Automotive Communications

Better Than Best Effort

Jeremy Wright
Arizona State University
jlwrigh1@asu.edu

***Abstract*—Vehicle's are quickly becoming distributed comupting platforms on wheels, and teh integration of these system is essentail for both the safety and comfort of the passengers. Over the last few decades there has been increasing integrtion of these systems to perform highly advanced functions, but never losing thier core safety and realibility guiarntees. This survey will look at the 4 most popular industial networks in vehciles, how they differ from the enthernet based protocols we are used to in the internet domain, and how the physical layers and software layers interact to make a truely safe system.**

***Index Terms*—CAN, LIN, MOST, FlexRay, safety, reliability**

I. Introduction

Something flashes across the road. Instinctively you slam on the brakes. ABS kicks in to preserve tire contact with the road. Your body begins to fly forward, your head towards the steering wheel. Inertial sensors deploy a series of events collision management events. The fuel pump is shut down to reduce the risk of fire. Body dynamic sensors adjust suspension forces to keep the vehicle level, and in a safe driving position. The vehicle signals emergency responders of a crash event with the current GPS location. You are caught by the air bag. The crash is over. You are safe.

This is the environment of industrial networks. The hard real-time communication channels where failure means people die. Advanced made in this area have increased vehicle safety, reduced vehicle weight, and improved overall comfort of the system. Many of us are familiar with internet application network, such as TCP, UDP and Ethernet. These routing protocols were originally developed to reduce the ability of an attacking nation to take down the United States' communication infrastructure. Ethernet is fault tolerant and employs a concept called best effort routing, where packets are routed to a destination in the most likely path for success. Packets have a time to live, and if they dont reach the destination in time, drop off the network. Consider since a "best effort" approach in a vehicle. If the music player is shipping data over the vehicle network, and the air bag deploy message cannot get any bandwidth catastrophe. Instead of best effort, industrial protocols take a different approach focused on safety, reliability, and guaranteed delivery. This focus usually is a trade-off for performance. You may not be able to ship a great deal of data, but what data can be sent is sent reliability since, when the air bag needs to deploy, being late is useless.

This survey will discuss the industrial physical layers commonly used in vehicles today: CAN [1], LIN [2] and FlexRay std$_{f}lexray, andthesoftwareprotocolsthatrunoverthem, IS$
$Triggeredmessaged, andPriorityMessages.TimeTriggere$
$collectorfunctionimplementsaprimitive, yetveryeffective$
$comfort, chassis, engine, anddescribehowthesefunctionsu$

Vehicle functions are segregated into discrete Electronic Control Units (ECUs) distributed around the vehicle. These ECUs provide raw sensor data, engine statistics, trouble code information, and even dynamic suspension information, all in real-time. Before the advent of CAN in 1986, these systems were completely segregated, and often implemented by different vendors e.g. the door lock system would be physically separated from the truck latch. Segregated there was no issue of contention since the system fully owned the communication channels it needed. hwever this also resulted in a great deal of redundency, cost, and weight . Furthermore, many functions can have enhancled accuracy or precision by combining several different data sources in a scheme called sensor fusion. CAN was intrduced to address these issues. CAN allowed ECUs to be linked together with a single twisted pair of copper

cite bmw weight

wires, and included a novel prioirty scheme for routing higher prioirty messages ahead of lower porioty ones. This was the advent of the industrial protocol in automotive vehciles.

one level of abstraction above the ECU are the system categories: powertrain, comfort, and chassis. powertrain systems involve engine and transmission data, and have the very tight timing, and jitter specification since these systems are responsible for function such as variable valve timing, spark advance/delay and other critical engine functions. comfort is the other end of the spectrum, and provides the environment controls such as AC, heating, and radio. Increasingly these comfort systems have grown to include cellular phone integration, and even hotspot functionality. This network categroy requires higher bandwidth, and higher speed but with a lower enphasis on safety, and reliability. Late message may disrupt the music, but it will not likely result in harm. Chassis systems are responsible for maintaining control of suspension, steering and braking. These are a high reliability network type. [3].

Industrial protocols allow networked ECUs to communicate in our vehicles, and airplanes. Protocols such as CAN, LIN, or AFDX, and their associated physical layers CAN, UART, Ethernet allow for reliable, scalable, and safe operation of electronic systems within our vehicles. But what is it that separates an industrial protocol from a non-industrial one. Namely, reliability, and safety. Industrial protocols can be evaluated in how they meet criteria related to confirmed delivery. Industrial protocols typically reduce the bandwidth and speed of the network to add extra reliability. For instance, CAN uses an open collector signaling scheme which increases the power required to drive the network than the magnetic isolation technique of Ethernet, but this simple fact implements an OR operation. This OR operation is used by senders to verify that each bit they send was received by the rest of the network.

CAN was the first industrial protocol introduced by Bosch in 1983 [1]. Software assisted vehicle functions were connected by point to point wiring. Once CAN allowed multiple ECUs to be reliably connected on a common pair of wires, vehicle manufactures saw improved reliability and reduced vehicle weight [3]. Industrial portals also allow ECUs to work cooperatively merging sensor data from multiple end points to achieve advanced vehicle functions. Today, the X-by-wire systems are the epitome of this capable of detecting road obstructions and even stopping the vehicle if necessary.

So how is reliability defined? Withing vehciles, reliability maps to the security concept of availability. The message bus must be available when a high prioiy message is to be sent, and the latency must be abslutely bounded. Furthermore vehicles are electrically very harsh environments. Temperatures can be extreme, sensors, and system are exposed to weather. Because of this the physical layers must continue to function in the presense of high electric fields or magnetice fields or other anomouly. Ethernet for example doesn't meet this requirement. Within HVAC, one must be carefy to lay ethernet lines around flourcent tube lighting. The magnetic fields genertaed by the neon gasses arching can disrupt the ethernet cables high higher speeds. In a vehcile this variably of network quality is unacceptable.

II. Reliable Networks

Reliability is an ECU knowing that a message sent was received by its intended receiver. Realtime. Vehicle busses must allow message to arrive in a deterministic amount of time. Since message could contain life critical message such as deploy air bags such highest priority message must get through. This is also related to safety, at the protocol level, message must get though, at the signal level vehicles are electrically very noisy. Noise can induce eddy currently or other anomalous bits in the digital networks. The physical layer must protect against these to achieve safe operation. This survey will look at 4 ground based vehicle industrial protocols, CAN, LIN, and FlexRay examine the network and physical layers to how they achieve safety, reliability, data integrity and some of the security implications of each. Lastly we will look at time triggered, verses event triggered message schemes an how each system fits into the overal safety case.

Besides relability networks provide different levels of performance separated by their class.

TABLE I
NETWORK CLASSES BY SPEED

Network Class	Speed	Typical Use
A	$<$ 10 Kbps	Body domain
B	$<$ 125 Kbps	Sensor Sharing
C	$<$ 1 Mbps	Powertrain and Chassis Domain
D	$>$ 1 Mbps	Media and infotainment

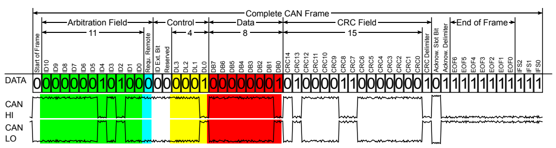

Fig. 1. CAN Frame without bit stuffing

A. CAN

CAN is a Class C, half-duplex, self-initated network type. CAN provides prioity based messaging by implementing an OR function into the physical layer itself.

Can was the first industrial protocol for vehicles, and CAN is used for nearly all systems of a vehicle, except for the comfort system which require higher bandwidth than CAN provides. The novel concept introduced by CAN was the bit priority voting system built into the FlexRay Flexray did some stuff that some people care about, do I care, probably not, but whatev.

Show network packet structure

B. LIN

LIN is a class A, half duplex, master initiated network type. It provides a low cost network capable of interfacing up to 16 separate slave units. LIN is a half- Lin bus is a serial bus designed for ultra-low cost low data rate systems.

Show how the voting/priority works

C. Flexray

FlexRay is a Class D, full duplex self initiated, network type. It provides very high performance up

describe now the internal hardware

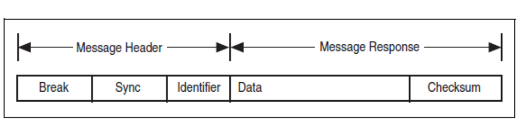

Fig. 2. LIN frame

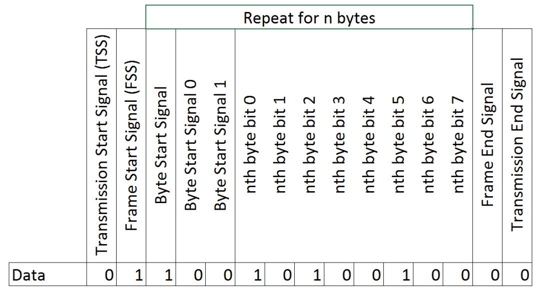

Fig. 3. FlexRay frame

to 10 Mbps while retaining a strong transmission error correctino scheme.

III. MESSAGING SCHEMES

Each of the network types we've looked at are single media, multiple access networks. All ECUs, share a single set of wires to communicate to each other. Ethernet is also such a configuration. However Ethernet's start of transmission scheme is in start contract to industrial protocls presented here. Ethernet has a randomized backoff scheme which manaifest a variable network latency scheme. If a device is a very loud talker, it can push out all other communication creating a classic denial of service. In a vehcile bus, denial of service, i.e. the steering wheel cannot contact the power steering unit as in a steer-by-wire system. Such an event renders the vehcile an uncontrollable missle. But where Ethernet has variable latency due to its randomized start of transmission scheme, industrial protocols have two major schemes time triggered, and event triggered messaging for dealing with denial of service, and define a fixed latency.

A. Time Triggered Messages

Time triggered message schemes send data at a rated defined by a network "master schedule". This is essentially time division multiplexing the communication channel. The upseide to time triggered messaging is the simplicy of analysis. When all messages are defined for bounded windows of transmission, it is excplicitly known what all message latencies are. The downside is composability. Vehicle manufactures tend to build vehicle systems over time, making small improvements and composing new functions reusing smaller functions which already exist. Since the "master schedule", is truly a single document describing all traffic, adding a new ECU to the network requires the entire schedule to be redesigned and evaluated.

Time triggered messaging is primarily used in fail-safe systems such as steering and braking. BMW's steer-by-wire systems use FlexRay for very high speed communication, between the steering wheel, and the steering actuators. The steering wheel sends it's current angle, and velocity periodically to the actuator. If the actuator doesn't recieve a message from the steering wheel on the scheduled time, it can perform some error mechanism to protect the vehcile from a potentially failed steering wheel. Braking is a similar design allowing the vehicle to fail safely if communication channels are faulty.

B. Event Triggered Messages

Event triggered schemes preserve bandwidth over time triggered schemes since ECUs are not sending repeat messages at defined rates. This allows lower speed busses such as Low speed CAN (125Kbps) to more efficiently use the limited perforamnce. This however can make the latency more difficult to reason about. If the message schema does not support priority, then its possible for lower priorty messages to flood the bus, and prevent higher piroity messages from reaching the destination before the deadline.

IV. Conclusion

Vehicle electronic are trending toward higher connectivity, higher security, and greater integration within the vehcile as well as new out of vehicle systems. These trends are already pushing the performance limits of its backbone protcol CAN, and while MOST provides a higher bandwidth link, it cannot complete with the safety offered by CAN. It is an exciting time to see what advanced will be made in the realm of vehcile protocols to meet this growing bandwith bottleneck, but maintain the critical safety specifications which keeps us blissfully unaware of the mountain of software that make our cars function.

References

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