAXIMUM BUS LENGTH	Not Specified	30 meters	Not Specified	40 meters
MAXIMUM NODES	Not Specified	64	Not Specified	32
μ NEEDED?	YES	NO	YES	YES
SLEEP/WAKEUP	NO	YES	YES	YES
H/W AVAIL?	NO	FPGA	NO	YES
COST	HIGH	LOW	MEDIUM	LOW

Table 8b: Comparison of Drive-by-Wire Protocols

CONCLUSION

Multiple buses per vehicle have been a reality for some time. Primarily this has been because of re-use, and carryover of existing networks and protocols. However, in the near future new functions such as smart connectors, drive-by-wire, and mobile multi media has been forcing the need for additional protocols and networks. Despite the best intentions of OEMs, this will continue. There is no "one bus fits-all". Instead, there are different buses for different things.

REFERENCES

1. SAE 2001-01-0060 "Multiplex Bus Progression" Lupini
2. SAE 950293 – "Aspects and Issues of Multiple Vehicle Networks" Emaus
3. SAE 2001-01-0072 "LIN Bus and its Potential for Use in Distributed Multiplex Systems" Ewbank, Lupini, Perisho, DeNuto, Kleja
4. ISO 7498 - Data Processing Systems, Open Systems Interconnection Standard Reference Mode.
5. www.lin-subbus.org

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