STREET DEPLOYMENT OF PEDESTRIAN CONTROL

SMART TRAFFIC SIGNALS

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16. Abstract

Smart Signals is a term used to describe the application of network based distributed control technology to the control of traffic signals at signalized intersections. Presently, signalized intersections use a centralized control approach where all of the controls are initiated by a single controller located in a traffic controller cabinet. Dedicated wires are used to turn signal lights on and off. The Smart Signals paradigm uses microprocessors located in the signals to distribute the control intelligence. The advantages of this approach extends the fault coverage, has the potential to reduce the physical size and cost of the traffic controller cabinet, allow for more precise control of intersection movements, and allow the inclusion of future innovations in sensors to traffic control. Our research has explored ways of integrating the new methodologies with existing practices for a more cost effective way of updating intersection traffic controls. We have demonstrated that Smart Signals and conventional traffic signals devices can effectively and reliably simultaneously operate using a single NEMA TS2 traffic controller. For street deployment, the Smart Signals devices must operate with the same degree of reliability as conventional traffic signals do today. Conventional traffic control systems use a malfunction management unit to monitor correctness of traffic controller outputs. However, a new approach to monitoring is required for the distributed control approach used by Smart Signals. We applied Ethernet safety critical control practices to Smart Signals resulting in synchronized time division multiplexing communications to ensure network devices are generating correct outputs.

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PROBLEM

The Smart Signals concept was first investigated in 2004 with the object of generating an architecture of an enabling technology to support advanced capability for traffic signals based on a network-based plug and play distributed control concepts. Work completed in 2005, 2006 and 2007 resulted in demonstration systems that proved that smarter (computer enhanced) traffic signal devices can improve operational safety by providing more reliable information to vehicle operators and pedestrians.

As the Smart Signals concepts matured, based on the advice of our advisory team (representatives university researchers, equipment manufacturers along with state and federal highway agencies), the network communications was migrated from an internet protocol based on the IEEE 1451 standard to communications based on the National Transportation Communications for ITS Protocol (NTCIP). Making this transition helped us realize two significant advantages: it was possible to establish a direct interface with NEMA TS-2 traffic controller devices and because of the implied compliance, we achieved greater industry acceptance.

It became apparent that in order to motivate the traffic operations industry to consider an enabling infrastructure, that we would have to demonstrate the need for such capability with new devices that offer high benefits but are incapable of functioning with existing traffic controls. Our advisory team also recommended that we initially focus on areas of traffic control that represent low risk and high potential benefit. To use an analogy, we have proposed a super highway system for traffic signals, but we must also build the cars and trucks that would benefit from the existence of a transportation system with super highway capability.

Therefore starting with the 2005-2006 research, we directed our research toward pedestrian controls and signals. There are two major areas where pedestrian signals can be currently enhanced but only when operating with the aid of the smart signals architecture. In the area of device operations, the present countdown pedestrian timer can fail when the intersection timing plan changes, with two ramifications. The first is that an incorrect time is displayed during the cycle that the timing plan changes. The second is that, depending upon the manufacturer, the timers will not display the clearance time for one or two cycles following the changed cycle.

The second major area for improvement of pedestrian signals is in the area of pedestrian interface with the pedestrian button. Highway construction practices have been and continue to make the assumption the only way to for a pedestrian to place a call is to by using mechanically operated button, physically placed in the intersection. Due to infrastructure limitations and/or antiquated installations, blind and mobility-impaired pedestrians can be placed at a severe disadvantage. Regardless of the predominant mode of transportation, walking is the mode that connects all other modes and is the most fundamental and essential mode. For people with physical disabilities, walking may be the primary mode of transportation.

As identified by our advisory team, validating traffic controls has two critical elements: demonstrating correct operation and proving that an operation is correct at all times under all possible conditions. The first validation is achieved by decision path coverage where the code is shown to operate in the prescribed manner for all possible inputs while in all possible operational states. Any failures at this level are a result of design errors. It is suitable to perform this validation prior to system deployment.

The second validation is continuous and in real-time. Conventionally, the malfunction management unit (MMU) device in the traffic controller cabinet is responsible for ensuring that the traffic controller operation is in compliance with safe intersection operations. The MMU functions under the premise that all control decisions are made only by the traffic controller and that the state of all signals is observable by the outputs of the load switches. The MMU, functioning as an independent monitoring device, increases the reliability of the system by detecting failures not found by design testing as well as mis-operations due to component failures.

In a distributed control environment such as the Smart Signals architecture, intelligent devices spatially distributed throughout the intersection make decisions based on algorithms that use information received by communications. Hence the state of the signals is no longer observable by a single device operating at a single physical location. The loss of MMU capability must be accounted for by software, hardware or both. A street demonstration of the Smart Signals architecture depends on demonstrating correct functionality for both design testing and providing the MMU type of functionality.

APPROACH

The Smart signals architecture shown in Figure 1 illustrates the concept of integrating NTCIP network-based traffic controls with conventional traffic controls that use NEMA TS-2 controllers. Although not shown, the architecture can function correctly with any mixture of conventional and Smart Signals lights, detectors, and buttons. The implication is that intelligence can be added as required without the need to replace all of the intersection electronics.
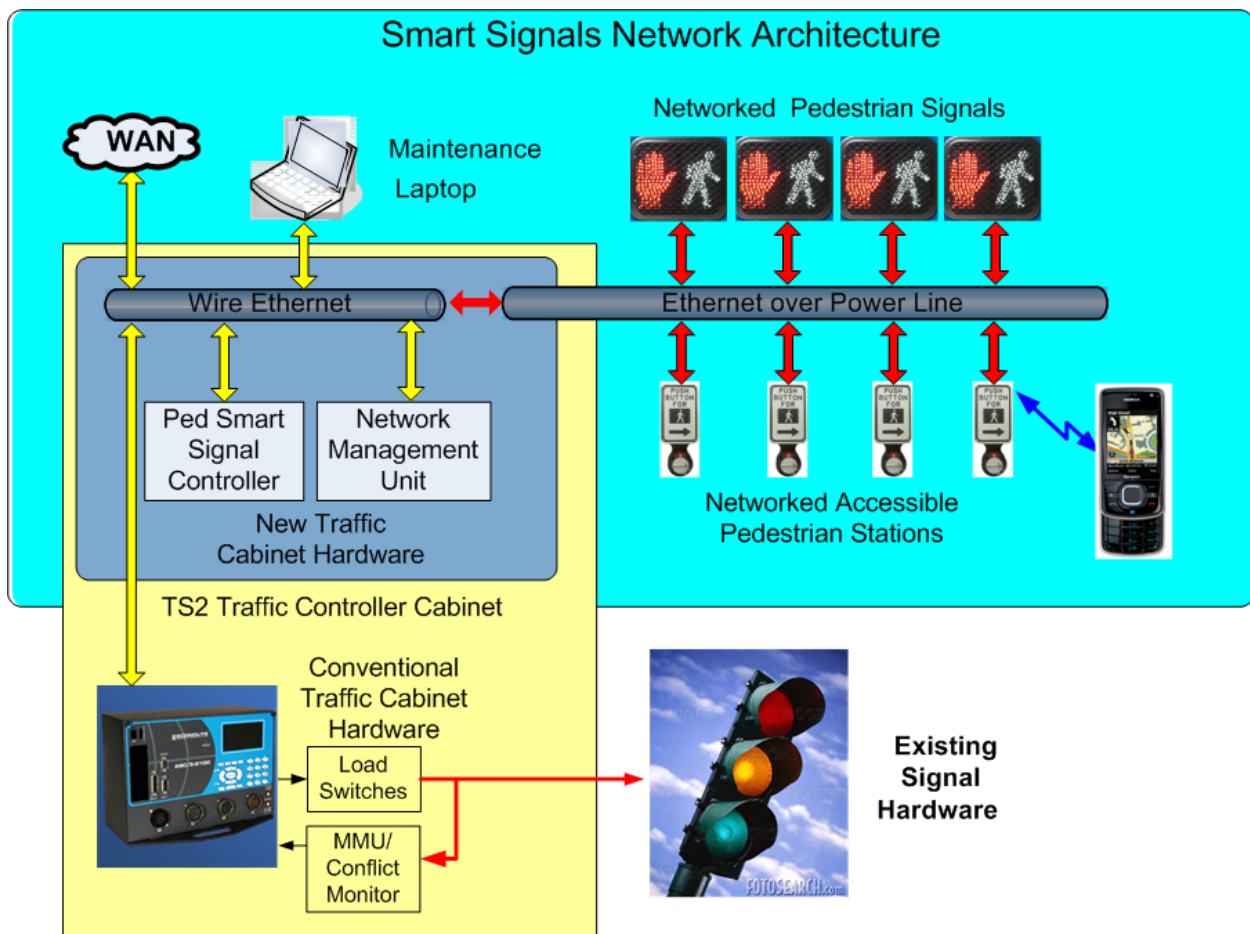

Figure 1: Block diagram of Smart Signals architecture for traffic signal control.

In this diagram, the Smart Signals network controls interface at set of smart pedestrian signals and pedestrian buttons. Using a homogeneous information environment that uses common software objects to describe control variable, input, output and control devices all speak the same language. The information portal into the traffic controller data base gives access to a wealth of

information that is not possible to obtain using the conventional control outputs. This allows Smart Signals devices to "anticipate" controller outputs and respond more quickly as opposed to being strictly reactionary to output based on past decisions.

Two elements of the Smart Signals network are worthy of particular note: the Pedestrian Smart Signal Controller and the Network Management Unit. The pedestrian Smart Signal Controller is a microprocessor-based device needed to compensate for limitations in the Econolite ACS3 implementation of the NTCIP standard. The Network Management Unit functions as the MMU for the Smart Signals Network.

Figure 2 shows equipment we assembled to create a duplicate of the controls that would feasibly be used at the Intersection of 6th and Deakin Streets in Moscow, ID. This gave us the ability to experiment and in a safe and developmentally friendly environment that resulted in fast turnaround development cycles. By using authentic traffic control equipment, we could be confident that our results are representative of those that could be collected in the field but operating without risk or loss of traffic performance.

Figure 2: Laboratory equipment representing traffic controls at 6th and Deakin Streets.

We modified commercial MUTCD compliant pedestrian signals [1] and accessible pedestrian stations [2] with network capable commercial low-cost microprocessors [3]. Using existing hardware reduced development costs and allowed us to focus on the development of software independent of hardware that will ultimately employed in field devices.

Our approach to disseminating the results of our work is to publish articles in a series of conference papers that describe the building blocks of the Smart Signals system. We choose to use conference papers in lieu of journal papers because of the long periods between paper submission and publication. The sequence of articles allows us to construct a detailed picture of our work and reference previous published work to fill in gaps in information.

METHODOLOGY

The Smart Signals paradigm is an enabling technology. Initially, we envisioned an entirely new system that meant that there were no constrains on infrastructure capability so long as we could demonstrate that we could achieve a significant economic, performance, or safety advantage. After demonstrating the reduced scale models in 2005, the feedback from our advisory team pointed out the shortcomings of the new approach relative to the "way things are done today." Politics and economics dictated that acceptance that Smart Signals technology would be on an incremental basis where new devices would have to be integrated with existing traffic controls while not adversely affecting the performance of existing traffic control systems.

We have intentionally avoided designs that require significant (if any) modifications to existing traffic controllers. We have chosen the data portal that has minimal impact on the algorithms and real-time performance designed into conventional TS2 traffic controllers. Using the Ethernet interface, the traffic controller services the data requests when it is convenient for the controller and not at the behest of some external device or agent. Our design methodology resulted in creating an independent control device called the "Ped Smart Signal Controller" (see Figure 1) that performs the operations that are required for robust and reliable Smart Signals Network operations.

The "Ped Smart Signal Controller" is strictly a software-based device that pools the required data from the traffic controller and rebroadcasts this information over the network to the spatially distributed smart signal devices. The logic provided by the software that the "Ped Smart Signal Controller" executes logically should reside in the traffic controller. There would be no need for "Ped Smart Signal Controller" if the TS2 controllers we worked with were 100 percent NTCIP compliant.

The "Network Management unit" (NMU) depicted in Figure 1 is responsible for detecting and responding to failures in any Smart Signals Device or in the communications network. In order for failures in the conventional traffic signals to be coordinated with the Smart Signals system devices, the NMU has a hardwired interface with the TS2 MMU device. Failures detected by the MMU are communicated to the NMU and vise-versa so that when a either the NMU or the MMU detects a failure, the entire traffic intersection is placed in the safe-fail mode of operations.

The NMU utilizes concepts developed by the industrial control community specifically for safety critical applications where there is high probability of high economic loss or danger to human life. A search of the literature shows that the predominant requirement for safety critical networks is that they operate deterministically [4] This means that all network communications and delays are bounded and that there is a guarantee that all devices confirm all communications.

Network communications has been traditionally modeled as a stack of operations represented by layers as shown in Table 1. Information starts at the application layer where the data is organized into a continuous string or session of bytes in the computer memory. This block of data is passed to a lower layer that appends information to original data that helps in the delivery of the date to the proper destination. The process is reversed at the receiving devices. An analogy would be to have a handful of notes for different people at a remote office. The handful of notes is put into an inter office envelope and passed to the mail room. The mail boy places the inter office envelope in a US mail envelope and gives it to the postal worker who puts in on a truck and so forth.

Table 1. Seven-Layer Operations System Interconnection (OSI) network model

LAYER	EXAMPLES
7) Application	HTTP, FTP, Telnet
6) Presentation	ASCII
5) Session	SSL, PPP
4) Transport	TCP, UDP
3) Network	IP, IPX
2) Data Link	Ethernet, Token Ring, FDDI
1) Physical	UTP cable, coax, voltage levels, signaling

Although we have chosen Ethernet as the data link layer (layer 1) and the Internet Protocol (IP) for the network layer, the NTCIP uses the User Data Protocol (UDP) for the transport layer (layer 3). Layers 5 and 6 as shown in Table 1 are not implemented and the Simple Network Management Protocol (SNMP) is implemented in the applications layer (layer 7) that manages the NTCP control objects. Although some data validation occurs when information is passes from layer to layer, the determinism required for safety critical network operations is not provided by any layer. We selected the IEEE 1588 Precision Time Protocol (PTP) [5] that manages a Time Division Multiple Access (TDMA) network communications scheme at the

application layer. The PTP software ensures that all Smart Signal nodes on the network are synchronized with respect to time and the TDMA software controls when each node is allowed to transmit the data on the network. The time sharing of the internet resources in the predictable manner provides the expectation and determinism needed for safety critical networked operations. Any operation outside the bounds of the designed determinism and expectation constitutes a detectable system failure.

FINDINGS

The results of our development efforts have been or soon will be published in four conference papers and one Masters Degree thesis. The work is summarized in the abstracts below.

Distributed Smart Signals Architecture
A Distributed Smart Signal Architecture for Traffic Signal Controls
Dustin DeVoe and Richard Wall [6]

This paper describes an architecture based upon the IEEE 1451 plug and play distributed smart sensor network standard. The system integration with a commercial of the shelf traffic controller requires a minimum of software modifications. This demonstrates an incremental path to integration of smart signals with conventional traffic signal devices. The system design focused on countdown timers for pedestrian signals because the current designs can give incorrect times when the signal timing changes. The system also demonstrates the ability to provide remote access to the call button to assist visually and mobility impaired pedestrians.

1. Networked Based Pedestrian Controls

Pedestrian Navigation and Integration with Distributed Smart Signal Traffic Controls
Gabriel DeRuwe and Richard Wall [7]

Pedestrians with special needs encounter accessibility challenges and are exposed to even greater risks when using signalized traffic intersections. Even modern accessible pedestrian stations present significant challenges for pedestrians with physical and sight disabilities. This paper describes an interactive traffic controller for allowing the intersection to receive pedestrian call requests from users with special needs and for providing the user with guidance and signals status feedback information from the intersection. Feedback from the intersection enables individuals with low vision to know the state of the intersection, as well as receive guidance from the traffic controller based on the pedestrian's location.

A Distributed Ethernet Network of Advanced Pedestrian Signals
Dustin DeVoe, Sanjeev Giri, and Richard Wall [8]

For over 60 years, traffic signals have used direct wire connections between the traffic controller cabinet and the signals and detectors dispersed throughout the intersection. This paper reports on a networked based approach for distributed control and sensing of traffic signal devices. The motivation of our research has been to improve safety and performance while reducing the cost of a signalized intersection installation. We present an Ethernet based network architecture that uses NTCIP for real-time signal control that is combined with the IEEE 1588 precision time

protocol for robust operation of safety critical applications. Our investigation focuses on improving the accessibility and safety for pedestrians through the use of Smart Signals.

The Smart Signals paradigm is the basis of an enabling technology that permits complex functioning signals and detectors with self-test capability. The bi-directional communications provides the ability to monitor the operational status of signals and detectors that are currently unobservable by the automated traffic controls. The elements of network messaging that enable NTCIP to be used for real-time intersection signal control are presented. The concerns of signals outputs being generated outside the scope of observation for malfunction management units are addressed by implementing a deterministic network. The time performance of the system is evaluated for SNMP and STMP network messages. The results of test on the global network time synchronization are presented and show that inexpensive microprocessors can achieve stable long-term time division multiplexed operation with one hundred microsecond accuracy.

2. Development of a Network Management Unit:

Application of a Safety Critical Network for
Distributed Smart Pedestrian Signals in a Road Traffic Intersection System
Sanjeev Giri
Master of Computer Engineering Thesis
January 2008

In a distributed environment, the MMU can no longer observe traffic signal states using current method. This MMU's loss of capability to observe traffic and pedestrian signal states is due to the replacement of its point to point communication with a new bi-directional serial communication bus. In order to compensate for this loss of capability to monitor all distributed smart traffic signal states within 450 ms as specified by the National Electrical Manufacturers Association Traffic Control System 1 (NEMA TS 1) standard, the concept of a safety critical network is introduced. This safety critical network provides a safe-fail environment for communication of traffic signal state data via the Ethernet bus. It implements a scheduling scheme in which a global time base is divided into mutually exclusive time slots during which specific device is allowed to access the communication bus. This global base is generated using the IEEE 1588 Precision Time Protocol (PTP). In this thesis, we present a safety critical network with a communication scheduling scheme that facilitates detection of all critical device failures within 450 ms.

3. A Safety Critical Network for Distributed Smart Traffic Signals

Sanjeev Giri and Richard W. Wall [9]

Distributed control can improve and expand the current methods of intersection management by using a different infrastructure, having sensors to provide detection of pedestrians and vehicles and using a smart control process that can use this information. Since January 2006, researchers at the University of Idaho's National Institute for Advanced Transportation Technology (NIATT) have investigated methods of applying networked based distributed control in the operation of traffic signal lights. Public safety is a top priority and it is necessary to ensure safe and reliable operation of the control system for industry and public acceptance. In this paper, we describe a current traffic controller system and then discuss the hardware and software architecture for implementing a safety critical network using a time-triggered protocol for distributed smart traffic signals.

CONCLUSIONS

> *In a world that has a long history of mousetraps, it is insufficient to build a better mousetrap that anticipates a smarter mouse. We have had to give the world the smarter mouse as well.*

The value of the work on Smart Signals research started in 2004 is being tested in an environment that duplicates field installations. Our work has two focuses: the Smart Signals infrastructure and the devices that can use the advanced capability. Our design approach enables the new distributed networking architecture to be integrated with conventional unmodified NEMA TS2 controllers. Following this course of action requires additional hardware and software to compensate for using the Ethernet port and the NTCIP object data base for real time traffic signal operations.

As long as the Smart Signals architecture must operate in mixed mode with conventional signal traffic signals control devices, many of the space and cost advantages offered by an exclusive Smart Signals system will not be realized.

The Smart Signals architecture has demonstrated its ability to support devices that require more information masked behind the wall of traffic controller hardware outputs and signal load switches. We will continue to focus our design attention on accessible pedestrian signals and in particular, providing better access and safety for those individuals who are visually or mobility impaired.

RECOMMENDATIONS

The hardware and software has matured sufficiently to move to the area of packaging. This will require the cooperation of manufacturers and highway agencies to accommodate the environmental needs for new hardware.

Collaborative efforts bring the NIATT research together with manufacturers to transform these innovations into real world enabling solutions for the nation's transportation system

Additional resources are needed to accelerate the development of the "Smart Signals" devices--not merely financial support, but a team of researchers with a common vision and a wealth of experience. I would like to see a team made up of multiple universities that would pool their resources to bring students and faculty from the multiple engineering disciplines as well as business, psychology (human factors) and manufacturing. The state and federal highway agencies have a major role to play in any emerging technology to ensure that we are operating at the highest level of productivity possible. The problem being addressed is simply too extensive for a small group of electrical, computer and civil engineers in Moscow, ID, to manage.

REFERENCES

[1] Gelcore, Digital Countdown Pedestrian Signal,
http://georgefrancisonline.homestead.com/cntdwn.html Accessed 4/2/09.

[2] Campbell Company, Accessible Stations,
http://www.pedsafety.com/Accessible_Stations.html Accessed 4/2/09.

[3] Rabbit Semiconductor, RCM3000 RabbitCore,
http://www.rabbit.com/products/rcm3000/rcm3000.pdf. Accessed 4/2/09.

[4] Pascoe, J. S. and J. Loader, *A Survey on Safety-Critical Multicast Networking,"
Department of Computer Science*. The University of Reading, ROYAUME-UNI, 2000.

[5] Lee, Kang, "Workshop on IEEE-1588, Standard for a Precision Clock Synchronization
Protocol for Networked Measurement and Control Systems."
http://ieee1588.nist.gov/z_Workshop_2003_proceedings.pdf Accessed 4/2/09.

[6] DeVoe, D. and R.W. Wall, "A Distributed Smart Signal Architecture for Traffic Signal
Controls," 2008 IEEE International Symposium on Industrial Electronics, Cambridge,
UK, July 2, 2008 , paper # CD-004928

[7] DeRuwe, Gabriel and R. W. Wall, "Pedestrian Navigation and Integration with
Distributed Smart Signal Traffic Controls," The 34th Annual Conference of the IEEE
Industrial Electronics Society, Orlando, FL, November 11, 2008, Paper # HD-010979

[8] DeVoe, D. S. Giri, and R. W. Wall, "A Distributed Ethernet Network of Advanced
Pedestrian Signals," 88th Annual Meeting of the Transportation Research Board,
Washington, DC, January 11-15, 2009

[9] Giri Sanjeev, and R. W. Wall, "A Safety Critical Network for Distributed Smart Traffic
Signals," *IEEE Instrumentation and Measurement Society Magazine*, scheduled for
publication, December 2008