Emerging Trends in Intra Vehicle Networks for Data, Control and Power Distribution

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Abstract

Current and future military vehicles will be expected to not only last longer than their predecessors, but also operate with a flexible mission package. These vehicles must be architected for lifecycle multiple upgrades of electronics and general product improvements.

The ability to be upgraded and reconfigured for flexible mission profiles compels the vehicle's architecture be centered around a "data bus" network backbone that facilitates "universal plug and play" of electronic payloads. The vehicle's over all data stream will consist of at a minimum of voice, video, control and diagnostics. To maintain flexibility as well as to be cost effective in support of the "plug and play concept" for new and upgraded electronic payloads it is a fundamental requirement that every type of current and foreseeable data streams be able to coexist on one single network backbone. Only this architecture will guarantee the most flexible, and scalable reconfiguring for future expansions or mission equipment changes.

Military vehicles use higher and higher resolution multiple wavelength sensors for target acquisition, a proliferation of cameras for both day and night driving and (360°) situation awareness. The need/demand for any selection of available video at various crew stations with less and less latency is on the rise.

The growing trend within the military is to follow the commercial world of delivering both video and voice over the digital IP network. Within a military vehicle, the trend is consistent with the adoption of digital voice IP and video IP networks. The issues of capacity and bandwidth are ever present, coupled to the need for faster speeds, less latency, secure, self diagnosing networks, self reconfiguring networks and scalability.

The need for flexibility and growth for vehicle controls and health management (which today is supported by the vehicle's 1939 can bus) requires a vehicle architecture which allows tunneling that the control signal data has a guaranteed delivery, and further the architecture can be expanded to accommodate new controls, and low band width data such as vehicle health management.

A power distribution network also needs to coexist with the control and data networks. The authors will discuss the emerging trends in all three areas, together with the need to operate asynchronously yet allow tunneling of the control and data networks. We will discuss the trends in topologies for all three networks, and how to ensure that they are scalable, and fault tolerant, self diagnostic and self reconfigurable, together with a fault tolerant communication protocol. We will also discuss the work primarily being developed at DRS TEM and DRS SSI in regards to these networks.

1 Introduction

There is a distinct shift in military doctrines towards peace and support of peace enforcement operations and away from the more conventional warfare aimed at defeating a disciplined uniformed enemy. The contiguous battlefields of Europe of the Second World War are being replaced by the non-contiguous battlefields of today in Iraq and Afghanistan (1) as illustrated in Figure 1.

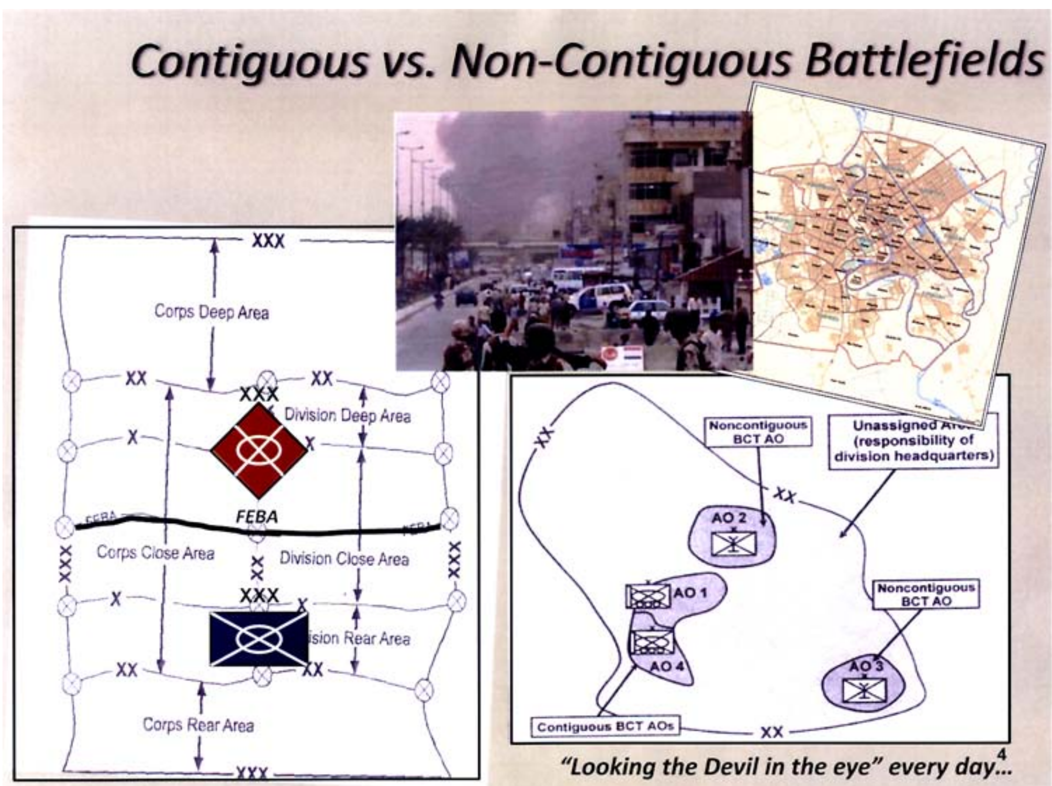

Figure 1- The New Battlefield Paradigm

The enemy today is a very formidable adversary who can be transparent as a foe until he/she decides to strike, and then can melt away equally quickly. The enemy is fast and flexible. We must counter by equipping our soldiers with the ability to collaborate and exchange information, such that local decisions can be made at the lowest soldier levels.

The prior model (which has been so effective in the past) with the information and knowledge available only at headquarters and the resultant decisions flowed down as orders, is being replaced with a new model that permits the decision making to be carried out at all levels of soldiers because of the ability to share information.

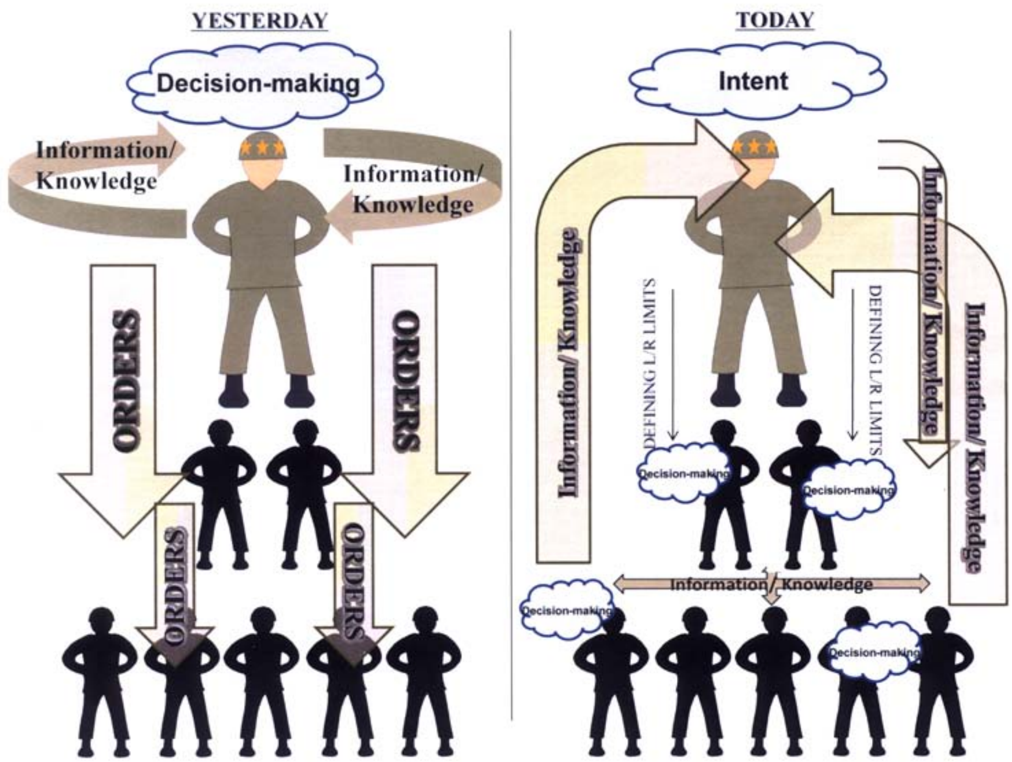

Figure 2-The Migration of Decision Making

The information required for any soldier to make decisions germane to his/her situation is reflective in the more commonly used term situational awareness (Figure 2). Technology has revolutionized the battlefield (Figure 3). Today's battle command requirements demand as illustrated in Figure 4 (1):

- Communication on the Move
- GPS, Navigation and Mapping
- (Vehicle) Health and Maintenance Monitoring
- Command and Control
- Imagery, Sensor Integration
- Situational Awareness
- Reach back to DISN/GIG

The game changer is not new weapons, or new platforms or new vehicles; it is information technology including the appropriate distribution of information. The information has to be timely (zero latency); reliable (information assurance); complete, consistent and secure (so the enemy cannot exploit it). Information, especially visual information because of the data associated with it tends to consume bandwidth

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Figure 3-The Role of Technology on Battlefield

Figure 4- The New Information Requirements

The consensus is that we are driving towards building a single network on the battlefield with "Everything over Internet Protocol" or EoIP as the network architecture as the technical standard.

Young soldiers of today enjoy and take for granted commercial technology at their fingertips. They are the "connected generation". The commercial cell system has migrated from 2G to 2.5G to 3G in the decade from 1995 to 2005 (Figure 5). Commercial necessity is driving today's market to 4G. The gap between commercial rates and those afforded by our tactical communications is ever widening. It is the commercial marketplace that is driving innovation. The DoD would be wise to leverage commercial innovation into its environment.

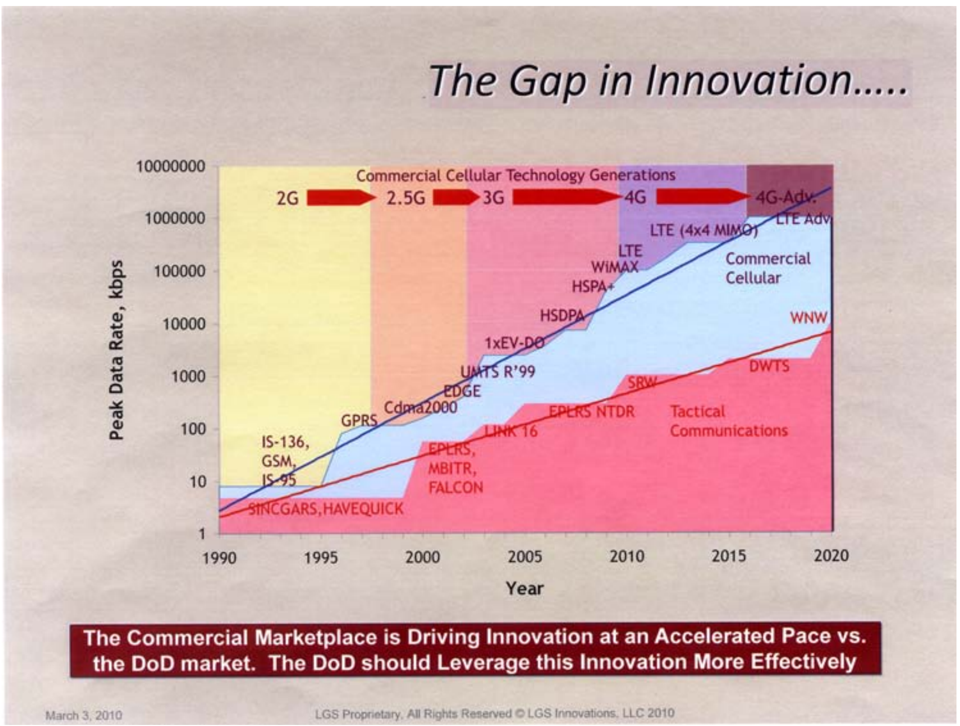

Figure 5- Commercial to DoD Gap

Vehicles and soldiers are becoming nodes of a wireless EoIP mesh network architecture (Figure 6) in which soldiers and vehicles are connected with many redundant interconnections. This new battlefield network architecture using vehicles as nodes has to address the issues of self configuring and self recognizing its assets. Everyone will be on one, single integrated communication system. Furthermore, to assure the information as well as secure the information, we will have to adopt a standards–based solution with an open architecture.

Today's data is stored in multiple, local, non-interoperable data bases with proprietary formats. We must progress to an established set of standards to support distributed operation. Protocol adapters can serve as an interim solution instead of rewriting huge amounts of software. The key to the future is to remove stovepipes within not just the

Army but the joint community and replace it with a secure, standards based solution that provides for timely and in some cases latency free information.

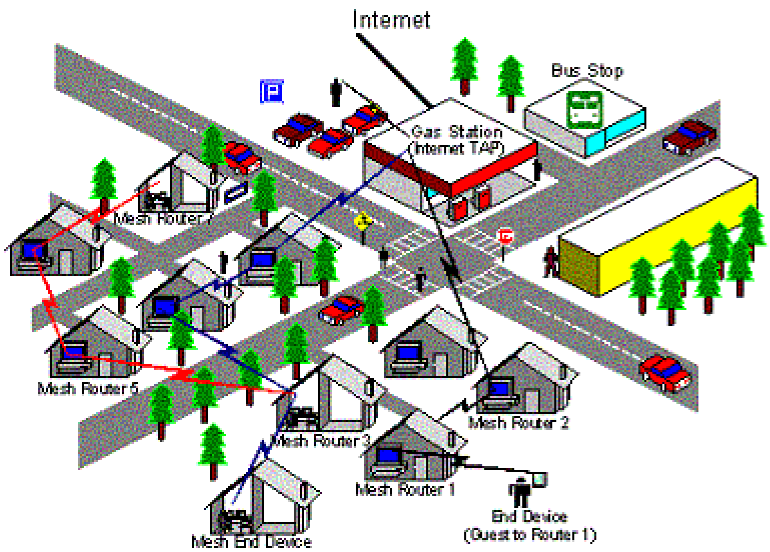

Figure 6-Commercial Mesh Network Example (Self Organizing Wireless Mesh Networks)

How do the vehicles of today and the vehicles of the future fit into this information network? Prior generation vehicles were remarkably deprived of electronics, with the exception of basic radio communication. Over the last three decades there has been a continuing growth in vehicle electronics related to reconnaissance, surveillance and target acquisition, navigation, health management, mapping and displays. The growth has been exponential

2 Military Vehicles

2.1 Current Vehicles

The current fleet of United States military land vehicles is enormous (Table 1). In fact if one were to place all these vehicles in a convoy spaced about 175 feet apart, the convoy would stretch half way around the globe.

The fleet would be dominated by the HMMWV fleet of which there are approximately 160,000 vehicles. This fleet is worth more than one billion dollars. The HMMWV has been in service since 1984, and boasts 17 variants to include cargo/troop carriers, automatic weapons platforms, ambulances and S250 shelter carriers. It is the vehicular backbone of the US Forces around the world. It was designed primarily for personnel and light cargo transport behind the front line.

Class/Category	Number of Types In Category	Types with Significant Inventory	Total Number In Type
Main Battle Tank	1	M1 Abrams	7,851
Infantry Fighting Vehicles	1	M2/M3 Bradley	6,724
Armored Personal Carrier	10	M113	10,000
		Stryker	2,575
		LAV	1,500
Light Armored Vehicles	12	HMMWV	160,000
		M1117 Armored Security Vehicle	1,836
Mine Protected Vehicles	8	RG31	1,963
		RG33	1,735
		Cougar	3,500*
		International MaxxPro	5,250*
		BAE Caimen	2,800*
		Oshkosh M-ATV	5,244*
Combat Engineering Vehicles	10	-	-
Self Propelled Artillery and Anti-Air	14	-	-
Prime Movers and Trucks	13	Medium Tactical Vehicle Replacement	7,500
		M939 Truck	32,000
		Family of Medium Tactical Vehicles	80,000
		Heavy Expanded Mobility Tactical Truck	13,000
Misc	7	-	-
Unmanned Combat Vehicles	6	-	-
Total Number Of Vehicles			334,642
**** - Vehicles on Order***			

Table 1- List of Currently Active Major Military Vehicles (2)

However the battlefield of today has no front line. The basic HMMWV has no armor or nuclear biological chemical (NBC) protection and therefore is questionable as a front line fighting vehicle. Asymmetric warfare has forced the HMMWV into urban combat roles for which it was never designed. After the Somalia losses, AM general developed the

M1114, an armored HMMWV which could withstand small arms fire. It went into service in 1996. The vehicle holds up well to lateral attacks and there has been a continuous series of improvements to its armor kits starting with the Armor Survivability Kit (ASK), the FRAG 5 and FRAG 6 kits. However, the vehicle offers little protection from buried IED or land mines. Furthermore, explosively formed penetrators (EFP) can defeat these current kits.

Because of the heavy losses with the HMMWV, the government has announced its intention to replace all HMMWVs in IRAQ with MRAP (Mine Resistant Ambush Protected) armored vehicles. These are about 20,000 MRAP vehicles, 6 MRAP vehicles types dominate these numbers are BAEs Caiman RG-31 and 33, Force Protections Conger, International’s MaxxPro 5250 and Oshkosh’s M-ATV.

Whether it is a HMMWV, or an MRAP, studies show that survivability for the crew is greatly enhanced by comprehensive situation awareness. Information is equally important as passive armor for survivability. The classical layers of the survivability onion (Figure 7) (3) reinforce this need for total situation awareness within the vehicle itself. Inter and intra vehicle high band width, timely, secure communication is vital to survivability.

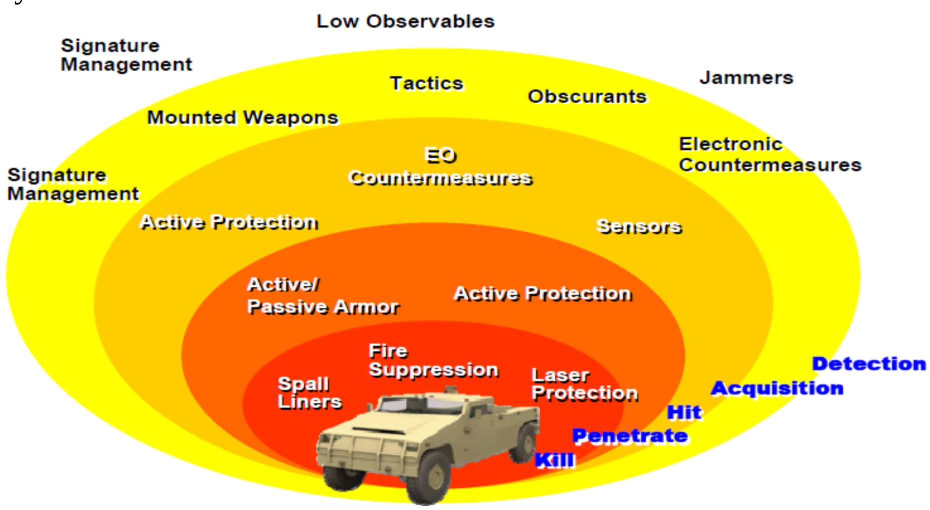

Figure 7- The Survivability Onion

2.2 Future Vehicles

MRAP is seen as the short term replacement of HMMWVs and essentially exploits commercial off the shelf vehicles. The future long term replacement efforts include the JLTV (Joint Light Tactical Vehicle) and future tactical truck systems to include FMTV (Future Medium Tactical Truck). We believe that these platforms will continue in operations beyond 30 years. These roles and missions are very likely to change, and it would be difficult to anticipate all the future different roles and missions of each vehicle. What we consider important is that as missions evolve, as sensors improve, as communication demands increase, the vehicle is re-configurable, in a plug and play manner.

Re-wiring a vehicle for every discrete sensor does not make sense. A bus becomes the answer. Issues with signal to noise in a vehicle environment imply these needs to be a digital bus. The bus has itself to be readily expanded. The band width needs for modern sensors continues to rise doubling every four years.

Army discussions of future vehicles should include the Ground Combat Vehicle (GCV). GCV development will take 5 – 7 years. It will be a heavy vehicle, but it will be a generic vehicle capable of multi roles, and multi mission packages. Situation awareness used is no less important with this vehicle than any other. The ability to operate seamlessly with existing vehicles and also to be active nodes in the network is permanent.

3 Sensors & Communication Today and Tomorrow

The Army has given the future vision statement (4):

> *An armament carrier cannot be fully employed in combat useless it has the armor and Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance (C4ISR) package envisioned for them.*

What is interesting to note, is that with the exception of armor, all of the functions in the Army's vision statement that make a combat vehicle usable and survivable are network oriented. The Survivability Onion's (Figure 7) backbone is becoming and the vehicle's network.

Most of the sensors and communication devices carried on military vehicles in the past have been stand alone devices. That is devices that do not talk to other devices and systems, and have a single fixed purpose interface. The capability of these devices double every four years. The bottle neck is getting the information to the right user at the right time. Information may be in the form of audio, video, radar tracks, text reports, etc. The sources for this information may be sensors carried on board the user's vehicle, a remote vehicle sharing information, or remotely operated unmanned platforms.

The future will see the wired networks inside of vehicles connected together by wireless links into a constantly evolving and moving ad hoc mesh network so that information and situational awareness can be provided by sharing information between vehicles or from unmanned platforms. Security, latency as well as complexity will be key issues to making sure the right information, gets to the right user, when the information is needed.

The Army Brigade Combat Team (BCT) modernization strategy is a vision that mixes mobile and networked BCTs in a way that leverages the right combination mobility, information, protection systems, and precision fire for survivability and effectiveness across the broad spectrum of envisioned future conflicts (5). The first test of what the networked BCT may evolve to, took place in mid July 2010 at White Sands with the **Brigade Combat Team Network Integration Exercise** (6). A seamless battlefield network was created. Integrated onto this network were nodes consisting of soldiers, commanders, and sensors. Across this network were shared voice, video, data, and images, all in real-time. The key network hubs to this exercise were vehicles outfitted with Network Integration Kits (NIK). These hubs served to connect the terrestrial and satellite portions of the network together. Each NIK consisted of a computer, JTRS Ground Mobile Radio, and Blue Force Tracker display.

The ground (terrestrial) network of sensors sent voice, imagery, and data through the JTRS using the high bandwidth waveforms, e.g. Solder Radio Waveforms (SRW). The information sent through the ground network was then linked to the Warfighter Information Network-Tactical (WIN-T), which is a satellite network with long range capability.

Using the NIK's ability to send voice, and imagery, sensors like the Unattended Ground Sensors (UGS), Small Unmanned Ground Robots (UGR), etc. were instantly shared from the squad up to battalion levels. The NIK's had the ability to view and share the information streams in real time on the Blue Force Tracking displays in the vehicles while on-the-move, with WIN-T sending the information back longer distances. WIN-T linked the information stream back to a "Command Post of the Future" display screen.

The demonstration is so new; results have not become widely available of the successes and problems identified.

4 Vehicle Control & Health Monitoring

4.1 Current Capabilities

Vehicle control in military vehicles began with mechanical linkages to the engine and transmission. As automatic transmissions gained acceptance, hydraulic controls were developed for military vehicles. Digital communication was then adopted in light tactical vehicles between the engine and transmission, to coordinate shift timing based on engine status using sophisticated shift tables. Tactical vehicles utilize a Controller Area Network (CAN) bus standard for the physical layer of vehicle communication. Heavy combat vehicles adopted the MIL-STD-1553 bus for vehicle communication.

Health monitoring in a military vehicle allows the warrior to know the status of the vehicle. Health monitoring may exist as a discrete status signal on the data bus, yielding PASS/FAIL status of a component. Health monitoring may also be a collection of detailed data, which allows profiling and a prediction of failure. The increased amount of data in health monitoring can be a major enabler, but also may be taxing on a data bus with limited bandwidth. A control bus in a combat vehicle requires guaranteed bandwidth and a maximum delay. As additional data is added, the bus must undergo a new safety checkout. Simple status is required for components on the military vehicle data bus today, but additional health data requires an independent bus or higher bus bandwidth.

4.2 Future Capabilities

The Army states that it must maintain the technological advantage by continually improving capability, capacity, connectivity and operational effectiveness (7). The Warfighter Information Network (Tactical) (WIN-T) and the Joint Tactical Radio System (JTRS) will provide the external network to enable increased data communication capabilities. A common intra-vehicle communication network will facilitate future autonomous vehicle status communications for strategic and tactical asset management.

The Army has developed an initiative for the Common Logistics Operating Environment (CLOE) to address the intelligent management of assets. This logistics situational awareness increases agility and effectiveness with total asset availability and status. The immediate or autonomous access to vehicle data will allow substantially better and more cost-effective sustainment support (8). The CLOE effort is synchronizing with Program and Project Manager (PM) onboard vehicle health management efforts as well as the Army's centralized data management Condition Based Maintenance Plus (CBM+) initiative for common models.

Health management is most prevalent in aircraft, where component failure can be catastrophic, but ground vehicle adoption has been slow. PM Heavy Brigade Combat Team (HBCT) has focused on development of vehicle health management. They have funded studies performed by Pennsylvania State University to determine the top degraders in heavy combat vehicles (9) and develop the cost-benefits analysis for implementing health management (10). The need and cost benefits have been defined, but the cost-effective solution is yet to be integrated. Cost continues to increase in importance as a driver in health management implementation. Combined with military spending reduction, it is clear that a health management solution must be cheaper and smarter for the most return on investment to be accepted.

A common and effective hardware layer is a critical part of the solution for health management. Data management is critical for systems which could be overloaded by information. The solution must be well-structured and standardized for the multitude of systems which may communicate on the network. The Machinery Information Management Open Systems Alliance (MIMOSA) is an alliance of Operations & Maintenance solution providers which develop open standards to enable interoperability [10]. MIMOSA publishes an XML-based specification for end-to-end information integration. Products compliant with these specifications allow access to data in a highly organized and accessible infrastructure. MIMOSA provides the intelligent solution to organizing the large amounts of data and making sure data is transmitted efficiently on the intra- and inter- vehicle networks.

4.3 Current Buss Capabilities

CAN bus is an industry standard bus for vehicle communications, with strong noise immunity and robustness of message integrity and low processor overhead. Specific protocol standards exist for CAN within various classes of vehicles. The J1939 protocol was widely adopted by diesel engine manufacturers in the Engine Control Unit (ECU) on heavy industrial vehicles for control and diagnostics. CAN has matured to become a protocol standard beyond engine control, and now integrates control of a variety of body electronics. CAN speeds have been increased to keep up with demand, where today CAN 2.0b allow a 1 Mb/s transmission rate. CAN developers continue to push the protocol to meet future needs. Soon Time Triggered CAN (TTCAN) will be available for mission-critical deterministic control systems (11).

Various standards exist today in vehicles which trade cost and message integrity. The Local Interconnect Network (LIN) bus is a very low cost networking bus for commercial vehicles. The CAN bus adds robustness to the data integrity, with a higher cost than LIN. MIL-STD-1553 was developed for military communications, where bus integrity is critical. 1553 is more expensive to implement than CAN, in which it provides a redundant physical data bus, and a host computer to manage the data on the network. 1553 has been dominant in avionics, and later adopted by heavy combat vehicles. The 1553 bus carries control data and component diagnostics on the vehicles, and allows a 1 Mb/s transmission rate.

4.4 Future Buss Needs

The military vehicle data bus as it exists today will not support the stated needs of tomorrow. Additional information on the bus will require more bandwidth. Increased capability will require more control and more intelligence. Integrated Power Management will require communications with the engine to increase efficiency and performance. Unmanned systems will require more computer interaction with the vehicle control than manned systems.

The data bus will require more flexibility for future growth. In addition to these increasing requirements, low cost had become a driver. The military is now looking for the defense industry to leverage commercial technology developments. Commonality will become more important, as vehicles will need to leverage economies of scale. When vehicle networks were initially adopted, Ethernet was not a viable option based on speed and message integrity. Ethernet has grown rapidly and the technology for information transmission has matured. Gigabit Ethernet is a bus which can now meet the needs of vehicle control and health monitoring, while being a low cost solution.

To meet these needs, the intra-vehicle network will not only benefit from the common physical layer of the network, but also from a standardized message structure, with intelligent control of data flow. Leveraging Ethernet and the commercial advances in Ethernet data management will lower the cost of implementing this model.

A common bus yields economy of scale for components which span vehicle classes, and a common electrical network further reduces cost of implementation. A common bus allows sharing of information needed by various components, such as GPS data, without duplicating transmission lines. Eliminating protocol converters will reduce size, weight, and cost. A common bus with physical and protocol architecture flexibility will allow the quick development and adoption of new sensors and components.

5 Future Network Architectures

The Vehicular Integration for C4ISR/EW Interoperability (VICTORY) Architecture "provides a framework to integrate Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance (C4ISR) and Electronic Warfare (EW) systems on Army Tactical Wheeled Vehicles" (12). The framework defines hardware and software such that many electronic components can interact seamlessly on the vehicle. The physical layer is defined as gigabit Ethernet, which allows the flexibility and control necessary to integrate the diverse needs. The architecture accommodates CLOE, and facilitates transmission of the intra-vehicle network data to external networks (13). The architecture also makes allowances for control systems with high data rates and deterministic requirements to be partitioned from the backbone, where backbone published data can be filtered.

Control architectures would benefit from converting to the common bus architecture. However, architectures such as VICTORY will permit a transition through protocol adapters. Ultimately, elimination of protocol adapters will reduce the complexity, size, weight, and cost. A major concern for transitioning to Ethernet will be the guaranteed bandwidth. This is being addressed by the commercial world with technology advances such as the Quality of Service (QoS) model. QoS allows prioritization of network data to guarantee the necessary bandwidth and maximum message delay for critical systems. QoS has been studied for military use in the Joint Battlespace Infosphere [(14), (15)], so the technology is effective for both intra- and inter- networks.

5.1 Power

TARDEC (16) vision is that future military vehicles will continue to evolve their mission-critical electronics functions of:

- Command,
- Control,
- Communications,
- Computer Intelligence,
- Surveillance, and
- Reconnaissance.

These evolving functions will collectively place an increasing load on a vehicle's electrical systems. Without proper power management ability, prioritizing critical mission needs, either the vehicles electrical power generation capability will be exceeded, or a vehicles will be forced to have the ability to generate power to supply an unmanaged peak power load for all varieties of mission operational requirements.

Even with power management, new techniques and technologies will be necessary as the underlying physics of traditional vehicle electrical generation methods reach their practical limitations. Electrical power needs will be further burdened as more vehicle subsystems are electrified to save fuel economy and increase mission capability.

The US Army is looking at two combined approaches to meets the needs for increasing electrical power,

- efficiency in power utilization, and
- allowing plug and play incorporation of additional powers sources as mission needs require.

Power management is seen as the concept addressing both these issues to more intelligently control electrical power generation and consumption by using hardware and software algorithms. In other words a “systems engineering approach” is needed to assure power needs can be efficiently met for current and future military vehicles.

Research and development efforts have produced prototype hardware and software algorithms. The hardware (termed PCUs) consists of “smart switches” interfaced to embedded microprocessors. This switch network protects and extends the life of critical mission hardware, by shutting only equipment in danger of overload leaving all other equipment fully operational. PCU communication is carried out on the vehicles CAN bus. By allowing the PCUs to respond autonomously to “out-of-range” conditions the systems is more robust then requiring communication at all times with a centralized computer.

The crucial purpose of this power management approach is to optimize system wide power usage. Power draw is balanced from all sources (batteries, alternators, ultra-capacitors, fuel cells, etc.). Current predictions are for improvements in efficiency of about 20%. Initial platforms planned for this approach include MRAP and RG-31.

This approach is being evolved into a standard to allow for hardware and software obsolescence with the advance of technologies. The standard termed PMAPI, specifies the functions of hardware, software and the interfaces. Initially PMAPI was adopted by Future Combat Systems (FCS), and has resulted via Small Business Innovative Research (SBIR) programs in the Advanced Electrical Power Architecture (AEPA) and the Advanced Electrical Thermal Management (AETM). At the 2008 Automotive Engineers World Conference an AEPA power management prototype was demonstrated by TARDEC. Current focus of the SBIR is applying the approach to MRAP RG-31 and one variant of the Medium Tactical Vehicle Family.

5.2 Data

The data networks of the next generation military vehicles will have to meet an ever growing demand for bandwidth to provide crew members with the information they need to operate most efficiently. This data network will have to allow for multiple audio/visual displays, inter vehicle communication, situational awareness, etc as discussed earlier. Commercial industry is already developing the network standards needed to support the new generation of in-vehicle entertainment systems for automotive applications, featuring very high quality video as well as audio for rear-seat and passenger displays. The two preeminent standards currently vying for position as the final standard are IDB-1394 (an offshoot of Firewire) and Media Oriented Systems Transport (MOST). Both these standards are envisioned to provide high bandwidth and high quality of service to enable the applications such as rear-seat entertainment systems and real-time cameras.

5.2.1 IDB-1394

IDB-1394 (17) has the ability to provide bandwidth up to 800 Mbs (1600 Mbs and 2400 Mbs are planned) to meet the needs of multimedia applications in a vehicle. Different network nodes may be connected up to a distance of 100 meters without the need for repeaters. Additionally IDB-1394 allows multiplexed transmission of audio and video content which can be transmitted on the network simultaneously on different logical channels. Users can then choose the stream (channel) which contains the information they are interested in viewing or using.

IDB-1394 additionally has mechanisms in the protocol to handle real-time latency and synchronization. This is done with isochronous channels that can assure a predefined bandwidth and maximum latency. These isochronous channels can be used to synchronize data streams, in particular audio and video streams at the receiver/display node.

The IDB-1394 network has a ring structure increasing fault tolerance. Any one branch within network can fail or be removed without leading to a network failure. In particular the network is fault tolerant enough that even with one branch removed there will be no degradation of data streams such as video. Multiple data streams can be broadcast from different nodes onto the network, and be randomly selected for use (display) by any other node on the network. Additionally hot plug and play is supported for the addition and discovery of new devices.

5.2.2 Media Systems Oriented Transport (MOST)

Media Systems Oriented Transport (MOST) is a multimedia fiber-optic network optimized for vehicle applications. MOST was envisioned to interconnect multi-media applications in a vehicle environment. MOST networks typically use a ring topology, but star configurations and double rings for critical applications are possible. MOST may have up to 64 nodes (devices) and support plug and play for discovery and addition of new devices and may include up to 64 devices or nodes. MOST has a current maximum payload capacity of 22.5 Mbs, and even with plans to reach 150 Mbs, lags well behind the abilities of IDB-1394.

5.3 Control

A fact of life today, is that the commercial sector is where advances in information and control architectures will be derived. The internet was invented in a government research lab, but it was only once the technology evolved out of the lab with commercial interest, that the backbone exploded to carry and deliver the bandwidth we all take for granted today.

The commercial transportation market is developing the vehicle control architecture standard of the future. This architecture is the “FlexRay” (18) being developed by a consortium consisting of the following core members:

- BMW
- Volkswagen
- Daimler AG
- General Motors
- Robert Bosch GmbH
- NXP Semiconductors
- Freescale

FlexRay is predicted to eventually replace the CAN bus and its variants because it has the following characteristics:

- Support of two communication paradigms
    - Static time driven communication
    - Dynamic event driven communication
- Mixed configuration possible
- Flexible extendibility, even after deployment
- High data rate (10 Mbit/s) and bandwidth efficiency
- Scalable fault tolerance
- Support of electrical and optical physical interfaces
- Support of star and bus topologies
- Low overall system cost

FlexRay's error tolerance and time-determinism performance meet the requirements for applications referred to as "x-by-wire" such as brake-by-wire, or steer-by-wire. The CAN bus standard is unable to provide for advanced control and safety systems that combine multiple sensors, actuators and electronic control units and require strict synchronization, and high bandwidth. Many of today's vehicles must utilize over five separate CAN busses. Table 2 illustrates the difference between the two existing standards CAN, LIN and FlexRay.

Another feature that separates FlexRay from CAN, LIN or even Ethernet, is topology. FlexRay can support simple passive multi-drop (Figure 8), or active star (Figure 9), or even more complex hybrid configurations (Figure 10). The ability to select network topology allows for an optimization of cost, reliability and performance to a specific vehicles needs.

Figure 8-FlexRay Multi-Drop Topology (18)

Figure 9-FlexRay Star Topology (18)

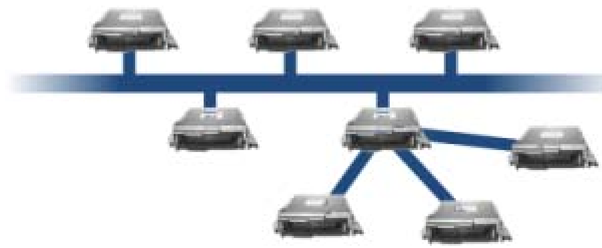

Figure 10-FlexRay Hybrid Topology (18)

FlexRay is multi-drop bus. Like all multi-drop busses only one node can electrically write data to the bus at a time or data becomes corrupt. FlexRay's method of avoiding buss contention is seen as an improvement over CAN's scheme where nodes will yield to other nodes if they see a message with higher priority being sent on a bus. CAN's methodology is easy to expand but does not permit very high data rates and cannot assure timely data delivery.

FlexRay arbitrates data contention between multiple nodes with a *Time Division Multiple Access* or TDMA scheme. FlexRay nodes are synchronized to a common clock, allowing each node to waits its turn to write on the bus. The consistent timing of TDMA assures "determinism" e.g. consistent data deliver to nodes on the network. When dealing with "x by wire" systems, dependable up-to-date data exchanges between nodes is critical.

FlexRay's unique time-triggered protocol in fact allows data delivery of deterministic data that is predictable down to the microsecond. Additionally FlexRay allows dynamic event-driven data as provided for by CAN. The methodology to mix both event-driven and deterministic data (static frames and dynamic frames) is a pre-set communication cycle that includes a pre-defined space for static and dynamic data. It is the designer's responsibility to configure how this space is used allowing optimal tailoring to the vehicles needs.

Figure 11 illustrates the FlexRay's communication cycle, consisting of four main components (18):

1. **Static Segment**
   Reserved slots for deterministic data that arrives at a fixed period.
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.

3. **Symbol Window**
   Typically used for network maintenance and signaling for starting the network.
4. **Network Idle Time**
   A known "quiet" time used to maintain synchronization between node clocks.

The network designer fixes the duration of the cycle and is typically around 1-5 ms. The *macrotick* is smallest unit of time on a FlexRay network. *Macroticks* are synchronized to occur at the same point in time on every node by the FlexRay controllers adjusting local clocks. *Macroticks* are designer configurable but typically are 1 microsecond in duration. Data that relies on macroticks is automatically synchronized.

Bus	**LIN**	**CAN**	**FlexRay**
Speed	40 kbit/s	1 Mbit/s	10 Mbit/s
Cost	$	$$	$$$
Wires	1	2	2 or 4
Typical Applications	Body Electronics (Mirrors, Power Seats, Accessories)	Power train (Engine, Transmission, ABS)	High-Performance Power train, Safety (Drive-by-wire, active suspension, adaptive cruise control)

Table 2-Comparison between Vehicle Bus Standards (18)

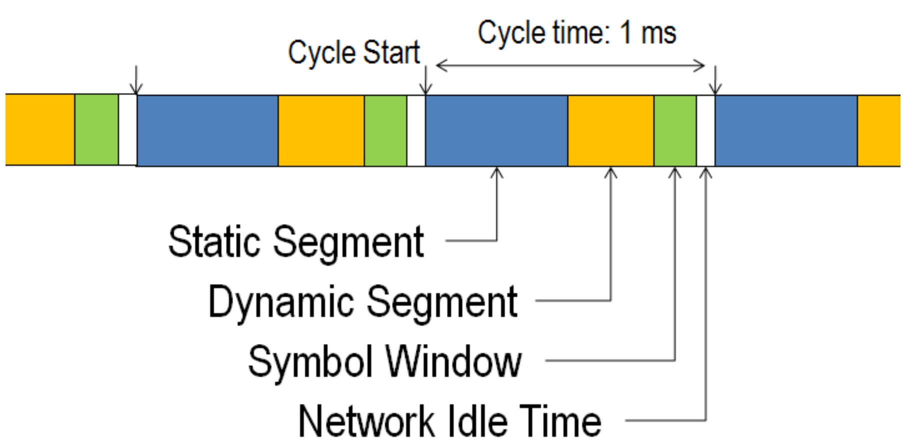

Figure 11-FlexRay Communication Cycle (18)

6 Conclusion

Military vehicle digital communication technology continues to advance. In the earliest stages of use, technology was selected based on the fundamental needs of the immediate application. Communication is fundamental to military operations, where “Move, shoot, and communicate” rank as the top three priorities. Not only has the communication technology evolved in the military, the processing and utilization of the information has changed. A great deal more information is available, and decision-making is more distributed.

Intelligent management of that information is critical to speed and effectiveness. Vehicle networks must evolve to meet broader needs, and therefore the requirements of the data bus must extend beyond the immediate application. Data must be shared beyond the local application in order to gain the synergy and enhanced value of the information, and minimize the footprint of the hardware as well as the technology interface requirements, where "plug-and-play" is the ultimate goal. Hardware bandwidth has matured for most applications using IP networks. Intelligent management of the IP data continues to evolve, especially with commercial adoption of Voice and Video over IP, which place a high demand on the maximum latency.

Critical vehicle control functions will require that technology to mature before industry will adopt an IP solution for control, but the strategic technology leadership will continue to push the value of intelligent information management, especially as unmanned systems grow.

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