Smart Cities: Vehicle to Infrastructure and Adaptive Roadway Lighting Communication Standards
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Contents

Introduction .................................................................................................................................................. 4
Interoperability and the Seven OSI layers .................................................................................................... 7
What is the Institute of Electrical and Electronics Engineers (IEEE) Standard 802.11p? .............................. 7
What is IEEE 1609? ........................................................................................................................................ 8
What is the Society of Automotive Engineer's Standard J2735? ............................................................... 9
What is SAE J2735 SE? ................................................................................................................................ 9
What is US DOT ITS NTCIP 1213 "ELMS"? ............................................................................................... 11
How will this all work together - The V2I - ELMS Connection? ................................................................. 12
Summarizing: V2I, Adaptive Roadway Lighting and The Smart City ........................................................ 13
References .................................................................................................................................................. 14
Introduction

Smart Cities is a term commonly used to refer to the creation of knowledge infrastructure. Smart City, in everyday use, is inclusive of terms such as ‘digital city’ or ‘connected cities’. Smart Cities as an applied technology term often refers to smart grids, smart meters, and other infrastructure for distribution and metering of power and water supply as well as the waste management system.

As Hans Schaffers, Nicos Komninos, Marc Pallot, Brigitte Trousse, Michael Nilsson, and Alvaro Oliveira write in "Smart Cities and the Future Internet: Towards Cooperation Frameworks for Open Innovation":

In the early 1990s the phrase "smart city" was coined to signify how urban development was turning towards technology, innovation and globalization. The World Foundation for Smart Communities advocated the use of information technology to meet the challenges of cities within a global knowledge economy. However, the more recent interest in smart cities can be attributed to the strong concern for sustainability, and to the rise of new Internet technologies, such as mobile devices (e.g. smart phones), the semantic web, cloud computing, and the Internet of Things (IoT) promoting real world user interfaces. The concept of smart cities seen from the perspective of technologies and components has some specific properties within the wider cyber, digital, smart, intelligent cities literatures. It focuses on the latest advancements in mobile and pervasive computing, wireless networks, middleware and agent technologies as they become embedded into the physical spaces of cities. The emphasis on smart embedded devices represents a distinctive characteristic of smart cities compared to intelligent cities, which create territorial innovation systems combining knowledge-intensive activities, institutions for cooperation and learning, and web-based applications of collective intelligence."

This paper examines the substantial impact of Smart City technologies; specifically the communications and applications supporting the technological convergence of networked vehicles and the electrical and lighting infrastructure of the nation's roadways.

Roadway lighting control systems have been commercially available in the United States for the last decade. Today over twenty systems have been introduced to the US market. The great majority of these systems use time and ambient light levels to control individual luminaire light output.
In the next few years, a number of standards and initiatives will impact these applications in very dramatic and exciting ways.

In 2015, automotive manufacturers will introduce a revolutionary new feature - wireless broadcast of vehicle operational data. This will be used both for vehicle-to-vehicle communications (V2V) as well as for vehicle-to-infrastructure communications (V2I). In essence, the vehicle will become a "networked computer on wheels". As you may already be aware, vehicles such as the General Motors VOLT currently include over 100 electronic control modules, the great majority of which communicate on the digital backbone of the vehicle. Similarly, the Intelligent Transportation Systems (ITS) applications resident in roadside infrastructure also include microprocessor controls communicating on the ITS data network.

It is the merging and interoperability of these two systems of distributed intelligence that will drive innovative as yet un-thought-of applications and solutions.

This standardized vehicular data will be used to drive interoperability of truly adaptive control systems for both roadway lighting and traffic signalization.
The Evolution of the Car: A Connected Vehicle
(a networked computer on wheels)

Data Sent from the Vehicle
Real-time location, speed, acceleration, emissions, fuel consumption, and vehicle diagnostics data

Data Provided to the Vehicle
Real-time traffic information, safety messages, traffic signal messages, eco-speed limits, eco-routes, parking information, etc.

Improved Powertrain
More fuel efficient powertrain including; hybrids, electric vehicles, and other alternative power sources

Photo Credit - USDOT
**Interoperability and the Seven OSI layers**

The Open Systems Interconnection (OSI) model was developed by the International Organization for Standardization. It characterizes and standardizes the functions of a communications system in terms of abstraction layers. Similar communication functions are grouped into logical layers. The model promotes the concept of a consistent model of protocol layers, and defines interoperability between network devices and software.

<table>
<thead>
<tr>
<th>OSI Model</th>
<th>Data unit</th>
<th>Layer</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Host</td>
<td>Data</td>
<td>7. Application</td>
<td>Network process to application</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6. Presentation</td>
<td>Data representation, encryption and decryption, convert machine dependent data to machine independent data</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5. Session</td>
<td>Interhost communication, managing sessions between applications</td>
</tr>
<tr>
<td>Segments</td>
<td></td>
<td>4. Transport</td>
<td>End-to-end connections, reliability and flow control</td>
</tr>
<tr>
<td>Media</td>
<td>Packet/Datagram</td>
<td>3. Network</td>
<td>Path determination and logical addressing</td>
</tr>
<tr>
<td>layers</td>
<td>Frame</td>
<td>2. Data link</td>
<td>Physical addressing</td>
</tr>
<tr>
<td></td>
<td>Bit</td>
<td>1. Physical</td>
<td>Media, signal and binary transmission</td>
</tr>
</tbody>
</table>

Let's discuss the standards that comprise the V2I initiative, and examine their compliance to the OSI interoperability framework. The relevant standards include IEEE 802.11p, the IEEE 1609 family and SAE J2735 SE.

**What is the Institute of Electrical and Electronics Engineers (IEEE) Standard 802.11p?**

In 2004, The IEEE Task 802.11 Group p began to develop an amendment to the 802.11 standard to include vehicular environments. This amendment adds wireless support to the vehicular environment. Known as 802.11p, it provides specifications required for the "Physical" and the
"Data Link" OSI layers (layers one and two in the graphic above) for specific needs of vehicular networks.

As George Wayne, ITS system designer and a developer of IEEE 1609 and 801.11p solutions states:

"There are three salient functions and purposes to 802.11:

1.) Generally speaking, 802.11 technologies are used to reduce cost and maximize scalability and interoperability.

2.) The 802.11 wireless standard was amended to allow an 802.11 compliant device to communicate directly with another such device (vehicular or roadside) outside of the normal wireless service infrastructure. This is done to enable near instantaneous, short-lived communications.

3.) New regulated spectra has been allocated for 802.11p operations around the world. In the U.S., the FCC allocated the upper end of the 5 GHz spectrum, 5.850-5.925 GHz, exclusively for ITS usage."

**What is IEEE 1609?**

IEEE 1609 is a family of standards that deals with issues such as management and security of the network. These are described in the "Network" and "Transport" OSI layers three and four in the graphic.

The 1609 family includes:

- **1609.2** -Security Services for Applications and Management Messages
- **1609.3** -Networking Services: This standard addresses network layer issues.
- **1609.4** -Multi-channel Operation: This standard deals with communications through multiple channels.
A vehicular communication network that complies with the above standards supports both vehicular on-board units (OBU) and roadside units (RSU). An RSU acts similar to a wireless LAN access point and can provide communications with infrastructure.

What is the Society of Automotive Engineer's Standard J2735?

The Society of Automotive Engineers (SAE) J2735 standard supports interoperability of vehicular applications by use of standardized messages. Users include application developers, equipment manufacturers and system integrators.

More specifically, SAE J2735 defines standard messages that allow interoperability between Vehicle-to-Vehicle (V2V) and Vehicle to roadside Infrastructure (V2I). The standard also supports innovation and product differentiation by allowing message access by proprietary applications.

A major attribute of SAE J2735 is the Heartbeat message. Data fields residing within this message include:

- temporary unique identifier
- time
- latitude
- longitude
- elevation
- speed
- heading (compass direction)
- acceleration
- brake system status
- vehicle size

What is SAE J2735 SE?

The US DOT is in the process of updating the SAE J2735 Standard to J2735 SE by applying the Systems Engineering Process (SE).

The US DOT has determined needs for:

- A clear definition of the standard’s scope
• Definition of user needs and requirements mapped to data concepts, dialogs, messages, data frames and data elements

• Traceability from needs through data concepts

• Additional input from the transit and freight communities and other stakeholders

The US DOT's goal is to create a complete and correct standard, which includes creating a set of verifiable requirements as well as support international harmonization.

The current SAE J2735 SE document contains the Concept of Operations (ConOps) and the Software Requirements Specification (SRS) for the J2735 SE standard, which covers the information exchange between applications in conjunction with wireless communications related to the next generation integrated transportation system, specifically, the interface to connected vehicles and infrastructure.

The objectives for this SE update to SAE J 2735 are to:

• Create a complete and correct standard that includes creating a set of verifiable requirements.

• Incorporate lessons learned from the Michigan test bed, which performed testing of aspects of SAE J2735.

• Ensure that the developed standard addresses needs relating to transit vehicles, public safety vehicles, and commercial vehicles.

• Ensure that the standard reflects the inputs from a broad range of Connected Vehicles developers.

After the SE process has been completed, the US DOT will deliver a draft J2735 SE standard document to SAE as a “comment” to the SAE J2735 Working Group.
What is US DOT ITS NTCIP 1213 "ELMS"?

NTCIP 1213 "Electrical Lighting and Management Systems" is a US DOT Intelligent Transportation Systems standard describing the control and monitoring of roadway lighting, revenue grade energy metering, and safety equipment like ground fault interrupters. It includes support for adaptive lighting functions. Support for expanded adaptive lighting through SAE J2735 SE is a current initiative before the NTCIP 1213 ELMS Working Group.

In September 1996, an agreement was reached between AASHTO, ITE, and NEMA to jointly develop, approve, and maintain the ITS NTCIP standards. In 2002, the Joint Committee on the NTCIP accepted the invitation from Karl Burkett (Texas DOT) to transfer the initial work of an ad-hoc committee of the Illuminating Engineering Society of North America (IESNA), and formed the NTCIP ELMS Working Group to further develop the control objects based on NTCIP.

NTCIP 1213 v02 defines the generic reference model and conformance requirements for traffic management centers (TMCs) that wish to provide interfaces to field devices. NTCIP 1213 v02 defines requirements that are applicable to all NTCIP TMCs, and contains optional and conditional sections that are applicable to specific environments for which they are intended. NTCIP 1213 v02 defines the Electrical and Lighting Management System (ELMS) data element objects that are supported by the NTCIP. An ELMS is defined as any system capable of monitoring, controlling, and communicating certain electrical and lighting system parameters using NTCIP.

The effort to develop an NTCIP ELMS standard began with the International Technology Exchange Program’s European Road Lighting Technologies scan tour in April of 2001 (Report FHWA-PL-01-034 dated September 2001). This technology and implementation plan was further developed by the AASHTO Task Force for Highway Lighting and is being implemented as the Master Lighting Plan in the AASHTO publication entitled Roadway Lighting Design Guide. The Task Force's original desire was to define the features, functionality, and point of interoperability for ELMS equipment.

The ELMS specification V2.0 was published in March 2011. Subsequently the US Department of Energy has referenced ELMS as a Smart Grid standard. Earlier this year, both the Smart Grid
and ITS Working Groups of the United Nation's International Telecommunications Union referenced ELMS as a standard as well.

In addition to the integration with SAE J2735 SE, ELMS V3.0 enhancements including support for electric vehicle charging stations and greater interoperability with the US Department of Energy's Smart Grid standards.

How will this all work together - The V2I - ELMS Connection?

Due to the efforts of the ELMS ITS Working Group, the V2I ITS J2735 SE standard will soon be supported by roadside electrical infrastructure. The effort currently underway is to harmonize and integrate SAE J2735 SE with NTCIP 1213 ELMS assuring standardized, open protocol interoperability. Upon completion of this effort, vehicle data points of speed, location, ambient light level and road friction, as well as many other inputs such a humidity, temperature and road reflectivity will be used as inputs to an ELMS system. The ELMS will then dynamically adjust, or "adaptively control" the light levels applied to the road.
Summarizing: V2I, Adaptive Roadway Lighting and The Smart City

The Smart City is a radically different mobility landscape where pedestrian, bicycle, car, truck, and bus traffic are integrated into a single connected network to save time, improve safety, and reduce emissions.

As Bill Ford, Chairman, Ford Motor Company, recently stated "Now is the time for all of us to be looking at vehicles on the road the same way we look at smart phones, laptops and tablets as pieces of a much bigger network."

The city of the future will feature much greater technological integration. Vehicle to Infrastructure communications will drive many very exciting, revolutionary applications from adaptive traffic signalization and adaptive roadway lighting controls to many more solutions for saving time, saving energy and saving lives on the nation's roadways.
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