ENTERPRISE

FINAL REPORT

TEST OF PERSONAL COMMUNICATION SERVICE (PCS) DATA SERVICES FOR TRAFFIC SIGNAL CONTROL

MAY 2004
Revision 2.0

DELCAN   Ontario   Transport Canada   Transports Canada

DELCAN

TEST OF PERSONAL COMMUNICATION SERVICE (PCS) DATA SERVICES FOR TRAFFIC SIGNAL CONTROL

Final Report

Revision: 2.0

Prepared for:

ENTERPRISE, Transport Canada
and Ontario Ministry of Transportation

Prepared by: R. Grandhi / B. Tritter	**Reviewed by:** A. Byrne
Date of Issue: May 2004	

Distribution:
ENTERPRISE and Transport Canada
Ministry of Transportation – Attn. H. Wong
Transport Canada – Attn. B. Marshal

TABLE OF CONTENTS

1 Executive Summary

Cellular communication service providers are rapidly moving to deploy all digital networks in order to provide advanced cellular services to their subscribers. These new digital networks provide personal communication services (PCS) for both voice and data. The digital service is a significant advance over previous commercial wireless data offerings providing Internet Protocol (IP) access and data rates from 40 to 144 kb/s.

Delcan Corporation proposed and undertook this study to determine if these new digital data service offerings, utilizing 1xRTT[1] technology, are suitable to provide effective communications for urban traffic signal control systems.

Digital wireless communication service is of interest to transportation agencies for this purpose since:

- Civil construction, to provide local cable access to intersection controllers, is not required resulting in lower capital costs and more rapid deployments,

- Recurrent costs are lower than for dedicate leased lines and the rates, which are usage based, are distance independent.

The characteristics of the 1xRTT network however, are different from traditional copper or fibre optic circuits used in traffic management systems. In particular, the wireless network provides its own addressing scheme assigning dynamic IP addresses. Legacy urban traffic control systems utilize fixed addresses with a poll – response access method. Packet delay times with PCS also vary from message to message.

The challenge of this project was to evaluate a 1xRTT network and conduct actual testing with a variety of types of existing, legacy traffic signal controllers using an existing urban traffic signal control system. The results of the study are therefore not based solely upon a paper study or test configuration but include testing in the "real world".

This Enterprise project was structured as a private, public partnership (PPP.) The public partners are: Transport Canada, the Ministry of Transportation of Ontario and the Regional Municipality of York. The private partners are Delcan Corporation, Bell Mobility, Blue Tree Wireless Data Inc. of Quebec, and Novax Inc. of British Columbia. Delcan conceived the project and put the team together in response to a request from MTO for innovative, unsolicited proposal ideas for PPP's in the area of ITS. A proposal was subsequently sent to Enterprise to execute the project.

In order to successfully complete this project it was necessary to overcome significant technical hurdles including the dynamic nature of the wireless Internet technology and the limitations of the existing controller's protocol and command set.

[1] 1xRTT, Single carrier radio transmission technology provides 3rd generation digital voice and data services on the cellular network.

The project consisted of three phases: study of the characteristics of the 1xRTT network, development of test hardware and software for bench testing, and finally successful live testing in a street environment with a real traffic control system.

The results of the project are very positive exceeding the best case expectations. Our conclusions are:

- The 1xRTT network is very suitable for traffic intersection control without replacement or modifications to existing controllers. It will operate with a range of standard NEMA controllers.

- All of the communication requirements for a distributed urban traffic control system (that is central systems which are not "second by second") can be met by the 1xRTT service.

- The service meets the most demanding communication requirement, which is to monitor intersection operation in real time with response times ranging around 1 second.

- Capital and lease cost of operation will be less than competitive services and rapid implementation is possible.

- The evaluations and conclusions indicate that NTCIP protocols can also be applicable, and

- 1xRTT networks can provide Centre to Roadside communication solutions for a variety of ITS applications.

Recommendations are also made for on going work. It is recommended that pilot implementations be developed in order to:

1. Demonstrate suitability to meet the communication requirements of other ITS subsystems,

2. Provide a longer term operational period to assess performance over time, and

3. Confirm compatibility with selected NTCIP protocols.

2 Introduction

The explosive rate of deployment of digital personal communication services (PCS) worldwide, is creating new opportunities for deploying ITS technology in remote locations otherwise unreachable by economically viable methods.

The digital PCS data services are cost competitive and offer a means of reducing the recurrent costs of existing distributed ITS systems. Several agencies in Ontario, including the City of London and York Region are interested in verifying this communications technology for traffic signal control systems (TSCS) communications.

The purpose of this project was to test the next generation of digital wireless technology offered by PCS (personal communication service) service providers and determine if it can support the communications requirements for the urban traffic signal control systems utilising legacy NEMA traffic signal controllers.

The main body of this report discusses the project objectives, overview, and summary of the test results, conclusions and recommendations. The Appendices contains additional details of the testing including descriptions of test equipment, photographs and details of the test results.

3 Project Overview

Delcan Corporation had been monitoring the development of the digital PCS data services for some time. It is also very aware of its clients' need for reliable and cost effective communications between their traffic control centres and traffic signal controllers. So when the Ministry of Transportation of Ontario (MTO) issued a request for innovative ideas for public, private partnerships (PPP) in the area of ITS, Delcan developed the concept of testing the suitability of the data PCS, or more precisely the 1xRTT, 3G wireless technology, for the traffic signal control application. The "idea" was submitted to MTO and eventually the partnership was developed and a proposal made to Enterprise to undertake the project.

3.1 Organization and Partnerships

The partners responsible for funding and contributing to the projected included all three levels of the Canadian government, service providers, equipment manufacturers and Delcan. Enterprise served as the client and contract administrator. The roles and contribution of each of the other members are described below:

- Transport Canada, the project's main funding agency, provided support through its Transportation Development Centre. Funding came from the Program of Energy R&D, Natural Resources Canada.

- The Regional Municipality of York (York Region) is a key stakeholder representative of the user community. York Region contributed its Traffic Signal Control System as a test bed, provided controllers for testing and provided a financial contribution. Staff provided invaluable assistance during field testing –selecting appropriate interchanges, monitoring on-street conditions and providing positive feedback.

- The Ministry of Transportation of Ontario (MTO) is also an important stakeholder, driving many ITS initiatives in the Province. MTO provided guidance to the project team as well as providing the overall Project Manager. He was the interface with Enterprise and Transport Canada.

- Bell Mobility, a leading provider of PCS service has contributed their technical expertise and airtime to support the demonstration.

- Blue Tree Wireless Data Inc. of Quebec has contributed 1xRTT- modems and antenna hardware for the duration of this demonstration.

- Novax Inc. of British Columbia furnished two traffic controllers supporting the TrAP protocol for testing.

- Delcan Corporation was responsible for all technical aspects of the project. Delcan provided technical management of the project and co-ordination between all project team members. It provided the majority of the engineering services and was responsible for developing the test bed, interface software, system integration and developing, implementing and analysing the tests. Delcan also contributed, in kind services, central computer hardware / software, field interface computers and ITS application software.

3.2 Issues & Challenges

There are a number of reasons why wireless PCS is attractive to agencies which are responsible for traffic signal control. However, there are technical issues which must be overcome to take advantage of this technology. These issues relate to characteristics of the traffic signal controllers and traffic signal control systems as well as the characteristics of 1xRTT networks.

3.2.1 Agency Considerations

The rapid deployment by the cellular industry of networks to support personnel communication services (PCS) utilizing third generation digital wireless technology, providing both high quality data and voice, offers an alternative communications method for ITS Centre to Roadside Communications.

Specific advantages perceived for agencies responsible for traffic signal control systems are related to the cost and timelines in comparison with traditional leased lines and dedicated agency owned facilities.

In order to provide traditional communication services to an intersection, the telephone company needs to install a local circuit. This requires civil construction, the cost of which is borne by the lessee. The cost can vary from under $1,000 to $10,000 depending on the location. In addition to cost, the time required to implement the service can be excessive. Wireless options eliminate these variable costs and lead times for implementation. This is a very significant advantage to agencies such as York Region which cover a large geographic area with rapidly expanding population base.

A second advantage of wireless PCS data services it that the recurrent cost can be much lower than the cost of conventional leased lines. Service costs for dedicated circuits are distance based in most jurisdictions; for large regions the costs can be very significant. The lease cost of wireless PCS data services on the other hand are distance independent, based only upon usage thresholds. Modern traffic signal control systems, such as in York Region, utilise a distributed architecture which makes best use of the intelligences of the traffic signal controller. Data are only communicated when required, so the usage levels can also be managed to maintain the lowest possible leased charges.

Although the primary focus of the research study was on the potential to utilize 1xRTT services for urban traffic signal control systems the results are applicable to other ITS applications. Similar benefits can also be identified to support road weather information systems, remote dynamic message signs, permanent and temporary count stations, commercial vehicle enforcement and licensing stations etc.. The results from this testing can be used to determine the applicability of PCS, 1xRTT communications not only for TSCS but also for many other ITS applications.

3.2.2 Traffic Signal Controller Protocol Issues

Commercial traffic signal controllers utilizing NEMA standards have communication protocols which were developed to operate on conventional copper wire pairs. They can also operate over fibre optic circuits or dedicate wireless links such as in York Region.

The key project considerations relating to the characteristics of the traffic signal controller and TSCS are:

- The majority of installed TSCS systems in North America employ traffic signal controllers, which utilize non-standard, proprietary poll-response protocols. These controllers are supplied by multiple vendors and operate over low speed asynchronous serial channels.

- Many traffic signal controllers use proprietary legacy controller hardware, which offer little or no room for significant adaptation of the installed controller software.

- These protocols may also impose rigid response time criteria over the communications requirements to provide deterministic performance. The communications response times are an issue at the protocol level as well as the central computer application level.

- Traffic signal controllers have a limited address range, some as little as provided by a single byte, 1-255.

To overcome these characteristics of legacy, control systems required custom software and hardware solutions.

3.2.3 Technical Challenges of 1xRTT Networks

The 1xRTT network is designed to provide digital data packet based services suitable to provide web enabled features on handsets, personal digital assistance (PDA) devices and to control advanced user features. The characteristics of a network designed to accommodate the above type of applications present technical challenges when one is attempting to communicate with traffic signal controllers, including:

- The 1xRTT network exclusively operates using Internet (IP) based protocols. Some of these IP protocols can be made to operate with some level of deterministic timing; however, the media over which these protocols are delivered is not deterministic. Reliability is uncertain and ultimately performance over these networks is controlled by data demand and policy set by the service provider.

- The limited single byte addressing scheme employed by some of the signal traffic controllers is adequate in traditional configurations, as the systems are deployed with their addresses multiplexed with the corresponding multi-dropped serial channel identification numbers to provide a system wide unique identification. However, the IP protocols demand that each host (controller/server) should be provided with a unique IP address.

- In addition to this requirement for a larger addressing scheme, most service PCS service providers only provide a dynamic address management scheme for the assignment of these addresses on their networks. This implies that, any address assigned to a traffic controller operating on the 1xRTT PCS network would only be temporary.

The above characteristics of the traffic signal systems and the 1xRTT are the challenges which were necessary to overcome in order to test and evaluated the 1xRTT communications for traffic signal control.

4 Testing

Testing was conducted in three phases. The initial test phase was developed to characterize the 1xRTT network in order to determine the real network characteristics. This was necessary in order to develop the software for the test platform. The second stage of testing involved conducting bench tests using the test platform and controllers in the lab connected to the network. The final stage was a field test utilising existing traffic signal controllers connected to a traffic signal control system.

4.1 Test Environment

Reviewing the “Issues and Challenges” one could easily come to the conclusion that 1xRTT type PCS services are not compatible with the communications systems for traffic signal control. In order to precede beyond this initial analysis a more detailed evaluation was required in order to overcome the constraints identified.

The following technical requirements were addressed through software in a PC at central and a complementary field interface device:

a) Functionality to communicate asynchronous serial based poll-response protocols through the TIA-232 interface over the 1xRTT IP protocol. This functionality was deployed at the central computer as well as at the traffic controller in the field.

b) Mapping functions to map the legacy controller ID and channel ID to a unique IP address.

c) The dynamic IP address assignment schemes offered by the PCS service provider were addressed through test software in the central interface and field device. Network testing was conducted prior to testing using the traffic protocol, to determine how "dynamic" the IP address assignment is in reality.

Once the required hardware and software was developed testing was undertaken.

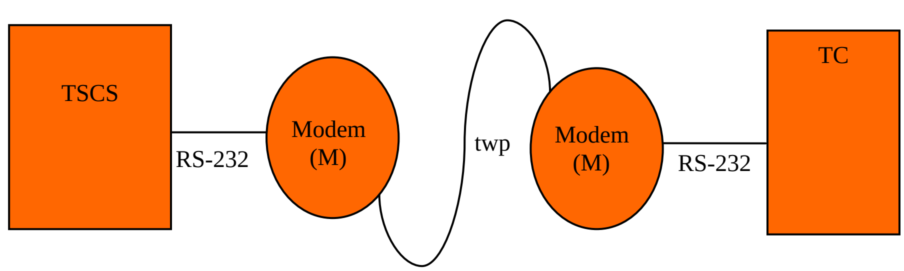
4.2 Test Configurations

4.2.1 Phase 1: Baseline Tests

The first phase tests were developed in order to characterize the communications between traffic controllers and the central computer system in a typical traffic signal control system and the communication parameters of a typical 1xRTT, digital data PCS, network. The results of these tests are applicable to communications between the traffic management centre and traffic signal controllers or other ITS field devices and the associated control centre.

Serial Communication Test Configuration

This test was designed to establish the baseline characteristics of the communications between a traffic signal control system (TSCS) central computer and a traffic controller (TC). In a normal communications arrangement the TC would be configured with similar TCs multi-dropped on the same physical link. The physical link, illustrated by the modem to modem link in the diagram below, represents the different types of deterministic media such as copper twisted wire pair (twp), fiber optic or point-to-point radio. For the test configuration a fixed twp was used.

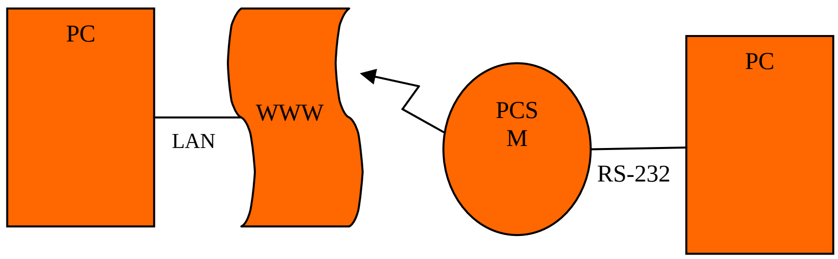


Normal application level poll packets transmitted from the TSCS are received by the TC, processed and a response to the poll request is returned. The baseline response times were measured at the TSCS. These times, represent the total time from transmission of the poll request to the reception of the response.

The results showed that the Novax controller utilizing the TrAP protocol has a response time of approximately 0.2 seconds and the other NEMA controllers had a response time of less than 0.5 seconds. Appendix A provides additional test result data.

Wireless IP Communications Test Configuration

This test was designed to characterize 1xRTT PCS services



Open source IP protocol testing tools were used to establish the characteristics of the 1xRTT PCS communications. These tests were conducted using standard PC hardware and software independent of any traffic signal control applications. These tests measured throughput of the 1xRTT network utilizing UDP and TCP/IP which were measured at 40 and 30 kb/s, respectively. Appendix A provides additional test result data.

4.2.2 Bench Tests

In order to transport the character based serial protocols over an Internet protocol (IP) and to measure communications performance two test programs were developed; the PCS Server and the PCS Client. For the purpose of this testing they have been arranged to operate independent of the TSCS hardware and software and support both proprietary and TrAP protocols.

The PCS Server is configured on a dedicated CPU, which interfaces to the central TSCS computer system through a serial port. The PCS Server attaches to a fixed address serving connections to any PCS client. The PCS Server host CPU is configured to provide permanent presence with a fixed IP address on the Internet.

The PCS Client is configured on a dedicated CPU, which interfaces to the traffic controller (TC) system through the TC's standard serial port. The PCS Client interfaces to the 1xRTT PCS modem through a second serial port with PPP over a serial link. The PCS Client establishes communications to the PCS Server thereby providing a full duplex communication channel through the 1xRTT PCS service. Details and photographs of the PCS Server, PCS Client and 1xRTT Modem are provided in Appendix B.

Bench tests were conducted to validate and test a number of different operational scenarios, which tested communications over the 1xRTT network with:

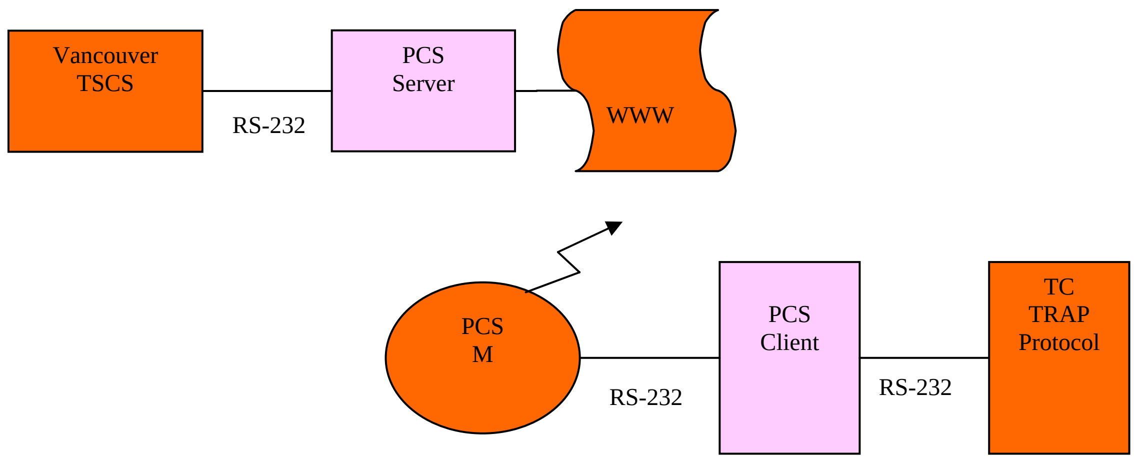
- a single traffic signal controller using TrAP
- multiple traffic signal controllers using TrAP
- a single traffic signal controller using vendor's proprietary protocol
- multiple traffic signal controllers using both vendor's protocol and TrAP.

These test configurations are illustrated in the following subsections of the report.

TrAP Protocol Based Traffic Controller

The test configuration is illustrated in the diagram below. Polls and data from the traffic signal computer are delivered by the PCS server through the Internet to the service provider who broadcasts them through its wireless network to the IP address of the PCS client. Responses from the traffic signal controller are delivered to the service provider's network through the 1xRTT airside link, the packets are then routed through the Internet to the target IP address of the PCS Server host CPU.

To monitor performance the poll requests are time stamped at the PCS Server as they are received on the serial port of the PCS server and the response packets are time stamped when they are received from the Internet connection.



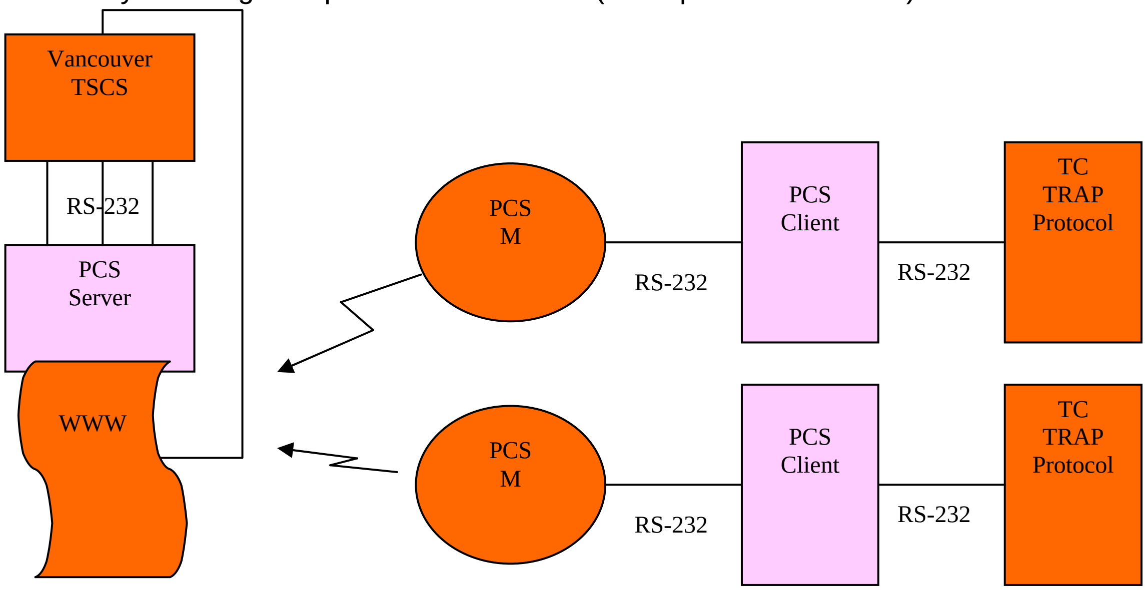
Data was collected while exercising various traffic functions utilizing the TSCS operator's graphical user interface. The following application functions were exercised during the tests:

- Second-by-second intersection monitoring
- Status monitoring
- Download timing plans, Daily, Weekly
- Upload timing plans, Daily, Weekly

The majority of the data was collected automatically during routine status polling of the TSCS central computer.

Multiple Traffic Controller with 1xRTT Communications

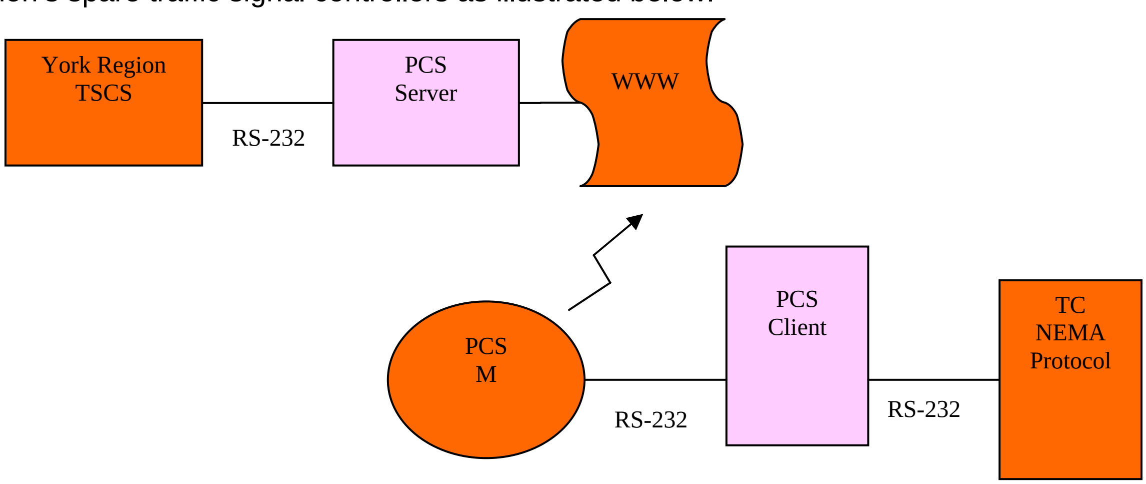
This configuration demonstrates that the 1xRTT PCS communications is capable of simultaneously handling multiple traffic controllers (as required in all TSCS).



Each TC receives a unique IP address from the service provider and these IP addresses are mapped to the controllers configuration in the system database.

Traffic Signal Controller Vendor's Protocol with 1xRTT Communications

In order to confirm that 1xRTT communications are a viable option of other legacy controllers and to enable the field testing a bench test was conducted using one of York Region's spare traffic signal controllers as illustrated below.

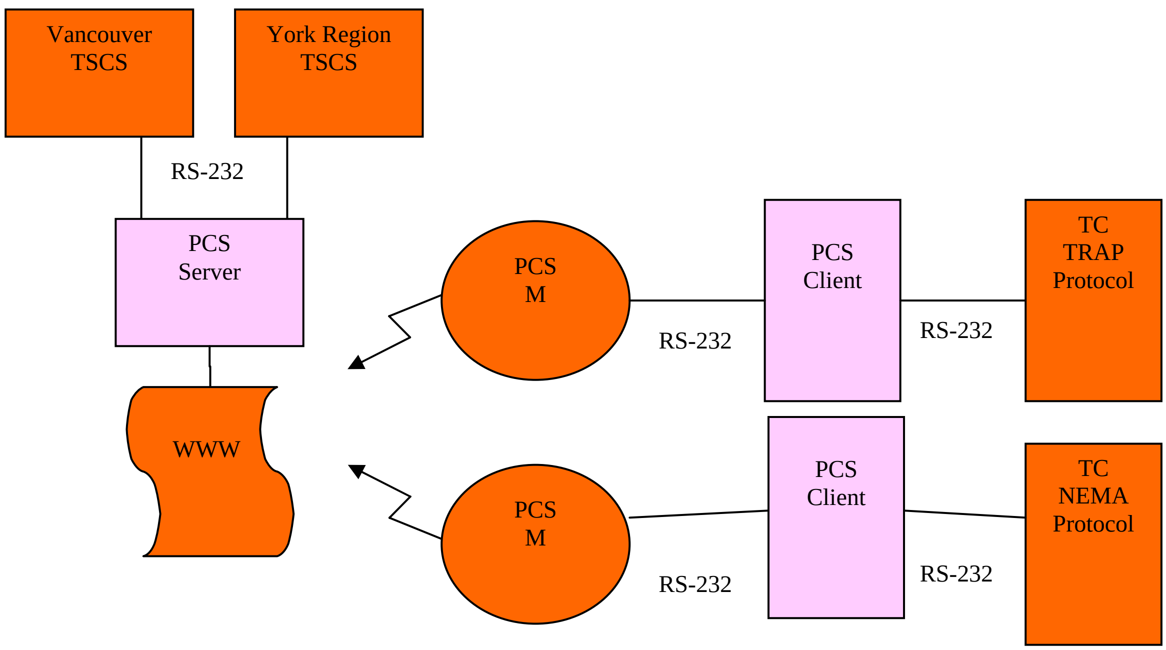


This test was arranged similar to the test configuration for the TrAP protocol and the same type of data was collected. The PCS Server and the PCS Client operate independently of the protocol whether it is TrAP or the other protocols, providing a relatively transparent connection between the traffic signal control centre and the controller.

Multiple Protocols and Multiple Controllers

The final bench test, illustrated below determined that the PCS Server and Client could deal with multiple protocol and multiple types of traffic signal controllers.

Multiple Protocols and Controllers using 1xRTT Communications



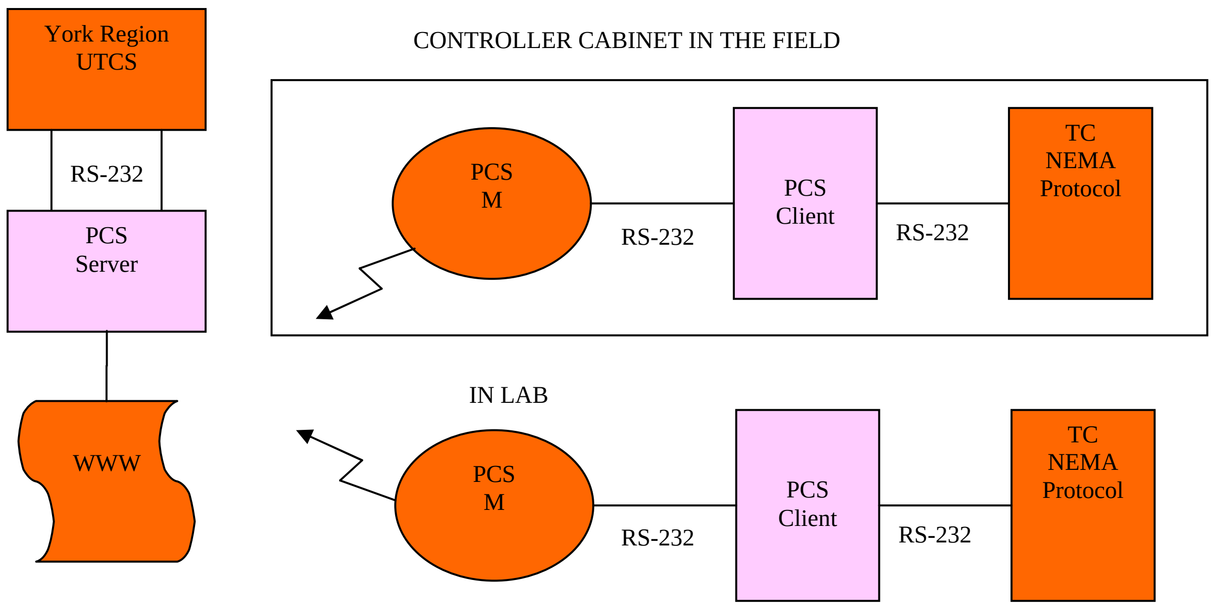
Agencies, such as York Region, which utilise a wide range of types of controllers from a variety of manufacturers require this level of inter-operability.

Since the 1xRTT PCS service only supports the IP protocols, all other protocols must be handled through subordinate protocol data units within the IP protocols. This test, through the use of the PCS Server and the PCS Client, demonstrated that multiple, different traffic signal controller protocols could be simultaneously accommodated.

4.3 Field Testing

Testing was conducted in the field using York Region's traffic signal system software and actual field controllers. The capability for an actual traffic signal system to effectively communicate with multiple traffic signal controllers over the 1xRTT PCS communications was demonstrated. The configuration utilised is illustrated below.

1xRTT Communications with Live Field Controller



The testing included utilizing the traffic monitoring functionality of the central system such as status polling and uploading of the current configuration information in the TC. Control operations were only exercised with the presence of support personnel at the TC field cabinet site for safety reasons. Data was collected over several days from the live TC in the field.

5 Results and Analysis

The testing of the PCS communications for the traffic control application revealed several areas that must be considered in addition to just the performance measures over the communications medium.

5.1 Interface Equipment and Software

The fact that environmentally hardened modems and controllers, suitable for outdoor use, are available in the market and that they can be readily adapted to ITS applications has been demonstrated by this project.

Communication interface equipment and 1xRTT modems are readily available with support for multiple operating systems through well established interfaces. The testing has demonstrated the use of the 1xRTT modem with 3 different operating systems; Windows, Linux and QNX.

It has been demonstrated that it is not only possible, but also feasible, to establish interfaces to the IP based 1xRTT communications media through an independent intelligent processing unit (PCS client), providing a transparent protocol independent communications interface. The PCS client effectively deals with the conversion of the poll – response message protocols of the traffic control industry and converts them to the IP based Internet.

5.2 Addressing

The challenge of address translation and management has been shown to be successfully handled in order to provide transparent communications between the central traffic control system and legacy traffic controllers.

It was also demonstrated that dynamic 1xRTT-modem IP addresses assignment schemes offered by the PCS service providers could be managed to conform to the static address mapping arrangements of legacy traffic systems.

5.3 Latency

The 1xRTT modem is known to have 3 distinct states of operation Idle-State, Dormant-State and the Active-State. If the modem is not in the Active-State the transition to Activate-State will incur a penalty in latency of between 4 to 8 seconds.

The transition of the 1xRTT-modem state from the Active-State to the other states is controlled by the service provider. We were initially informed by Bell Mobility that data inactivity over the established 1xRTT link would transfer the Active-State modem into Dormant-State and 15 minutes of further inactivity would transfer the modem into the Idle-State. We were unable to find this pattern through our testing. However, we discovered that the modem is forceably disconnected from the 1xRTT service (including loss of IP address) after approximately 12 hours of continuous connection. The reconnection time was less than 30 seconds. We also observed on one occasion that just prior to disconnection, the Active-State seem to drop more frequently to the Dormant-State or the Idle-State. This was indicated by an latency of 6 seconds to 8 seconds for initial packets within a group of packets.

These latencies have not caused any major communications problems during our testing, since most of the observed latencies are infrequent and due to known factors. The infrequent nature of these latencies allows for development of methods to reduce their impact on **distributed traffic signal control systems**. However, such latencies can not be tolerated by **second-by-second** or non-distributed control systems.

5.4 Response Times

The typical response times utilising the 1xRTT network were measured. The typical response time and the variation in response times are important considerations in current traffic control systems. The 1xRTT PCS service has demonstrated an average response time of 0.75 seconds with 98% of the responses coming back within 1.2 seconds. The resulting overhead over the base line communications is approximately ¾ of a second.

Second-by-second urban traffic signal control system (UTCS) systems require constant communications to all controllers and the necessary response times are typically less than 1 second and variations can not be tolerated.

Distributed traffic signal systems, including those used in these tests, utilise the traffic signal controllers intelligence and hence do not require “second by second” communications. They are resilient to sporadic or less deterministic communications. However, even in a distributed system, sometimes it is important to be able to communicate to a selected controller or a limited set of controllers on a more frequent (<= 1 sec) intervals for a short duration for the purpose of performing intersection monitoring.

All functions of the distributed TSCS were verified successfully including the most demanding intersection-monitoring operation which provided monitoring with a range around a 1 second resolution

5.5 Communications Overhead

The 1xRTT network, by definition, imposes the overhead of the IP protocol. The raw sustained throughput for the 1xRTT was practically measured at 40kb/s for UDP/IP traffic and 30kb/s for TCP/IP traffic; illustrating that performance can vary depending on the choice and arrangement of protocols. In either case, the throughput is considerably more than that currently available to most traffic controllers. The 1xRTT network is designed to provide double or triple this data throughput; however, overall network data demand and policy of the service provider will determine the real throughput at any point in time.

6 Conclusions

It has been clearly demonstrated that 1xRTT PCS services are suitable to provide Centre to Roadside Communications for distributed traffic signal control system.

This project has successfully demonstrated full operations over 1xRTT communications with legacy NEMA traffic controllers operating with proprietary protocols and the TrAP protocol. All functions, including the most demanding operation intersection monitoring, were successfully demonstrated.

The test results indicate that NTCIP protocol for traffic control should also be suitable for use over1xRTT networks. NTCIP is also a poll-response protocol and the TrAP protocol, which was successfully demonstrated, is very similar to NTCIP.

We can conclude that PCS is NOT suitable to provide communications for second by second traffic control systems or “non-distributed” traffic signal control systems. Even though the average response times measured were less than ¾ of a second the response times are not deterministic and there is no guarantee of performance.

The service provider will not guarantee response times or instantaneous throughput for networks utilising 1xRTT. However, the base line measurements for the 1xRTT services indicate that there is significant room for expansion in performance. The maximum data rate that was used at the application level for this testing was 9.6 kb/s. The 1xRTT was observed to provide 4 times this level. However, this test only used two 1xRTT modems. Further testing and analysis is required to estimate a baseline for system wide performance. Although the information gained during this testing is not adequate to extrapolate to any size system. We expect that commercial considerations and the over all data demand, performance thresholds and policies set by the PCS service provider will dictate the system wide performance.

Challenges with protocol incompatibility, legacy controller addressing limitations and IP address incompatibilities were overcome. This project has successfully demonstrated the feasibility to using 1xRTT communication networks with traffic control systems. It can also be concluded that1xRTT communication networks should be well suited to provide "Centre to Roadside" communications for other ITS subsystems such as to support DMS signs, RWIS and remote VDS.

7 Recommendations

Although the project results indicate that the 1xRTT, PCS data services will be suitable to support other ITS subsystems, this should be demonstrated through one or more additional pilot projects.

The test of PCS Data Services shows that the networks are capable of meeting the requirements for traffic signal control systems. Although the actual tests in the field confirm this, a pilot project is recommended to monitor longer term performance. The field trial was operational for a period of weeks without significant network problems; however the overall long term reliability of the network could not be assessed. This will become particularly important as use of the data network by other users and the general public increases.

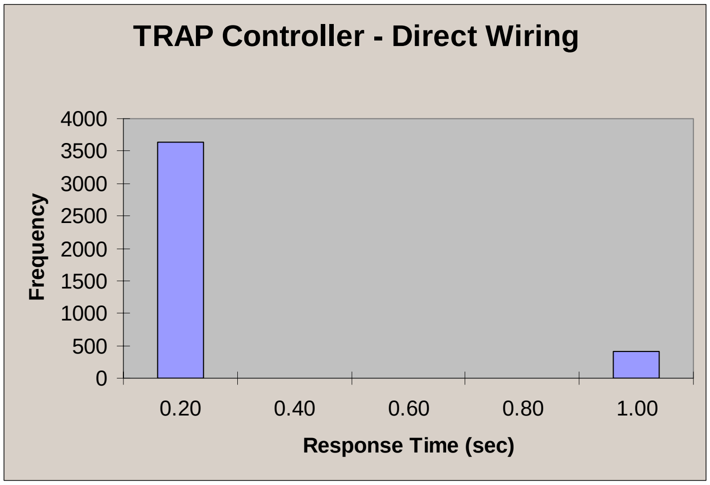
The issue of security has not been addressed by the study. The PCS Server and Client could provide encryption and security however an appropriate approach had not been investigated. Additional work in to how to provide the required security without significantly degrading performance is suggested.

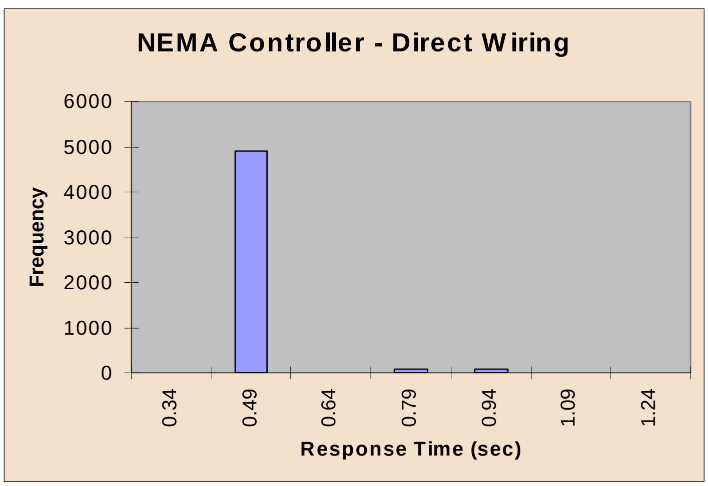
The characteristics of the 1xRTT network and the successful use of TrAP indicate that NTCIP for traffic signal controllers will perform well. However, tests and further analysis are warranted to confirm these conclusions.

The Study has successfully demonstrated that PCS Data networks, specifically 1xRTT networks, are suitable to provide cost effective communications for traffic signal controllers. Additional work is recommended to assess the longer term reliability of the networks, support for other ITS subsystems and compatibility with NTCIP.

Appendix A: Data Analysis

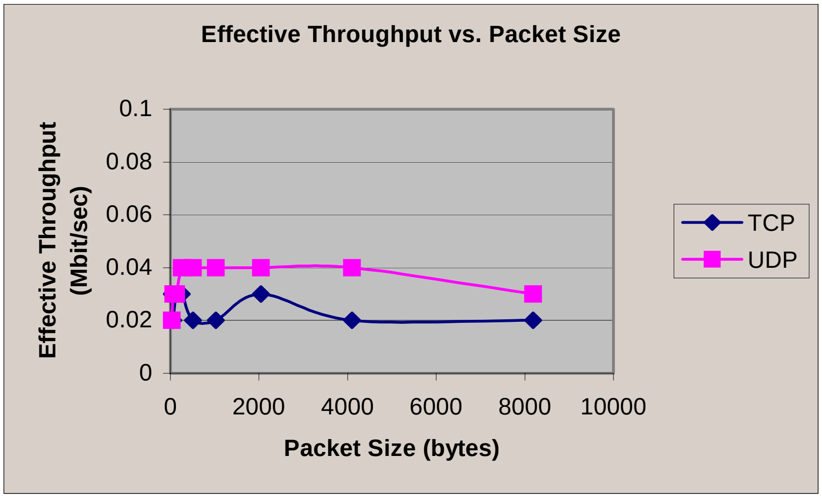
1. Serial Communication Tests





The base line response time measurements for the TRAP and the NEMA protocols summarized in the two histogram graphs. The above graphs clearly indicate the response times for the traffic controllers are deterministically contained within 1 second. However, the bulk of the responses are much less than ½ second.

2. IP Communications Tests

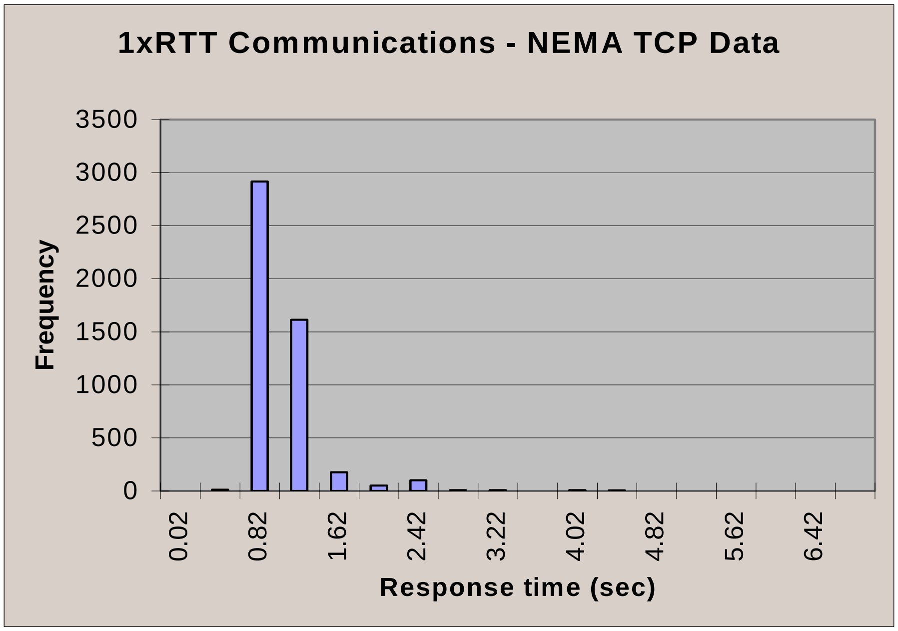


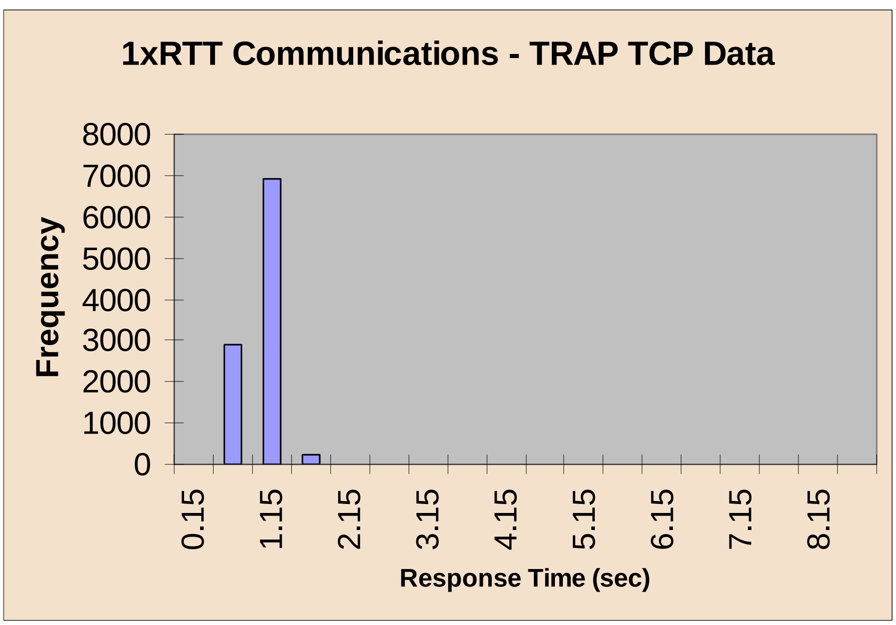
The above graph is a sample measurement of the raw sustained throughput for the 1xRTT communications services. This establishes a base line measurement for the communications over the 1xRTT. For UDP traffic, 40 Kbps sustained data rates were observed. For TCP/IP, greater than 30 Kbps sustained data rates were observed.

DELCAN

3. Summary of 1xRTT Communications for TRAP and NEMA Protocols

The graphs below represent a histogram of measurements of UTCS data communications collected at different intervals during the bench testing as well as the field-testing. The data for the TRAP protocol was collected only for the bench testing stage.





The communications over the 1xRTT did not differ between the bench tests and the field tests as expected. The average response time of the UTCS application over the 1xRTT network was measured to be less than 0.75 seconds for the total set of 27,000 packets of sample data.

A subset of this data was analyzed for error rate and it was observed that from a subset of 22,341 packets the 1xRTT link provided better than 99.8% error free communications.

4. Anomalies

ICMP anomalies

Initial tests using the “ping” command to observe response times were not successful in both directions. The ping command always produced an initial latency of 3 to 8 seconds.

Also the use of the “traceroute” command always resulted in dropped connections.

Discussions with the modem supplier indicated that the 1xRTT network will not fully support the ICMP commands from the interface.

However the above anomalous behaviour could not be reproduced with the application level data communications.

Dropped Connections

It was also observed that the 1xRTT connections were dropped by the service provider after approximately 12 hours of continuous connection time. For our testing this also coincided with 11:00pm to 1:00am time period.

We had also discovered that the IP connection is lost once the RF signal strength fades below certain threshold. We forced the RF signal to become weaker by manipulating the position of the antenna. For the actual application data test the RF signal strength was always better than 60% as indicated by the diagnostic tool.

Appendix B: Test Equipment and Configuration

1. PCS 1xRTT modem and Antenna

The 1xRTT modem was selected to meet the following requirements:

1. Communication provided over a standard RS-232 interface and supporting the standard AT modem command set.
2. IP communication protocol interface through standard serial based PPP.
3. External device and operate independently from any host computer (independent power supply).
4. Rugged and environmentally hardened to operate in outdoor environments.
5. Operates over the Bell mobility 1xRTT (800/1900MHz) network.

1xRTT-modem and antenna equipment was supplied by Bluetree Wireless Inc. (http://www.bluetreewireless.com)

2. TRAP based Traffic Controller

Hardware: Novax Industries Corporation Traffic Controller, Model 6905
Supplied by Novax Industries Corporation (http://www.novax.com)

Port settings: Baud rate = 9600, 8 bits, 1 stop bit and No parity

Firmware: Running TRAP protocol

3. NEMA Traffic Controller

Hardware: NEMA Traffic Controller, Model: EPAC-300
Supplied by The Region of York

Port settings: Baud rate = 1200, 8 bits, 1 stop bit and No parity

Firmware: Running proprietary NEMA protocol

4. Host Computer running as the PCS Server

Hardware:	Pentium II 400MHz, (Supplied by Delcan) 256 MB RAM, 6 GB HDD – Multi partition and multi OS platform.
Port settings:	COM1: Baud rate = 9600, 8 bits, 1 stop bit and No parity COM2: Baud rate = 1200, 8 bits, 1 stop bit and No parity
Software:	Mandrake Linux Version 9.1 Windows NT 4.0, SP6
Application:	PCS Server

5. Host computer running as the PCS Client

Hardware: Pentium 166MHz (Supplied by Delcan)
128 MB SDRAM
2 GB HDD

Port settings: Baud rate = 9600, 8 bits, 1 stop bit and No parity

Software: Mandrake Linux Version 9.1

Application: PCS Client

6. Region of York UTCS Central Server

Hardware: Pentium 166MHz (Supplied by Delcan)
128 MB RAM
2 GB and 800 MB HDDs

Port settings: Baud rate = 1200, 8 bits, 1 stop bit and No parity

Software: QNX 4.25

Application: Running Delcan’s UTCS application
(Communications with the NEMA TC)

7. City of Vancouver UTCS Central Server

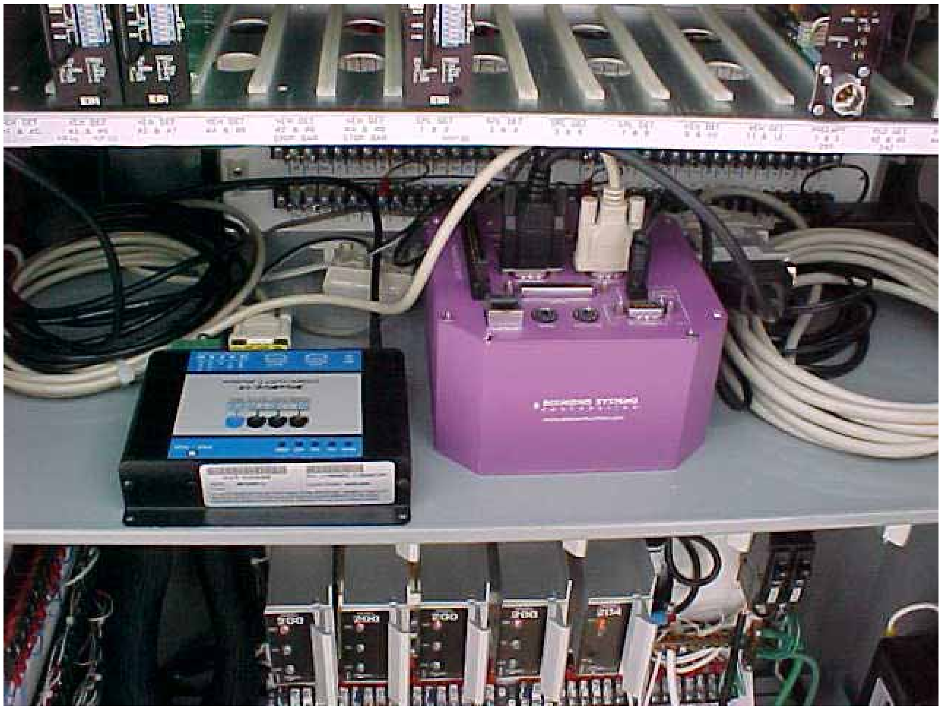
Hardware: Pentium 166 MHz (Comm Server - Supplied by Delcan)
128 MB RAM
1.5 GB HDD

Port settings: Baud rate = 9600, 8 bits, 1 stop bit and No parity

Software: QNX 4.25
Application: Running Delcan's CTCS application
(Communications with the TRAP TC)

DELCAN

8. Embedded Controller
PCS Client Interface to NEMA field TC



Hardware:	ZFx86 (ZF Micro Devices) 100 MHz CPU (Supplied by Delcan) Manufactured by Diamond Systems corporation (http://www.diamondsystems.com/) 32 MB RAM 32 MB Flash Disk
Port settings:	Baud rate = 9600, 8 bits, 1 stop bit and No parity
Software:	QNX Version 6.2
Application:	PCS Client (Interface to the NEMA field TC)

Appendix C: Test Tools and Utilities

1. TTCP and PCATTCP IP throughput analysis utility

Test TCP (TTCP) is a command-line sockets-based benchmarking tool for measuring TCP and UDP performance between two systems.

- TTCP was used to determine some of the raw throughput measurements over tcp and udp protocols independent of the Traffic signal equipment.

- PCATTCP was used to generate IP traffic with known characteristics.

2. Ethereal

Ethereal is an open source Network protocol analyzer (http://www.ethereal.com/)

- Ethereal was used to determine the traffic on the Internet link, and
- used to measure the response times with its time stamped logging capability.

3. BlueVue Modem manager

This is a configuration and diagnostic utility for the BlueTree 1xRTT modem. This utility operates in MS-Windows environment. (http://www.bluetreewireless.com)

- BlueVue was used to configure the 1xRTT modems, and
- to determine the RF signal strength with its built in power level indicator.