White Paper

Advances in technology and features drive real-time Ethernet for mobile equipment controls network

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ETHERNET POWERLINK Standardization Group

Executive summary

Already high tech

In the eternal quest to improve upon safety, efficiency, comfort, productivity and return on investment, and to meet some legislative requirements (see Tier 4 emissions), the mobile equipment world has embraced numerous advances afforded by technology.

All around the big trade shows like Agritechnica, CONEXPO-CON/AGG, ICUEE and Bauma you will find components, equipment and exhibits which provide wonderful examples of the advances made for the greater good in the world of construction and agricultural equipment. OEMs, dealers, renters, operators, service technicians and owners will all be able to point out technologies which have helped them to better handle the daily challenges they face. And some of those advances have added to the controls network requirements, particularly as they relate to bandwidth and real-time determinism. While CAN networks have become increasingly common in mobile equipment over the last 10 to 15 years, there is now a growing interest in alternative control network technology which offers much better performance.

What's driving the interest in alternative networks?

One only has to look around at the equipment on display to understand the demands being placed on the controls networks. Automated grade control using GPS for dozer operation is already making for faster and more efficient completion of the earthmoving portion of construction projects, similar to how the integration of positioning systems and variable rate seeding and spraying control has also contributed to the advances in precision farming.

Rental equipment companies and equipment owners use GPS systems to not only locate the equipment and manage their fleet, but enhanced features like starter-disabling, curfew alerts and geo-fencing can also help to substantially lower the risks and insurance costs associated with equipment theft and misuse. The life of the operator has improved dramatically with all of the advances in cab design. Climate control, air filtration, stereo systems, and joystick controls make it a much more pleasant environment in which to work while service technicians can now use the latest remote communication technology to help troubleshoot and identify issues in a timelier manner, without immediately needing to travel to the machine.

More advances to come

Technology does not stand still, and the level to which it is integrated into future equipment designs will continue to increase quickly. Safety will continue to improve with the increasing use of cameras on large equipment and refuse trucks, and owners will have the ability to equip operators with RFID, log and retrieve data from the equipment to evaluate efficiency and then tailor training to the requirements of each individual to improve performance. Color screens with multi-touch technology and load sensing controls, will help to ensure a new operator can easily navigate safe machine start up and operation, and the pre-set maintenance alarm and on-screen access to documentation and video clips will help that operator to ensure maintenance is not overlooked.

Owners of many pieces of equipment will be able to take fleet management to a whole new level in order to maximize their return. GPS and other positioning technology will ensure the most efficient job completion possible, while "Connected" machinery will increasingly help to prevent collisions between pieces of equipment on site. The "Condition Monitoring" sensors and control system on the machines will automatically send an email or text when a component is showing the first signs of failure. This means the part will be ordered, replacement scheduled and repair completed without the machine missing any of its scheduled operating time.

Hybrid diesel – electric drive technology will be more common across the board, and all things "electric" will likely see more attention as OEMs consider cleaner and more efficient alternatives to diesel, particularly for applications like underground mining. Robotic type automation and control technology will also be more prevalent as OEMs cater to the remote control of demolition and mining equipment in restricted or more risky environments, and the stability of equipment on rough or uneven terrain will also be enhanced by using more advanced stability control systems and smart cylinders with electronic position feedback.

Where does this lead?
As mobile equipment becomes more automated and connected, CAN-based onboard networks are showing their age. The advances noted above mean construction, agricultural and other categories of mobile equipment often require much greater bandwidth, determinism and data handling sophistication than in the past, and these requirements will continue to grow – most likely in an exponential manner.

Ethernet
The result has been for OEMs to investigate Ethernet, the network standard that has become ubiquitous from business to home to industrial and now automotive applications. The solution appears obvious until one asks, which flavor of Ethernet? Because there are many. And depending on the application, each has its advantages and disadvantages.

Hoping to gain maximum economies of scale, many in the mobile equipment field are looking to the Ethernet variants vying for dominance in the automotive industry. After all, this is where CAN came from.

But the equipment world faces more mission-critical demands than automotive, so OEM R&D leaders would do well to investigate Ethernet as it has evolved in a more relevant market: that of deterministic industrial control. Doing so will save enormous resources, not the least of which is time to market.

Which flavor of Ethernet?
Although the pre-eminent network of the workplace, Ethernet TCP/IP does not provide the determinism needed for manufacturing processes. Data packets are allowed to crash and be resent with delays that won't be noticed waiting for a page to print. In applications where many nodes must be tightly synchronized to achieve high precision and speed with absolute reliability, this is unacceptable. And increasingly, this is the world of the mobile equipment design.

Modern silicon strategies have rendered economies of scale irrelevant in terms of chip cost versus performance tradeoffs. Field programmable gate arrays (FPGAs) have made purpose-built solutions cost competitive, so it's no longer necessary to compromise functionality to leverage the cost of high volume application-specific integrated circuits (ASICs). In capital equipment, these performance advantages quickly outweigh the few dollars potentially saved, a fact that machine tool designers came to realize as early as the 1980's.

One industrial Ethernet standard has emerged that warrants the attention of mobile equipment designers because it has proven extremely robust yet truly open source, meaning license- and patent-free. It features an open source safety protocol, conforms to IEE 802.3 and IEC 61784-2, and is endorsed by the products of thousands of industrial device and machinery makers worldwide.

POWERLINK is a patent-free, open source protocol that is very efficient and effective at handling large real-time data requirements of modern off-road vehicles and equipment. This paper will show how this real-time Ethernet standard addresses both data and control needs on a single wire, while reducing design costs and minimizing system jitter to achieve maximum system performance. And all while using standard Cat 5 or 7 Ethernet cables and connectors (which any other flavor of Ethernet likely will not).
Its support organization, the Ethernet POWERLINK Standardization Group (EPSG), is exhibiting at events including Bauma, Agritechnica and IFPE (co-located with CONEXPO-CON/AGG) in its outreach to mobile equipment makers.

Why POWERLINK?

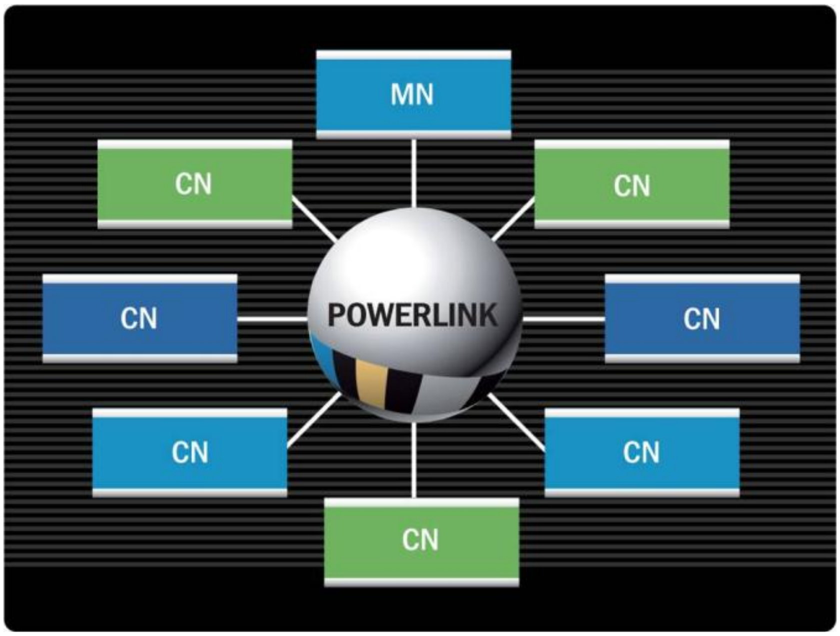

Figure 1

POWERLINK was designed and developed to address the needs for reliable and deterministic real-time communications for automation. POWERLINK is an open source protocol which solves the determinism problem using a simple collision avoidance scheme. The POWERLINK protocol uses standard Ethernet frames. It introduces the concept of a bus master (figure 1) called the Managing Node (MN). All other components on the network are Control Nodes (CN). POWERLINK is a cyclical protocol. The bus cycle time is determined at the time of configuration. The cycle is split into two phases (figure 2). During the first phase of the cycle (isochronous phase) the-time critical information is transmitted by the MN and CNs in a scheduled manner, avoiding frame collisions. During the second part of the cycle (asynchronous phase) all nodes may communicate as needed using standard Ethernet protocols such as TCP/IP, SNMP, etc., to communicate non time-critical data.

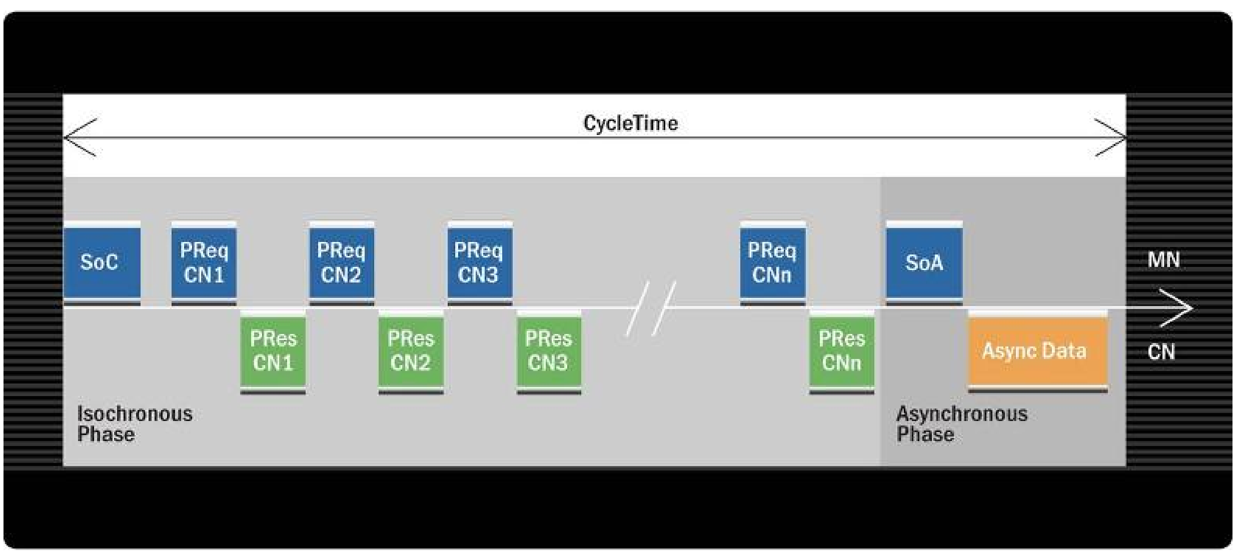

Figure 2

The cycle is initiated by the MN placing a start-of-cycle (SoC) frame on the bus. This indicates that each node must get ready to transmit its frame. To start the data communication for each cycle, the MN sends a Poll Request Frame (PReq) to each individual CN on the network. Each CN then responds by immediately placing its data in an Ethernet multicast frame (PRes), making the data available to all nodes on the network. This mechanism allows for real-time deterministic cross-communication and synchronization between all nodes on the network

An automation network typically contains a variety of components such as drives and encoders (requiring high frequency data updates) and sensors (requiring lower frequency updates). To make the network efficient, the network protocol must allow for high frequency data to be placed on the bus at every cycle, while low frequency data is only placed on the bus every nth cycle. The bus multiplexing feature in POWERLINK addresses this requirement as shown in figure 3.

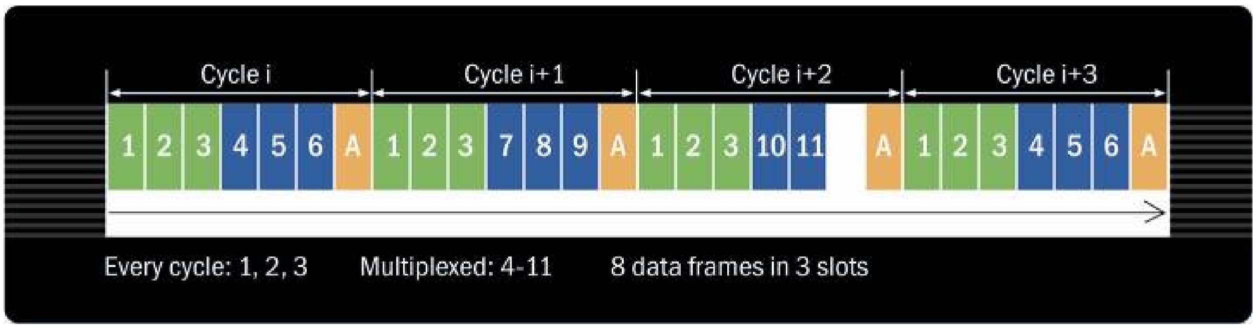

Figure 3

Figure 3 shows how nodes 1, 2, and 3 publish their data every cycle while nodes 4, 5, 6, nodes 7, 8, 9 and nodes 10, 11 are multiplexed. This multiplexing scheme is configured at startup. Bus multiplexing allows all components to operate optimally on the network without degradation in performance for the component or the network itself.

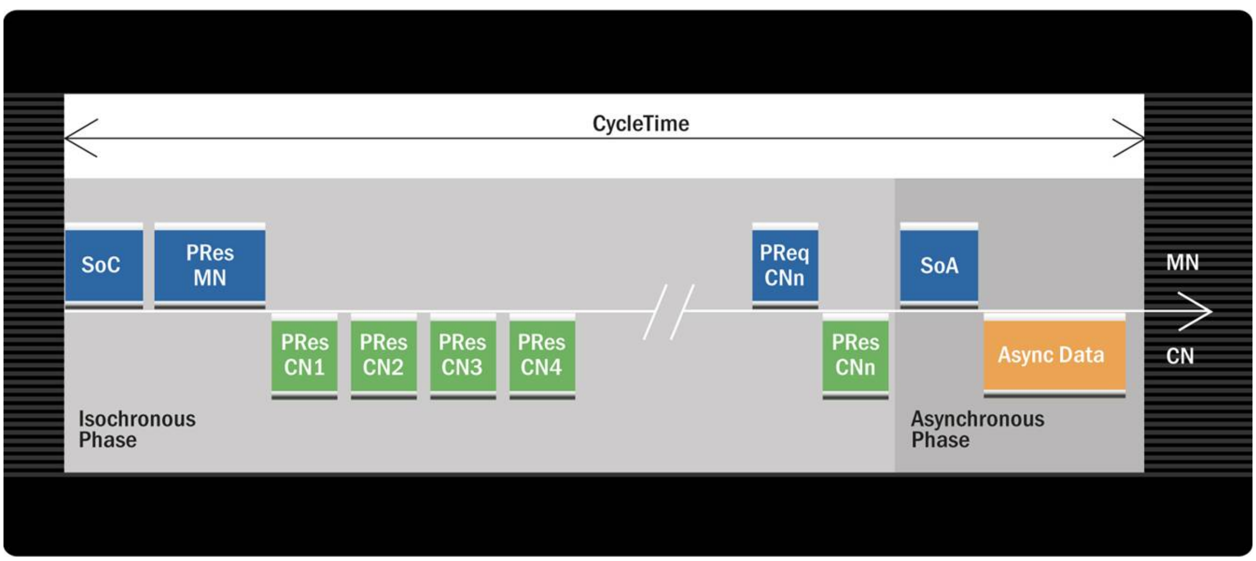

Figure 4

Another form of network efficiency is illustrated in figure 4. This mode is known as Poll Request Chaining. In this mode the MN issues one poll request to all nodes which prompts each node to place its data on the network after a unique set delay which is configured for each node during startup. This is ideal for network scenarios containing many nodes running at high frequencies.

POWERLINK and CAN
POWERLINK = CANopen over Ethernet

POWERLINK uses the same device description files as CANopen, the same Object Dictionaries, and the same communication mechanisms, such as Process Data Objects (PDO), Service Data Objects (SDO), and Network Management (NMT). As with CANopen, direct cross-traffic is also one of POWERLINK's essential features. All CANopen applications and device profiles can immediately be used in POWERLINK environments as well. Applications will not see a difference between the protocols. POWERLINK can therefore also be referred to as CANopen.

Application complexity is generally increasing, which leads to a greater number of nodes, rising data load, and higher performance requirements. A simple migration to POWERLINK is an ideal alternative for users who wish to continue to enjoy CANopen's benefits in spite of more demanding requirements. Moreover, POWERLINK gives them one consistent medium throughout the entire application.

CAN networks tend to operate at a maximum baud rate of 1Mbit/sec, and CAN frames have a typical payload of a few bytes. POWERLINK tends to operate at 100Mbit/sec with an Ethernet frame of 1.5K byte thus allowing for a much higher bandwidth of data. While CAN Networks tend to operate at minimum of 2 to 3 millisecond cycle-times, POWERLINK typically runs at 250 to 400 micro second cycle times for medium-size systems. For small systems even considerably lower cycle times are possible.

Alternative real-time Ethernet solutions
Alternative real-time Ethernet protocols provide a fast and low latency communications solution, based on a token-ring concept. They use the concept of a sum frame whereby an individual frame is passed from one node to the next on a ring. Each node adds its own data to the frame and passes the frame onto the next node on the ring. While this approach works well on systems with a small number of nodes it has the following limitations:

Limited Network Topology:
If the Network topology is anything other than a ring, e.g. a star or tree topology, the communication becomes more inefficient. The frame starts at the central node and then gets passed to each leaf node, and back to the central node. This process is repeated for each leaf node slowing the network down significantly with the addition of each new node to the network. With POWERLINK, adding more nodes to the network introduces minimal delays.

No Cross Communications:
Using the sum-frame concept, node-to-node communications and synchronization slows down as the number of nodes on the network increases. With POWERLINK all nodes use multi-cast frames so data published by a node is available to all nodes on the network at once. As the number of nodes increases the communication between nodes does not slow down.

EMI (Electromagnetic Interference):
Passing a single frame, from one node to the next increases the probability of frame corruption due to EMI, as the number of nodes on the network increases. Using POWERLINK, resistance to EMI is much larger and the probability of failure is substantially lower in noisy environments such as slip rings.

Non real-time data
The POWERLINK cycle is split into two phases. The first phase (isochronous phase) is where all the real-time communications takes place. The second phase (asynchronous phase) is used for standard TCP/IP, UDP, SNMP, or any other status and non-real-time communications. This allows networked components to transmit status data, or any other low priority data such as video frames without impeding the performance of the network.

High availability networks
It is typically very costly when an automation network goes down, requiring the protocol to support high availability capabilities. POWERLINK is designed to handle three forms of high availability. The simplest form is ring redundancy shown in figure 5. Each POWERLINK CN has two Ethernet ports connected internally by a hub. To form a ring, the CNs are daisy-chained and the last CN is connected back to the MN. In this configuration the network will continue to operate if any single cable is broken or accidentally disconnected.

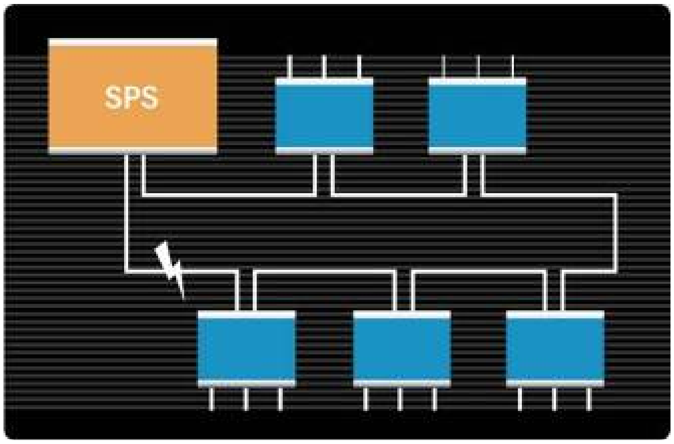

Figure 5

Full medium redundancy is another form or high availability (figure 6). In this scheme there are 2 physical cables and networks connected to each node via a link selector. The link selector will detect when the network on one cable is down and will automatically switch over to the network on other cable.

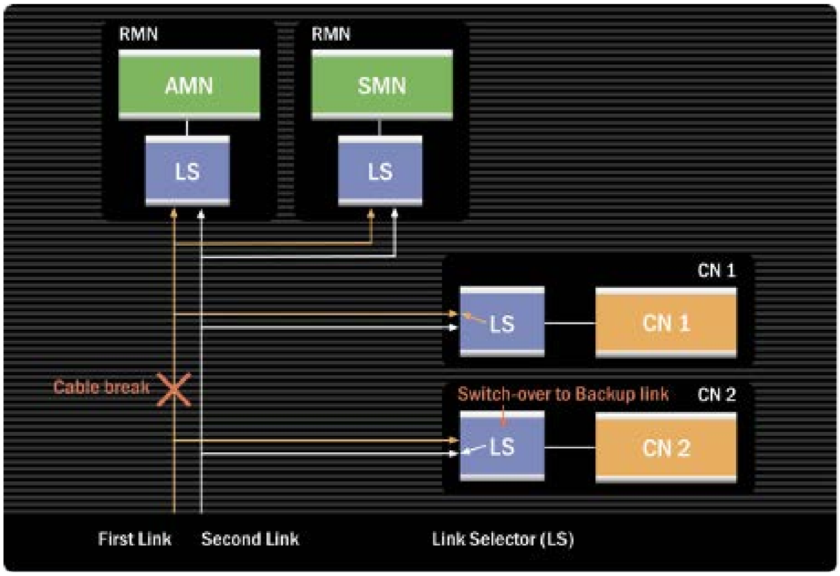

Figure 6

Figure 6 also shows a third form of high availability implemented through Master Node redundancy. The MN is responsible for the network timing and synchronization. If the MN goes down the entire network will halt. To avoid this from happening POWERLINK allows up to 9 additional redundant masters, where

control will automatically get passed to an available MN should the main MN go does. This switchover takes place within one bus cycle and causes minimal interruption to the network.

Performance and diagnostics
Due to its guaranteed collision-free behavior it's easy to intuitively understand why the POWERLINK protocol can deliver high performance in automation even at high percentages of network utilization. As an example, it is possible to run a system with 800 digital I/O points, 180 analog I/Os, and 24 axes of motion, at a 250 micro-second cycle time.

Due to the recommended use of hub technology, the network transparency afforded by hubs make it very easy to debug a POWERLINK network using standard tools such as Wireshark, Omnipeak, etc. Figure 7 illustrates a typical network configuration being debugged.

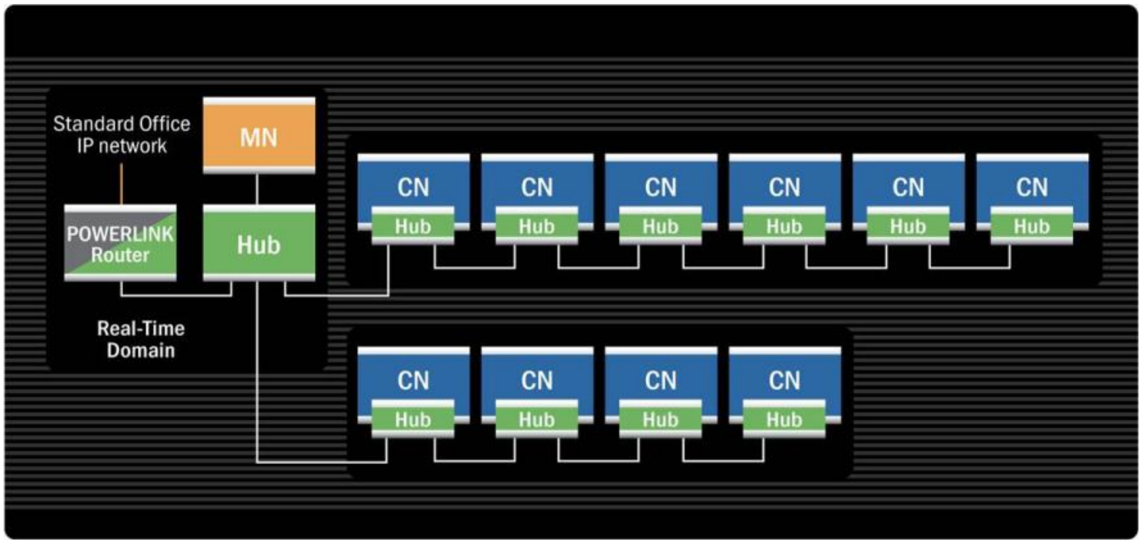

Figure 7

Adhering to open standards
The Ethernet standard has been available since 1972. Ethernet POWELINK has been designed to use standard Ethernet frames with Ethertype 0x88AB. This is significant because it allows for standard hardware to be used. It also allows for standard software tools to be used to analyze the network. It is simple to connect standard Ethernet devices to a POWERLINK network. However, they need to be connected to the network through a gateway. The gateway essentially passes frames to and from the standard devices during the asynchronous phase of the cycle ensuring that each device does not speak out of turn during the time-critical isochronous phase. This feature makes it easy for service technicians to plug their laptop into the network for system maintenance and diagnosis.

POWERLINK is compliant with IEE 802.3 and IEC 61784-2. Adhering to standards allows POWERLINK devices to be hot-pluggable. So any device may be replaced without shutting down the network. This reduces the cost of service and maintenance.

POWERLINK is open source, patent-free and license free. The source code may be downloaded from Sourceforge.net. The network interface may be implemented as a software-only solution running on a microprocessor. However, microprocessors running a standard RTOS may suffer from jitter thus reducing efficiency. For a jitter-free high performance environment a POWERLINK network interface may be implemented using an FPGA (FPGA code is also available in open source) or using many off-the-shelf ASICS developed by leading ASIC manufacturers such as Hilscher, HMS, Intel, ST and TI. Standard Ethernet has a high degree of immunity to Electromagnetic Inductance, making POWERLINK ideal for implementing remote I/O in environments with a high degree of electrostatic noise.

Conclusion
POWERLINK allows system designers to build a completely integrated architecture with all remote I/O connected to one network. Having an open standard define how devices communicate in a uniform and efficient manner allows device manufacturers (sensors, motors, actuators, vision systems) to focus on developing best-in-class devices without being concerned with efficiency or communications overhead. It also allows OEMs, machine builders and system integrators to develop high performance systems with a large choice of components without being limited to a single component provider.

POWERLINK users enjoy six main benefits:

i) Open source technology: The technology is freely available, license free and patent free.
ii) Flexible Communications Scheme: A cycle allows for a real-time communications phase and asynchronous phase guaranteeing that important real-time data is not lost, while low bandwidth non-real-time data is also passed through.
iii) High availability and redundancy: With 3 forms of redundancy POWERLINK system developers can deliver highly reliable systems.
iv) Hot pluggable: Devices may be swapped out without shutting down the network. This means the cost of maintenance is significantly reduced.
v) Network Topology: A system may be commissioned and deigned with any network topology without degrading performance.
vi) Low sensitivity to Electromagnetic Inductance: This means that the system will be highly immune to electrical noise.

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