Implementing Energy Efficient Networks with IP-485® Technology

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Abstract—The needs for integrating IP-enabled edge devices and connecting them to the Cloud is expanding rapidly in the industrial, commercial, energy and defense markets where much of the growth is based on a desire to establish open standard IP connections throughout network infrastructure. In contrast, the last thirty years has witnessed significant deployment of serial device networks configured to operate as "closed-systems," that have been engineered to maintain end-to-end performance, security and reliability. The challenge now faced by designers and system integrators is to develop a cost effective and energy efficient way to integrate IP devices and transform closed systems into systems that can interact, access or migrate to open standard networks. In this paper, we present an energy efficient networking technology called IP-485® that enables both Ethernet/IP upgrades on existing wired infrastructure while preserving existing serial data and legacy operations, and does so while assuring high Quality of Service, Reliability, Security and optimizing energy efficiencies and communication power requirements. We describe the IP-485® technology and discuss commercial deployment of products. Applications serviced by PCN networks include Smart Grid integration, SCADA migration, Video & Access Security upgrades, PCI compliance upgrades, digital signage and media, and VoIP among other.

Keywords—IP-485®, Networks, Routers, Switches, Ethernet, TCP/IP, exploitation of physical infrastructure, energy efficiency.

I. INTRODUCTION

The past two decades have witnessed an unprecedented growth in IT infrastructure deployments, driven largely by a desire to increase productivity through applications within consumer and office operations by corporations big and small. In recent years, there has also been a push to integrate IP-enabled edge devices into commercial and industrial networks, and connect them to the Cloud. Motivations for the upgrade range from technical considerations such as Cyber Security to operational efficiencies delivered by Hosted Applications enabled by models such as Software as a Service. However, IT advances have found relatively little traction in the brownfield environments typically located in commercial and industrial markets, where serial device networks have been configured to operate within closed-systems that have been engineered to maintain end-to-end security, performance and reliability.

The challenge faced by designers and system integrators planning these infrastructure upgrades is to develop a cost effective and energy efficient way to integrate IP devices and transform, converge or migrate closed systems into open standard networks. The critical Infrastructure found in brownfield environments consists of disconnected, disparate networks with little or no integration. For example, Figure 1 shows the typical network configuration in a factory environment. The Corporate IT network is disparate from the SCADA control networks, which in turn may be separated from the device networks. In addition to these, there may also be digital voice networks with switches at premises, an access control network, a network of analog cameras with storage media maintained in the premises; and an asset management network in the warehouse with an IP gateway for Cloud connectivity. These networks operate in a stand-alone (often closed) manner. Over time, it becomes quite complex for facilities & IT managers to even maintain these networks – upgrading them or scaling up becomes an expensive, time consuming and laborious proposition.

Figure 1: Typical System in an Industrial Facility

II. CHALLENGES IN WIRED NETWORK INFRASTRUCTURE UPGRADES

Upgrades to commercial and industrial networks are expensive. New wires have to be pulled across the entire facility to support the new applications. The existing wires are usually left in place since pulling them out is typically not worth the cost. Further, upgrades tend to be complex. Often decisions need to be made on which parts of the existing networks need to be left as-is, and whether integrated into the new infrastructure and
with those which need to be left alone. For example, while an upgrade of analog cameras to IP-enabled cameras may be part of the overall network change-out, the facilities administrator may not include the installing of an IP gateway into the HVAC network within his budget. Regardless of the nature and scope of the network upgrade, it is safe to say that there will be a need for additional wires, and all of the existing wires will probably be left in place or ripped out and thrown into landfills. This means that, by nature, all network upgrades leave behind a negative carbon footprint. This, when combined with the fact that the manufacturing processes involved in the production and transportation of copper cables are environmentally harsh, leads to the conclusion that network upgrades are environmentally unfriendly.

III. IP-485® TECHNOLOGY: A RADICALLY NEW APPROACH TO “GREEN” ENERGY EFFICIENT COMMUNICATION NETWORKS

Figure 2: Dynamic Adaptive Channeling Algorithm

PCN has developed a unique and differentiated technology called IP-485®, which enables the transport, deployment and access of Ethernet/IP data for Ethernet/IP extensions, IP Gateways and IP-enabled networks on existing wired infrastructure (twisted pair, discrete, co-ax, etc.) while preserving the existing functionality already on the infrastructure [5]. The term literally means the ability to deliver Ethernet/IP and RS485® twisted pair networks. The foundation of IP-485® lies in an algorithm called dynamic adaptive channeling which implements the physical level of Level 1 of the network and is capable of assessing its capacity in real-time at a given Quality of Service (QoS) and subject to other channel constraints. The algorithm, shown in Figure 2, divides the communication channel into Orthogonal Divisional Frequency Multiplexing (OFDM) sub-channels. It conducts a spectral sweep of the channel and assesses the Signal-to-Noise (SnR) of individual OFDMs and determines which of the channels are usable [6]. In the current implementation, the analysis is completed within 2.5mS, and can be reduced in the future as needed with higher performance computational engines. Adaptive channeling naturally recognizes:

- White noise in the channels which degrade the communication bandwidth
- Other applications in the channel which shows up as interference and blocks it from use during those times.
- Colored noise in the channels which also shows up in the analysis as periodic interference and blocks it during those time windows from use.

With the adaptive channeling algorithm in place, when PCN products are connected to a wire, it has the ability to recognize the ongoing serial communications or legacy operations and adapt the IP communication in such a manner that both applications co-exist on the same physical medium.

The second aspect of the IP-485 technology is network management at the physical level. In each 2.5mS window, our proprietary Level 2 algorithms determine how to encode data into the available channels. Metrics such as data priority and network management protocols are implemented so that packets can be organized and routed through the network. This permits the deployment of IP-enabled networks on serial and analog multi-drop or daisy chain wiring architectures. This feature not only provides a great deal of flexibility in re-using existing wires, it also minimizes the number of new CAT 5 wires deployed since they do not have to be structured for point-to-point physical connectivity [4].

The proprietary methods described here for the management of the physical and the link layers of the network, in effect, enables the exploitation of existing physical infrastructure for communication, and is the first aspect of energy efficiency in our network implementation. In addition, because SnR metrics are used in the selection and use of channels, the power requirements for transmission of information is minimized across the entire network.

IV. IP-485® NETWORKS

Figure 3 shows a typical IP-485® network [4]. It consists of a PCN Router that is connected to the Cloud via an ISP line (T1, Fiber or Satellite) using a standard CAT 5/6 connection. It may also be connected to 1-4 serial networks on its Low Frequency (LF) Bus(es). The PCN Single Channel Router (SCR) accepts a single serial network connection, while the Multi-Channel (MCR) version permits the integration of up to 4 serial networks. In such a configuration, the Router is able to accept both IP data and serial data and converge them on to a single output channel, called the Broadband (BB) Bus. SCR would
have a single BB Bus, while MCR would have up to 4 separate BB Buses [1].

PCN BB Bus represents a unique physical infrastructure for our networks. Each BB Bus wiring can be multi-dropped into 4 (up to 8) PCN Network Switches (NS). Each NS functions as a 4-Port IP switch (1 input and 3 outputs) with serial access that can complete the connection of the serial network to serial edge devices. Serial devices are connected using the LF Bus connection found in each NS. In certain cases where applicable, NS can also be used as a standard 3-Port IP Switch at the edge. In this manner a single SCR can establish a network of 12 IP edge devices (some of which may themselves be traditional switches, hubs or wireless gateways) while a MCR can establish a network of 48 devices. In each case, the IP network would co-exist with the serial network without any impact on the performance of one network from the other. In our current product implementation the BB Bus as well as the LF Bus consists of standard twisted pair (TP). However, the technology has been validated on a variety of analog (current loop, co-ax, etc.) and digital (RS 485/422/232, Modbus/Fieldbus/Profibus, etc.) wiring. There is even a demonstration of video and audio streaming over a length of barb wire in the PCN Laboratories in San Diego, CA.

PCN networks also have the ability to operate in harsh, electrically noisy environments that are typical in industrial, energy, and commercial applications. In these environments, PCN Routers are rated to deliver a dedicated bandwidth of 2 – 4 Mbps at each switch, with burst rates of 20 Mbps. This enables PCN networks to service a variety of industrial and commercial networking applications including SCADA control of discrete machines and process lines, energy management in larger buildings and campuses, secure payment processing, surveillance and access control for physical security, and digital-out-of-home (DOOH) signage and media.

V. REAL-LIFE APPLICATIONS OF IP-485® NETWORKING TECHNOLOGY

PCN networks have been deployed in the Oil & Gas industry for downstream applications, and have been thoroughly tested and are commercially deployed for payment and media applications both in the field and in PCN laboratories. In this section, we will describe the specifics of these application networks and present the state of maturity in the way of field installations.

A. Retail Forecourt Network Application

Most retail fueling forecourts contain twisted pair wiring or current loop wiring that runs from the forecourt store to the tank system, electronic signs and dispensers in conduits that are buried underground beneath the concrete. These wires are connected on the forecourt side to electronics that drive relevant equipment, and to specialized networking hardware in the store. The networking hardware, in turn, is connected to one or more PCs that contain pump control, signage, tank management and payment software [3]. An upgrade of the network involves making a choice between completely bypassing the wires and deploying a wireless network, or conducting extensive construction work to deploy new CAT 5/6 cables under the concrete. The former, while inexpensive, is unreliable and insecure and the latter, while reliable, is expensive and time consuming with business risk. So, both choices are equally problematic for station operators.

Figure 4 shows a forecourt network deployed using the IP-485® technology, which enables IP-enabled forecourt networks on the existing twisted pair cables. The specific applications serviced by the network are PCI compliant network upgrades, media and digital signage delivery at the pumps, integration of forecourt equipment and sensors to the Cloud for the delivery of remote web-enabled services.

To date, deployment of IP-485® based forecourt networks have been completed in hundreds of locations, with an estimated thousand installations under contract for completion by end of 2012. Deployments have now been operating in the field for over a year (through all four seasons, both under extremely cold and extremely hot conditions) without any field issues.

Figure 3: IP-485® Network

Figure 4: Forecourt Network with IP-485® Technology

B. Building Management Network Application

Commercial and industrial building (and campus) environments consist of a variety of networks, each operating...
in a closed standalone manner [2]. Typically, there is at least one access control network for employees, one or more energy management networks controlling equipment such as HVAC and lighting, analog cameras that are networked to some in-facility media storage system, networks that integrate some combination of analog, digital and Voice over IP (VoIP) telephones to switches and exchanges in the back-room, and data networks that connect users to the Internet and share services such as printing and scanning across the building LAN. Depending on facility type, there may also be additional networks in warehouses for asset management. Clearly, such environments pose significant challenges to facilities Directors in the determination of how to assess the risks and costs associated with infrastructure upgrades. As an example, a simple business decision to move analog cameras to IP-enabled cameras that are connected to the Internet for Cloud-based analytics involves complex technical decisions on how best to upgrade the infrastructure to achieve the objective.

Figure 5 shows how upgrade decisions can be made very easy through the use of PCN’s Routers and Switches. For camera upgrades, the facilities director may simply re-use the legacy wiring (or exploit available legacy telephone lines nearby to transform the camera network and connect it to the Cloud. We have done extensive testing of IP-camera control and integration using twisted pair and co-ax both in our laboratories as well as at customer facilities and have demonstrated that our networks can fully support H.264 payloads. We have also successfully conducted a variety of energy management tests both at PCN and at customer facilities. We are currently working with a large system integrator to demonstrate a full end-to-end system in the field.

Our products have been deployed at our San Diego offices for over six months to deliver VoIP services within the building to offices using standard POTS lines. The performance of this system remains indistinguishable from either the digital phone lines and associated services within the building or the VoIP lines (on CAT 5) and associated services.

Our Routers and Switches have also been successfully tested for command and control applications in environments typical to nuclear submarines.

Given that Ethernet/IP applications and services can rapidly be integrated into critical infrastructure environments by using the same “operational” copper wiring already in place; the energy efficiency of networks are greatly increased by eliminating the need for production and transportation of copper wire[7].

With the accelerated and rapid integration of new IP enabled services and applications through IP-485® technology and products end users can also create additional business models and services that enable more energy efficient business models without impacting the existing security, reliability and efficiency of private control and automation networks.

An example of this includes rapid integration of IP enabled smart grid devices that connect to existing private automation and control network wiring where both use an already installed and paid-for infrastructure. The new IP enabled devices such as Solar and Wind generation devices ensuring rapid monitoring and application of “green” field devices for immediate acquisition of benefits without requiring truck rolls, additional copper integration[8]. This same type example is realized in multiple markets creating benefits for network owners, integrators and society as a whole.

VI. SUMMARY AND FUTURE WORK

In summary, we have described in this paper a new approach to networking at the edge using IP-485® Technology. Our products have demonstrated the ability to exploit a variety of existing infrastructure and operate in harsh and electrically noisy environments that allow rapid “applications” and integration of services using Ethernet/IP technologies over existing operational installed wiring. The key to our technology is the ability to detect and adapt our communication strategy to line noise, interference and other users of the channel. The key to our value proposition is the ability to establish a virtual bus on legacy wiring that is capable of simultaneous transport of serial and IP data.

PCN networks are energy efficient. They fully exploit and leverage the existing wiring infrastructure, network hardware, and business operations of installations while enabling rapid integration of new Ethernet/IP applications & services providing a strategy for the deployment of network upgrades with minimal negative carbon footprint. Further, the algorithms used for channel selection guarantee optimality in communication power usage for a given QoS metric and bandwidth.

To date, we have many thousands of our network switches and hundreds of our multi-channel routers deployed in the...
field. By the end of 2012, we anticipate a doubling of the install base.

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