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ADVANCED INFORMATION AND COMMUNICATION NETWORKS FOR VEHICLE CONTROL

Florian Dietze, Štefan Kozák

Abstract:

The paper deals with the design and application of advanced communication technologies for vehicle process control. We propose the modification of existing bus systems in order to create a unique system which grants benefits for a radical approach. The sum of all modifications will lead to a revolutionary new bus access method which is suitable for existing control units and fit for future demands by eliminating the restrictions of existing bus technologies and simultaneous implying the benefits of the different access methods.

Keywords:

Applied informatics, communication networks, Bus technology, CAN bus, FlexRay Bus, Most Bus.

Introduction

From the very beginning of automobile creation in the late 19^{th} century, the benefits of individual travelling caused more and more people to use cars. The demands of the owners and legal regulations to increase safety have increased the features enormously and force the automotive industry to continuously develop better cars. The electronics have a severe influence to the convenience and safety of the customer. Just 50 years back, the light was the only electronic device on board. Now, electronic is a major part of every single car concept. While some electronics are hidden (like electronic fuel injection), others bring new experiences to the customer, like global positioning system (GPS) based navigation.

For all vehicle concepts, which are considered in this document, there are requirements for the cross-linking, which may be identical. This is because all vehicles have the commonness to meet the requirements of traffic safety. So, in any small cars as well as the most expensive luxury vehicle blinkers, we can find wipers and brake lights, to list just a few common examples. While the design of the systems often differs fundamentally, the connection to a vehicle networking concept does not necessarily. Whether chic LED or old-fashioned light bulb taillights: in both cases, a signal from the brake pedal to the brake light in the rear is routed. There are also components that despite the same tasks have very different demands on the network. The headlight of a small car has light bulbs for low beam, high beam, parking lights and turn signals. To realize a luxury car add some motors and positioning controllers to adaptive headlights, automatic headlamp levelling, bi-xenon function and different brightness of the LED strip to DRL or sidelight. The fog lights in addition unilaterally light up when cornering. Hence, there is need to create individual concepts for different classes of vehicles.

However, this can then be used for several variants, as another body style (e.g. station wagon instead Saloon) has no dramatic effect on the functions. In modern vehicles almost all electrical components are interconnected [2]. The degree of crosslinking is dependent on the number of electronics, the field of use of the vehicle and in particular the class.

In order to control all the functions required of the vehicle, the car manufacturer could use a central computer, which would have to be very fast and expensive and had to connect each actuator, sensor or switch with at least one line (safety components additional monitoring lines).

This would result in a thick and heavy harness and in addition lead to higher fuel consumption, significantly higher manufacturing cost, since copper cables are not cheap at all. Alternatively, you can split the functions of the car. For similar tasks create functional blocks, which can then be laced into a closed area to avoid long connections. Another advantage of this concept is that it is characterized by short connection injects less conducted and radiated interference into the line. In the automotive world these function blocks are called electronic control units (ECUs) or components.

The components are in most cases not able to perform its task without information from other components. But not all of the data of each control device is important for the function. The stability management certainly needs the wheel speed sensor data, but no information on whether the rear wiper is currently active. The components must indeed exchange data, but they can be summed up in one another (more / less) independent groups. The demands on the data rate are quite different. A power window switch is usually operated less often than a wheel sensor passes its speed value. The faster the data transfer needed, the more expensive is the essential bus. The current bus systems are currently used in the following chapter explained again in detail. Certain information is important for all components, such as whether the ignition is turned on, or the car is parked and every single component should change to a low-power mode in order to save battery power. The essential information needed by several groups, are transported via a gateway control device into the respective group. Individual groups of controllers can be combined in bus systems that are significantly different.

The choice of the appropriate bus system depends on many factors: the required data rate and quantity, safety requirements, portability to other vehicle concepts, expandability and more. But certainly a big factor is the affordability of the concept. Especially in the compact car class, cost pressure assumes enormous influence on the decision of the applicable options. In general, the price of a bus system increases with its transmission speed. Universal and widely used systems are also cheaper than exotic custom solutions. Such special buses are found hardly. Systems from other areas (eg, Ethernet), which, although cheap and widely spread and would therefore be seen gladly for financial reasons. But these systems often do not meet the stringent technical requirements for automotive electronics. Thus, for example, Ethernet devices designed for room temperature and plugs of patch cables do not provide sufficient protection against dust and vibration in the engine compartment. Systems for military applications provide certainly technically perfect conditions, but considering the cost would cause tears to the watchful eyes of the controlling department. For derivatives that are designed for entry markets, rather simple networking concepts are in the specifications. This allows cost savings in the double sense:

The number of networked control units is reduced and also the wiring harness of the vehicle is less expensive and lighter. Since common networks, especially in the low-price segment are based on copper interconnects, this means cost reduce due to currently high raw material prices.

High-priced luxury cars have networked features that would not be possible without networking: camera-based environmental sensors, ultrasonic based parking systems, distance RADAR and LIDAR can be merged so that the sensor cloud creates a digital image of the vehicle environment. The mutual plausibility of data of different measurement methods can be life saving in certain circumstances, important decisions, such as pre-crash detection, multi-collission brake assists, safety isolation of high-voltage systems.

Here classic CAN-based networking solutions are reaching their limits. Firstly, the bus load increases with the number of networked control units and the associated bus load. Too high bus load makes the crosslinking unstable, so in these cases the control units, after their installation or area separated into different sub-buses (which means that, in some currently produced SUVs up to seven CAN bus via a gateway, communicate with each other). Secondly, just safety-critical applications need to check the plausibility of data not only the readings but also a temporal mapping in order to derive the change and the rate of change from it.

1 Automotive Communication Systems

This part of paper provides information about bus systems which are used in nearly every single car produced nowadays.

A bus is a subsystem that transfers data between components inside a device or between devices inside of a system. Unlike a point-to-point connection, a bus can logically connect several electronic control units over the same set of wires.

Each bus defines its set of physical connectors, timing and access methods together. In the automotive industry, several bus system have been established, tailored to the requirements that are expected in today's vehicles. CAN and LIN are the most established, MOST has found its place with the implementation of multimedia interfaces in 21st century. The latest bus system is currently FlexRay.

2 Advanced Automotive Bus Systems

FlexRay marks the latest development of bus systems at the moment (Fig.1). It was created by a consortium of car manufacturers, suppliers and semiconductor producers in the years 2000 to 2010. It is found in high-class premium cars like Audi Q7, BMW X5 and 7series, Mercedes S-class.

It is a serial deterministic and fault tolerant bus system, which should be up to the task on the vehicle network in the near future. Advantage over the CAN is the real-time capability, higher data transfer rates and reliability. Several channels (typically two) that are synchronized with each other, can interconnect the participants. In case of short circuit /interruption of a single channel communication still takes place [1]. Similarly to CAN, data is packed into frames, but the access to the bus is managed differently. There is a static segment, in which participants are allowed to send in a defined sequence data packets of fixed length (a ECU may also several packets send by it is assigned multiple IDs) and a dynamic segment, messages in the subscriber in a fixed oder flexible length. The fixed order is necessary since (unlike CAN) no arbitration is possible due a missing recessive bus level. FlexRay has three states: "0", "1" and "idle", and all three are dominant. The sender of a message that reads back the same time and therefore cannot see any bus errors due to collisions. It is not specified to send error frames by other participants on the bus during transmission. Fault is detected at the end of the frame for several error sums (CRC header and data CRC).

FlexRay charakteristics and parameters:

- max. data transmission: 10 Mbit/s per channel
- max. length of wiring: 24m (48m in an active star topology)
- based on twisted pair copper harness
- guaranteed latency
- flexible topology

The FlexRay communications bus is a deterministic, fault-tolerant and high-speed bus system developed in conjunction with automobile manufacturers and leading suppliers. FlexRay delivers the error tolerance and time-determinism performance requirements for x-by-wire applications (i.e. drive-by-wire, steer-by-wire, brake-by-wire, etc.). This appendix covers the basics of FlexRay. Increasing Communications Demands For automobiles to continue to improve safety, increase performance, reduce environmental impact, and enhance comfort, the speed, quantity and reliability of data communicated between a car's electronic control units (ECU) must increase. Advanced control and safety systems--combining multiple sensors, actuators and electronic control units--are beginning to require synchronization and performance past what the existing standard, Controller Area Network (CAN), can provide.

Coupled with growing bandwidth requirements with today's advanced vehicles utilize over five separate CAN busses, automotive engineers are demanding a next-generation, embedded network. After years of partnership with OEMs, tool suppliers, and end users, the FlexRay standard has emerged as the in-vehicle communications bus to meet these new challenges in the next generation of vehicles. Adoption of a new networking standard in complex embedded designs like automobiles takes time. While FlexRay will be solving current high-end and future mainstream in-vehicle network challenges, it will not displace the other two dominant in-vehicle standards, CAN, and LIN. In order to optimize cost and reduce transition challenges, the next generation of automobiles will contain FlexRay for high-end applications, CAN for mainstream powertrain communications and LIN for low-cost body electronics.

Understanding how FlexRay works is important to engineers across all aspects of the vehicle design and production process. This article will explain the core concepts.

Many aspects of FlexRay are designed to keep costs down while delivering top performance in a rugged environment.

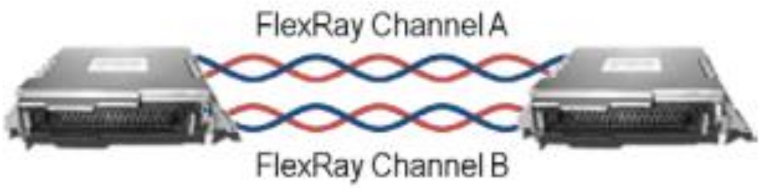

Fig.1. FlexRay system basic communication structure.

FlexRay uses unshielded twisted pair cabling to connect nodes together. FlexRay supports single- and dual-channel onfigurations which consist of one or two pairs of wires respectively. Differential signaling on each pair of wires reduces the effects of external noise on the network without expensive shielding. Most FlexRay nodes typically also have power and ground wires available to power transceivers and microprocessors.

Dual-channel (Fig.1) configurations offer enhanced fault-tolerance and/or increased bandwidth. Most first-generation FlexRay networks only utilize one channel to keep wiring costs down, but as applications increase in complexity and safety requirements, future networks will use both channels.

FlexRay buses require termination at the ends, in the form of a resistor connected between the pair of signal wires. Only the end nodes on a multi-drop bus need termination. Too much or too little termination can break a FlexRay network. While specific network implementations vary, typical FlexRay networks have a cabling impedance between 80 and 110 Ohms, and the end nodes are terminated to match this impedance. Termination is one of the most frequent causes of frustration when connecting a FlexRay node to a test setup. Modern PC-based FlexRay interfaces may contain on-board termination resistors to simplify wiring.

2.1 FlexRay Topology and Layout

One of the things that distinguishes FlexRay, CAN and LIN from more traditional networks such as ethernet is its topology, or network layout. FlexRay supports simple multi-drop passive connections as well as active star connections for more complex networks. Depending a vehicle's layout and level of FlexRay usage, selecting the right topology helps designers optimize cost, performance, and reliability for a given design.

Multi-drop Bus FlexRay is commonly used in a simple multi-drop bus topology that features a single network cable run that connects multiple ECUs together. This is the same topology used by CAN and LIN and is familiar to OEMs, making it a popular topology in first-generation FlexRay vehicles.

Each ECU can "branch" up to a small distance from the core "trunk" of the bus. The ends of the network have termination resistors installed that eliminate problems with signal reflections. Because FlexRay operates at high frequencies, up to 10 Mbit/s compared to CAN's 1 Mbit, FlexRay designers much take care to correctly terminate and lay out networks to avoid signal integrity problems.

The multi-drop format also fits nicely with vehicle harnesses that commonly share a similar type of layout, simplifying installation and reducing wiring throughout the vehicle.

2.2 Star Network

The FlexRay standard supports "Star" configurations which consist of individual links that connect to a central active node. This node is functionally similar to a hub found in PC ethernet networks. The active star configuration makes it possible to run FlexRay networks over longer distances or to segment the network in such a way that makes it more reliable should a portion of the network fail. If one of the branches of the star is cut or shorted, the other legs continuing functioning. Since long runs of wires tend to conduct more environmental noise such as electromagnetic emissions from large electric motors, using multiple legs reduces the amount of exposed wire for a segment and can help increase noise immunity.

2.3 Hybrid Network

The bus and star topologies can be combined to form a hybrid topology. Future FlexRay networks will likely consist of hybrid networks to take advantage of the ease-of-use and cost advantages of the bus topology while applying the performance and reliability of star networks where needed in a vehicle.

The FlexRay Protocol protocol is a unique time-triggered protocol that provides options for deterministic data that arrives in a predictable time frame (down to the microsecond) as well as CAN-like dynamic event-driven data to handle a large variety of frames. FlexRay accomplishes this hybrid of core static frames and dynamic frames with a pre-set communication cycle that provides a pre-defined space for static and dynamic data. This space is configured with the network by the network designer. While CAN nodes only needed to know the correct baud rate to communicate, nodes on a FlexRay network must know how all the pieces of the network are configured in order to communicate. As with any multi-drop bus, only one node can electrically write data to the bus at a time. If two nodes were to write at the same time, you end up with contention on the bus and data becomes corrupt.

There are a variety of schemes used to prevent contention on a bus. CAN, for example, used an arbitration scheme where nodes will yield to other nodes if they see a message with higher priority being sent on a bus. While flexible and easy to expand, this technique does not allow for very high data rates and cannot guarantee timely delivery of data. FlexRay manages multiple nodes with a Time Division Multiple Access or TDMA scheme. Every FlexRay node is synchronized to the same clock, and each nodes waits for its turn to write on the bus.

Because the timing is consistent in a TDMA scheme, FlexRay is able to guarantee determinism or the consistency of data deliver to nodes on the network. This provides many advantages for systems that depend on up-to-date data between nodes.

Embedded networks are different from PC-based networks in that they have a closed configuration and do not change once they are assembled in the production product. This eliminates the need for additional mechanisms to automatically discover and configure devices at run-time, much like a PC does when joining a new wired or wireless network. By designing network configurations ahead of time, network designers save significant cost and increase reliability of the network. For a TDMA network such as FlexRay to work correctly, all nodes must be configured correctly. The FlexRay standard is adaptable to many different types of networks and allows network designers to make tradeoffs between network update speeds, deterministic data volume, and dynamic data volume among other parameters. Every FlexRay network may be different, so each node must be programmed with correct network parameters before it can participate on the bus.

To facilitate maintaining network configurations between nodes, FlexRay committee standardized a format for the storage and transfer of these parameters in the engineering process. The Field Bus Exchange Format, or FIBEX file is an ASAM-defined standard that allows network designers, prototypers, validaters, and testers to easily share network parameters and quickly configure ECUs, test tools, hardware-in-the-loop simulation systems, and so on for easy access to the bus.

2.4 The Communication Cycle

The FlexRay (Fig.2) communication cycle is the fundamental element of the media-access scheme within FlexRay. The duration of a cycle is fixed when the network is designed, but is typically around 1-5 ms. There are four main parts to a communication cycle:

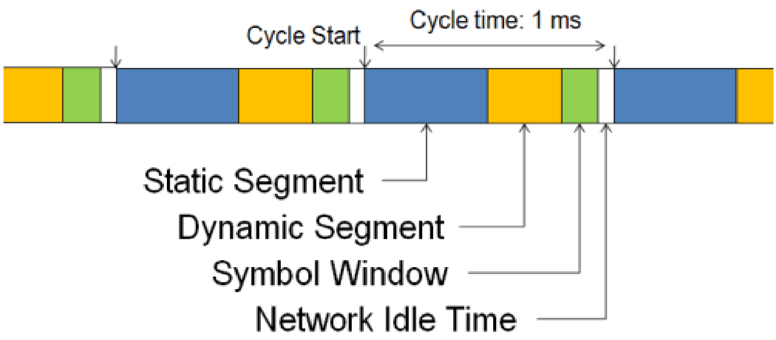

Fig.2. Communication cycle in FlexRay.

2.4.1 Static Segment

Actual FlexRay networks may contain up to several dozen static slots - reserved slots for deterministic data that arrives at a fixed period (Fig.3).

The static segment, represented as the blue portion of the frame, is the space in the cycle dedicated to scheduling a number of time-triggered frames. The segment is broken up into slots, each slot containing a reserved frame of data. When each slot occurs in time, the reserved ECU has the opportunity to transmit its data into that slot. Once that time passes, the ECU must wait until the next cycle to transmit its data in that slot.

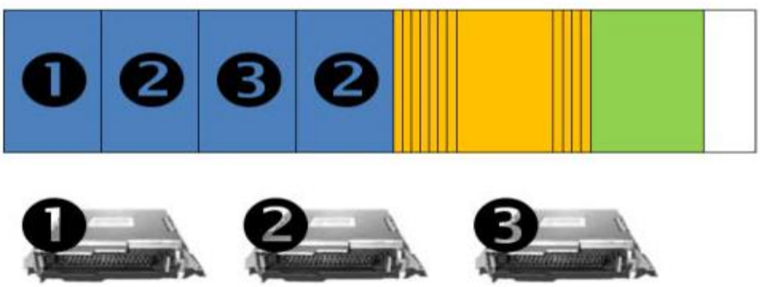

Fig.3. Illustration of a static segment with 3 ECUs transmitting data to 4 reserved slots.

2.4.2 Dynamic Segment

The dynamic segment behaves in a fashion similar to CAN and is used for a wider variety of event-based data that does not require determinism.

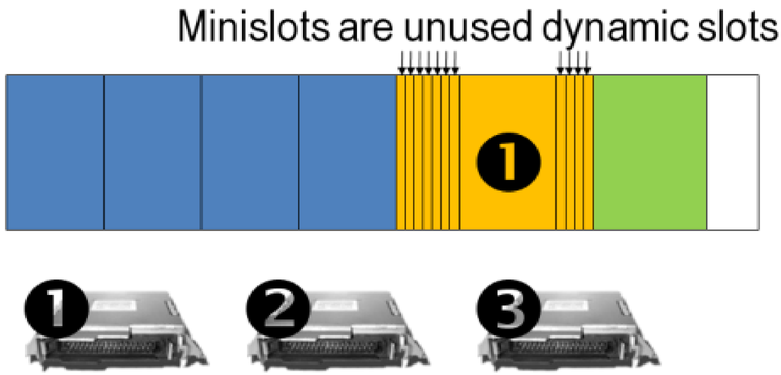

Fig.4. Illustration of FlexRay dynamic slots with one ECU broadcasting data.

Most embedded networks have a small number of high-speed messages and a large number of lower-speed, less-critical networks. To accommodate a wide variety of data without slowing down the FlexRay cycle with an excessive number of static slots, the dynamic segment allows occasionally transmitted data. The segment is a fixed length, so there is a limit of the fixed amount of data that can be placed in the dynamic segment per cycle. To prioritize the data, minislots are pre-assigned to each frame of data that is eligible for transmission in the dynamic segment.

2.4.3 Symbol Window

The Symbol window is primarily used for maintenance and identification of special cycles such as cold-start cycles. Most high-level applications do not interact with the symbol window. Typically used for network maintenance and signalling for starting the network.

2.4.4 Network Idle Time

A known "quiet" time used to maintain synchronization between node clocks.

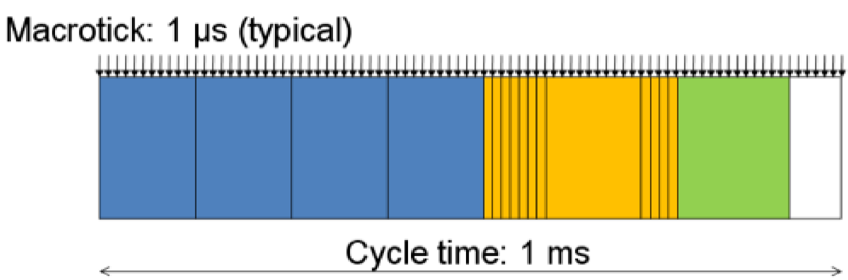

Fig 5. Detail of the FlexRay macrotick.

The smallest practical unit of time on a FlexRay network is a macrotick. FlexRay controllers actively synchronize themselves and adjust their local clocks so that the macrotick occurs at the same point in time on every node across the network. While configurable for a particular network, macroticks are often 1 μs long. Because the macrotick is synchronized, data that relies on it is also synchronized.

3 Modification and Improving Existing Bus Technology

The proposed modifications will lead to a revolutionary new bus access method which is suitable for control units and fit for future demands by eliminating the restrictions of existing bus technologies and simultaneous implying the benefits of the different access methods:

Modification of the physical layer

The aim is to slightly modify the physical properties. It would be perfect to find a way of using the complete physical properties of an existing bus technology, since this would mean to be able to keep all established communication modules, dirvers, wiring, impedance networks, architecture and monitoring. The scientific scope of this paper is to describe a modification, which causes minimal modification effort on established technology. This is the base for building of the bus infrastructure needed to develop the communication systems itself. It is necessary to introduce three logical levels to realize differential signals with two dominant levels and a recessive level for arbitration algorithms. The choice of levels themselves is not really easy: on the one hand a low differential voltage offer advantages in current consumption, when establishing a system with quite low impedance (around 120 Ohms). On the other hand the logical levels have to differ quite enough during arbitration in order to be assigned correctly, even in critical situations (more than one ECU is trying to manipulate the logical level at slightly different).

Time management

The time management is essential for a TDMA by topology. Therefore most of the scientific work will be in this domain. The demand is to create a way to literally avoid collisions on the data highway. It is comparable to trying to find a way of merge railway and motorway. The challenge is to put a rail on the same lane a car uses without delaying the time schedule. Scientific contribution is to provide ideas to future bus access methods. The ultimate goal is to keep all existing priority tables of arbitration systems and time tables of deterministic systems.

Applied algorithm with software modification

Modification of both physical layer and network timing properties logically leads to modifications of the data containers themselves. The aim is to adapt the data security, error and fault management to the changed environment. The scientific work is to restructure the frame format of each communication package: The header is responsible for both arbitration and determinism. The payload needs to be flexible and predictable. The trailer contains error and fault confinement. But in order to minimalize the influence of a new bus communication, the changes should not result in dramatic restructuring of the used software. It is the clear aim to carry over as much as possible of given software models. This leads to acceptance. There would be no benefit of introducing new features at the cost of complete remodelling of software.

Conclusion

The paper deals with design and modification of existing BUS technology for modern vehicles. The proposed control methodology for existing FlexRay BUS guaranteeing network stability and high performance. The scope of this paper is to presents a new methods and modification of physical layer, time management and control software in order to implement arbitration into a system. This means a technical adaption of new access methods on existing bus technology. The benefit is to provide hard- and software engineers with ideas for designing new bus structures, which are able to introduce.

Acknowledgement

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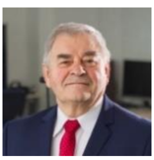
Authors

Florian Dietze
Porsche AG, Stuttgart - Zuffenhausen, Germany
Institute of Automotive Mechatronics
florian.dietze@outlook.de
M.Sc. Florian Dietze, PhD. is a young researcher working on advanced communication systems for automotive vehicles. He completed his PhD studies at the Institute of Automotive Technology, FEI STU in Bratislava in 2015 in Study Program Automation and Control. He is currently a researcher at Porsche AG, Stuttgart - Zuffenhausen, Germany.



prof. Ing. Štefan Kozák, PhD.
Faculty of Informatics,
Pan-European University in Bratislava, Slovakia
stefan.kozak@paneurouni.com
His research interests include system theory, linear and nonlinear control methods, numerical methods and software for modeling, control, signal processing, IoT, IIoT and embedded intelligent systems for digital factory in industry and medicine.