IDEA

Innovations Deserving Exploratory Analysis Programs

Intelligent Transportation Systems Program

DATA COMMUNICATION WITH REMOTE SENSORS USING REFLEX NARROWBAND PCS TECHNOLOGY

Final Report for ITS-IDEA Project 74

Sudhir Murthy, Lexington Consulting Company, Lexington, MA

December 2001

TRANSPORTATION RESEARCH BOARD • NATIONAL RESEARCH COUNCIL

INNOVATIONS DESERVING EXPLORATORY ANALYSIS (IDEA) PROGRAMS MANAGED BY THE TRANSPORTATION RESEARCH BOARD (TRB)

This investigation by Lexington Consulting Company, Lexington, MA was completed as part of the Intelligent Transportation Systems (ITS) IDEA program which fosters innovations in development and deployment of intelligent transportation systems. The ITS-IDEA program is one of the five IDEA programs managed by the Transportation Research Board (TRB). The other four IDEA program areas are: Transit-IDEA, which focuses on transit practice in support of the Transit Cooperative Research Program (TCRP), NCHRP-IDEA which focuses on highway systems in support of National Cooperative Highway Research Program, High Speed Rail-IDEA (HSR), which focuses on high speed rail practice, in support of the Federal Railroad Administration, and Transportation Safety Technology (TST), which focuses on motor carrier safety practice, in support of the Federal Motor Carrier Safety Administration and Federal Railroad Administration. The five IDEA program areas are integrated to promote the development and testing of nontraditional and innovative concepts, methods, and technologies for surface transportation systems.

For information on the IDEA Program contact IDEA Program, (phone: 202/334-3310, fax: 202/334-3471, http://www4.nationalacademies.org/trb/dive-idea.nsf)

Table of Contents

Chapter

1

Introduction

This project titled ***Data Communication with Remote Sensors Using ReFLEX Narrowband PCS Technology*** was funded by the ITS IDEA Program of the National Academy of Sciences – Transportation Research Board in Washington DC. This project, categorized as a Product Test, involved the system development and testing of a communication device based upon the ReFLEX Narrowband PCS technology commonly used in two-way pagers. The pager-based communication device was tested with three different remote sensors in the Boston Metropolitan area with assistance and support from the Massachusetts Highway Department. This product is extremely cost effective for transmitting data from Highway Performance Monitoring System sites, and in event-based data transmissions such as incidents, weather, equipment failure, etc. It can be a cost-effective alternative in typical ITS application in situations when traditional methods such as telephone, spread-spectrum or cellular either are technical infeasible or have high installation costs.

Report Intent & Organization

This report is intended to document the system hardware and software design. It also provides a description of the system tests conducted and costs associated with the system.

The report is organized into six chapters. Here in Chapter 1, a brief introduction provides the context and an overview of the project. Chapter 2 describes the overall system architecture. The details of the hardware and software design of the various system components are discussed in Chapter 3. Chapter 4 lays down the testing plan and the results of the tests conducted using the proposed data communication method. Chapter 5 provides information of the capital and operating costs, as well as a comparison with the traditional leased-line telephone based data communication. Finally, Chapter 6 provides the conclusion and the project findings.

Project Context and Overview

Project Context

Figure 1 illustrates the context under which this project was conceived off. It deals with the data communication between a remote field device, such a traffic-monitoring device, and a workstation either in a Traffic Operations Center (TOC) or any division/district of a state highway department or at an ISP.

Data communication between a remote traffic detector in the field and a workstation may be either via land lines or wireless means. Land lines include leased telephone line, fiber-optic cable, or dedicated twisted-pair hardwire cables. Wireless means include Radio Frequency (RF), cellular, microwave or spread-spectrum. Each of these communication methods can sometime prove to be either difficult or not cost-effective for a large scale region-wide implementation.

Telephone companies have limited interest or sometimes charge high fees for installation of telephone service connection at the remote traffic detectors. This is because the connection to a remote field device terminates at the device, and is dedicated to that device alone. It is not part of any network that has multiple users, where cost recovery on initial investment is easier for the phone companies.

Dedicated hardwire or fiber-optic cabling is expensive due to the high cost of installation of underground conduits and potential right-of-way issues. These dedicated communication methods are cost-effective as a communication backbone within a typical Advanced Traffic Management System (ATMS).

Wireless means such as radio need FCC licenses, which could prove to be cumbersome, expensive or unavailable. Cellular methods are still expensive. Microwave, similar to the dedicated cables, is good as a communication backbone.

Recently, spread-spectrum has become the common choice for wireless communication. Yet, this technology suffers from a few problems that cast doubt as to its reliability. Spread-spectrum needs direct line-of-sight for communication between two points. This is usually difficult, given the amount of roadside development, foliage and general highway topography within any urban area. Further, spread-spectrum operates on an open frequency. Consequently, there is a high chance for loss of communication due to interference.

The proposed communication system, described in this report and the subject of this project, responds to an immediate need by ITS implementers throughout the United States and the World. There is a need for a reliable, cost-effective, and convenient communication method between the various remote field devices, such as traffic sensors, and a central workstation within an ATMS in any urbanized area.

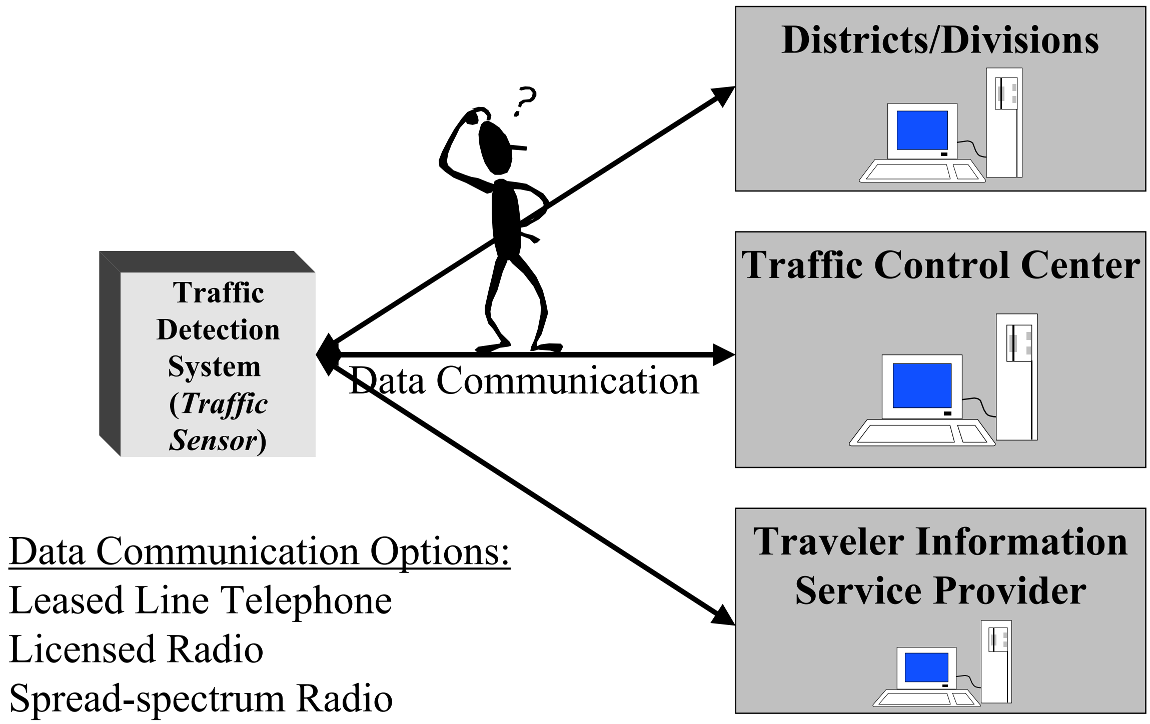

Figure 1: Project Context

Project Overview

The project was an evaluation of the two-way narrowband Personal Communication Services (PCS) supporting the ReFLEX™ associate protocol, which is also widely used for two-way pagers. The project evaluated the applicability and feasibility of using this two-way pager-based communication system for data communication between a remote traffic monitoring devices and a workstation. The project utilized three types of remote traffic monitoring devices including a Type 170 controller-based detection system, a TrafiCOMP III Model 241 automatic traffic recorder, and the Remote Traffic Monitoring System (RTMS). Data communication between each of these types of remote traffic monitoring devices and a workstation was through the proposed pager-based communication system. This was achieved by using the CreataLink2 and newly released CreataLink2 XT pager modems developed by Motorola.

Panel Meeting

In order to obtain input, comments and suggestions on this project, a panel meeting was organized before the hardware and software design efforts were begun for this project. The panel meeting was held on March 27, 1999 in Downtown Boston. The meeting was intended to bring representatives from both the public and private sectors, present to them the project and solicit input as to the design and system testing. Table 1 provides the list of attendees at the panel meeting and their affiliations.

At the panel meeting, the project overview was presented, including the system architecture, system components, and the testing plan. After the presentation, the meeting was opened to questions/answers, comments and suggestions.

Following were some of the important comments made at the meeting:

- The system should be able to interface with existing field devices, many of which are old, and may not be supported by their original manufacturers.
- The system components cannot be exposed but should be housed within an environmentally protected enclosure. Conditions within the field cabinets are bad in terms of dust, temperature, moisture, etc.
- Many existing field cabinets do not have AC power. The proposed system should be able to work with alternate power sources such as battery and/or solar power.
- The system should not affect the on-going functions of the highway department or the operations of the existing equipment.
- The system should allow both periodic as well as as-needed data transmissions. Periodic data transmissions could be once every 5-10 minutes, once every hour or once in 24 hours etc, while as-needed data transmissions would be in response to significant changes in travel characteristics, such as resulting from an incident.
- The operating cost of the system should be more cost-effective than existing data communication methods.

The panel members agreed that the proposed system would indeed be useful to both the private as well as public sector entities.

Table 1: Panel Meeting Attendees

Attendees at Panel Meeting	Affiliation
Mr. Keith Gates Program Manager	ITS IDEA Program National Academy of Sciences
Ms. Michelle Maffeo Director	ITS Programs Unit Massachusetts Highway Department
Ms. Carol Cox Project Engineer	ITS Programs Unit Massachusetts Highway Department
Mr. Donald Page Supervisor	Data Collection Unit Massachusetts Highway Department
Mr. Jeff Larason Manager	Traveler Information Systems SmartRoutes Systems, Inc.
Mr. Syed Salam General Manager	Transportation Consulting Louis Berger & Associates, Inc.

Chapter

2

System Description

Before going into the details of the system components, this chapter provides an overall description of the proposed pager-based communication system. In this chapter, first, a brief description of how the paging works and what is the ReFLEX communication protocol are provided. These are followed by a description of the system layout.

How Paging Works

Following is an extract from the Motorola Web Site on how the paging system works:

Paging uses radio technology to transmit small amounts of data over a wide area. Of course, today's paging systems are very sophisticated, featuring access that crosses national borders, word messaging, a variety of alert methods, group calling and voice storage, but all of these applications are made possible by basic paging technology. By using the radio spectrum efficiently, the paging system can provide service reliably and inexpensively. As a result, the paging industry has steadily expanded in recent years.

And while some countries adopted paging relatively late, the technology continues to grow as a worldwide alternative to daily communication needs.

When a caller dials a pager phone number, they are actually dialing into the paging terminal of the company licensed to operate the paging system. The call reaches the paging terminal over telephone company lines in much the same manner as when you call a friend across town. The tone a caller hears after dialing the pager number is the paging terminal telling the caller that it is ready to accept the page. Pressing the pound sign (#) after entering the numeric message lets the terminal know that the message is complete. The terminal is signaled to send the message to the pager.

The paging terminal is linked to numerous transmitters through the paging coverage area. When it receives a message for a specific pager, the terminal converts the message into a pager code and relays this code to the transmitters. The transmitters send out the code as a radio signal throughout the entire coverage area. The code is picked up by all of the pagers within the coverage area on that particular frequency, but only the pager with the proper code is alerted and will display the message

ReFLEX Paging Protocol

The following is an extract from the Motorola Web Site that explains what the ReFLEX paging protocol is:

The FLEX™ Technologies include the family of FLEX paging protocols (FLEX one-way, ReFLEX™ two-way and InFLEXion™ voice protocols), as well as a robust product portfolio of pagers, components, infrastructure, test equipment, application protocols, and software.

The FLEX protocol, created by Motorola, is the global de facto standard for high-speed paging. It has been adopted by 18 of the top 20 U.S. service providers, as well as by market-leading providers in Canada, Latin America, Asia, Africa, the Middle East and Europe. The FLEX Protocol is the national standard for high-speed paging in Japan and Korea, and is also a national standard in India and Russia. In addition, it has been adopted by China's MPT (Ministry of Posts and Telecommunications) as its nationwide high-speed paging standard and it is included in an ITU (International Telecommunication Union) Recommendation. FLEX Protocol-based operators are in all of the top ten world's largest paging markets. There are over 160 FLEX technology-based systems in commercial operation in 36 countries, which represents 93% of the world's paging subscriber base. In addition, there are over 100 licensees of FLEX/ReFLEX/InFLEXion technology. More than 35 million FLEX Protocol-based pagers have been shipped worldwide since production began in January 1995.

System Description

Figure 2 illustrates the overall system layout, with its various components, that is involved in the data communication with remote sensors using the proposed pager-based communication system.

The system can best be described in terms of data flow. As stated previously, the goal of this project is to transmit the data collected by the traffic-monitoring device to a workstation located at some central location such as a Traffic Operations Center. Using the paging network, it was achieved in the following steps:

1) Connected to the traffic monitoring devices is a micro-controller (μC). The software on the μC periodically communicates with the traffic monitoring devices to request a download of the data collected.

2) Once the μC obtains the data from the traffic-monitoring device, it then communicates with the pager modem interfaced with it. The μC uploads the data onto the pager modem. Once the data is uploaded, the μC then waits till

the next time period to request yet another download of the data from the traffic-monitoring device.

3) Upon receiving the data from the μC, the pager modem packages the data using the ReFLEX protocol and introduces it into the paging network.

4) Through either the base stations or the satellite network, the data reach the pager service provider's Network Operations Center (NOC), and is stored on a server in a pre-assigned "mailbox". This data will remain in the mailbox till it is download by the workstation.

5) Finally, the end-user communicates with the NOC to download the data stored in the mailbox on to his/her workstation.

The above steps are repeated periodically at each location. The periodic queries of the micro-controller are independent of the periodic downloads of the message string by the workstation. In fact, the frequency of downloads by the workstation would need to higher, as the NOC can receive information from several locations at different times. The frequency of queries by the micro-controller can also be high; in fact, it can be once every 30-seconds. However, the frequency in which the micro-controller uploads the information in to the pager modem needs to be controlled due to operating cost issues as discussed later in this report.

Design Issues

Communication cost of a pager-based system is directly proportional to the frequency of message transmission. The higher the frequency, the higher the communication costs. A frequency of once every 5-10 minutes will prove to be manageable.

In addition to the frequency of message transmissions from the pager modem, communication cost of a pager-based system is also affected by the size of the message transmitted. Though, the pager modem can transmit a message of 128k bytes, sending such large messages every 5-10minutes could result in very high communication costs. However, the size of typical traffic information, by its very nature, is small. For example, traffic volumes within a 10-minute period could easily be accommodated within a 2-byte integer. Information such as occupancy, and speed could be stored within just 1-byte as these data rarely exceed the value 128 (largest integer that can be stored in 1-byte; and assuming speed is in MPH). Consequently, traffic information can be transmitted using messages no more than 8-bytes. At the range of 4-8 byte message sizes transmitted once every 5-10 minutes, the pager-based communication system would be comparable in communication cost terms to other methods of data communication.

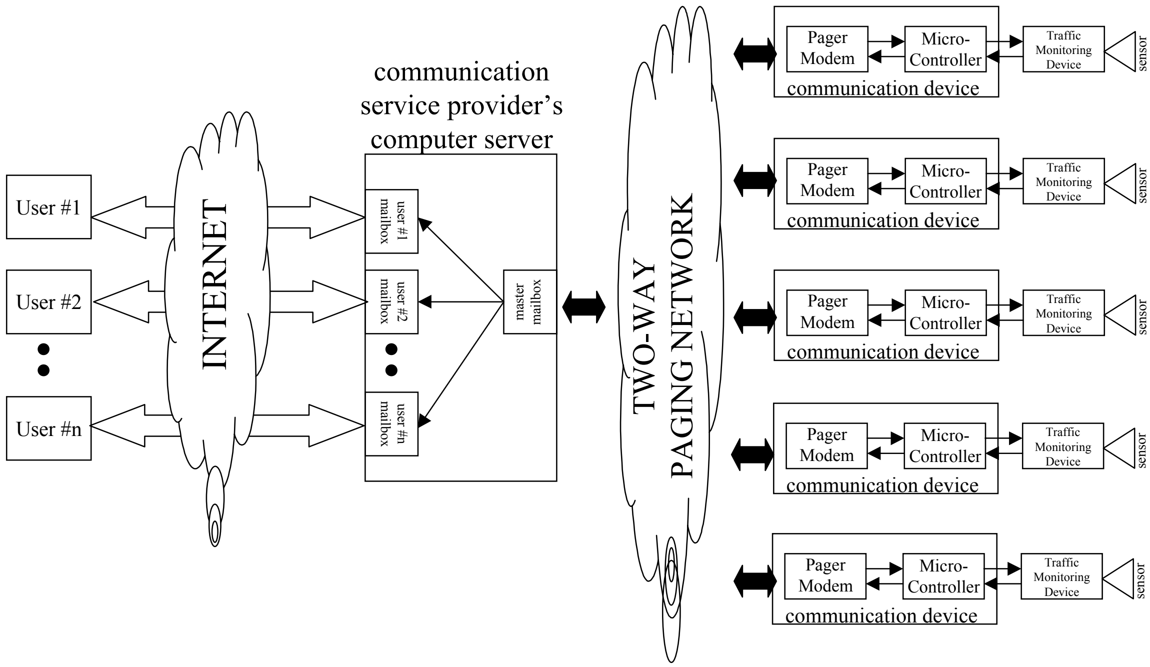

Figure 2: Overall System Plan

Typical ITS communication systems use modems as simply "conduits" between a workstation and a traffic-monitoring device. The workstation sends a data request command to the traffic-monitoring device through the modem; the traffic-monitoring device responds and sends back the data to the workstation, again through the modem. A pager modem can also be used in this manner. However, when near real-time traffic information is needed, this method may prove to be ineffective given the time it would take from the instant the workstation sends the data request command to the time it finally receives it. A better method would be to have the Traffic monitoring device automatically send the data periodically. This would eliminate the time it takes for the data request command from the workstation reach the pager modem. This method is also better suited for a pager-based communication system. A message sent from a remote pager modem reaches the NOC more quickly than from the NOC to the remote pager modem. This is because of the way messages are transmitted within a paging network. Some details of this are provided in the next section - System Components: Paging Network.

Figure 2 shows the proposed system to use a micro-controller that acts as the "broker" between the traffic-monitoring device and the pager modem. In this instance, the above three system components are separate from each other. However, one can also envision other designs where the functionality of the micro-controller is either within the traffic-monitoring device or the pager modem itself.

An alternate system design would be where the functionality of the micro-controller is incorporated into the traffic-monitoring device. For example, the software installed within the Remote Traffic Monitoring System (RTMS) can be such that it incorporates the functions of the micro-controller. This design is quite prevalent now where many of the traffic-monitoring devices already include functionality that allow communication using a leased-line telephone modem and/or other wireless means. However, to date, no traffic-monitoring device allows communication using the paging network.

Yet another system design would be to have the functionality of the micro-controller incorporated into the pager modem itself. Motorola has developed such a pager modem called the CreataLink2 XT (the successor to CreataLink2). The XT provides additional 64k bytes of RAM to store user-developed application software.

Advantages of Proposed System

The above section discussed some of the design issues to be kept in mind when developing and/or using a pager-based communication system in ITS. There are several major advantages to this system as listed below:

- Typical traffic data used in ITS such as volumes, occupancy and speed are all small quantities of data in terms of bytes needed to store the data. The paging-based communication system is best suited for transmission of small quantities of data.

- The proposed system is wireless. Consequently, the installation cost is significantly less than the traditional telephone-based communication system. There is no need for the expensive trenching and installation of conduit as is necessary in a telephone-based system.

- As the proposed system is wireless, it can also be removed and moved to another location. Such a system would prove very useful in area of event-based traffic management system used in major construction projects as well as near major traffic events (ball games, conventions, etc.).

- The pager-based system as is proposed here in this report results in decentralized communication system, where each traffic detector location is responsible to automatically transmit traffic information periodically. There is no need for the workstation in a TOC to constantly poll the various field devices.

- The proposed system is intrinsically conducive for sharing data among various agencies and information service providers. This is so as the proposed system uses the idea of a "mailbox" - a one central location that is accessible to several users.

- The proposed mailbox idea also results in a more efficient data communication system. Instead of a workstation in a TOC having to make repeated calls to each field device, under the proposed system, the workstation makes one call to the central location and downloads data from every field device.

Chapter

3

System Components

The previous chapter described the overall system layout. As illustrated in Figure 2, it includes several components. These components may be categorized into hardware, interface, and software. A description of each of these components is provided below.

Hardware

The hardware components include the traffic-monitoring device, the micro-controller (µC), the pager modem, the service provider's paging network and its Network Operations Center (NOC), and the workstation.

Traffic Monitoring Device

This could be any traffic data collecting system installed on the roadway to collect volume, occupancy, speed, temperature, etc. The technology used to collect the data could either be loops installed within the pavement, or overhead radar or microwave equipment, or other types of sensors. Typically, these equipment are connected to a micro-processor unit that processes the signals received from the detector.

The following three detection systems were utilized in this project. The three types represent three different classes of detection systems currently used on our highway systems throughout the country.

1) A 170E-controller with overhead radar detectors as the traffic sensors.

2) A TrafiCOMP III Model 241 automatic traffic recorder with inductive loops as the traffic sensors.

3) Remote Traffic Monitoring System (RTMS), which is an overhead microwave-based traffic sensor.

The first traffic-monitoring device utilizes a controller to process the contact closures from the sensors, record traffic information, and allows a workstation within a TOC to communicate with it. This type of detection system can be commonly found in any ITS deployment. The second traffic-monitoring device is more typical to the Highway Performance Monitoring System. These detection systems are meant to record traffic information for off-line processing to determine traffic pattern changes, growth trends, pavement design etc. They are typically not installed as part of an ITS. The last traffic-monitoring device utilized in this project, the RTMS, represents a new class of traffic detectors, where the controller function is integrated with the traffic sensor within one enclosure. Further discussion on each of the above listed three traffic monitoring devices is provided below.

170E Controller-based Traffic Monitoring Device

The 170E controller is a general purpose controller. It has been used for a range of applications from controlling traffic signals, to ramp metering, to application involving freeway and/or highway surveillance. The 170E controller is just the hardware; the software is installed on its EEPROM by the user. Hence, its ability to support various applications. The software installed on the 170E determines its application. The controller is constructed based on specifications developed by CALTRANS. Consequently, there is virtually no difference between the various equipment manufacturers. The software typically incorporates specific communication protocols to allow extraction of the data collected and stored in the 170E controller.

The traffic sensor used with a 170E controller can be anything from inductive loop detectors in the pavement, to overhead radar or microwave sensors, to image-based sensors. Any sensor system than can emulate the contact closure of a loop detection system can be used with the 170E controller.

Typically, the 170E controller is provided with a 110 VAC power. They are also typically installed within a controller cabinet that has limited temperature control capability.

TrafiCOMP III Model 241 Traffic Monitoring Device

This detection system is specifically for traffic counting purposes. It is usually not deployed as part of an ITS. It allows various traffic information to be collected including traffic volumes, speeds, headway, gap, and vehicle classification. The TrafiCOMP III Model 241, developed by PEEK-Traffic of Sarasota, FL, can accommodate several types of traffic sensors such as loops, pneumatic road tubes (also called axle sensors), and piezo sensors. This type of detection system is typically used as a permanent or continuous traffic recording station, where traffic data is collected 365 days of the year. The Model 241 has a key-pad and a LCD screen which can be used to program the detection system, including the specific time intervals the counts are collected and accumulated. The Model 241 allows communication via a RS-232 port and supports the use of a telephone modem.

Power to the Model 241 could either be 110 VAC, or a 12 VDC battery. Many agencies use solar panels as a means to charge the battery.

Remote Traffic Monitoring System (RTMS)

The RTMS is manufactured by EIS Electronic Integrated Systems Inc. of Toronto, Canada. It is an overhead microwave-based traffic-monitoring device. It is designed to serve both in applications of actuated intersection traffic control as well as in highway traffic management. The RTMS is a true-presence detector and can provide traffic volumes, occupancy, headway, classification and speed information for up to 8 lanes from just one detector. The detector is mounted 17 feet from the ground level, at about 10 feet from the edge of the road. The RTMS can be mounted either forward-looking, or in a side-fire position. The RTMS can also provide contact closures to existing controllers or directly provide the traffic information through serial communication.

The RTMS requires 12-24 V AC/DC. Using an appropriate transformer, the power source could be 110 VAC as well.

Micro-controller (μC)

The micro-controller in the proposed system acts as the "go-between" between the traffic-monitoring device and the pager modem. For this project, the Flashlite 386Ex micro-controller (see Figure 3), manufactured by JK Microsystems of Davis, CA was used. The Flashlite 386Ex is a single board computer based upon the Intel 386Ex micro-computer, with 512 bytes of RAM memory, and 512 bytes of Flash memory. The Flash memory is equivalent to the hard-disk in a standard PC. It operates in the DOS environment. It has two serial ports for communication.

Software development for the Flashlite is relative simple. The user develops software for a particular application. Once the programs has been debugged and tested on a standard PC, it is then simply uploaded on to the Flashlite using any telecommunication protocol supporting the X-Modem protocol. The upload is via the Console serial port (which is also the COM2 serial port). A STARTUP.BAT batch file is then created that allows the application to load and execute upon reset or power-up.

The power to the Flashlite can be either 110 VAC using an AC adapter. A 12 VDC battery may also be used with a 1 Amp fuse for safety.

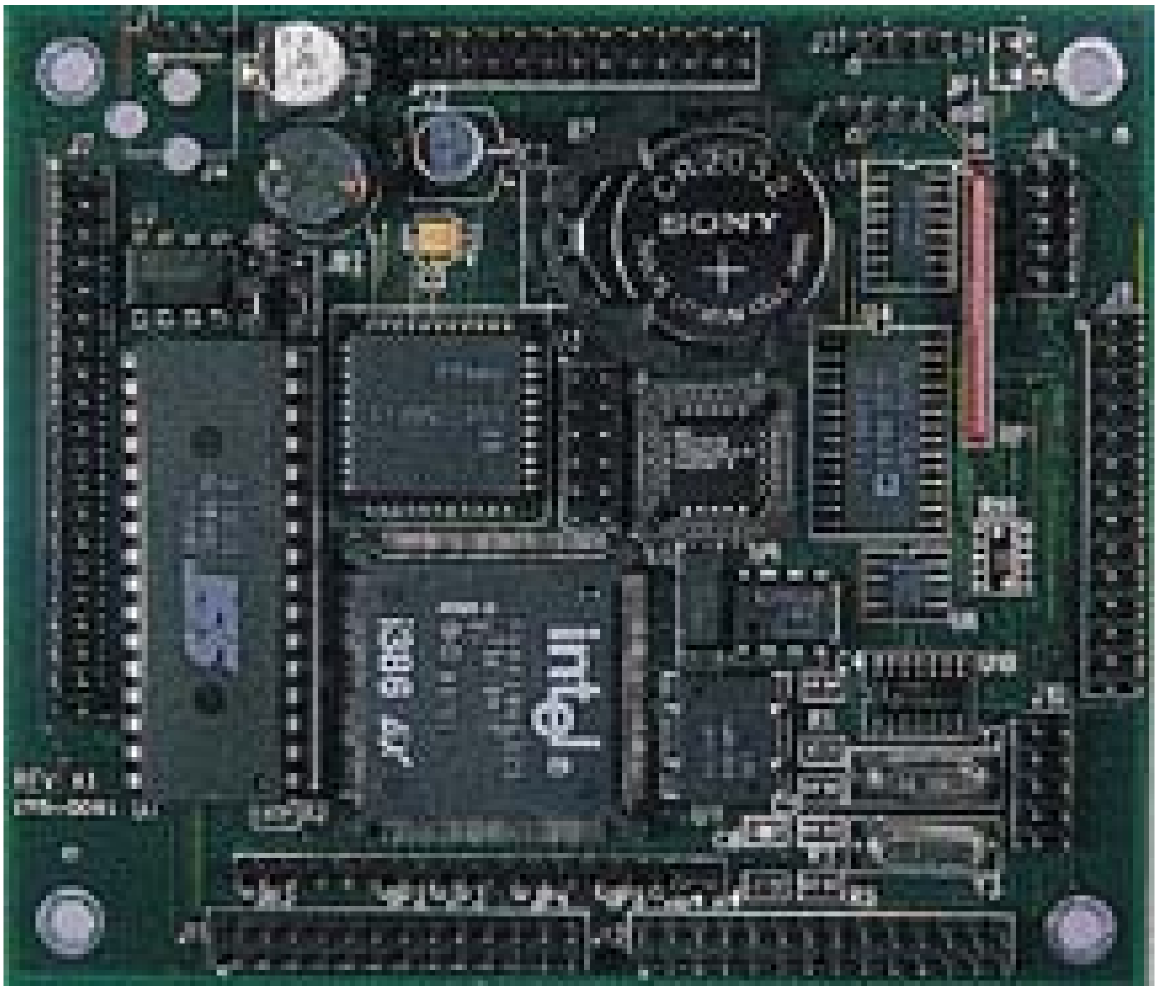

Figure 3: Micro-controller

Pager Modem

The pager modems used in the project were the CreataLink2 and the CreataLink2 XT data transceivers (see Figure 4). Both are two-way narrow-band Personal Communication Services (PCS) modems supporting the ReFLEX 50 protocol for two-way paging. Using a Transistor-Transistor Logic (TTL) serial port, the pager modem can initiate message transmissions into a FLEX two-way paging network as well as decode, store, and forward messages received from a FLEX two-way paging network to an interconnected host device. The serial port data interface supports the Communication Linking Protocol (CLP). The CLP provides commands to obtain status of the pager modem, transmit messages and download received messages.

Figure 4: Pager Modem

As the coverage of the paging network may vary, the CreataLink2 comes into two configurations, one with an external antenna and the other with an internal antenna. As this project involves use of the pager modem in remote field areas, the external antenna model with the antenna was used in this project.

The power to the pager modem is 5 VDC for the CreataLink2 and between 5-12V DC for the CreataLink2 XT. Power from a 110 VAC may also be used and using an AC adapter. The latter method was utilized in this project when the CreataLink2 was used as the accessory kit not only provides the 110 VAC to 5 VDC transformation, but also provides the connection between the TTL serial port on the pager modem and the RS-232 serial port on the micro-controller. The kit also incorporates a level-shifting circuit to allow interface between the TTL port (which operates at 3 VDC) and the RS-232 port (which operates at 5 VDC).

Paging Network

SkyTel was the service provider of the paging network used in this project. SkyTel paging network support the FLEX protocol used by the pager modem. Figure 5 illustrates the SkyTel paging network. The paging network consists of a "Forward" channel and a "Reverse" channel. When a page is sent from a remote pager modem, it is transmitted to a ground-based transmitter/receiver. Then, through a frame relay system, the page is forwarded to the SkyTel's Network Operations Center (NOC). If this page is destined to the NOC, it is stored in a "mailbox" on the NOC server for download by a user at a later time. If the page is addressed to an e-mail address, the NOC server delivers the page using the Internet. If the page is destined to another remote pager modem, the NOC then enters the page into the forward channel. Here, through satellites and ground-based transmitter/receiver, the page finally reaches the pager modem.

Coverage of the paging network may vary. Figure 6 shows the coverage in the Boston metropolitan area.

Network Operations Center (NOC)

The SkyTel's NOC server is located in Jackson, MS with a secondary server in San Antonio, TX. NOC receives all pages sent by the pager modems, and depending upon the recipient's address forwards the page accordingly. In this project, all traffic information was sent to a "mailbox" on the NOC server for download by a workstation. Data is stored in the mailbox for a maximum of 72 hours. The download may be either via a dial-up telephone modem, or via the Internet.

Workstation

This is the workstation within a typical Traffic Operations Center (TOC). For this project, an Intel Pentium workstation was used. The workstation houses the software that can access the NOC and download all the data transmitted by the modem. The PC had an internal modem. Internet connection was through a local Internet service provider.

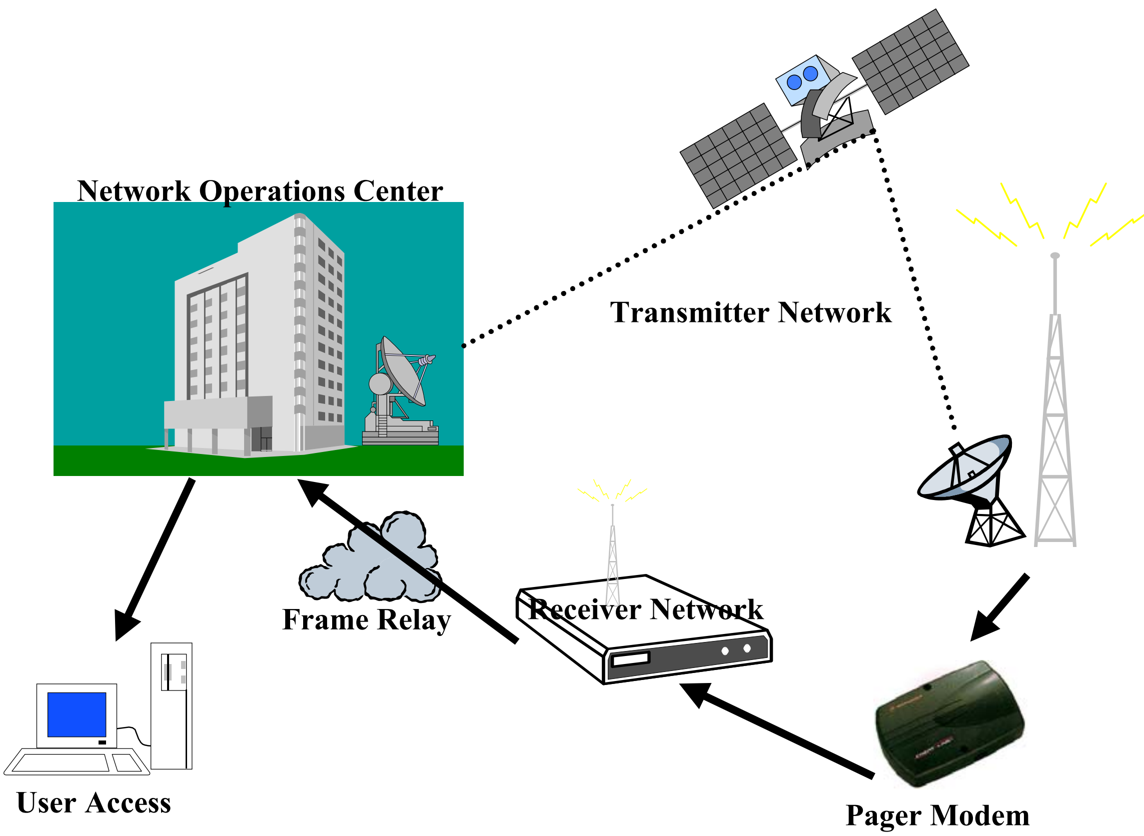

Figure 5: SkyTel Paging Network

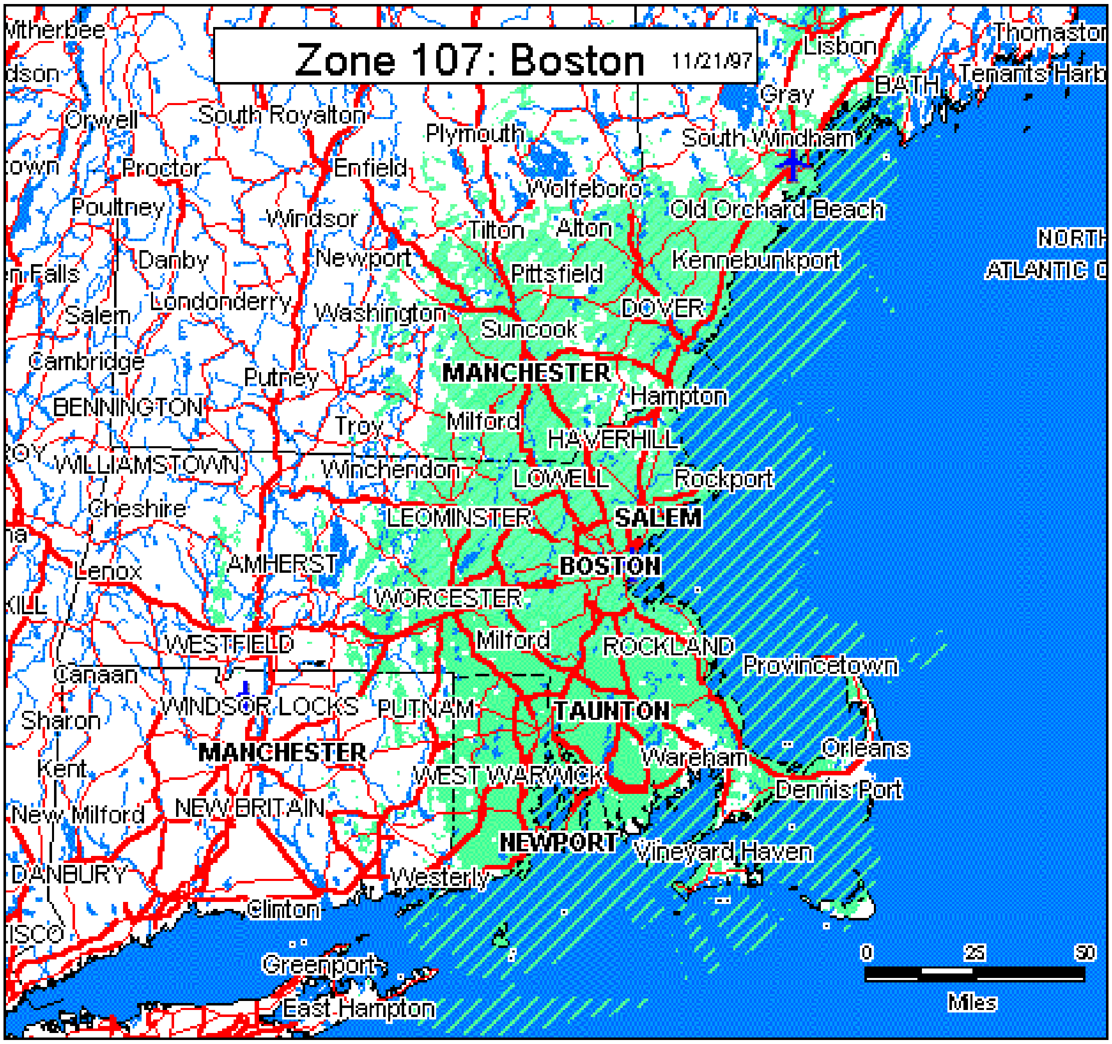

Figure 6: SkyTel Coverage in Boston Metropolitan Area

Interfaces

There are two main interfaces: one, between the µC and the traffic-monitoring device, and the other, between the µC and the pager modem. Figure 7 details these two interfaces graphically.

Interface between Micro-controller and Traffic Monitoring Device

The interface between the micro-controller and the traffic monitoring device was through the J11 (COM1) serial port of the micro-controller and the serial port of the device.

The J11 serial port of the micro-controller is a 10-pin data port. A 10-contacts IDC socket was used in this project to connect to the J11 port. From the IDC socket, a 10-wire ribbon cable was used, with the other end of the ribbon cable terminated into a DB-9 (male) connector.

The serial port on a 170E controller is the C2 port, which is a 14-pin AMP socket. Connection to the port was through a M-series AMP connector. The cable used was a 24 AWG 14 conductor cable. The other end of the cable was terminated into a RJ-45 plug. A RJ-45 jack to DB-9 (female) adapter was used to connect the 170E controller to the µC.

Both the TrafiCOMP III Model 241 and the RTMS provide RS-232 serial ports. In both cases, manufacturer-supplied cables were used, with one end connecting to the device through special connectors, and the other end terminated into a DB-9 (female) connector.

Interface between Micro-controller and Pager Modem

The interface between the micro-controller and the pager modem was through the J6 (COM2/console) serial port of the micro-controller. The CreataLink2 was interfaced using the DB-9 (female) connector of the pager modem's power cord . The CreataLink2 XT was also interfaced using a DB-9 (female) connector, however through use of custom-made wiring and connectors as per manufacturer specifications.

The J6 serial port of the micro-controller is a 10-pin data port. A 10 contacts IDC socket was used in this project to connect to the J6 port. From the IDC socket, a 10-wire ribbon cable was used, with the other end of the ribbon cable terminated into a DB-9 (male) connector.

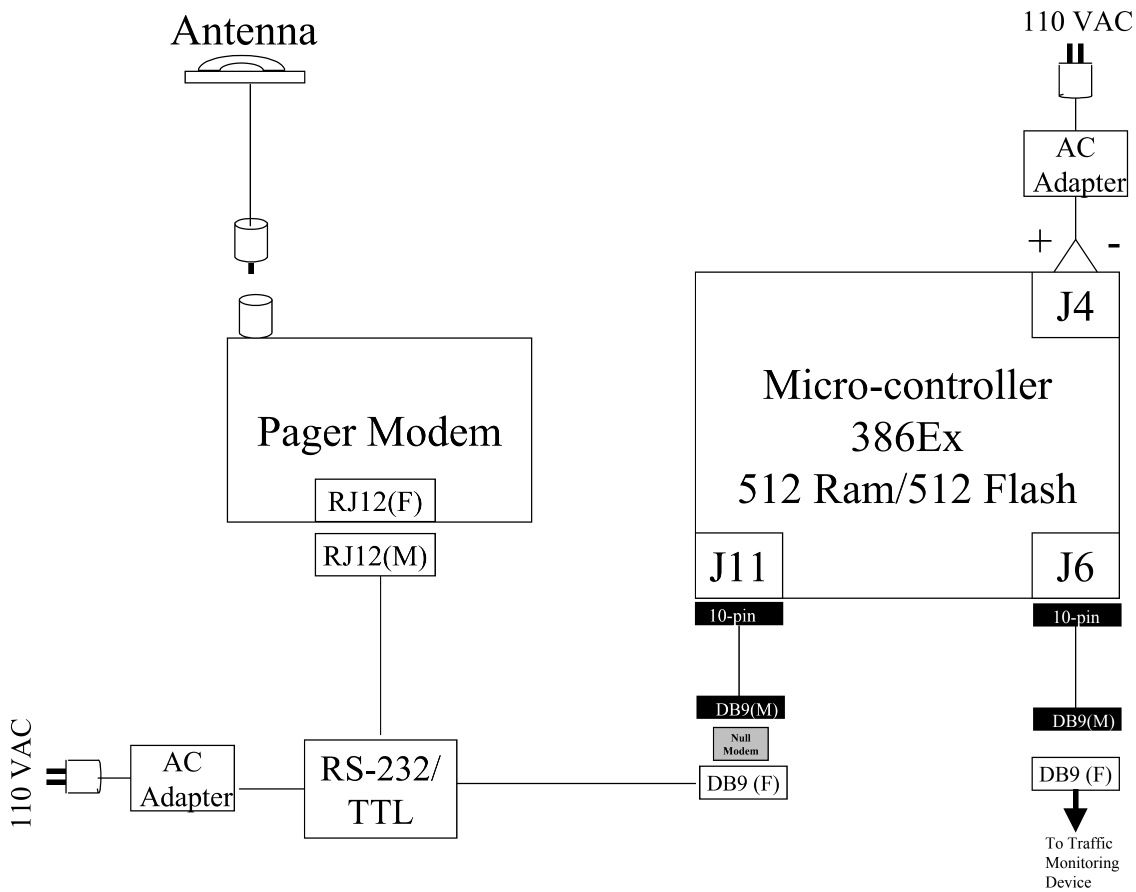

Figure 7: Interface Between Micro-controller and Pager Modem

Connection between the DB-9 (male) connector from the micro-controller and the DB-9 (female) connector of the pager modem had to be established through a NULL MODEM (to account for the pin-out for transmit/receive on the micro-controller).

Software

The above described interfaces and functions of various components are achieved though two software components developed as part of this project. They are the μC software and the workstation software. Discussion of each of these components follows.

Micro-controller Software

Figure 8 presents the overall logic of this software. In general, the µC software consists of two parts. In the first part, the µC communicates with the traffic-monitoring device, periodically. Once the µC has collected data for that certain period, the software passes control to the second part. In the second part, the µC communicates with the pager modem to transmit the data. The above two parts are implemented in a **while () {…}** loop for constant monitoring. Each of these two **while () {…}** loops are in turn enclosed within a **while () {…}** loop for constant operation of the system.

Part 1: Data Download from Traffic Monitoring Device

For the first part of the µC software, three separate functions were developed: Read170 (…), Read241 (…) and ReadRTMS (…), for each of the three types of traffic monitoring devices used in this project.

Each of the above three functions first execute an initialization of the serial port. The serial port settings for each of the three devices are different as shown in Table 2.

Table 2 - Port Settings for the Traffic Monitoring Devices

Port Setting	170E Controller	Model 241	RTMS
Baud Rate	1200	9600	9600
Number of Bits	7	8	8
Parity	None	Even	None
Stop Bits	1	1	1

Once the port has been initialized, the "read" functions mentioned above send a data request command to the traffic-monitoring device. The communication protocols for each device specify the format of the message string. The communication protocols for the traffic monitoring devices were obtained from the manufacturers.

Finally, the above "read" function processes the data downloaded by the monitoring device. The communication protocols for each device specify the format of the output data, which were obtained from the manufacturers.

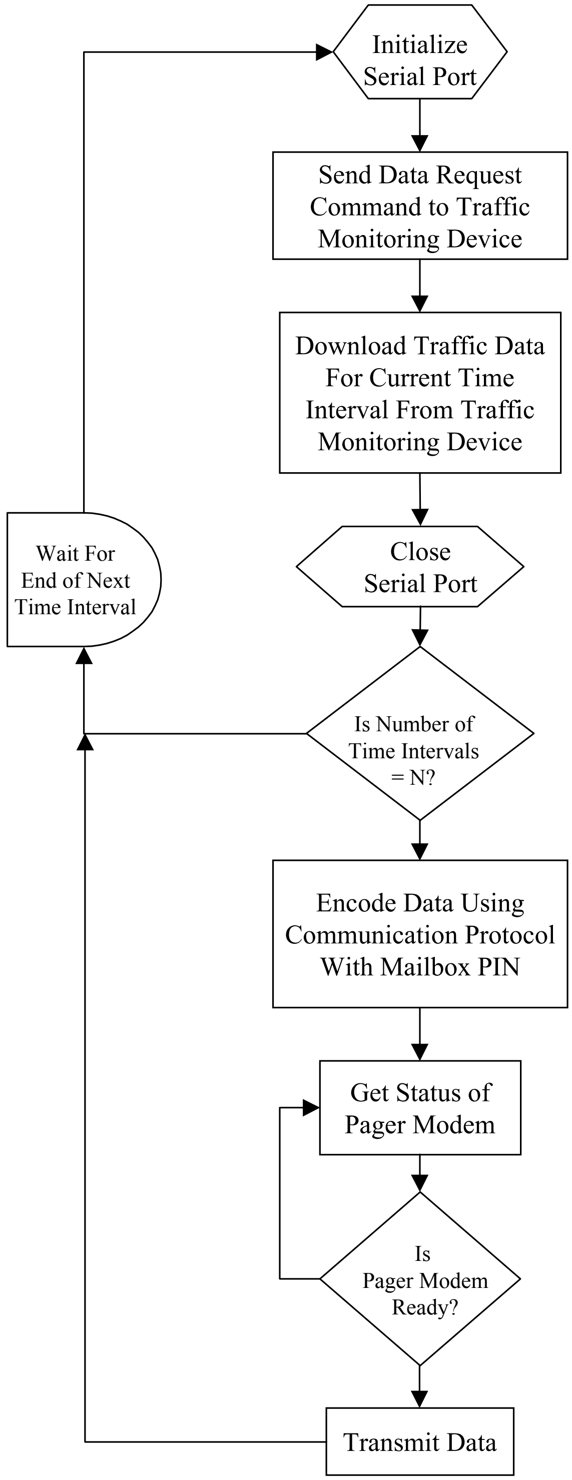

Figure 8: Micro-controller Software Logic

The above steps are repeated periodically. The software was setup so that this could be varied. For example, the data download from the 170E and the RTMS was once every 30 seconds. On the other hand, data download from the Model 241 was setup for once every 5 minutes as well as for once every hour. It is important to note that even though data was obtained from the monitoring device once every 30 seconds, it was transmitted more infrequently, say once every 5 minutes. The intent of collecting data every 30 seconds was to allow implementation of an Incident Detection Algorithm on the μC at a later time.

Once the data is accumulated for a certain period, say 5 or 10 minutes, the software then passes control to the second part as discussed below.

Part 2: Data Upload to Pager Modem

The first step in this part by the software is to check the status of the pager modem using the CLP command **Get Status.** This command provides one of the following indications: either the pager modem has temporarily suspended transmission, or it is currently busy transmitting a message, or it is ready to accept the message. Using the **Get Status** command, one can also find out if the previous message transmission was successful or not. If the software gets a busy signal from the modem, it keeps checking the status of the modem once every 2 seconds till successful or for a maximum of 20 seconds. If a ready to transmit signal is not obtained from the modem for over 20 seconds, the software aborts after logging the error in a **Errorlog** file.

If the **Get Status** command was successful, then the data to be transmitted is formatted into a message string. Format of the message was obtained from Motorola for this project.

Upon packaging the message string, the software then uploads the message onto the pager modem using the CLP command **Transmit**. If the message is successfully uploaded, the pager modem sends an acknowledgement back to the μC software.

Three separate software programs were developed for the three traffic monitoring devices. **TEST170.EXE** is for traffic monitoring devices using a 170 controller. **TEST241.EXE** is for those involving the TrafiCOMP III Model 241 automatic traffic recorder from PEEK-Traffic. **TESTRTMS.EXE** is for the RTMS by EIS, Inc.

Workstation Software

SkyTel provides software tools that allow the download of data from the NOC server mailbox. For this project, software was developed in Visual C++. Figure 9 illustrates the overall logic of this software.

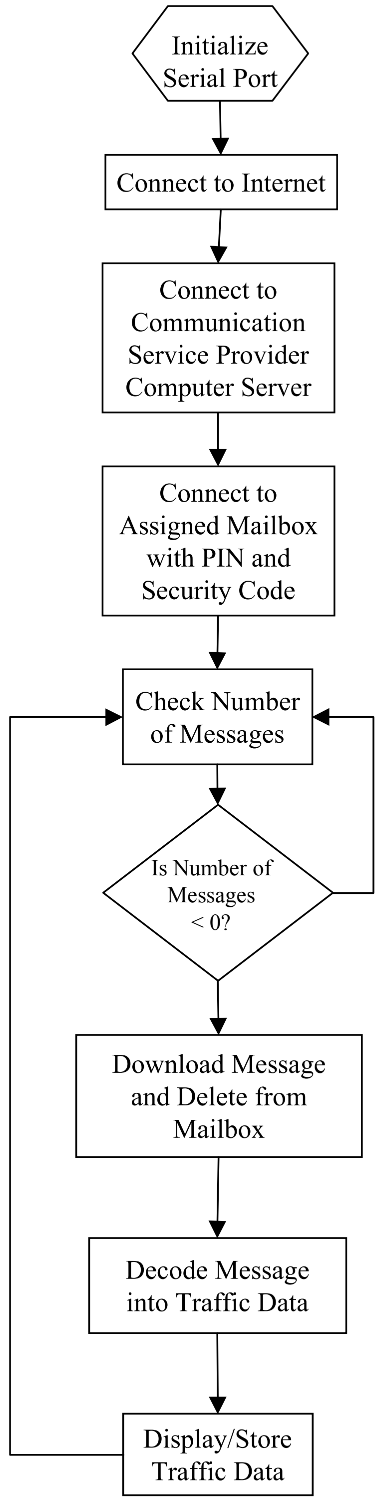

Figure 9: Workstation Software Logic

The software first initializes the modem settings. Subsequent to this, one of two methods to contact the NOC server may be adopted: either using a direct dial telephone number of the NOC server, or over the Internet. In the former case, the software dials a 1-800 number to connect to the NOC server. In the latter case, the software connects to the Internet Service Provider as established on the user's workstation.

Upon connecting to the NOC server, the software checks the number of messages in the mailbox. If the number of messages is greater than one, it downloads them. If not, the software waits for the next message to arrive at the NOC server mailbox.

Once the data is downloaded from the NOC server mailbox, the software in the workstation decodes the data using the encoding procedure used in the micro-controller in reverse. The data can then be either displayed on a map or simply stored for later processing.

Software program **CLSKYTEL.EXE** was developed as part of this project.

Chapter
4

System Testing

This chapter discusses the testing that was conducted on the proposed communication system. Three traffic monitoring device locations were selected. A description of each location, the various tests conducted and the results are described below.

Detector Locations

As discussed previously, three traffic system detection locations were selected. Table 3 provides the location and type of detection system.

Table 3 - Traffic Monitoring Device Locations for Testing

Location (Type of Facility)	Type of Monitoring Device and Coverage
I-93/Route 3 northbound Junction, Braintree - (4-lane one-way sub-urban freeway)	170E Controller with Overhead Radar covering two lanes on I-93 NB and two lanes on Route 3 NB.
Route 2, Concord – (4-lane two-way sub-urban highway)	TrafiCOMP III Model 241 with Loop Detectors on all four lanes in both directions.
Route 2 southbound, Arlington – (3-lane one-way urban expressway)	Remote Traffic Monitoring System (RTMS) mounted on a sign bridge to cover the three Route 2 SB lanes.

Data Communication Tests

Following were the tests conducted at the above three detection system locations. The tests were designed to evaluate the effectiveness of the proposed pager-based communication system under various circumstances. The testing involved first an overall system test of the pager-based communication system followed by tests at each of the three detection system locations.

Overall System Testing

The overall system testing was intended to document the efficiency of the pager-based communication system. This test involved determining the time it takes for the pager modem to successfully transmit messages. This would be the period from the instant the message is uploaded onto the pager modem to the instant the pager modem receives a successful transmission flag from the Network Operations Center. The test was conducted at the office of Lexington Consulting to facilitate documentation of the test results. The tests were performed using 4-byte and 8-byte data strings transmitted once every 5 minutes and once every 10 minutes.

Tests at Individual Locations

The following tests were conducted at each of the three detection system locations.

I-93/Route 3 Junction, Braintree: At this site a 4-byte data string containing speed by lane was transmitted once every 5.

Route 2, Concord: At this site, two sets of tests were conducted: (1) a 4-byte data string was transmitted once every 5 minutes; followed by (2) data collected by the device in 1-hour intervals was transmitted once a day. The latter test was to determine how well the pager-based communication system handles long data strings.

Route 2 Arlington: At this site, a 8-byte data string was transmitted once every 10 minutes.

Test Results

The description of the test results is first given for the overall system testing followed by the test results at individual locations.

Test Results – Overall System Testing

Table 4 presents the results of the overall system tests. It indicates the on an average the time the pager modem takes to successfully transmit messages is about 30 seconds. The testing indicated some minor variations between the morning and evening peak periods, and during the off-peak periods. Further, no significant variations were found between message lengths.

Table 4: Overall System Testing Results

Time Period (message length)	Duration for Successful Transmission (in seconds)		
	Minimum	Maximum	Average
Morning Peak (6-10) (4-bytes)	29	34	30
Morning Peak (6-10) (8-bytes)	30	35	31
Evening Peak (3-7) (4-bytes)	30	42	35
Evening Peak (3-7) (8-bytes)	31	43	36
Off-peak (4-bytes)	26	31	28
Off-peak (8-bytes)	27	32	29

System Testing at Individual Locations

I-93/Route 3 Junction, Braintree: At this site a 4-byte data string containing speed by lane was transmitted once every 5. The test was conducted from August 18 through August 22, 1999. Every 5 minute data was successfully received.

Route 2, Concord: At this site, two sets of tests were conducted: (1) a 4-byte data string was transmitted once every 5 minute from August 29 to August 30, 1999 followed by (2) data collected by the device in 1-hour intervals was transmitted once a day from September 13 to September 20, 1999. The latter test was to determine how well the pager-based communication system handles long data strings. All data transmissions were successfully received.

Route 2 Arlington: At this site, a 8-byte data string was transmitted once every 10 minutes from August 23 through September 7, 1999. Apart from the time when the battery had to be replaced, every 10-minute data transmission was successfully received.

Chapter

5

Cost

Equipment Cost

Table 5 shows the equipment cost involved in the proposed pager-based communication system. Cost of the traffic-monitoring device is not included as it would remain the same irrespective of the communication method. Further, the cost of the workstation is also not included for the same reason.

Table 5 - Equipment Cost

Equipment	Cost ($)
Micro-controller with AC adapter	$ 275.00
CreataLink2 XT Pager Modem	$ 125.00
Miscellaneous (cables, connectors)	$ 50.00
TOTAL Equipment Cost	$ 450.00

Table 3 above assumes that 110 VAC power is available at the traffic-monitoring device. However, if batteries are to be used, an additional $50-$100 would have to be added to the total equipment cost.

Operating Cost

In a pager-based communication system, the operating cost aspect is a very important factor. Table 6 shows the monthly cost for several different scenarios of message length and frequency of transmission.

Table 6 Monthly Operating Costs

Message Length (in bytes)	Once every 5 minutes	Once every 10 minutes	Once every 1 hour	Once every 24 hours
4-bytes	$370	$180	$20	$6
8-bytes	$370	$180	$20	$6
16-bytes	$720	$360	$40	$6
32-bytes	Not cost-effective	$720	$160	$6
96-bytes	Not cost-effective	Not cost-effective	$200	$6

The above message lengths need to be looked in some context to understand their significance. A 4-byte message can be used to send volumes by direction on a two or more lane highway as long as the total volume during the selected time period for transmission frequency does not exceed 32,000. An 8-byte message can be used to send volume, occupancy and speed by direction for a two or more lane highway as long as the total volume during the selected time period for transmission frequency does not exceed 32,000. A 16-byte message can be used to send the above volume, occupancy and speed information for a 4-lane highway by each individual lane. A 32-byte message would accommodate an 8-lane highway. Finally, a 96-byte message could be used to send volumes by direction per hour over a 24-hour period. The above message lengths are only a small sample of combination. However, they allow one to understand the significance of message length and frequency of transmission in a pager-based communication system.

Table 6 indicates that the pager-based communication system would have higher operating costs if the frequency of data transmission is high, say once every 5 or 10 minutes. This is because the cost to transmit data during peak hours, defined as between 7:00 AM and 9:00 PM, is higher than the cost to transmit during the remaining hours. This can be seen when the data transmission frequency is less frequent which results in less data transmissions during the peak period. The operating costs using a pager-based communication system is extremely low if the frequency of transmission is greater than once every hour.

Cost Comparison

The pager-based communication system may not be applicable in all situations. There are some instances were the pager-based communication system is clearly superior, while in some other cases, it may be cost-effective to utilize more traditional communication methods such as the leased-line telephone. For instance, if the frequency of data transmission is greater than once every hour, the pager-based communication will be less expensive than leased-line telephone. Similarly, if the data transmission is once a day, the pager-based communication will be significantly less expensive than the telephone, even for large data transmissions.

Leased-line telephone is typically used for transmitting large quantities of data frequently. It has low monthly charges, however, it could have high installation costs when underground conduits would be needed. The pager-based system has very low installation cost but could prove expensive from a monthly operating cost point of view.

The cut-off point in cost when one should use the pager-based communication and when to use a telephone-based communication, would depend primarily upon the length of underground conduit needed to establish the telephone service connection. For sake of simplicity, let us assume that the monthly charges for a telephone connection will be $45. Let us also assume that the cost to install underground conduit is around $20 per linear feet. In order to compare costs on a monthly basis, let us amortize the conduit installation cost over a 5-year period at a rate of 8 percent per year.

Table 7 provides the breakeven point between pager-based communication and telephone communication in terms of the length of underground conduit. As can be seen, the pager-based communication system would be cost-effective when the cost to install a traditional leased-line telephone would be high due to long underground conduits to bring the service from a nearby utility pole or manhole to the traffic-monitoring device.

In most ITS, data is transmitted once every 20 or 30 seconds to the TOC for incident detection purposes. Such a frequency of transmission is either infeasible or cost-prohibitive using a pager-based communication system. However, the device described in the previous section can support incident detection. Instead of transmitting data to the TOC, one could install the incident detection logic on the μC itself. In such a situation, an alarm could be transmitted at the time an incident is detected. A unique feature of the pager-based system is that the incident alarm could either be send to the mailbox on the SkyTel NOC server, or to a personal pager, or to an e-mail.

In order to reduce the frequency of data transmissions, similar to the incident alarm, the software on the µC could be such that an alarm or the data transmission occurs only when the volume, or occupancy or speed crosses a certain pre-set threshold.

Table 7 Breakeven Analysis of Pager-based & Telephone Communication Systems

Transmission Frequency/Data Size combination	Length of Conduit to Breakeven with Telephone communication
4 bytes every 5 minutes	1200 feet
8 bytes every 5 minutes	1200 feet
16 bytes every 5 minutes	2200 feet
4 bytes every 10 minutes	600 feet
8 bytes every 10 minutes	600 feet
16 bytes every 10 minutes	1100 feet
24 bytes every 10 minutes	1700 feet

Chapter

6

Conclusion

This project involved the system development and testing of a communication device using the ReFLEX narrow-band PCS (two-way paging) technology. The system was tested under actual field conditions at three locations through assistance from the Massachusetts Highway Department. Following were the major conclusions from this effort.

1. The pager-based communication system provides a reliable and cost-effective solution to transmit small quantities of data.

2. The operating cost of the system depends upon the size of the data and the frequency of data transmission.

3. The system is very inexpensive if the frequency of data transmission is greater than once every hour.

4. If greater frequencies of data transmissions are needed, one needs to conduct life-cycle cost comparison with alternate technologies before adopting this system.

5. The pager-based communication system is extremely well-suited for event management, where data is transmitted only in case of an event which could be an incident; or when either the volume, or occupancy or speed cross a certain pre-set threshold; or when certain thresholds are exceeded in a weather station etc.

6. The system provides a unique feature of allowing data to be transmitted either to a mailbox on the service provider's Network Operations Center or to a personal pager or to an e-mail address. The last two options will prove very useful for incident management. This feature can also be used to flag equipment failure and request maintenance.

7. As the proposed system is wireless, it can also be removed and moved to another location. Such a system would prove very useful in the area of event-based traffic management system used in major construction projects as well as near major traffic events (ball games, conventions, etc.).