Development of Wireless Traffic Monitoring System for ITS Instruction and Research

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ABSTRACT

Transportation engineering has evolved into a broad multidisciplinary field during the last few decades. This multidisciplinary nature of the profession has become more profound and visible since the advent of the Intelligent Transportation Systems (ITS) early last decade. The remarkable advances in computers, communications, electronics, control, and other related technologies have found important applications in the transportation system.

Universities are expected to fulfill their mission by meeting the growing and changing needs of the transportation profession. As far as the ITS is concerned, this requires building new skills and cross-cutting competencies in engineers beyond the traditional knowledge and skills being offered in the transportation discipline for decades now. Means towards that end may include transportation program curricula changes/revisions, offering ITS-related multidisciplinary courses, building new capacities into transportation labs to support some of the important ITS applications, and conducting field trips to ITS projects as part of course requirements or student organization activities.

This paper presents the development of an on-line wireless traffic monitoring system as part of building ITS capacity in the transportation lab at Montana State University (MSU). This new capacity is expected to support ITS instruction and research in the transportation program. The paper will discuss conceptual system design, evaluation of existing technologies, and the selection of the most appropriate system being implemented in the MSU transportation lab.
INTRODUCTION
Transportation engineering has evolved into a broad multidisciplinary field during the last few decades. The multidisciplinary nature of the profession has become more profound and visible since the advent of the Intelligent Transportation Systems (ITS) early last decade. The remarkable advances in computers, communications, electronics, control, and other related technologies have found important applications in the transportation system. The use of ITS applications in the transportation system requires transportation professionals at all levels to incorporate and apply new skills and competencies in their daily work activities. This paper presents an overview of the role of education in building ITS-literate engineers and moves to discuss in more detail a case study of incorporating ITS in transportation education. A new capacity is being built in the transportation lab at Montana State University (MSU) that consists of a wireless traffic monitoring system for ITS instruction and research. The paper will discuss in detail conceptual system design, evaluation of existing technologies, trade-offs and selection of the most appropriate system that is being implemented in the lab.

ITS & TRANSPORTATION EDUCATIONAL PROGRAMS
Universities are expected to fulfill their mission by meeting the growing and changing needs of the transportation profession. This requires building new skills and cross-cutting competencies in engineers beyond the traditional knowledge and skills being offered in the transportation programs. There has been a gap between the new needs of the transportation industry and what has been offered in transportation educational programs. Part of this gap is attributed to the lack of consensus in the profession on the following issues [1]:

− Required ITS skills
− Responsibilities of people who are in charge of ITS projects
− Similarities and dissimilarities of the role of ITS trained personnel and the traditional transportation engineers
− The academic discipline that should take the lead role in providing ITS related educational and training programs

Means to bridge this gap encompass a variety of measures including:

− Classroom education through curricula changes and modifications: examples would be offering courses on ITS applications and technologies and/or inclusion of ITS materials in other relevant transportation courses

− Due to the large multidisciplinary nature of the ITS systems and projects, developing new cross-disciplinary courses with students from multiple disciplines learning new skills that would complement their background in their majors.

− Lab experimentations, field studies, etc. need to reflect the use of advanced technologies in transportation applications.

− Arranging field trips to ITS projects as part of course requirements or the ITE student chapter activities
CASE STUDY: MSU TRANSPORTATION LAB

To test different traffic control strategies and other advanced ITS applications, traffic monitoring at highway sites of interest is very important for field evaluation of those ITS applications. While traffic simulation is being used to evaluate many ITS applications, field evaluation upon implementation is critical to validate the improvements and benefits as initially estimated in the lab. Also, it is envisioned that this capacity will increase students’ awareness of ITS applications and technologies. It is for those reasons that an online traffic monitoring system was identified as one the basic needs of the new transportation lab at Montana State University (MSU). This system could serve research and instruction in both graduate and undergraduate transportation programs.

Goal and Objectives

The goal of this investigation is to develop a wireless traffic monitoring system for the new transportation lab at MSU that is: 1) cost effective, 2) within budget constraints, and 3) meeting or exceeding system requirements. To achieve the aforementioned goal, the study developed the following set of objectives to guide the development process:

− Minimize amount of maintenance required
− Minimize operating costs
− Maximize operating duration without staff attendance or maintenance
− Maximize reliability and flexibility of use
− Maximize the compatibility of the new system and the data acquisition equipment already available at the CE Department

Study Plan

The current study is to be performed in two phases:

Phase I: In this stage, the problem at hand is defined, goal and objectives are specified, and requirements of the proposed system are formulated. All possible solutions to the problem are investigated, i.e. alternative systems that satisfy, to one degree or another, system requirements. Evaluation of alternative systems is based on the following criteria:

− The degree of meeting user requirements and constraints
− Technical aspects of system such as efficiency, flexibility, reliability, etc.

At the end of this stage, the conceptual design that is deemed most appropriate is selected for the proposed traffic monitoring system.

Phase II: In this stage, the technical features of the system are developed and designed in detail. System components, technologies, technical attributes, and cost (for each component) are to be specified. The outcome at the end of this stage is a working demonstration of the data acquisition system integrated with the traffic sensors and the server at remote location.

System Requirements:

From transportation engineering point of view, the proposed traffic monitoring system should satisfy the following minimum requirements:
− Be able to monitor traffic conditions at one or more stations (sites) within the boundaries of the coverage area. Sites could be intersections or mid-block locations.
− Coverage area should include highway sites of interest in the city of Bozeman and the surrounding areas.
− System should be able to support fixed as well as portable stations.
− System should be able to transmit traffic data as well as on-line update of video images at intervals typically used in practice.
− Communications should be two-way, with flexibility in the allocation of bandwidth upstream and downstream.
− System should support flexible assignment of capacity among the traffic monitoring stations.
− The proposed system must communicate wirelessly between traffic monitoring stations and the new transportation lab.
− System should be able to function under different operating conditions, e.g. temperature, humidity, precipitation, etc.

Development of Communication System Technical Requirements

The wireless communication system will interface with traffic sensors in the field and with the data acquisition server in the transportation lab. This wireless system is considered the backbone of the proposed traffic monitoring system. Therefore, a significant part of the current investigation deals with this system component.

Based on the minimum system requirements and the goal and objectives set forth, the following technical requirements of the wireless communication system are identified:

− Range: the system must be able to collect data from sensors at a distance of at least 8-10 miles from the data acquisition server in the transportation lab.
− Capacity: the system must be able to collect data from at least 4 field sensors simultaneously, with each sensor generating 100-150kb/s.
− The system must be two-way enabling command and control messages to be sent from the data acquisition computer to the sensors.
− The system must be able to operate on battery power at the sensor sites.
− The system must use unlicensed radio spectrum
− The system should use IP protocols and be compatible with Ethernet.

System Concept

In concept, the traffic monitoring system is viewed to consist of three components:
− Fixed station (e.g. a server in the transportation lab)
− Mobile stations with sensors and data acquisition system
− Wireless communication system that interfaces with the fixed base and mobile stations

Each of those three components may involve a wide array of products with different technical features. Two system topologies (configurations) were investigated that are both consistent with system conceptual design: point-to-point or point-to-multipoint as shown in Figure 1. After careful consideration, the research team selected the point-to-multipoint system configuration.
Point-to-multipoint topology was selected as it is highly scalable, uses wireless bandwidth efficiently and can be deployed cost-effectively. With this topology, the base station equipment is shared among all field sensors. In the point-to-point case, the addition of a new field sensor requires an additional base station transceiver and antenna. The point-to-multipoint topology does have the potential of bandwidth limitations, as the communication capacity is shared by all the sensors, but as described below, this limitation can be effectively mitigated by use of dynamic resource management.

![Network Diagram using Point-to-Multipoint Wireless Ethernet Option](image)

![Network Diagram using Wireless Point-to-point RS-232 Option](image)

**Figure 1: System Topology** (a) point-to-multipoint, (b) point-to-point
Design Considerations

The most important design considerations defining the features of the proposed system are:

1) **Network protocol: data rates, reliability, compatibility with data transmit needs.** Modern data acquisition systems, data storage systems and data analysis procedures are all digital and most equipment is designed with Ethernet interfaces and utilizes IP protocols. These considerations strongly influenced the design decision toward the selection of a wireless system that emulates Ethernet transport and supports IP data traffic. Furthermore, modern traffic monitoring cameras are equipped with image analysis software and data compression algorithms that yield relatively low mean data flows ranging from a few kb/s to hundreds of kb/s. These data flows are often user selectable or event driven resulting in variable rates, warranting an adaptable allocation of communications resources.

2) **Network data capacity.** The total network data capacity is determined by the number of field sensors and their operation modes. The primary data flow is upstream (sensors to base station/laboratory) and for four filed sensors, can range up to 1 Mb/s. The downstream data flow (lab/base station) to sensors consists of commands and control information and is typically only a few kb/s.

3) **Network topology: point-to-point or point-to-multipoint.** As described above, a point-to-multipoint topology offers significant advantages for this system application. In addition to the efficient use of wireless capacity and lower equipment cost, point-to-multipoint topology allows for repositioning field sensors with the wide-area field of view of a wide-area base station antenna (typically 60° or more) without the need to realign the antenna. If needed, combinations of wide beam and narrow beam base station antennas can be used to cover a larger field area.

4) **Range of the proposed system.** The system range is determined by a combination of factors including operating radio frequency, antenna heights and gains, transmit power, receiver sensitivity and blockage along the line of sight. Ideally, line sight paths are desirable, but use of relatively low operating frequencies (below 1 GHz) offers the possibility of communication along partially obstructed paths. Coverage and range can also be improved by mounting the base station antenna on a tall building or tower (in this case, the antenna is mounted on a tower 25 feet above the roof of a six story building, commanding a clear view of the surrounding area for distances in excess of 50 miles in selected directions). Transmit power is dictated by FCC license considerations, and antenna gains depend on operating frequency and beam width. Receiver sensitivity is determined by the equipment used and channel bandwidth, and typically allows for detection of signals at power levels above a threshold of -90 dBm. For this deployment, monitoring of field sensors within a 20 mile range of the base station is required. The use of unlicensed spectrum in the 908-928MHz band meets the system requirements, providing good coverage of the roadways and intersections in Bozeman and the surrounding area out to about 20 miles.

5) **Operating conditions: temperature, humidity, and precipitation.** The system is required to work outdoors over a wide range of environmental conditions (temperature extremes of -35°F to +110°F, with rain, snow, and high winds). Fortunately, these requirements are shared by numerous other applications of radio systems, and vendors routinely construct RF transceivers and antennas to withstand and operate properly under these conditions. Highly integrated and compact equipment, with modest power requirements are readily available.
6) **Terrain.** The topography in the Bozeman area is flat in the vicinity of Bozeman and the nearby communities, high mountains surrounding the valley floor. The transportation lab is located in a six story building equipped with an antenna tower, ideal for wide area, near line of sight surveillance. The use of 900 MHz for radio communication facilitates coverage, as in this frequency domain line of sight is not a necessity (as with cell phones).

Furthermore, other aspects of the proposed system that guided the design process involved:

1) **Sustainability.** This system needs to be highly reliable. Little or no maintenance is desired for many years of functioning. Highly integrated, modular equipment was selected for the system. The RF transceivers are compact and monolithic, with remote test, monitoring and control capabilities provided through Ethernet ports using standard and widely used command sets.

2) **Manufacturability.** Parts and components of the system need to be available in the years to come to provide flexibility for future expansion. The selected equipment supports additional field sensors without hardware changes at the base station. Radio system capacity can be dynamically allocated under software control. Use of wide field of view “sector” antennas allows the placement of new field sensors without the need to realign the base station antenna. The base station and field sensor transceivers are connected to their respective antennas with RF cables, allow changes in the antennas without the need to replace the transceivers. A vendor with a proven record in wireless equipment (Motorola) was selected to ensure the future availability of components.

3) **Ethical.** The radio frequency used should not interfere with the licensed radio spectrum or other electronic equipment. Unlicensed radio spectrum was selected to minimize the need for administering radio licenses and frequency coordination. Unlicensed spectrum does have the potential of unwanted interference from other users in the nearby area. However, frequency agile transceivers, which automatically tune to one of 28 channels within the operation band with the minimum noise, were selected for the system, to minimize this risk.

4) **Health and Safety.** The power provided to the mobile stations via solar or battery needs to be housed and safely insulated. The cabling between the transceivers and the base station and sensor equipment is low-power Ethernet rather than RF, and carries only low voltage current to power the equipment. Antennas are grounded to assure protection against lightning.

### Equipment selection

Careful review of these requirements and available radio products led to the selection of the Motorola Canopy 900MHz radio system. The specifications of this system are compared to the requirements in Table 1.

<table>
<thead>
<tr>
<th>Feature</th>
<th>Requirements</th>
<th>System Selected (Motorola Canopy)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range</td>
<td>8 miles min</td>
<td>40 miles</td>
<td>Range well exceeds the requirements</td>
</tr>
<tr>
<td># of sensors per location</td>
<td>2</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Throughput per sensor</td>
<td>115.2 kbps</td>
<td>115.2 kbps</td>
<td>The 115.2 kbps limitation was due to the Autoscope equipment. Motorola Canopy has a maximum baud rate of 3.3 Mbps.</td>
</tr>
<tr>
<td>Interface</td>
<td>Ethernet</td>
<td>Ethernet</td>
<td></td>
</tr>
</tbody>
</table>
System Testing & Experimentation

A series of testing procedures were conducted before the proposed monitoring system becomes fully functional. This involves the following tests:

− Site survey: The site survey is to determine the amount of radio interference present on the 902-928 MHz channel that the Motorola access point uses. The site survey test was done using the Motorola 900MHz antenna that is designed for the system and a radio frequency spectrum analyzer. The results showed that there is minimal interference in the area. Tests were carried out aiming the receiving antenna in four directions covering 360 degrees in azimuth. Interfering signals were detected on several of the channels in the 925-928 MHz range but there is ample unused bandwidth in the lower frequency channels to enable the system to perform as needed.

− Hardware Compatibility Test: This test confirmed that the Motorola Canopy hardware is compatible with the existing hardware in the system. Specifically the test demonstrated that the subscriber unit can connect to the control device. Connections between the Autoscope sensors and the data acquisition computer were established using static IP addresses and the control messages and sensor data were transmitted in IP packet streams using Ethernet.

− Line of Sight Tests: The line of sight test is to determine the utility of using the roof of Cobleigh Hall as a permanent site for the Motorola access point. The test was accomplished by selecting various sites around the Bozeman area and setting up a Motorola Canopy subscriber unit and determining the connection characteristics of each site.

− Traffic Data Transfer Test: The traffic data transfer test is to determine if traffic data (e.g. video images, tabulated data, etc.) can reliably be transmitted from the Autoscope hardware at an intersection to a computer in the Transportation Lab in Cobleigh Hall using the designed system. This test was done by setting up a camera and subscriber unit at an intersection and transferring data wirelessly to the lab using the Motorola Canopy equipment. Results for typical traffic measurements sites around Bozeman are given in Table 2, and show that data rates in excess of 1Mb/s were achieved for all the selected locations. Figure 2 shows the sensor and wireless equipment deployed at one of the Bozeman locations using a test van provided by the Western Transportation Institute (WTI). Figure 3 shows a video image obtained using the Autoscope camera at the remote site and transmitted to the campus lab using the wireless network. The lines and other annotation of the image were produced by the traffic analysis software and indicate the data management capability provided by the system.

<table>
<thead>
<tr>
<th>Location</th>
<th>Downlink rate, kb/s</th>
<th>Uplink rate, kb/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>19&lt;sup&gt;th&lt;/sup&gt; and Main</td>
<td>1183.7</td>
<td>144.2</td>
</tr>
<tr>
<td>7&lt;sup&gt;th&lt;/sup&gt; and Oak</td>
<td>1158.1</td>
<td>161.2</td>
</tr>
<tr>
<td>19&lt;sup&gt;th&lt;/sup&gt; and Durston</td>
<td>1314.8</td>
<td>211.9</td>
</tr>
<tr>
<td>19&lt;sup&gt;th&lt;/sup&gt; and I-90</td>
<td>1380.3</td>
<td>329.4</td>
</tr>
<tr>
<td>College and Main</td>
<td>1133.6</td>
<td>213</td>
</tr>
</tbody>
</table>
Figure 2. Autoscope Sensor and Wireless Equipment at Bozeman Test Site

Figure 3. Traffic data acquired using the Autoscope and wireless network
CONCLUSIONS

A project to incorporate one of the ITS applications into the transportation lab at Montana State University is presented in this paper. It involves building a wireless traffic monitoring system using mobile monitoring stations. This project demonstrates effective incorporation of new information and communications technologies to enable more effective educational and research activities in transportation. The advent of IP-based equipment, Ethernet interfaces and programmable data acquisition and computing platforms assures easy integration of technologies from disparate disciplines. Modern transportation labs can readily take advantage of innovation in computing and communications, utilizing inexpensive and easy-to-configure wireless systems to enable real-time high-speed data acquisition to support a wide range of transportation research and instructional activities.

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REFERENCES


Authors’ information

Ahmed Al-Kaisy is an assistant professor in the Civil Engineering Department at Montana State University, Bozeman, Montana. Prior to joining MSU, Dr. Al-Kaisy served as an assistant professor at Bradley University, Peoria, Illinois, and has held positions as research associate, project engineer and highway design engineer in the public and private sectors. Dr. Al-Kaisy holds a Ph.D. in Transportation from Queen's University in Kingston, Ontario, Canada. His research interests encompass many areas in traffic engineering including traffic operations, capacity and quality of service, heavy vehicles operations, traffic control at work zones, and ITS applications in traffic operations and control. He has published widely in transportation journals and presented research in National and International conferences.

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Doug Rust & Kyle Lyson are senior students in the Electrical and Computer Engineering Department at Montana State University. Doug & Kyle worked on the wireless traffic monitoring system as part of their senior design project while finishing up their degree at MSU.